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State of the Environment Report

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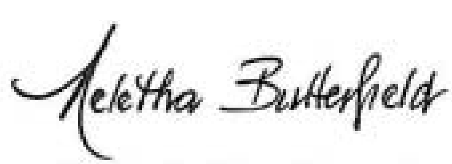
Foreword

State of the environment reporting is common in many countries across the world and has become increasingly popular since 1992 as a result of the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. It is with great pleasure and pride that I am able to present to the public Bermuda's first State of the Environment Report.

The information contained in this report is extensive and covers a range of different topics describing the Island's environmental health at the year 2000. Its purposes are to improve public understanding of the Island's environmental issues, to provide better information for decision makers in assessing priorities for action to resolve the Island's environmental problems, and to help establish the foundations for the production of a long term sustainable development strategy for the Island. Much of the information contained in this report has already been used as background material in the preparation of Bermuda's Sustainable Development Strategy and Implementation Plan.

The production of this report heralds an important milestone in the collection and dissemination of environmental information about the Island. It also helps to meet some of the Bermuda Government's key objectives as a signatory to the UK Environment Charter.

This State of the Environment Report has been a number of years in the making and I should like to express my sincere gratitude to technical officers in the Department of Planning for their sustained hard work and dedication to the coordination and production of this valuable report. I should also like to thank all the individual authors who contributed their knowledge and expertise to this report and to the copy editing team at the Department of Communication and Information for their work in producing such a high quality document.



The Hon. D. Neletha I. Butterfield, J.P., M.P.
Minister of the Environment

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Department of Planning Team

Editors: Julie Marshall
Heather DeSilva
Tamsyn Doran

Department of Communication and Information Team

Design: Margaret Simmons

Copy Editor: Jackie Aubrey

Production: Jackie Aubrey
Margaret Simmons
Jamie McDowell

Contributions

Appreciation is granted to the following for their contributions to this Report. Whilst we have tried to accurately present the information contributed, there may well be errors in the report and we accept responsibility for these.

Peter Adwick, formerly Department of Planning

Jackie Aubrey, Department of Communication and Information

John Barnes, formerly Department of Agriculture and Fisheries

Patricia Begeman, Department of Environmental Protection

Jane Brett, formerly Ministry of Works and Engineering and Housing

Lennox Boodram, Keep Bermuda Beautiful

Wayne Carey, formerly Bermuda Electric Light Company Limited

Keith Claridge, formerly Ministry of Works and Engineering and Housing

Barry Coupland, Department of Marine and Ports

Heather DeSilva, formerly Department of Planning

Chrystal Gatare, formerly Department of Conservation Services

Anne Glasspool, Bermuda Zoological Society

Jennifer Gray, Department of Conservation Services

Lisa Greene, Bermuda Aquarium Museum and Zoo

Mark Guishard, Bermuda Weather Service

Allan Hunt, formerly Ministry of Works and Engineering and Housing

Larry Jacobs, Ministry of Transport

Bill Jewell, formerly Bermuda Electric Light Company Limited

David Kendell, Department of Environmental Health

Brian Luckhurst, Department of Environmental Protection

Sarah Manuel, Department of Conservation Services

Kevin Monkman, formerly Transport Control Department

Lester Nelson, formerly Department of Airport Operations

Michael Osborn, Department of Airport Operations

Richard Owen, formerly Bermuda Biological Station for Research

Andrew Peters, Bermuda Biological Station for Research

Julie Marshall, Department of Planning

Mark Rowe, Department of Environmental Protection

Dan Simmons, Public Transportation Board

Kent Simmons, Bermuda Biological Station for Research

Margaret Simmons, Department of Communication and Information

Thomas Sinclair, Department of Conservation Services

Thomas Sleeter, Department of Environmental Protection

Erica Smith, Department of Planning

Struan Robertson Smith, formerly Bermuda Biological Station for Research

Wolfgang Sterrer, Bermuda Aquarium Museum and Zoo

Desmond Trott, Department of Statistics

Jack Ward, Department of Conservation Services

Roger Williams, Bermuda Weather Service

Introduction

State of the Environment reporting

State of the Environment (SoE) reporting or environmental monitoring is a process for describing, analysing and communicating information on conditions and trends in the environment.

Internationally, SoE reporting began with the emergence of national environmental policies, the first reports being produced by Japan in 1969 and the United States in 1970. SoE reporting was given a higher profile during the United Nations Conference on Environment and Development (UNCED), the Earth Summit, at Rio de Janeiro in 1992. The international programme for sustainable development, AGENDA 21, which was adopted at UNCED called for improved environmental information to help countries make environmentally informed decisions. Since 1992, SoE reporting has become increasingly popular, with many countries of the world having produced at least one SoE report and a number of countries producing SoE reports on a regular basis, varying between annually and every five years.

How clean are the air that we breathe and the water that we drink? How healthy are our fish stocks and our marine ecosystems? How much of our land do we cultivate and how much are we building on? What is the state of our environment and how well are we looking after our Island? These are some of the issues to be addressed in this State of the Environment Report.

This is the first comprehensive report produced by the Bermuda Government on the state of Bermuda's environment. *Bermuda's Delicate Balance*, a book written nearly 20 years ago and sponsored by the Bermuda National Trust, is probably the closest Bermuda has had to a SoE Report in the past. It examines the interactions between the various forces at work in Bermuda's physical, economic and social environments and the delicate balance between progress and nature.

This first official SoE report provides a snapshot of the Island's environmental health at the year 2000 with selected updates where further information has been available. The report describes and analyses scientifically-based information on environmental conditions and outlines the effects that human activities have on them. It also summarises the roles, strategies and programmes of the principal environmental management institutions on the Island.

The report examines Bermuda's natural resources including its climate, geology, water, energy supplies, biodiversity and natural habitats. It examines our use of these resources including agricultural production and the fishing industry. It describes the ways in which we manage these resources and discusses land use planning and transport issues, the Island's system of waste management and environmental health issues. It provides a list of key environmental indicators for each topic to help monitor changes and detect problems which should be addressed.

There are some topics, such as housing, population and economic development that are not covered in this SoE report. It is anticipated that these topics will be addressed in future SoE reports as well as the Government's Sustainable Development Strategy and Implementation Plan.

This SoE report will help identify priorities for action to resolve environmental problems and will enable us to make more informed decisions concerning the Island's future development and to sustain environmental resources into the future. It will provide a 'baseline' and context for considering policies for strategies, programmes and plans and it will be used as a yardstick against which to assess the rate of progress towards achieving a more sustainable Bermuda.

In the late 1980s, the term 'sustainable development' began to be commonly used amongst land use managers after the World Commission on the Environment coined it from the publication of the Brundtland Report. The Brundtland Report defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It aims to reconcile two basic aspirations of society: to achieve economic development to secure rising standards of living both now and for future generations; and to protect and enhance the natural and built environment now and in the future.

There are opinions in our community that human activity is so intense on this small, densely populated island that sustainable development is not possible in Bermuda. Whatever the position taken, nobody can disagree that the need to strive toward sustainable development is critical. In order to maintain and improve the air that we breathe, the water that we drink, the ocean in which we swim and our quality of life as a whole, we must minimise damage to our environment.

Whilst this report discusses most of Bermuda's current and major environmental issues, it is does not cover every topic and is not intended to provide specific solutions to the problems or set targets or goals to work toward. These will come later. Rather, it provides an information source which improves public understanding of the Island's environmental issues and helps to guide policy making. The production of this SoE report is a first step in tackling the complex issues of defining what the Island's carrying capacity is and establishing the foundations for the production of a long term sustainable development strategy for the Island.

It is hoped that the general community, students, educators, managers and policy makers will read and deliberate on this report. It should help everyone to be better informed about the state of Bermuda's environment, the pressures we exert on it and the effectiveness of Government's policies and decisions to manage it effectively. It should further be a basis for discussion and deliberation in order that everyone can participate in choosing and working toward the kind of environment we desire in the future.

Overview of Bermuda

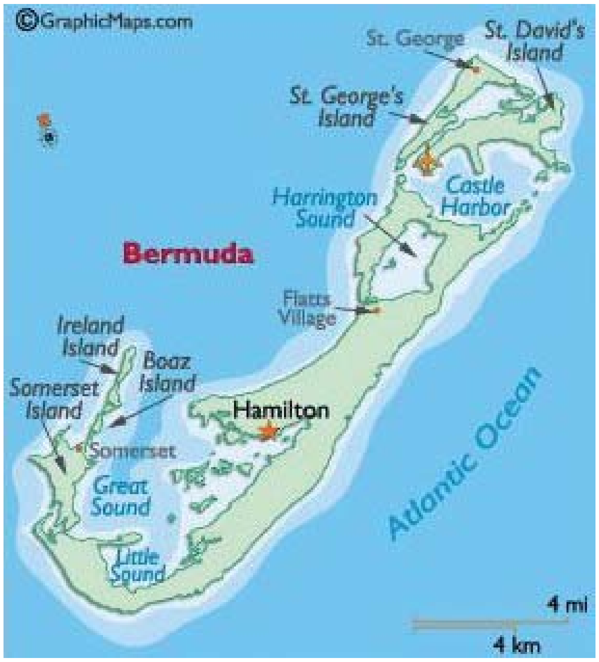
Bermuda consists of a group of over 150 islands and islets. It lies isolated in the western Atlantic Ocean at latitude 32º 19' N and longitude 64º 46' W giving it a sub-tropical climate. The closest point of land is Cape Hatteras, North Carolina, which is 965 km (570 miles) to the west. Often mistaken as a Caribbean island, Bermuda lies over 1,200 km (746 miles) to the north of the nearest Caribbean island.

Unique in that it forms the most northerly coral reef system in the world, Bermuda lies on the southern rim of the largest of three steep-sided seamounts. The two other sea-mounts, Challenger Bank and Argus Bank, lie submerged between 19 and 32 km (12 and 20 miles) to the south west of Bermuda. Originating through two periods of volcanic activity approximately 110 million years ago and 33 million years ago, these mounts rise from a depth of 4,270 m (14,000 ft) from the floor of the Atlantic Ocean.

On top of the volcanic pedestal, the shallow-water Bermuda platform comprises a limestone cap which is up to 100 m (300 ft) thick, and encompasses an area of approximately 1000 sq. km. (386 sq. miles). The very permeable nature of the limestone means that there are no rivers, streams, or freshwater lakes. Residents obtain their water primarily from rain that is collected from rooftops and stored in tanks.

In total the Island is 53.6 sq. km. (20.7 sq. miles). There are six main islands comprising Bermuda (also called Great Bermuda and Main Island) which is the largest, Somerset Island, Ireland Island, St. George's Island, St. David's Island and Boaz Island (see Figure i). The islands are connected by causeways and bridges to form a continuous fishhook-shaped landmass that stretches approximately 21 miles in length and averages less than a mile across (see Figure ii).

Figure i. The Islands of Bermuda



Source: Graphic maps.com

Figure ii. Aerial photo of Bermuda

Photo courtesy of the Department of Tourism

Bermuda is divided into nine parishes which are, from west to east, Sandys, Southampton, Warwick, Paget, Pembroke, Devonshire, Smith's, Hamilton, and St. George's.

Topographically Bermuda consists of a series of low-rolling hills with a maximum height of only 70 m (260 ft) at Town Hill in Smith's Parish.

Bermuda enjoys a mild climate because of the warming effects of the Gulf Stream. Another factor that gives Bermuda its sub-tropical climate is the Bermuda-Azores high-pressure system. Bermuda is far enough north to experience prevailing winds from the southwest. Hurricanes often pass by the Island and make landfall at Bermuda every few years.

Bermuda takes its name from the Spanish sea captain Juan de Bermúdez, who discovered the uninhabited islands around 1503. However, the Spanish did not claim the islands and no settlement was established at this time.

In 1609 Admiral Sir George Somers was en route from England with supplies for the recent British settlement at Jamestown, Virginia, when his ship, *Sea Venture*, was shipwrecked off Bermuda. Sir George Somers built replacement ships of Bermuda cedar but left some men behind to establish a British claim to the islands. The British renamed Bermuda the 'Somers Islands' in honour of the admiral but this name did not stick.

The Virginia Company took a keen interest in the islands and in 1612 a second group of British colonists arrived. However, they found that the shallow topsoil allowed limited agriculture and the lack of water prevented some commercial crops, including sugar cane, from being grown. The settlers started to import food from the American colonies, traded for with salt from the Turks and Caicos Islands.

In 1684, Bermuda became a British crown colony. Slaves were first introduced in 1616, most of them being brought from Africa. Later on Portuguese labourers from the Madeira Islands and the Azores were brought to the islands.

During the War of 1812, the British Navy used Bermuda as a base and during the American Civil War (1861 to 1865) confederate blockade runners were based in Bermuda.

Princess Louise, daughter of Queen Victoria, is credited with putting Bermuda on the tourist map after visiting the islands in 1883. By the turn of the century, Bermuda was becoming a fashionable winter destination for those wanting to escape the North American winter.

Bermuda's strategic location in the Atlantic established it as the winter naval station for British North Atlantic and West Indian squadrons. During World War II, sites on the islands were leased for 99 years to the United States for naval and air bases.

These sites were vacated in 1995. The United States also constructed an air base on St. David's Island, where the international airport is now located.

Bermuda became a self-governing dependency of the United Kingdom in 1968. The Bermuda Parliament produced a constitution that provided for full internal self-government, while leaving security, defence and diplomatic affairs to the Crown.

The Government of Bermuda consists of a Governor, a Deputy Governor, a Cabinet and a Legislature. The Governor, appointed by the British Crown, is responsible for external affairs, internal security, defence and the police and is advised by an executive council on other matters. The executive council consists of the Premier, who is the head of the governing party, and at least six other members of the Legislature. The Legislature comprises the elected House of Assembly and an appointed Senate. The 36 members of the House are popularly elected for terms of up to five years. The political organisations are the Progressive Labour Party, the United Bermuda Party and the National Liberal Party.

The Progressive Labour Party is the current Government elected in 1998. It retained power in 2003 in an historic election that introduced single seat constituencies. The current leader of Government is Premier The Hon. W. Alexander Scott. The current opposition party is the United Bermuda Party.

Bermuda's GNP in 2003 was over $2.3 billion, giving a GNP per head of more than $37,000, the fourth highest in the world.

The ‘twin pillars’ of Bermuda’s economy are its international business and tourism industries. The development of Bermuda's thriving financial sector began in the 1950s and today a wide variety of financial services are represented on the Island. By April 2002, Bermuda had 13,305 locally registered international companies 337 of which had a physical presence on the Island. In 1999 some 3,355 people were employed by the international business sector, 53% of whom were Bermudian. In 2002, this sector employed 3,587 people, 55% of whom were Bermudian.

Tourism was once the mainstay of Bermuda’s economy and peaked in 1980 with 491,000 visitors arriving by air and 118,000 cruise ship visitors. By 2002, however, air arrivals had declined to 351,923 whilst cruise ship arrivals had increased to 225,000. Cruise ship passengers make a smaller contribution to the local economy than do visitors who arrive by air and mostly stay in visitor accommodations on the Island.

Other industries include the manufacturing of structural concrete products, paints, perfumes and ship repairing.

A very small portion of the Island is under cultivation mainly for producing bananas, vegetables and cut flowers. Local food production includes vegetables, fruit, milk, honey and eggs. Food supplies and fuels form the major part of imports to Bermuda.

The number of persons who were employed, according to the Census 2000, was 36,878 of the population and 1,001 were unemployed (3% unemployment rate).

The estimated de facto population (or all people on the Island on Census day) including visitors and the institutional population, in 2000, was 66,545 whilst the de jure population (people normally living in Bermuda) was 62,059. Bermuda has a population density of nearly 3,000 persons per square mile. According to the Census 2000, there were 25,148 households on the Island, an increase of 12% since 1991.

The City of Hamilton is the capital and main commercial centre. The other main commercial centre is the Town of St. George.

Bermuda's small size, high-density population and half million visitors per year inevitably cause stress on the environment. These stresses will be examined in the following chapters.

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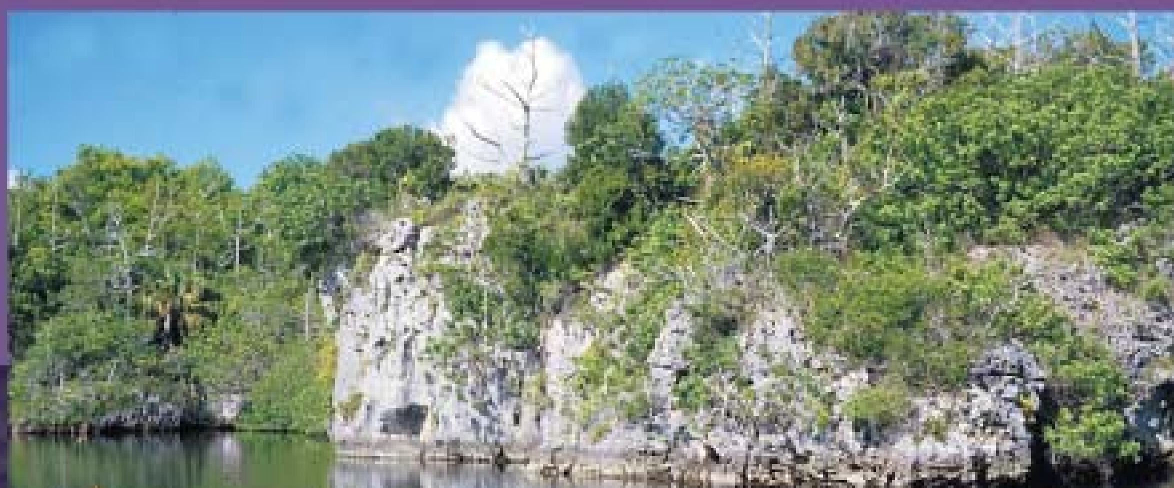
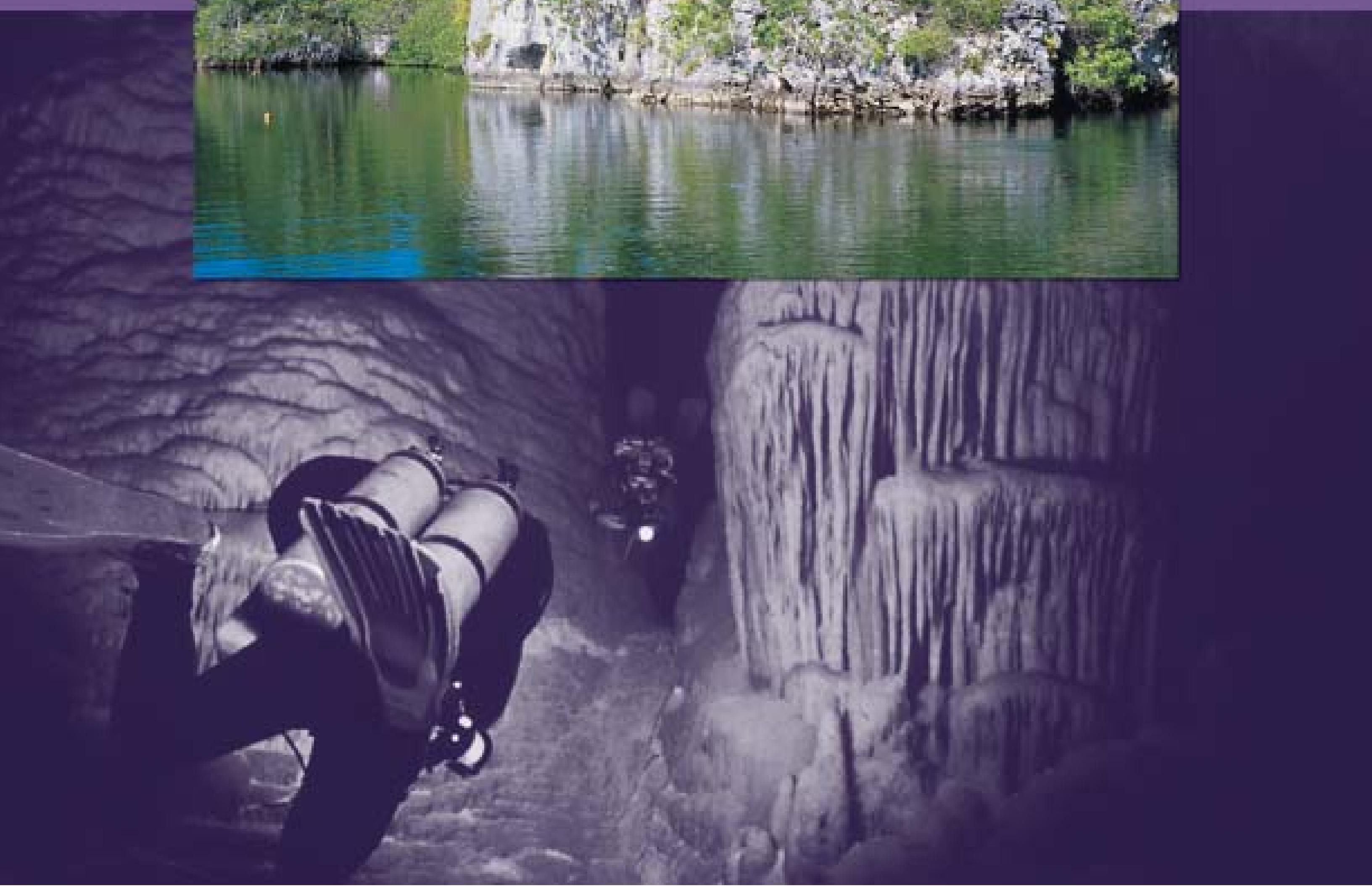
I

Natural Resources and Biodiversity





Chapter 1

Climate and Air

1

1.1 Climate and Weather

1.1.1 Introduction

Bermuda's climate has been described as one of its chief assets and a significant factor behind the Island's success as a desirable tourist destination.

Climate may be defined as the long-term atmospheric conditions over a given location. Weather, on the other hand, may be defined as the short-term conditions that contribute to climate. There are several factors contributing to the clemency of Bermuda's climate. This section explores some of the meteorological phenomena that comprise Bermuda's weather.

The weather experienced in Bermuda is interesting for a number of reasons, not least is its variation during short time-spans between minutes and days. This is in light of larger time-scales (weeks to months), when there is little average change in prevailing conditions. During the summer months, long periods of settled dry weather are punctuated by the odd heavy downpour in the form of showers or thunderstorms.

In the winter, the passage of frontal systems through the Bermuda area bring longer periods of rainfall, after which there are a few days of exceptionally cold and windy weather. There is little deviation from these typical two weather patterns, except when extreme and rare weather events are experienced, such as during the passage of a hurricane. These weather patterns are largely a consequence of Bermuda's location and geography.

1.1.2 Marine Influences on Bermuda's Climate

Bermuda's size and isolation from continents place the Island in an essentially marine environment. Very little effect is imposed on the local weather or climate by the small surface area of the archipelago. This marine environment is one of the most important factors influencing local conditions. Water has a higher capacity for absorbing and retaining heat than that of land. The result is that continents heat up and cool down more quickly and readily than oceans. The oceans are a great storage and source of heat, imposing a moderating influence on the lower atmosphere, compared to the continents.

While inland continental temperatures may be highly variable with scorching summers and frigid winters, changes in marine air temperature are relatively small, with mild winters and cool summers. This is evident in Bermuda, with average daytime high temperatures in the upper 60s °Fahrenheit (°F) during the winter months, and daytime highs rarely exceeding 90 °F in the summer (see Table 1.1).

Table 1.1 Bermuda's climatology 1949–1999 – mean temperature statistics

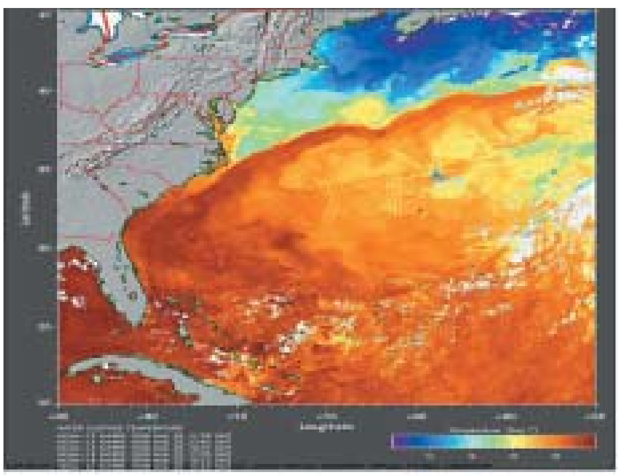
	TEMPERATURE							MEAN SEA TEMP
	Mean Monthly	Mean Daily		Extreme				
MONTH		High	Low	High	Year	Low	Year(s)	
January	64.8	68.7	60.9	77.0	1994	46.0	55,82,89	66.2
February	63.9	67.8	59.9	79.0	1991	44.0	1950	65.4
March	64.4	68.6	60.2	79.0	1990	45.0	1951	65.2
April	66.7	70.8	62.5	81.0	72 & 89	48.0	1971	68.0
May	71.6	75.4	67.8	86.0	1988	55.0	81, 84	72.1
June	76.8	80.6	73.0	90.0	1988	64.0	51,57,80,96	77.3
July	80.0	84.6	75.3	91.6	1994	68.0	51, 62, 70	81.6
August	80.9	85.7	76.1	93.0	1989	68.0	1957	82.8
September	79.1	83.8	74.3	91.8	1994	66.0	1986	81.2
October	75.0	79.4	70.6	89.0	1993	58.0	1972	76.8
November	70.1	74.5	65.7	84.0	1993	54.3	1996	72.7
December	66.2	70.6	61.7	80.0	1978	50.0	1955	68.0
Year	71.6	75.9	67.3	93.0	1989	44.0	1950	73.1

*Note: Temperature measured in ˚F. ˚C=5/9(˚F-32) e.g. 73˚F-22.8˚C *Sea Surface Temperature data are for the period 1949 to 1992*
Source: Bermuda Weather Service

Continental locations on the same latitude may experience greater ranges in temperature. One example is Birmingham, Alabama (at ~33.5 °N in the southern United States), which experiences nighttime low temperatures in the low 30s °F in winter to a few days with temperatures in the 100s °F during the height of summer.

Another major contributing factor to Bermuda's mild climate is its proximity to the Gulf Stream. The Gulf Stream is an oceanic current, which transports warm water from the Gulf of Mexico to the North Atlantic, skirting the eastern coast of the North American continent. Gulf Stream sea surface temperatures in the mid-latitudes are typically around 70 °F, compared with northern mid-Atlantic sea surface temperatures a few degrees cooler (see Figure 1.1), and much colder temperatures to the north of the current.

Figure 1.1 Satellite image showing Atlantic Ocean sea surface temperature



Note: The Gulf Stream is represented by the pronounced plume of warm SSTs (red and orange on this image) protruding northeast from the Gulf of Mexico.
Source: Johns Hopkins University Applied Physics Laboratory, 1996

Bermuda receives an average annual rainfall of 55.5 inches (1,410 mm) which tends to be fairly evenly distributed throughout the year (see Table 1.2).

Such an abundance of warm water contributes to the formation of an unstable boundary layer (the lowest level of the atmosphere upon which there are surface effects). Convection, (the process by which warm air rises, cools, and expands), is one of the main mechanisms for cloud formation and it is enabled and enhanced by an unstable atmosphere. The result is increased convection over sub-tropical marine areas (compared with continental locations at similar latitudes), and therefore, more convective clouds (e.g., cumulus, cumulonimbus) than layer clouds, such as stratus.

One other marine effect on cloud formation is the abundance of large cloud condensation nuclei. The formation of cloud droplets in the atmosphere is favoured by the presence of a surface on which water may condense when the air reaches its dew point. These surfaces are provided by suspended particles in the atmosphere, which are called cloud condensation nuclei (CCN). CCN with continental origins are mainly composed of dust and pollution, whereas the main composition over marine environments is aerosol salts from sea spray and bubble bursting at the surface.

Table 1.2 Bermuda's climatology 1949–1999 – mean precipitation and wind statistics

	PRECIPITATION							Thunderstorm	Prevailing Wind*	
	Mean	Extreme								
MONTH	Monthly	Most	Year	Least	Year	Rain Days		Days	Direction	Speed
January	5.06	9.86	1958	0.54	1950	17		3	SW	13
February	4.54	9.79	1972	1.56	1950	15		2	W	14
March	4.33	9.83	1986	1.31	1989	15		3	W	15
April	3.46	8.62	1984	0.33	1973	12		3	SW	13
May	3.26	11.7	1997	0.28	1991	10		3	SW	11
June	5.13	14.18	1962	0.84	1974	12		4	SW	11
July	4.51	10.58	1957	0.74	1975	13		5	SSW	10
August	5.15	12.23	1997	1.44	1967	14		9	SW	10
September	5.09	11.15	1983	0.94	1985	15		6	E	9
October	6.35	14.55	1967	0.96	1949	16		3	E	11
November	4.12	10.54	1962	0.78	1952	13		3	SW	11
December	4.50	11.73	1960	1.07	1999	17		2	W	13
Year	**55.50**	**75.42**	**1962**	**37.14**	**1975**	**171**		**46**	**SW**	**12**

Note: Differences between the sum of the monthly mean rainfall and the annual total, and similarly for rain days, are due to round-off error. A Rain Day is defined as any day with precipitation greater than or equal to one hundredth (0.01) of an inch.
** These data are for the period 1949 to 1992. Rainfall measured in inches. Wind speed measured in knots. (1 knot = 1.15M.P.H).*

Source: Bermuda Weather Service

Marine CCN are typically larger in diameter than continental CCN and so produce larger cloud droplets. The result is twofold: (a) marine cloud droplets are able to coalesce with others more readily than continental droplets, and are therefore rained out of clouds more quickly and (b) rain falling from marine clouds tend to have larger droplet sizes than continental drops. Therefore, Bermuda enjoys a significant amount of rain from convective clouds, in the form of showers and occasional thunderstorms.

Bermuda is also occasionally affected by other phenomena associated with a marine climate, such as tropical cyclones, water spouts and sea fog. Other large, or synoptic scale features, such as frontal zones, non-tropical cyclones ('lows' or depressions) and anticyclones ('highs') are modified over the ocean and frequently have differing characteristics than those over land areas.

The marine environment therefore has many implications for the climate and weather of Bermuda. The heat absorbed and stored by the ocean, complemented by the proximity of the Gulf Stream, ensures that there is an abundant source of energy for maintaining the mild temperatures that Bermuda enjoys all year round.

1.1.3 Seasonal Changes in Bermuda's Weather

It is a popular statement that Bermuda has two main seasons, winter and summer. The summer weather in Bermuda is typically warm with sunny periods and occasional showers, sometimes heavy and accompanied by thunder. Light to moderate southwesterly to southeasterly winds prevail, maintaining a source of warm, humid air from tropical regions. Winter weather is dominated by the passage of frontal systems over the Island and cyclonic storms that mainly pass to the north of the local area but can approach from other directions as well. These can produce large amounts of rainfall and temperatures dropping below 60 ºF. The spring and autumn months are typically transitional periods between these two phases and exhibit elements of both seasons.

Summer Weather (June – September)

One of the main effects that the marine environment has on Bermuda's local weather is that for much of the year, the average air temperature does not depart from the sea surface temperature by more than a few degrees Fahrenheit. So, during the summer months while the sea is particularly warm, the air temperature remains warm as well, even in an airflow that is from a generally cool source region.

Bermuda's position in relation to the global atmospheric circulation is also complicit in determining the local conditions. The local weather is often influenced by a large area of anticyclonic high pressure, often referred to as the 'Bermuda High', which dominates the northern Atlantic during the summer months. It is also known as the 'Azores High' or 'Bermuda/Azores High'. Anticyclones, such as the Bermuda High, have a clockwise rotation of winds around the centre of the high pressure. The centre of the Bermuda High is most often orientated to the east and southeast of the Island so the local prevailing wind direction is south to southwesterly. Later in the summer, the high pressure belt tends to move north, with southeast to easterly winds predominating over the Island.

Another effect of the strong Bermuda High during the summer is the blockage of frontal systems moving through the area. The main rainfall events comprise showers or thunderstorms, which mainly develop as individual cumulus or cumulonimbus cells, and are fairly short-lived, usually producing less than an hour of rainfall locally per event. Occasionally however, when the pressure gradient is slack and winds are light, slow-moving clusters of convective clouds may develop over the Island during the day. These effects are amplified when the light winds are from the southwest, or northeast (i.e., aligned with the geographical orientation of the Island) and often result in prolonged heavy showers, with accumulations of several inches of rainfall over 'favoured' areas of Bermuda.

The occurrences of hurricanes and tropical storms are also major events during the summer months and are revisited later in this chapter.

Autumn Weather (October – December)

During this period, the Bermuda High weakens and begins to allow the passage of frontal systems into the area. This season is often the most varied because the weather switches between a typically summer scenario and a winter pattern. The beginning of this season also heralds the most active portion of hurricane season in the North Atlantic, so these meteorological phases may be further disrupted by the passage of a tropical cyclone.

Cold fronts, which move into the local area during this season, are usually fairly weak in intensity by the time they reach this latitude. Often these fronts will approach from the northwest and weaken, producing showery rain as they move across the Island, and stall to the south. Occasionally, these stalled fronts will move back north over Bermuda as warm fronts, producing long periods of rain and drizzle.

Winter Weather (January – March)

The further weakening of the Bermuda High, and the subsequent invasion of well-developed cold fronts and North Atlantic storms into the region indicate the onset of winter weather in Bermuda. Thunderstorm activity and heavy rain are often associated with these storms, with frequent gales (mean winds of 34 knots or more) and occasional storm force winds (48 knots or more). These strong winds normally blow out of the southwest ahead of the cold front, switching to northwesterly on the frontal passage, often bringing very cold air into the area for a day or so. Temperatures occasionally can plummet to below 50 °F.

In late winter, the sea surface temperature typically drops to the low 60s °F. Cool air is not warmed as much by the ocean surface, as it is in the summer and autumn months. Air temperatures struggle to reach 70 °F by day and occasionally drop to the 50s °F and low 60s °F. In the occurrence of very cold air (<55 °F at the surface) invading the area behind a cold front, vigorous convection may be triggered by the temperature difference between the cold air and the warmer sea. In this scenario, heavy showers and thunderstorms with hail may affect the local area. The downdrafts created by these convective elements can cause very gusty winds and cold conditions. The lowest temperatures recorded in Bermuda have normally occurred in such circumstances.

During late February and March advection fog (also known as sea fog) can occasionally occur, when moist air of tropical origin affects the Island. Providing that winds are fairly light, the air in contact with the cold sea surface is cooled to its dew point (the temperature at which condensation occurs for a given air mass), causing fog (suspended water droplets) to form. With increasing wind the fog is lifted into a broken or overcast layer of low cloud (stratus). As a consequence of an absence of any major meteorological feature (e.g., frontal systems), persistent stratus frequently occurs with southwesterly winds in late winter and spring.

Spring Weather (April – May)

As with the autumn season, spring tends to be a mixture of weather patterns, with the Bermuda High building in and migrating northward. This high pressure tends to block active cold fronts from moving into the area. Cold fronts that do approach as far south as Bermuda from the northwest may not be as active as those experienced during the winter months. Occasionally during spring, depressions will move into the area from the southwest, and move northeast over Bermuda. The warm fronts associated with these low-pressure centres may bring overcast conditions with periods of rain and drizzle over Bermuda.

Hurricane Season (1 June – 30 November)

Hurricanes are intense marine weather systems that produce dangerous winds and seas that can be devastating to coastal and island environments. Bermuda is located in an area that is susceptible to tropical cyclone impact and is occasionally affected by the passage of hurricanes (see Figure 1.2).

Figure 1.2 Hurricane charts of the North Atlantic

Note: The most common area of June and September hurricane formation displayed in the boxes shown.
Source: Bermuda Weather Service

Hurricane season in the North Atlantic basin typically spans a full six months of the year from June through November, with overall tropical cyclone activity usually increasing as the season progresses, and peaking in the months of September and October. Tropical cyclones (TCs) may be categorised into tropical depressions, tropical storms and hurricanes (which are also known as typhoons or cyclones in other parts of the world), based on wind strength and central pressure (see Table 1.3).

Table 1.3 Saffir-Simpson scale for tropical cyclone classification

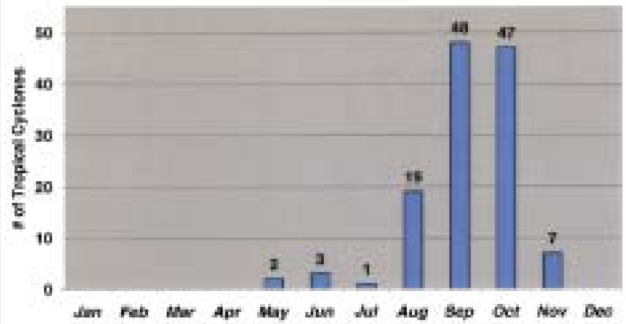
	Category	Pressure	Winds		Storm Surge
		Millibars	knots	mph	feet
Tropical Depression	TD	-----	<34	<39	-----
Tropical Storm	TS	-----	34-63	39-73	-----
Hurricane	1	>980	64-82	74-95	5-Apr
Hurricane	2	965-980	83-95	96-110	8-Jun
Hurricane	3	945-965	96-112	111-130	12-Sep
Hurricane	4	920-945	113-134	131-155	13-18
Hurricane	5	<920	>134	>155	>18

The initial formation of tropical cyclones is normally dependent on the presence of a deep layer of warm water at the ocean surface (temperature ≥82 °F), a moist and unstable atmosphere, a pre-existing disturbance (e.g., tropical wave or an old cold front), an environment of little or no vertical wind shear and a distance of at least 5° latitude away from the equator (to allow a rotational component to be established from the spin of the Earth). The presence of each of these parameters is necessary for tropical cyclone formation.

Throughout Bermuda's history, hurricanes have mainly approached from the south and west but have been known to advance from almost every direction. Hurricane season for the Northwestern Atlantic is most active during late summer and early autumn, as this is the time of warmest sea surface temperature over the tropical Atlantic, where most over the TCs are generated. Also during this time, the middle atmospheric winds (at the 10 to 20 thousand feet level) tend to steer the systems westward and then on a recurving path northwards around the Atlantic high pressure region (Figure 1.3).

North of Bermuda, hurricanes tend to lose their tropical characteristics, becoming 'extra-tropical' and rapidly moving to the northeast, where they dissipate or develop into normal depressions over the colder ocean surface. Occasionally the reverse process can occur, whereby TCs form from extra-tropical features such as cyclonic circulations in the upper atmosphere or old frontal zones.

Figure 1.3 Seasonal distribution of tropical cyclones passing within 180 nautical miles of Bermuda 1871–1979



Source: U.S. Navy data

Sub-tropical Storms

There has been much recent debate amongst meteorologists regarding the nature of sub-tropical cyclones, despite the fact that descriptions of their characteristics have been documented as early as the 1950s. Cyclones with fairly ambiguous origins and/or structures have often been classified as sub-tropical. When observing and forecasting sub-tropical cyclones, a consensus cannot always be reached regarding the extent of their tropical characteristics. Indeed, sub-tropical cyclones often form from old frontal systems and undergo transition into tropical cyclones.

As the weather produced both by sub-tropical and tropical cyclones is similar, the lay person does not notice any real distinction between the two. As a result, in 2002 tropical forecasters at the U.S. National Hurricane Center began to assign names to Atlantic sub-tropical cyclones, in the same way that tropical cyclones are named.

Bermuda's geographical location makes the Island vulnerable to these storms, as was demonstrated by the development of sub-tropical storm Karen on 11 and 12 October 2001. Winds were recorded up to 92 knots and widespread power outages and boat damage were reported during Karen's passage.

1.1.4 Selected Hurricanes

Hurricane Emily

On 25 September 1987, Hurricane Emily unexpectedly strengthened from Tropical Storm status and accelerated towards Bermuda, to pass directly over the Island just after dawn. Southeasterly winds of 50 knots were reported at the airport, with gusts up to 70 knots. The eye of the storm passed directly over Bermuda at around 9 a.m. local time, causing a brief period of calm winds and clear skies, before hurricane force winds of 60–80 knots began again from the northwest. There was evidence of tornado activity embedded within some of the more active rain bands in the system and nearly two inches of rainfall recorded. Although only a Category 1 Hurricane, Emily caused considerable damage to property on the Island, especially in areas affected by tornadoes.

Hurricane Felix

The year 1995 had a particularly active hurricane season, with 20 named storms in the Atlantic. On 14 August, Category 1 Hurricane Felix passed within 50 nautical miles of Bermuda, with marginal hurricane force winds affecting the area. However, three days of pounding surf badly eroded the south shore beaches and caused considerable damage to some beachfront properties.

Hurricane Gert

On 21 September 1999, Category 2 Hurricane Gert passed about 120 nautical miles to the east of Bermuda. Sustained winds of 30–40 knots occurred locally, with hurricane force gusts reported at the airport and at Harbour Radio. In the days prior to passage of Gert, heavy pounding surf damaged waterfront property and eroded beaches on the south shore.

Hurricane Karen

The 2001 season was quite active with seven TCs affecting the Island to some extent. The most noteworthy was Karen, which was technically classified by The National Hurricane Center in Miami as a sub-tropical storm when it passed by Bermuda on 11 September, although arguably it was, at that stage, of minimal hurricane strength.

There was considerable damage to vegetation and power supplies, with around 22,000 of the 30,000 power subscribers without electricity by the morning of 12 September. All schools and government offices, and many private businesses remained closed that day. There was also considerable damage and disruption to the marine community, including the two cruise ships that were in port.

Hurricane Fabian

Hurricane Fabian struck Bermuda on 5 September 2003 with its most powerful part, the eyewall, passing directly over Bermuda during the afternoon and evening hours, with maximum sustained winds of 105 knots and gusts up to 130 knots. It tragically caused the deaths of four people when they were swept off the Causeway. As a top-end Category 3 hurricane, Fabian was among the most powerful hurricanes to have directly impacted the Island in the last 150 years.

A very strong storm surge with huge battering waves caused extensive damage to the coastline, especially along the south shore (see Figure 1.4 a and b). The winds blew down hundreds of trees Island-wide. Power was lost in the majority of homes and businesses outside the City of Hamilton, with approximately 25,000 out of 32,031 electricity meters going out of service; however, restoration of power to all customers took only three weeks. Hurricane Fabian weakened parts of the electrical supply distribution system and a rehabilitation plan was implemented in October 2003.

There was damage to roofs from the loss of roof slate, damage to watercraft, flooding and damage to structures in coastal storm surge areas. Two large hotels suffered major damage and were closed for repairs until the spring of 2004.

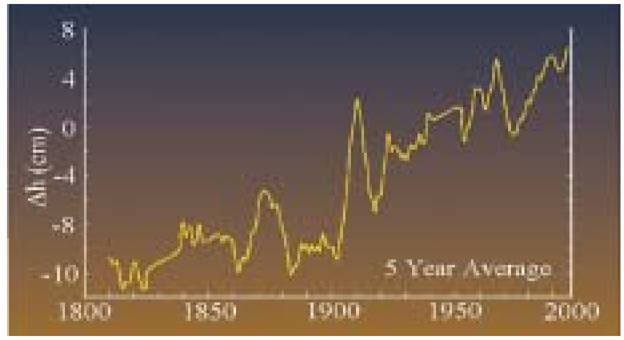
Figure 1.4 (a) John Smith's Bay before Hurricane Fabian

Photo courtesy of the Department of Planning

Figure 1.4 (b) John Smith's Bay after Hurricane Fabian

Photo courtesy of the Department of Planning

Figure 1.5 Sea level changes



Note: Sea level is changing. Observing stations from around the world report year-to-year changes in sea level. The report are combined to produce a glodal average time series. The year 1976 is arbitrarily chosen as zero for display purpose. (From Chapman, 1988).
Source: Chapman, 1988

Insurers estimated the damage caused by Hurricane Fabian in terms of local claims to total $125 million. In addition, the total claims of risks insured overseas, such as hotel and government property, is unknown but could add at least another $75 million to this total. (Titterton, 2003, pers comm.) In addition, there were uninsured losses ranging from citizens who did not insure their home contents to the damaged Causeway. In the future, the Government will produce an estimate of economic loss, for example, from hotel closures and other business affected by the hurricane damage.

1.1.5 Other Climate Issues Impacting Bermuda

Changes in global climate, on various time-scales, may have direct and indirect impacts on Bermuda. The greenhouse effect, global warming, ozone layer depletion and short time-scale atmospheric oscillations such as El Niño are some of the issues that not only affect the global climate but Bermuda's environment as well.

It has been hypothesised by climatologists that one direct effect of global warming would be sea level rise. Clearly, this is of concern, as Bermuda is composed of fairly low-lying islands, with elevations not exceeding 250 feet. Any significant rise in sea level in the North Atlantic would threaten to inundate the coastal areas of Bermuda. Such low-lying areas under threat include the International Airport, the Causeway connecting St. David's and St. George's to the main island, and businesses along Front Street in Hamilton. Sea level rise has been documented at various coastal locations around the globe and the data has indicated that mean sea level is rising (Figure 1.5).

The El Niño Southern Oscillation (ENSO) has a major impact on the hurricane season. During El Niño events, there is a marked decrease in hurricane season activity in the North Atlantic. The converse is true of La Niña years. In 1995 (a La Niña year), there were 20 named Atlantic storms, contrasted with eight in 1997, which was an El Niño year.

Changes in hurricane season activity during El Niño and La Niña events do not necessarily affect changes in the probability of a direct hit on Bermuda. Preliminary investigations by the Bermuda Weather Service indicate no obvious correlation between ENSO and the local occurrence of hurricanes. In fact, the last hurricane centre whose eye moved over the Island (Hurricane Emily in 1987) occurred in an El Niño phase, when Atlantic hurricane activity was at a low point. The initial relaxation of the trade winds, which triggers El Niño events, is still a topic of intensive research, as is the relationship between ENSO and Atlantic hurricane season activity.

1

1.2 Oceanography

This section briefly considers the main environmental concerns facing the North Atlantic Ocean surrounding Bermuda. Issues covered include plant and animal life, habitats, threats from pollutants and the introduction of protective measures.

1.2.1 The Sargasso Sea

The Sargasso Sea is an anticyclonic gyre in the central North Atlantic Ocean. Bermuda is its only landmass. Traditionally the boundaries of the Sargasso Sea were defined by the presence of pelagic Sargassum species. However, the Sargasso Sea is now defined in terms of physical boundaries – the Gulf Stream to the west, the North Atlantic Current to the north, the Canaries Current to the east and the North Equatorial Current to the south.

The Sargasso Sea is generally relatively free of pollution. The main environmental concerns within the Sargasso Sea area are long-range transport of contaminants from North America and some tar contamination from shipping traffic.

The Sargasso Sea has typical abyssal depths of 4,000 metres. The main organisms are pelagic and mid-and deep-water organisms of the Atlantic Ocean. Dr. William Beebe described many of these organisms in his record of bathyscaph dives off Bermuda in 1932, which resulted in the first live radio broadcasts from the deep ocean. Of specific interest in the Sargasso Sea are (1) the general biogeochemistry of the area that defines the open ocean communities, (2) the Sargassum community, (3) the annual eel migration/spawning activity and (4) the migration of marine mammals.

(1) The biogeochemistry of the area around Bermuda

It is thought that more is probably known about the Sargasso Sea area southeast of Bermuda than any other open ocean area in the world, for it has been the site of a number of long-term monitoring programmes. The longest, Hydrostation S., located 22 km southeast of Bermuda, was started by Henry Stommel and his colleagues in 1954 (Schroeder and Stommel, 1969), and is the longest continuous running open ocean time-series in the world. Bi-weekly sampling of hydrography at the site continues and provides critical information on the physical structure of the ocean, as well as a decadal scale framework for Bermuda Atlantic Time-series (BATS) programme. The BATS programme is a long-term time-series study which examines biochemical cycles in the Sargasso Sea (Michaels and Knap, 1996).

(2) The Sargassum community

The Sargassum community is perhaps the most unique open ocean habitat. It maintains its population entirely by vegetative growth. *Sargassum natans* and *Sargassum fluitans* are the two common seaweed species. The alga is restricted to the surface where it maintains itself by gas-filled bladder floats. Growth and propagation result from seasonal fragmentation, usually during winter, of the larger and older plant. Surprisingly the total organisation of the Sargassum community is relatively unknown.

A field guide of the community (Morris and Mogelberg, 1973) noted 101 species, and as many as 54 species of fish spend their time associated with the Sargassum for some stage of their life stage; however only two species of fish spend their whole life cycle in Sargassum. Sargassum provides protection from predators for juvenile fish and four species of marine turtles and is a floating habitat for 145 invertebrates and numerous seabirds.

Sargassum was used in Bermuda as fertiliser. Presence of 'pelagic tar' in the seaweed contributed to the decline in its use. There was concern that less Sargassum was found around Bermuda's shores than in the past; however it has reappeared in abundance in 2002 and 2003. Little is known about Sargassum's variability. Harvesting of Sargassum for cattle and hog feed in the southeast Atlantic has been practised by U.S. fishermen. However, National Oceanic and Atmospheric Administration (NOAA) Fisheries has approved and commenced implementation of a federal conservation plan that will protect floating sargassum seaweeds. The conservation plan, which became law in November 2003, is the result of a six-year effort to protect one of the most important habitats in southeast waters from commercial harvesting.

(3) Eel migration/spawning activity

One of the interesting aspects of the Sargasso Sea is the spawning of the American eel (*Anguilla rostrata*) and the European eel (*Anguilla anguilla*). *Anguilla* occupy freshwater streams, rivers, brackish waters and the open ocean in various stages in their life cycle. They spawn in the Sargasso Sea, and ocean currents transport the developing larvae northward until the young metamorphose into juveniles and then move upstream along the continents.

(4) The migration of humpback whales

Bermuda is located about half way between the major western North Atlantic humpback whale breeding areas in the Antilles and the northern feeding grounds extending from the New England coast to Iceland. Therefore, Bermuda provides an excellent place for observation of this species (Katona *et al.*, 1980). There are many reports of the sighting of whales off Bermuda going back to the early settlers. However, it was not until 1902 when Verrill described their seasonality as arriving off Bermuda in late February or early March and leaving at the beginning of June, mostly accompanied by suckling cubs (Verrill, 1902).

Whaling began in Bermuda in 1911 and finished in 1942. It has been suggested that the humpback whale population off Bermuda has decreased since the 17th, 18th and 19th centuries (Stone *et al.*, 1987) but this may be due to migration prompted by better food availability in other areas.

1.2.2 Environmental Concerns

There are a number of environmental concerns with regard to the Sargasso Sea. These are as follows:

(1) Tar

Due to tanker routes crossing the Sargasso Sea and the past practices of cleaning tanks in the open ocean, large quantities of petroleum residues were captured by the Sargasso Sea gyre. Generally tar in the open ocean lasts for up to a year before it breaks up into small particles. There have been reports in the 1970s of tar lumps the size of soccer balls being washed up onto local beaches. However, tar studies in Bermuda have demonstrated a continued decline in tar found on local beaches that indicate that newer operational methods for cleaning tankers and international pollution agreements appear to be working.

(2) Atmospheric transport of contaminants

Long-range atmospheric transport is responsible for the transfer of many types of contaminants to the Sargasso Sea. For organochlorine compounds, such as polychlorinated biphenyls and pesticides, atmospheric transport is the main route of these compounds to the ocean.

There have been many long-term studies of atmospheric transport to the Sargasso Sea, primarily using Bermuda as a base. Church *et al.* (1982) first reported ‘acid rain’ in Bermuda and showed that rapid long-range transport from North America brought anthropogenic sulphate to the Sargasso Sea resulting in lowering the pH in Bermuda rainwater from around 7 to 4. This prompted the start of the Western Atlantic Ocean Experiment (WATOX) that used a site at the west end of Bermuda as well as ships and aircraft. The aim of the programme was to detail the mode and extent of transport of trace metals (Church *et al.*, 1982), organics (Knap *et al*, 1988) and sulphur and nitrogen compounds (Galloway *et al.*, 1992). Generally, other than trace elements, there is little contamination of the waters of the Sargasso Sea.

Local sources of contaminants in Bermuda are small with elevated concentrations near the main harbours and boat marinas.

(3) Marine debris

The percentage of marine debris that washes up on our shores originating from outside of Bermuda, compared to the percentage that is caused by Bermuda residents, is uncertain. However, much oceanic debris originating from continents and transatlantic crossings by ships gets drawn into the anti-clockwise motion of the Sargasso Sea and ends up on Bermuda’s shores.

1.2.3 Protective Measures

The Sargasso Sea is governed by international conventions regarding the discharge of waste from ships at sea under the 1973 Convention for the Prevention of Pollution from Ships (the MARPOL Convention). Bermuda has an Exclusive Economic Zone which extends 200 miles around the Island that is governed by fishing and pollution regulations.

1

1.3 Air Quality

1.3.1 Introduction

Air is by far the most vital element to the existence of human and other forms of life and while we can survive several weeks without food and days without water, only a matter of minutes need to lapse before we begin to suffer the detrimental effects of lack of air. Despite the high level of importance it plays in our survival, it is surprising how little regard we have sometimes for maintaining its quality.

Air is actually comprised of a combination of gases, principal of which are nitrogen (78%) and oxygen (21%), and other gases such as carbon dioxide, argon, neon and methane in smaller amounts. While oxygen is the main life-sustaining component, the other gases play an important balancing role in the overall composition. Oxygen at levels very much above or below 21% invokes deleterious bodily reactions.

It has been recognised worldwide that many of our day-to-day human activities play a significant role in adding a variety of 'contaminant' gases to the air mix, some at levels that are referred to as pollutants. Activities such as fossil fuel combustion and waste incineration are responsible for sulphur and nitrogen gases linked to acid rain, whereas hydrocarbons and nitrogen oxides are linked to ozone/smog, comprising suspended particulates with a variety of metals and carcinogenic organics. Many of these are related to diseases of the eyes, mucous membranes and lungs.

Table 1.4 The Clean Air Act, 1991

The Clean Air Act 1991

- Provides enabling legislation for the control, construction, and operation of plants with the potential to pollute the air.
- Establishes the Environmental Authority
- Defines controlled plants
- Provides legislation for:

  a. construction permits for controlled plants
  b. operating licences for controlled plants
  c. regulations
  d. rules
  e. emission control orders
  f. stop orders
  g. appeals to the Minister and to the Court
  h. rights of entry and inspection
  i. power to obtain information and request data offences

The Clean Air Regulations 1993

- Makes regulations prescribing the maximum permissible concentration of 9 ambient air contaminants.
- Controls open burning of prohibited debris and makes restrictions on burning of horticultural debris.
- Controls emissions of dark smoke
- Controls import, use and export of "controlled chemicals"
- Controls maximum sulphur content of fuels

The Clean Air Rules 1993

- Prescribes administrative and procedural matters pertaining to applications for construction permits and operating licences.
- Prescribes procedures for meeting of the Environmental Authority.
- Prescribes procedures for appeals against decisions taken by the Environmental Authority.

Source: Bermuda Government

1.3.2 Air Quality and Local Regulations

The status of air quality on the Island is a function of both long-range transport of pollutants from U.S. industrial regions and from local air emission sources such as the Bermuda Electric Light Company (BELCO), the Tynes Bay incinerator, vehicular emissions and various other point and diffuse sources. In the past, leaded gasoline and currently smoke stack emissions are responsible for the observed levels of metals, organic contaminants and the acidity in rain.

Road traffic is a significant source of air pollution on the Island. The number of vehicles has increased by some 400% since 1950. Motor vehicles are responsible for a variety of gases including lead, sulphur dioxide, nitrogen oxides, hydrocarbons and particulates. Nitrogen oxides and hydrocarbons are the main components in the formation of ozone/smog in many countries. Prior to 1991 automobiles were responsible for 25 tonnes of airborne lead annually. This has since been reduced by greater than 98% as a result of a change from leaded to unleaded gasoline.

Recognising the growing impact of local activities on air quality, in 1991 the Bermuda Government introduced the Clean Air Act, 1991. This Act was followed in October 1993 by the introduction of the Clean Air Regulations (see Table 1.4).

These Regulations were designed to place stringent controls on open burning, the storage of hazardous chemicals and the operation of facilities that emit gaseous and particulate pollutants into the local atmosphere. The Regulations set standards for nine ambient air pollutants: sulphur dioxide (SO2), nitrogen dioxide (NO2); ozone (O3); hydrogen chloride (HCl); hydrogen sulphide (H2S); total suspended particulates (TSP), inhalable particulates (PM10); carbon monoxide (CO); and lead (Pb); they also placed limits on the concentrations in the ambient air (see Table 1.5).

The Clean Air legislation was enacted to address air quality problems associated with, for example, sulphur in fuel oils, lead in gasoline, the local power company, incinerators, asphalt operations and cruise ship stack emissions, and to put into place a framework to control future pollutant emitters. Operators of facilities that emit pollutants to the air are now required to obtain operating licences.

1.3.3 Air Sampling and Testing

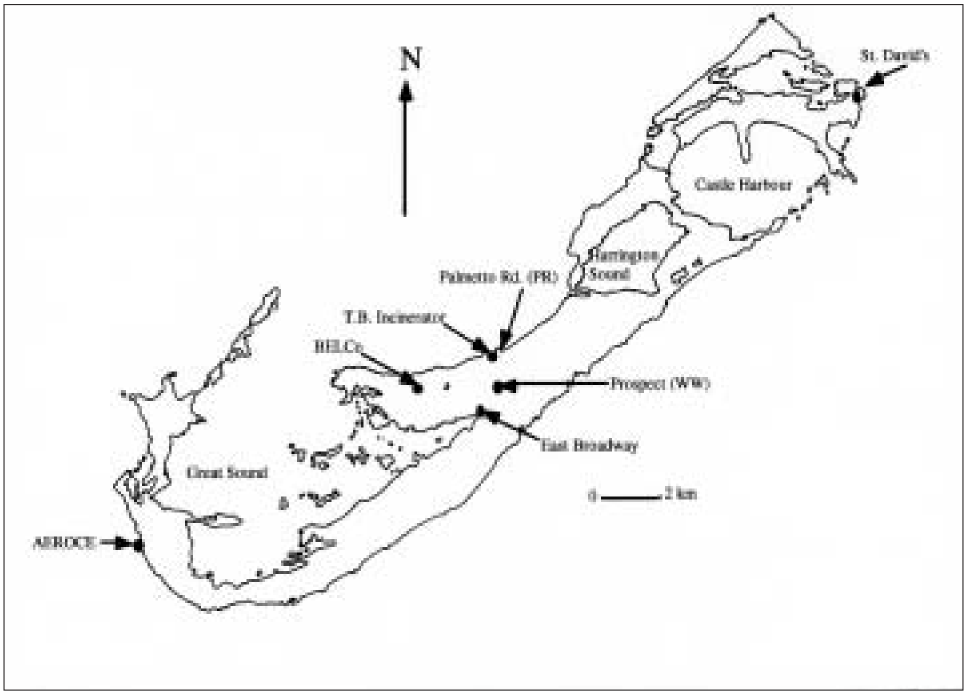
There are presently three government-funded sites at which air samples are being collected on a routine basis. At Prospect, the primary site, air quality is sampled on a continuous basis for precipitation, aerosols and pollutant gases. At the two other sites (East Broadway and BELCO) the samples are tested every six days for total suspended particulates (TSP) (see Figure 1.6). Previously, sampling has also been conducted at Palmetto Road (PR), St. David's (SD) and Tudor Hill, Southampton, and these have also produced data which is generally available as part of the database.

Table 1.5 Bermuda's air quality standards established October 1993

Air Pollutant	Measurement	Annual Arith. Mean	30 Day Average	24 hr. Average	8 hr. Average	1 hr. Average	1/2 hr.
sulphur dioxide	ppb	11	-	57	-	172	-
hydrogen sulphide	ppb	-	-	3	-	10	-
nitrogen dioxide	ppb	32	-	106	-	213	-
hydrogen chloride	ppb	-	-	27	-	-	67
ozone	ppb	31	-	-	-	81	-
carbon monoxide	ppb	-	-	-	5	13	-
			-				
suspended particulates	µg/m3	60	-	100	-	-	-
inhalable particulates	µg/m4	30	-	50	-	-	-
lead	µg/m5	-	-	50	-	-	-

Notes: µg/m3 = microgram per cubic meter of air; mg/m3 = milligrams per cubic meter of air
Source: Bermuda Government (1993) The Clean Air Regulations, 1993 (The Clean Air Act, 1991) BR44/1993

Figure 1.6 Air quality monitoring sites



Source: Bermuda Biological Station for Research

The Prospect site is centrally located at the top of a water catchment at the Ministry of Works and Engineering's waterworks depot at Headquarters Hill, Prospect. This site is at one of the highest points on the Island, approximately 65 metres above sea level and unobstructed in all directions. The site is 1 km due south of the Tynes Bay incinerator. Wind tunnel and computer modelling determined this site as the area most likely to have the highest ground level concentration of the stack emissions. Additionally, the Prospect site, located at a topographical high point, is an ideal site for monitoring pollutant emissions Island-wide.

The sampling station was set up to measure pollutant gases such as sulphur dioxide (SO2) and nitrogen oxide (NOx) and for the collection of aerosols, precipitation, and suspended particulate samples, and also for the determination of background atmospheric parameters such as the acid constituents of the precipitation and heavy metals. The Ministry of the Environment has installed a field laboratory at the site. The laboratory is equipped with instrumentation for the analyses of the pollutant gases, a high volume air sampler for suspended particulates, an automatic rain collector, an aerosol filter system and a weather vane and anemometer system for logging wind speed and wind direction.

East Broadway/Crow Lane (EB) is a roadside site located just east of the City of Hamilton. EB is a major artery into the City with maximum traffic flows at approximately 4,000 vehicles per hour at rush hour. The site is ideal for monitoring vehicular emissions. Sample collection at EB comprises high volume air sampling for particulates.

BELCO is the only power station on the Island. It is situated west of the City of Hamilton in a fairly industrial area and is a major contributor to atmospheric emissions on the Island, accounting for approximately 60% of the total sulphur dioxide emissions. On behalf of the Department of Environmental Protection, the Bermuda Biological Station for Research (BBSR) operates a high volume air sampler just outside the BELCO southeast fence for the collection of suspended particulates. As a condition of their operating licence, BELCO conducts their own ambient air monitoring programme and submits reports to the Environmental Authority, a statutory body established under the Clean Air Act, 1991.

1.3.4 Ambient Air Levels of Sulphur Dioxide and Nitrogen Oxides

Sulphur dioxide (SO2), nitrogen oxides (NOx) and hydrogen chloride (HCl) are pollutant gases formed during combustion processes. These gases are known to react with moisture and are the key components in the formation of acid rains and dry acid deposition. Fossil fuel combustion together with refuse incineration is responsible for 3,600 tonnes of sulphur dioxide annually. One of the main sources of SO2 is electrical power generation, while other sources include the Tynes Bay Waste Treatment Facility, boilers, vehicles, cruise ships and other emission sources.

Measurements have been made at Prospect on a continuous basis to determine ambient SO2 and NOx. Greater than 90% of the SO2 and NOx results are less than 25 µg/m^3 and few if any results are greater than 130 µg/m^3, which is low. These studies have concluded that the principal sources of the acid gases are generally located in and around the City of Hamilton.

1.3.5 Acid Rains

A 14-year rainfall record has been established at the Prospect station. The average pH of local rain is currently 5.4 (i.e., slightly acidic), having increased consistently from a mean value of 4.4 in 1988. This suggests that precipitation in Bermuda has become less acidic over this period. Results suggest that pollutant sulphate and nitrate from combustion are largely responsible for anthropogenic acidity in rain water in Bermuda with both local and long-range sources. By comparing the pollutant sulphate and nitrate content in rain at Prospect with offshore pollutant sulphate measurements, it is estimated that the local sources account for 51% of the pollutant sulphate and also 27% of measured nitrate. Other portions of this contaminant arrive on the Island by long-range transport from the industrial centres in the United States.

One of the most frequently asked questions regarding acid deposition is its impact on Bermuda's natural waters and vegetation. Bermuda is a calcium carbonate-based environment and acid rains are neutralised immediately upon contact with calcium carbonate containing soils and debris. As a result, the impact of acid deposition on the Bermuda environment appears relatively small and decreasing.

1.3.6 Suspended Particulates

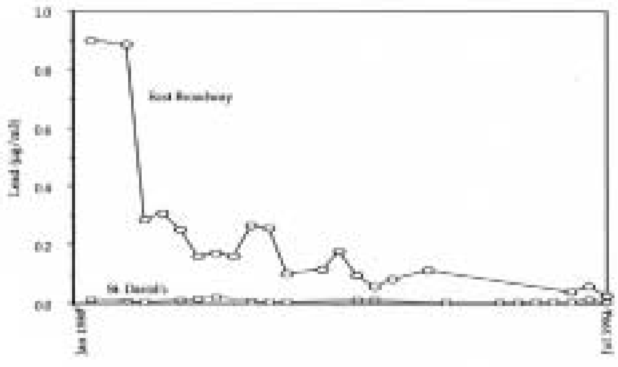
Airborne particulates have been measured at the five primary monitoring sites since 1987. Samples are collected once each week on a six-day cycle over a 24-hour collection period and the results have been used to monitor long-term trends in air quality. Values are highest at roadsides such as East Broadway due to traffic flow and lower at more remote sites such as St. David's Head. Despite some variability in the annual averages, there have been no observable increases or decreases in the total suspended particulates (TSP) levels over the past decade.

1.3.7 Lead in Bermuda Air

Prior to 1991, leaded gasoline was the principal type of auto fuel on the Island and the primary source of lead in the local environment. The lead concentration of gasoline was considered high at 0.8 gm/litre and accounted for approximately 25 tons of lead being emitted to the environment annually. This equated to about a half ton of lead per square kilometre. Automobile combustion in some instances accounted for ambient lead concentrations as much as one to three times greater than the U.S. EPA Ambient Air Quality Standard for lead of 1.5 µg/m3 measured as a quarterly average. Under the Bermuda Clean Air Regulations, 1993, the limit for lead in air is 1.5 ug/m3 as a 30-day average and 50 µg/m3 as a 24-hour average.

In 1989, the level of lead in gasoline was reduced and this is seen as important in terms of environmental quality and from a geochemical perspective. Lead in auto fuel was reduced from 0.8 grams/litre to 0.15 grams/litre as a first step towards the introduction of unleaded gasoline. This effectively reduced the amount of lead emitted to the local atmosphere by 80%. The use of unleaded gasoline followed in 1990. Gasoline was the single most important source of lead on the Island and its removal has shown a rapid decrease in airborne lead levels of greater than 90% (see Figure 1.7).

Figure 1.7 Ambient air lead concentrations vs. time at the East Broadway and St. David's sites



Note: Samples were taken prior to and through the leaded gasoline phase out period.
Source: Bermuda Biological Station for Research

1.3.8 Heavy Metals and Organics in Air

In addition to lead, air samples have been taken to determine the levels of other heavy metals and several organic constituents at the Government's established air quality monitoring sites. Many of the heavy metals occur at relatively low levels in comparison to air quality standards from other jurisdictions. Polyaromatic hydrocarbons (PAH's) and dioxins and furans have been detected and their role is still the subject of analysis and study. A major campaign to assess these chemicals is planned for 2004.

1.3.9 Other Air Quality Studies

In addition to the five stationary air quality monitoring sites, the Ministry of the Environment operates a mobile air quality monitoring response vehicle. The vehicle is fitted with a MDA 7100 toxic gas analyser for the determination of pollutant gases along with other apparatus and instruments for the measurement of suspended particulates, wind speed and direction. The vehicle has responded to complaints from cruise ship emissions at Dockyard and St. George's and conducted general monitoring at a site near the power company and a number of the Island's rock quarries.

Air sampling at Dockyard was undertaken in 1995 and 1996 in response to complaints from boat owners at the nearby marina regarding the emission of soot and gases from the cruise ships. Measurements showed that sulphur dioxide concentrations ranged from less than detection (13 $\mu g/m^3$) to levels, in some cases, as high as 21,000 $\mu g/m^3$. Air pollution at Dockyard is very intermittent. Prevailing winds for the Island typically carry the emissions offshore to the northeast, however, on occasions, turbulence created by southerly winds passing over the ship causes the particles and gases to down draft and disperse into the general Dockyard area.

1.3.10 The Tynes Bay Waste Treatment Facility

The incinerator burns 288 tons of solid waste per day. Whilst reducing waste volumes by up to 90% and providing for heat recovery, the combustion process has the disadvantage of releasing heavy metals, organic compounds and gases into the atmosphere.

In terms of environmental controls, the smokestack is fitted with an electrostatic precipitator that removes 99% of the particulates generated in the combustion process. There are, however, no controls, other than operational controls, which capture pollutant gases. Design considerations suggest that control of fly ash particles is most effective since these particulates have been shown to contain the bulk of the heavy metal and organic contaminants and that by exhausting the gases at a height of 90 metres in the air, atmospheric dispersion and dilution would reduce the gas concentrations to acceptable levels. Testing conducted at the Prospect monitoring station to date confirms this to be the case and suggests that other emission sources such as BELCO and vehicles are more significant sources of air pollution.

Air quality in Bermuda must be carefully monitored to identify trends. Our requirements for more vehicles, more power, incinerators for waste disposal and other combustion-based processes necessitate targeted monitoring to assess the state of air quality, particularly in regard to human health risks. Efforts must be made to educate the public and encourage residents to translate awareness into action. Another strategy lies in the efficiency of the combustion process, air emission controls and air quality regulation.

1.4 Summary

Bermuda's subtropical, mild climate has been described as being one of the Island's chief assets. The oceans impose a moderating influence on the climate. The heat absorbed and stored by the ocean, complemented by the proximity of the Gulf Stream, ensures an abundant source of energy for maintaining the mild temperatures that Bermuda enjoys all year round. Bermuda, therefore, tends to have two main seasons, winter and summer. Light to moderate southwesterly to southeasterly winds prevail in summer and the season is influenced by a large area of high pressure, known as the Bermuda-Azores High, which blocks frontal systems moving through the area. The main rainfall events comprise convectional showers or thunderstorms.

Bermuda is located in an area that is occasionally affected by the passage of hurricanes that mainly approach from the south and west. Hurricane season for the Northwestern Atlantic Ocean is most active during late summer and early autumn, as this is the time of warmest sea surface temperature. Hurricanes, such as Fabian in 2003, caused loss of human life, severe damage to the Island's utility infrastructure, buildings and the coastline.

One of the effects of global warming is a rise in sea level. Any significant rise in sea level in the North Atlantic would threaten to inundate the coastal areas of Bermuda as it is composed of fairly low-lying islands with elevations not exceeding 250 feet.

Bermuda is the only landmass in the Sargasso Sea. The main environmental concerns within this part of the North Atlantic Ocean are the long-range transport of contaminants from North America, marine debris and some tar contamination from shipping traffic.

Local air emission sources comprise the Bermuda Electric Light Company (BELCO), the Tynes Bay incinerator, vehicular emissions and various other point and diffuse sources. Bermuda also is affected by long-range transport of pollutants from industrial regions in the United States. Road traffic is a significant source of air pollution on the Island and is responsible for a variety of gases including lead, sulphur dioxide, nitrogen oxides, hydrocarbons and particulates.

The Clean Air Act, 1991 and Regulations introduced in 1993, address air quality problems associated with sulphur in fuel oils, lead in gasoline, BELCO's emission stacks, incinerators, asphalt operations and cruise ship stack emissions. The legislation sets standards for nine ambient air pollutants.

Air samples are collected and monitored on a routine basis from three government-funded sites. At Prospect, the primary site, air quality is sampled on a continuous basis for precipitation, aerosols and pollutant gases. The other two sites are at East Broadway and at BELCO. Fossil fuel combustion from vehicles together with refuse incineration and electrical power generation is responsible for 3,600 tonnes of sulphur dioxide annually. Studies have concluded that the principal sources of acid gases are generally located in and around the City of Hamilton.

Precipitation in Bermuda is becoming less acidic and because Bermuda's bedrock is calcium carbonate-based, acid rains are neutralised immediately upon contact. As a result, the rains have little impact on Bermuda's natural environment. Airborne particulates are highest at roadsides such as East Broadway due to traffic flow and lower at other more remote sites such as St. David's Head. Total suspended particulates (TSP) levels have remained relatively unchanged over the past decade.

Prior to 1989, gasoline was the greatest source of lead on the Island but with the introduction of unleaded gasoline, the amount of lead emitted to the local atmosphere was reduced by 80%. The use of unleaded gasoline in 1990 brought about a rapid decrease in airborne lead levels of greater than 90%.

Testing conducted at the Prospect monitoring station confirms that by exhausting the gases of the Tynes Bay Incinerator at a height of 90 metres in the air, atmospheric dispersion and dilution reduces the gas concentrations to acceptable levels. Other emission sources such as BELCO and vehicles are more significant sources of air pollution.

Air quality in Bermuda must be carefully monitored in accordance with air emission controls and air quality regulations to identify trends. Efforts must also be made to increase the efficiency of the combustion process.

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Chapter 2

The Geology of Bermuda

2

2.1 Geology

2.1.1 Introduction

The limestone islands of Bermuda are founded on a volcanic seamount which rises 4,270 metres from the floor of the Atlantic Ocean, originating through two periods of volcanic activity occurring approximately 110 million and 33 million years ago respectively. Since the last major eruption, erosion and coral growth has removed virtually all surface evidence of the volcanic origins.

The truncated top of the volcano is now submerged at an average depth exceeding 60 metres below sea level. It is buried by reefs and sandy limestone sediments composed of the skeletal remains of shallow water marine organisms. The hilly islands of Bermuda, perched on the southeasterly edge of the submerged volcano, are old wind blown dunes composed of limestone sands now hardened.

Most of the exposed limestones on the islands of Bermuda are less than two million years old, deposited during the Pleistocene ('ice age') epoch. Although in geological terms these can be considered very recent times, they were eventful. Climatic fluctuations of the Pleistocene were responsible for dramatic cyclical advances and retreats of continental ice sheets. Ocean waters were alternatively bound up in and released from these ice sheets causing global changes in sea level through ranges greater than 150 metres.

The legacy of these Pleistocene events at Bermuda is a 'layer cake' geology of fossil soils deposited during low sea level conditions, alternating with limestone dunes that were built at high sea levels. Presently, the globe is experiencing relatively warm 'interglacial' conditions and the sea level is high by Pleistocene standards.

Although dune deposits dominate the geology, there are isolated 'high' marine deposits on Bermuda's shorelines, which record periods when sea levels were even higher than at present. The age of these deposits and their exact sea level height have been the subject of much research and conjecture.

2.1.2 The Five Limestone Formations

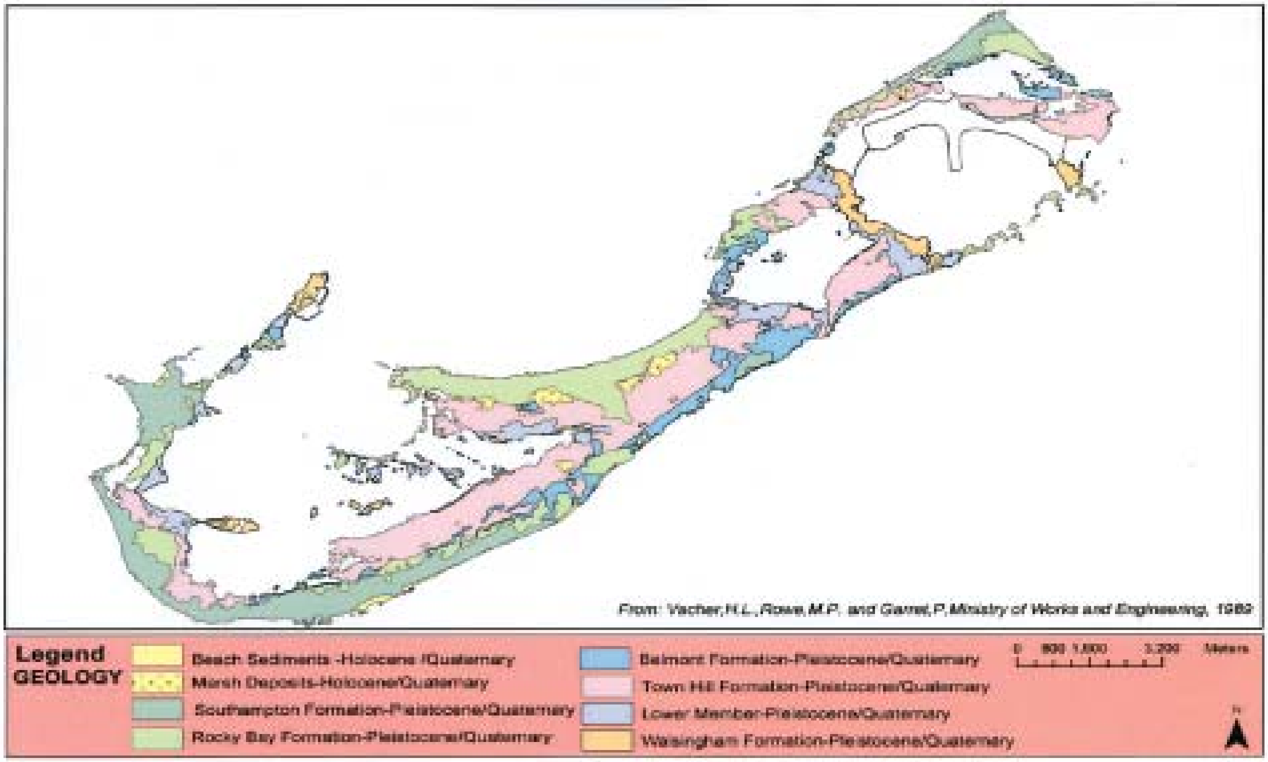
The five limestone formations identified on the Geological Map of Bermuda (Vacher, Rowe and Garrett, 1985) reflect chemical and physical variations due to ageing rather than fundamental rock-type differences (see Figure 2.1).

The youngest limestones comprise recognisable sand grains, as found on a beach, whereas in the older formations the sand grains have become chemically eroded and powdery. In the case of the oldest rocks, the original grains commonly are unrecognisable having become cemented into a dense, non-porous mass. The lack of pore space in these limestones caused groundwater flow to become channelled which in turn resulted in the development of extensive cave systems (see Chapter 4, Biodiversity and Habitats).

The variation in characteristics of the limestone formations has determined their respective uses as natural resources. The youngest formation, the Southampton, is a source of sand for building purposes. The Rocky Bay, Belmont, and Upper Town Hill formations are sufficiently well cemented to provide building stone and roof slate. The lower Town Hill and Walsingham formations have provided durable building stone in the past, as evidenced by 19th Century buildings at the Royal Naval Dockyard. Although this type of stone has now been replaced by concrete block, these older and harder limestone formations are still valued as a source of aggregate.

2

Figure 2.1 The Geological Map of Bermuda



Source: Department of Planning

2.1.3 Quarrying

A 1988 Government Department of Planning discussion paper entitled 'The Supply of Building Materials in Bermuda' stated that the last limestone quarry in Bermuda would reach the end of its lifespan by about 2014. It recommends that the development of new quarries in Bermuda be resisted because it would cause major environmental damage and there are few, if any, suitable new sites.

2.2 Topography and Geomorphology

2.2.1 Introduction

Bermuda comprises one main island linked by short bridges to smaller islands at its extremities. The narrow, elongated landmass curves around and all but encloses several large inshore bodies of water. Although the maximum land width is 2.5 kilometres (km), the average width is only about 1.5 km.

2.2.2 The Topography of Bermuda

Unlike many other small limestone islands, Bermuda can be described as 'hilly' as it has considerable elevation for its width. The land invariably rises quite steeply from the shoreline. Hilltops are typically 40 to 50 metres (130 to 160 ft) above sea level, with the maximum land height of 80 metres (260 ft) occurring at Town Hill in Smith's Parish. Natural flat areas are absent except at a few sea level marshlands, such as the Devonshire, Pembroke and Paget marshes in the middle of Bermuda.

2.2.3 The Island's Geomorphology

The accumulation of wind blown sand dunes, draped one upon the other which have become hardened into rock over time, are responsible for the construction of Bermuda. The narrow elongated shape of the Island is explained by the fact that the sand dunes never migrated far inland away from the source of their sand, the beaches. They were quickly stabilised in ridgelines, which parallel the coast.

Figure 2.2 Aerial photo of sand dunes along South Shore

Photo courtesy of the Department of Planning

The apparent flooded appearance of Bermuda's landscape can be explained by global sea level conditions, which are presently at a peak, compared to the average over the last two million years or so. The continual rise of sea level since the last glacial period has resulted in the submergence of land and has caused high erosion rates, manifested as coastal cliffs. Bermuda has experienced a long period of diminishing land area, which will continue, or accelerate, should the forecasted impact of global warming be played out.

2.2.4 Chemical Erosion

One final, important factor in determining Bermuda's topography and geomorphology has been chemical erosion. Rain in Bermuda does not run off as surface streams or rivers but soaks into the ground. Acidity picked up in the soil by rainwater causes the limestone to be slowly dissolved. Because this happens at different rates in different places depending on the flow of water and the thickness of the soil, peculiar landscape features, known as 'karsts', develop. Over tens of thousands of years, large caves were dissolved out of the older rocks while valleys became more rapidly lowered than hilltops. With the continued passage of time, the collapse of caves and the broadening and deepening of valleys into marshes, ponds and inland bays, produced a land morphology that is characteristic of current day Bermuda.

2.3 Summary

The limestone formations of Bermuda are predominantly wind deposited, 'aeolian' dunes of the geologically recent Pleistocene ('ice age') epoch. They are separated into formations by thin brown to red clay palaeosols (fossil soils) which represent long periods when conditions were generally unfavourable to dune formation.

Pleistocene sea level oscillations resulted in dramatic changes in the configuration and size of the land-mass perched on top of the Bermuda volcanic seamount. When the sea level was at its lowest, the coastline would have been beyond, and well below, the present reef-line. At higher sea levels, sand would have been mobilised across the flooded platform and driven towards beaches that were the source of sand dunes from which present-day Bermuda is built.

The youngest limestone dunes are lightly cemented into what barely qualifies as rock. Older limestones have been progressively altered and more tightly cemented, as the calcium carbonate was redistributed by slightly acidic, infiltrating rain water. In the very oldest limestones of the Walsingham formation, sufficient time has passed for the chemical dissolution of the strata into a substantial network of sub-sea level caves. Extensive collapse of these deep caves has been responsible for the development of secondary caves, some of which are accessible from the surface today.

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Chapter 3

Fresh Water Resources

3

3.1 Hydrogeology

3.1.1 Introduction

Bermuda's traditional method of water supply, using rainwater roof catchments and storage tanks, has served the community very well. It was, however, never intended to meet the demand within high occupancy buildings such as hotels. For the most part the primary source of the supplementary water,which had to be piped to these commercial developments was, and continues to be, groundwater abstracted from wells.

Most private households are still not connected to a piped public supply system. Even though they continue to rely on their rainwater tanks, some 3,500 households also now abstract supplementary water from private wells for flushing and other non-potable purposes. Other households rely on a backup supply delivered by water truckers who, in turn, draw on government or private commercial wells. Development of groundwater resources was therefore crucial in meeting a widespread increase in demand for water throughout Bermuda in the 20th Century.

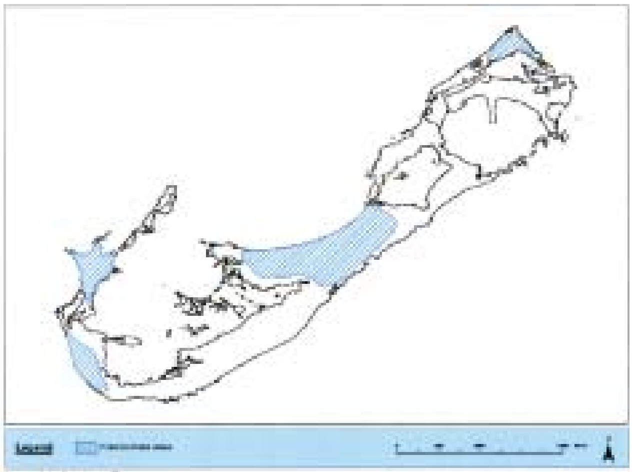
Groundwater exists everywhere in Bermuda at or very close to sea level. Much of this water is salty but Bermuda is fortunate in that the climate and the characteristics of some of the younger limestones have enabled the accumulation of several bodies of fresh groundwater known as 'lenses'. These lenses consist of rainwater that has trickled down to sea level and displaced seawater in the pores of the rock. The fresh water, which is of a lower density, floats on the seawater to the extent that some lenses, at their thickest points, have built up to depths of 30 feet or more below sea level.

3.1.2 Groundwater Lenses

Government and commercial water producers abstract groundwater from the Somerset, Port Royal, St. George's and Central lenses. Figure 3.1 shows the location of these lenses. Of these, the Central lens is by far the largest and provides up to 1.4 million Imperial gallons per day (Igpd) out of a maximum total of 1.7 million Igpd of groundwater going into public supply.

The limits on abstraction are set under the Water Resources Act, 1975 and administered by the Ministry of the Environment's Environmental Authority (previously the Water Authority) a statutory body established under the Clean Air Act, 1991. The limits are based on calculations of the rate of replenishment of the lenses with rainwater. Over-abstraction will cause well water to turn salty as the lenses become depleted and thin. Should the abstraction rate approach the rate of replenishment for a given lens then the lens will continually shrink until it is replaced by seawater.

Figure 3.1 Groundwater lenses



Source: Bermuda Government

The Water Resources Act 1975 administered by the Ministry of the Environment provides protection for Bermuda's fresh groundwater resources. It states in Section 34(1) that: *Any person who, save under the authority of this Act or any other statutory provision, interferes with or pollutes or fouls any public water, commits an offence.*

In 1989, 1990 and 1991 total rainfalls, were 43.5 inches (1,109 mm), 44.2 (1,123 mm) and 46.6 inches (1,184 mm) respectively, compared to an annual average for Bermuda of 58 inches (1,473 mm). This was an unprecedented run of 'dry' years. This was a testing period for the fresh groundwater resources, which do not react to monthly rainfall variations but instead are affected by sustained trends of above or below average rainfall. Apart from being deprived of recharge from rainfall, these resources were also being subjected to higher than normal demand for trucked groundwater from householders whose tank water reserves had become depleted. Measurements of the lens thickness, which are taken once per quarter in approximately 70 boreholes throughout Bermuda, showed a reduction in depths of fresh groundwater continuing through 1992. However, limits placed on abstraction and on well spacing introduced by the Environmental Authority served to preserve the lenses.

From 1993 until 1999, close to average rainfall conditions permitted a slow but sustained recovery of fresh groundwater reserves. This trend remained uninterrupted until 1999, which with only 45.9 inches (1,166 mm) of rain, produced an inevitable small reversal of the cumulative replenishment.

Bermuda's groundwater lenses are protected under the designation of 'groundwater protection areas' in section 12. WAT. of the Department of Planning's Bermuda Plan 1992 Planning Statement. The provisions in this section of the Bermuda Plan 1992 state that development must be designed to dispose of sewage and other effluent in a satisfactory manner without harm to the underlying water lens, and that the protection of Bermuda's groundwater resources takes precedence over all other planning considerations.

Restrictions come into effect where there is a high density development, which results in production of large quantities of wastewater on relatively small properties. Under these circumstances cesspit disposal is not acceptable, particularly in areas close to the coastline or over a fresh groundwater lens. For such developments, which are not sufficiently large to make secondary treatment practical, primary treatment in a septic tank followed by disposal via a deep sealed borehole can be an acceptable option. For developments up to 100 bedrooms, or equivalent, this type of system may also be acceptable depending on the location. For larger developments, conventional secondary treatment or even tertiary treatment may be required.

At the time of writing, approximately 150 sewage treatment systems have been constructed in Bermuda at the direction of the Environmental Authority.

3.1.3 State of Groundwater Quality and Supply

In February 2000, the Ministry of the Environment commissioned the Bermuda Biological Station for Research (BBSR) to undertake a preliminary survey to look for the presence of pesticides in the groundwaters of the Central, St. George's and Port Royal lenses. The areas of focus were those areas of relatively high pesticide application, such as areas underlying golf courses and agricultural land.

A background study was conducted to identify which pesticides were used by golf courses and the farming community and the potential for these compounds to leach into groundwater. Consideration of their toxicities was also given. Analytical techniques were developed according to protocols used by the U.S. Geological Survey National Water Quality Assessment Programme. This is an ongoing programme which has investigated pesticide contamination of U.S. groundwaters since 1991. Analytical instrumentation within the environmental chemistry laboratory at BBSR was optimised to undertake the analyses.

Results from the initial investigation helped to target more detailed spatial and temporal sampling within the groundwater lenses. The initial results from this study have shown limited contamination of groundwaters by several herbicides and metabolites. On the basis of these findings, an overview of the risk to public health posed by pesticides detected in Bermuda's groundwaters to date was presented. Individual pesticide concentrations were found to be well below the U.S. Environmental Protection Agency (EPA) and Environment Canada Drinking Water Regulatory levels.

The work was also considered against current legislation concerning restrictions on the use of these compounds in North America and Europe. Based on this review and in the context of data collected during the study, recommendations are being made concerning use of these pesticides in areas overlying groundwaters destined for public supply. Funding for the groundwater pesticide monitoring programme has been renewed for the year 2003.

Bermuda's fresh groundwater storage conditions can be described as good. Improved efficiencies in well spacing and individual well capacities are being investigated but further research is not likely to result in an increase in the calculated total capacity of the fresh groundwater resources.

3.2 Water Use, Water Resources and Water Treatment

3.2.1 Water Use

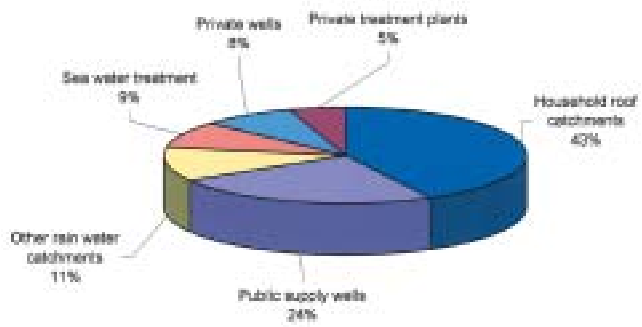
As there is little manufacturing in Bermuda, the predominant use of water is for domestic purposes and for services related to the tourism industry. Average per capita consumption among the 62,000 residents is about 30 Imperial gallons (Igpd) per day. Lower than average consumption occurs within traditional Bermudian households, whereas higher than average levels predominate in areas where piped water is available, such as within many condominium-based developments.

Among the 222,000 tourists who stayed in hotels in Bermuda in 2002, the per capita water use was approximately 110 Igpd. An average of 2,330,000 Igpd is used in homes and hotels. Other miscellaneous water users not accounted for are offices, restaurants, cruise ships, laundromats, farms and golf courses.

3.2.2 Water Resources

Figure 3.2 shows the supply potential of Bermuda's main water resources. These are used to a greater or lesser extent depending on rainfall. The actual average availability of water from roofs and other rainwater catchments is less than quoted in this report because during extended rainy periods water is commonly lost due to tank overflow.

Figure 3.2 Water resources of Bermuda (potential)



Source: Ministry of the Environment

3.2.2.1 Rainwater catches

The primary source of water for domestic use in Bermuda is rainwater collected by roof catchments. By law, each house must have 80% of its roof area guttered to collect rainwater and a storage tank (which is generally beneath the house) provided with a capacity of at least 100 Imperial gallons for every 10 square feet (1 sq. m.) of collection area.

This system has been successful because Bermuda's rainfall is relatively evenly distributed throughout the year. The average annual rainfall of 58 inches (1,473 mm) provides on average about 100 Igpd for each household. The lowest annual rainfall of 39.38 inches (1,000 mm) occurred in 1861 and the highest recorded annual rainfall was 89.64 inches (2,277 mm) in 1902. In the past, the annual average rainfall provided an ample water supply apart from during periods of severe drought. However, due to the subdivision of houses into apartments over the last few decades and the increase in the number of two storey buildings, periods of low rainfall now cause a widespread demand for supplementary water.

Whilst 2,200 households are connected to the Government system via limited water pipeline distribution systems, the two most important sources of supplementary water are private wells and water truckers. The latter comprises treated groundwater delivered in 900-gallon tanker loads by private water companies.

Household water catches can supply 2,100,000 Igpd and an estimated 560,000 Igpd can be supplied by other roof and constructed water catches.

3

3.2.2.2 Private wells

Even though households continue to rely on their rainwater tanks, 3,500 of them now abstract supplementary water from private wells for flushing and other non-potable purposes. Many of these wells produce fresh groundwater, but it is illegal under the Department of Health's Public Health Act, 1949 (section 29) to use such water for potable purposes without a licence and an associated schedule of quality testing. Private wells can supply 410,000 Igpd.

Section 29 of the Public Health Act, 1949 states that unless they are licensed by the Minister of Health that:

no person shall use, or cause or allow to be used, any water drawn or piped from any well or boring, or from any stream, pond or lake:

(a) for drinking; or

(b) for any process connected with the preparation or manufacture of any food or drink

3.2.2.3 Public supply wells

Large hotels and multi-storey office buildings cannot catch sufficient rain on their roofs to provide their own water supply in the traditional Bermudian manner even when rainfall is plentiful. This is the main reason that a piped public supply system was developed in Bermuda.

Bermuda's four fresh groundwater 'lenses' and the associated peripheral low salinity, 'brackish' groundwater have been the preferred sources of water for public supply (distributed by pipeline and water truckers).

3.2.3 Government Water Supply

3.2.3.1 Water sources

The government water supply system is under the control of the Ministry of Works and Engineering and Housing. The operation is based at four locations abstracting water from three underground lenses: Port Royal, Central and St. George's. The operation is licensed and monitored by the Ministry of the Environment. Government operates four well fields and these are listed in Table 3.1

Table 3.1 Government-operated well fields

Location	Abstraction Limit gals/day	Number of Wells
Port Royal	280,000	24 Freshwater Wells; 7 brackish wells
Prospect	544,000	74 Freshwater Wells; 28 Brackish Wells
St Brendan's	581,000	102 Brackish Wells
St George's	100,000	17 Brackish Wells

Source: Ministry of the Environment

In the early 1970s water was pumped from the lenses in an uncontrolled manner and as a consequence the lenses deteriorated and the water became more saline and near to undrinkable. Since then a more measured approach has been taken to restrict the pumping to maintain as far as possible the freshness of the water. Prior to the development of reverse osmosis technology the freshness of the water was more important to keep the water drinkable. Generally when the average dissolved salt content of the water rises above 1,200 parts per million (ppm) it is undrinkable, yet still compares significantly lower than seawater at 36,000 ppm. With the development of reverse osmosis it has been possible to use cost-effectively more brackish water in the range of 2,000 to 10,000 ppm of total dissolved solids. It should be noted that more recent development in energy recovery systems has also brought the cost of seawater desalination down significantly.

To provide a sustainable supply, water has to be skimmed off the top of the lenses using a widespread network of submersible well pumps. The pumps are required to pump at low flow rates continually. To obtain the low flow of 5 gpm, only domestic quality pumps are available. The well fields cannot be considered robust and failures in this area have an immediate impact on supplies. The power supplies to the well fields is not from a single point but is spread across 70 control points. In the event of a major hurricane, the well fields become inoperable and water production ceases until the wells are brought back into operation.

3.2.3.2 Brackish water treatment

The need for treatment reflects the degree of pollution as well as the salt content of the water. To bring the water to acceptable standards, reverse osmosis is used to reduce the dissolved solid content below 500 ppm as well as to remove contaminants such as nitrates and pesticides. In particular, the average nitrate level in well water can reach as high as 20 ppm and must be reduced below 10 ppm to meet the Department of Health's standards. In addition to reverse osmosis, two plants utilise microfiltration systems to remove microbial contaminants from the fresh water. The need for treatment has a cost not only in money terms but also in water quantity. Increasing treatment results in less water produced for drinking.

Table 3.2 details the maximum daily production of each plant with everything running 24 hours non-stop and the well fields. In 2002, an average daily production of 962,000 gals/day or 83% was achieved.

Table 3.2 Maximum daily production of the groundwater treatment plants

Location	Gals/day
Tudor Hill (Port Royal)	176,000
Fort Prospect (Central Area)	440,000
St Brendan's (Central Area)	470,000
St Georges (St Georges)	65,000
	Total 1,151,000

Source: Ministry of the Environment

3.2.3.3 Seawater treatment

Proposals are in hand to develop a seawater desalination facility adjacent to the Tynes Bay incinerator. The plant will be a reverse osmosis unit and will be capable of producing 500,000 Igpd of drinking water. This is required to meet the peak demands that occur during dry weather. The use of power produced by the incinerator is expected to keep production costs in line with those associated with brackish treatment facilities.

For now, government still relies exclusively on groundwater sources. In 1996, however, the largest private water company, Bermuda Waterworks, commissioned a 650,000 Igpd seawater reverse osmosis plant, having reached the limit for groundwater production from their well fields as set by the Environmental Authority. This company operates distribution pipelines to the City of Hamilton as well as to several of Bermuda's largest hotels.

3.2.3.4 Government water costs

Water is currently sold at $15.15 per 1,000 Imperial gallons to general customers and $14.15 per 1,000 Imperial gallons to water trucking companies. The current charge to householders for trucked water is $60 per 900 Imperial gallons.

3.2.3.5 Water storage/backup facilities

In traditional water systems large reservoirs are used to smooth out seasonal peaks and troughs in demand as well as back up for major plant failures. Such facilities require large amounts of land which are not available in Bermuda. Table 3.3 gives details of the government system's current storage capacities.

Table 3.3 Government water storage capacities

Location	Water Storage Capacity
Central Area	2,100,000 gallons (equivalent to 2 ½ days production)
Western Area	440,000 gallons (equivalent to 2 ½ days production)
Eastern Area	130,000 gallons (equivalent to 2 days production)

Source: Ministry of the Environment

Clearly the current storage facilities only offer assistance with daily peaks and troughs and cannot be considered as back up to a major plant failure.

3.2.3.6 Drinking water availability

Government distributes water through 31 miles of pipe ranging in size from 2 inches to 12 inches. The distribution system was never designed but rather grew from need. The system covers large areas of Bermuda, making water available in the following parishes: Southampton and Sandys – 8.4 miles of pipe; City of Hamilton, Hamilton, Devonshire and Smith's – 22.6 miles of pipe; and St. George's – 2 miles of pipe.

The initial distribution system was based on a pre-1900 cast iron fire main at Prospect. The last section of this main was replaced in March 2001. The variety of pipe materials used has been extensive and it is estimated that only 20% of the system is up to a standard able to withstand a pressure in excess of 100 pounds per square inch (psi). The system is operated at as low a pressure as possible to keep leakages to a minimum but this still results in losses of around 15–26%.

Lost water also includes meter inaccuracies which occur as the meters wear out. Such discrepancies can account for 3–5% losses. Also underground pipes will always weep at the joints and it is impractical to get losses below 5%.

The current losses are reasonable when compared with losses in a high-pressure system fed directly into houses. Such systems typically see losses between 25–40% found in the U.S., U.K. and elsewhere. Bermuda is therefore operating its water distribution system efficiently.

3.2.3.7 Demand on the system

Demand for water is highly variable and dependent on weather and the time of year. The maximum monthly water demand on the government system was recorded at 28 million gallons in June 2000 with the minimum of nine million gallons in February 2000. Generally around 200–250 million gallons is supplied to customers from the government water system on an annual basis. The government water service currently provides water through 840 meters to approximately 2,500 households, businesses and government facilities.

3.2.4 Private Water Treatment Plants

As in other countries, many Bermuda residents now either buy bottled water or have 'purifying' filters of a variety of types to treat their rain water supply. Treatment of well water for drinking is not commonly done because of the expense of small treatment plants and Department of Health licensing requirements.

Typically, those who opt for private well water treatment, invariably by reverse osmosis, have especially high water requirements such as for fresh water swimming pools or for irrigation of large grounds. Otherwise, they might have small tanks or roof areas relative to the number of occupants, as within condominium complexes and guesthouses.

There are 78 private reverse osmosis plants with capacities mostly in the range of 1,000 to 20,000 Igpd registered in Bermuda and 250,000 Igpd is the estimated potential production capacity of these plants.

3.3 Roof and Tank Systems

3.3.1 Introduction

Possibly the most distinctive aspect of Bermuda's architectural heritage consists of whitewashed water catchments, roofs and associated storage tanks (see Figure 3.3). It is unlikely that our forefathers anticipated that this legacy would one day globally distinguish Bermuda as an 'advanced' and 'sustainable' community with respect to the management of fresh water resources.

Figure 3.3 Rooftop water catchment

Photo courtesy of the Department of Planning

Bermuda residents have always used rain as the principal source of potable water because there are no rivers and lakes and potable groundwater resources are limited.

3.3.2 Sizing Catchments and Tanks

Bermuda's public health laws mandate an adequate supply of wholesome water for drinking and for other direct human purposes. When proposing to build a structure in Bermuda the design must include a roof catchment and a tank. The storage capacities of tanks are prescribed by the regulations set out in Table 3.4.

Table 3.4 The Public Health (Water Storage) Regualtions, 1951

Prescribed Catchment Area	Prescribed Tank Storage Capacity
Four fifths of the total roof area of the building	100 gallons for every ten square feet of prescribed catchment area

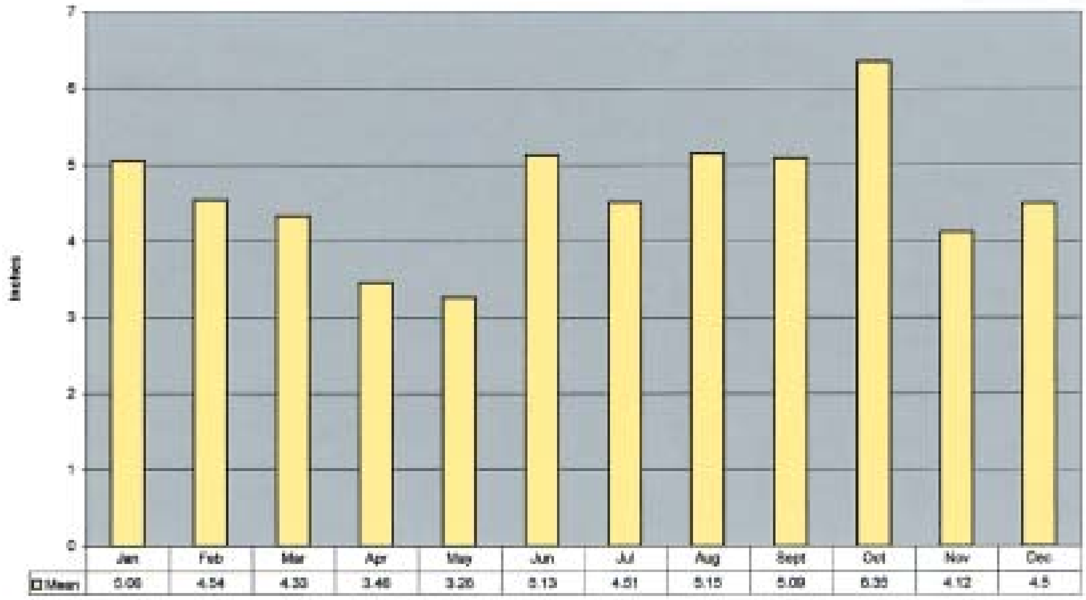
Source: Department of Health

To calculate the required tank size, the building requires water storage of eight Imperial gallons for every square foot of the total catchment (roof) area. This legal requirement is based on the scientific rationale that Bermuda's average total rainfall for one year is 55.5 inches distributed relatively evenly across all months, with higher averages for hurricane seasons, due to the torrential rains that these systems have generated (see Figure 3.4 and Table 1.2, Chapter 1).

One cubic foot of water is equivalent to 6.25 Imperial gallons and one-twelfth of that (or one inch of rainfall) consists of 0.52 of a gallon. A one square foot catchment collects 55.5 inches x 0.52 gallons or 28.86 gallons of water per year. For a 1,000 square foot catchment, 28,860 gallons of water are collected per year. Droughts make it necessary to have storage provision for at least one-quarter of this amount (i.e., three months worth of rain). This is equivalent to 7,215 gallons.

Bermuda's Water Storage Regulations are strict in that they require an 8,000-gallon cistern for a 1,000 square foot catchment. This can be justified because collection efficiencies are never 100% and can be anywhere between 75% to 90% with losses from evaporation from a hot roof, gutter over-splash and tank overflow.

Figure 3.4 Bermuda's mean monthly rainfall



Source: Bermuda Weather Service

3.3.3 Household Water Needs and Use

The above calculations and the Water Storage Regulations do not consider the occupancy of the structure. Apartment buildings, for example, have a high number of people living in them relative to the size of the roof catchment area. For example, a 3,000 square foot catchment 3,000 x 28.86 = 86,580 gallons per year. When divided by the number of days in a year, a catchment will only supply 237 gallons of water to use per day.

Table 3.5 examines the water demand for a three apartment dwelling unit that has a roof area of 3,000 square feet and a total occupancy of seven persons. The probable water demand for this dwelling unit is 307 gallons per day, but only 237 gallons of water will be available on average per day. Demand exceeds supply to the tune of 70 gallons a day. Over time the tanks will run dry and supplemental water (for instance from truckers) will have to be obtained.

Table 3.5 Water demand for seven persons in three apartments

FIXTURE	USE*	FLOW RATE	# OF USERS	TOTAL
Toilet	3 flushes per person per day	1.6 gallons per flush (new toilet)**	7	33.6
Shower	5 minutes per person per day	minute (restricted flow head)**	7	96.25
Bath	1/4 bath per person per day	50 gallons per bath	7	87.5
Faucets	Bathroom & kitchen sinks	10 gallons per day/unit	N/A	30
Washing Machine	1 load per day***	50 gallons per load	N/A	50
Dishwasher	1 load per day***	9.5 gallons per load	N/A	9.5
			TOTAL	306.85 gallons per day

Notes:

* *Duration and number of uses is assumed for this example with seven persons – this column can be customised for any scenario. NB: The above assumes a preference for showers*

** *All flow rates above are for new fixtures. Older tiolets use from 3.5 to 7 gallons per flush and older showerheads have rates as high as 10 gallons per minute. Some new appliances are energy saving models and have lower flow rates than stated.*

*** *Only the main dwelling has appliances*

Source: Department of Health

3

In existing structures practical ways to compensate for such a shortfall are frugality and modern appliances and fixtures that conserve water. Other strategies are not to install washing machines or dishwashers in every apartment, to install water meters, to monitor consumption, to separate tanks and tank accesses for each dwelling unit or to drill a well to supply flushing water.

With an expected collection rate of 237 gallons per day this seven-person household is risking a daily shortfall of 70 gallons of water.

For proposed dwellings and structures, it is important for architects to use calculations similar to the above to determine the anticipated water demand. Strategies include reducing the proposed occupancy, increasing the size of the water catchment, installation of a piped water supply service for potable water purposes and a well supply for flushing.

3.3.4 Rainwater Quality

Rainwater is one of the purest sources of water available and nears distilled water in its purity. Its quality almost always exceeds that of well water because it does not come into contact with soil and rocks and does not contain dissolved salts and minerals. Furthermore, it is subjected to fewer pollutants, such as cesspit recharge and pesticides that may contaminate groundwater.

Once rain comes into contact with a roof or catchment surface, the risk of contamination significantly increases. Many types of bacteria, moulds, algae, protozoa and other dirt and contaminants can be washed into the tank. Ash and products of incomplete combustion from bonfires and chimneys may be present. Bird droppings also may have collected on the roof and in the gutters during dry periods. Tree branches that overhang the roof need to be trimmed as they produce leaves and other contaminants. To keep leaves and other debris from entering the system, gutters should have a leaf screen, or 'pineapple', made of quarter-inch wire mesh. These need to be cleared regularly and especially after periods of high wind.

3.3.5 Water Pollution

The Public Health Act, 1949 recognises the potential for contamination and pollution of tank water and empowers authorised officers of the Department of Health to act proactively, rapidly and decisively to remedy situations where the water in a tank appears to be polluted or to be in danger of pollution.

'Pollution', in relation to water, means:

(i) pollution by reason of the presence of the dead body of any animal, bird or reptile, or of any faecal matter or filth;

(ii) pollution by reason of the presence of an amount of vegetation or fungus which, in the opinion of a Public Health Officer, renders the use of the water prejudicial to health; and

(iii) pollution by reason of a bacteriological or chemical content which, in the opinion of a Public Health Officer, renders the use of the water prejudicial to health.

The Department of Health officers may issue an order requiring the tank to be temporarily closed and prohibit the use of its water or they may require the tank be emptied and cleaned or the tank water be chlorinated or otherwise disinfected. Powers are given to require any other action to rectify the problem.

In addition, the Department of Health conducts water analysis services upon request including bacteriological tests of water to detect levels of coliforms conducted. The criteria used for determining if water is bacteriologically acceptable is shown in Table 3.6.

Water testing is performed at the Department of Health's Central Government Laboratory on a variety of water types including:

(a) Water produced at the government and private treatment facilities and along their distribution lines. These samples are monitored routinely; and

(b) Water from residential tanks. These samples are submitted by members of the public who either have a problem with their water or are just interested to know the quality of their water.

Most of the water testing is bacteriological, with bacterial indicators of pollution being determined. These include coliforms, which are widespread in the environment, and can originate from soil and vegetation, and faecal coliforms and E. coli, which indicate pollution originating from a faecal source.

Table 3.6 Indicator bacteria and their acceptable limits

INDICATOR GROUP	ACCEPTABLE LIMIT	RELEVANCE
TOTAL COLIFORMS	No more than 10 for residential tank water; No more than 1 for treated water	Total coliform bacteria are also found in the environment and are not a good indicator of faecal contamination or health risk. They are to be expected in water that has not undergone disinfection.
FAECAL COLIFORMS	<1 (None found in 100ml)	A subgroup of total coliform bacteria that better measures contamination from a faecal source. They should not be found in your water supply.
E. COLI	<1 (None found in 100ml)	Conclusive evidence of faecal contamination because E. coli is found only in the intestines of warm-blooded animals. Considered a potential health risk because disease-causing organisms may be present. They should not be present in your water supply.

Source: Department of Health

The presence of faecal coliforms or E. coli in water indicates that pathogens (disease-causing micro-organisms) could be present in the water supply and could cause people to become ill. Results of the water analyses are stored in a database, along with other information about the water sample (for example the source of the water, and whether it is a complaint or not).

In 2002, 98% of the samples from the distribution systems were bacteriologically acceptable. The total number of samples was 836. However, for the residential tank water samples taken in 2002, only 26% of the samples were found to be bacteriologically acceptable. The total number of samples was 483. On the basis of the above criteria it has been found that there is little difference between the water quality of those who have a complaint about their water and those who requested testing of their water for reassurance that it was safe. Of those with a complaint, 20% had acceptable water quality and of those requesting testing without suspicion that the water quality was poor, 24% had acceptable water quality.

Because of the open nature of Bermuda's tank water system, contamination is inevitable, and in order to maintain acceptable bacterial water quality according to the above criteria, treatment of the water is necessary.

Follow-up testing is done for tanks that are treated for contaminated water. In addition, the Department of Health tests drinking water from restaurants and hotels.

3

3.3.6 Water Tank Treatment

When water test results show exceedences in acceptable limits, a water supply should be disinfected. Chlorination is one method that is widely used and should be undertaken only if the water is clear and the tank clean. Regular household bleach, which is a form of chlorine, can be used by adding 1/2 cup (4 oz) for every 1,000 gallons of water and mixing it thoroughly using a water hose or a bucket. This procedure should be undertaken every three or four months. The Department of Health gives householders the following formula to calculate the amount of water in a tank:

(Length (ft) x Width (ft) x Depth of water (ft)) x 6.25 = Number of gallons

There are a number of tank water treatment options which are summarised in Table 3.7. A combination of these can be used to best ensure clean drinking water.

The last decade has seen changes in the way that Bermudians perceive the importance of good quality drinking water. This is as a result of increasing health consciousness in general, as well as a booming global market in bottled waters. The downside of this marketing phenomenon, however, is that for some of Bermuda's residents confidence in the quality of tank water has been somewhat undermined. Often this is solely based on perceptions rather than scientific fact. The fact is that Bermuda's water tanks are capable of delivering pure and wholesome drinking water for everyone's needs.

Table 3.7 Drinking water treatment techniques

METHOD	LOCATION	RESULT
SCREENING		
Strainers and Leaf Screens	Gutters and Leaders	Prevent leaves and other debris from entering tank
SETTLING		
Sedimentation	Within Tank	Settles particulate matter
FILTERING		
In-Line/Multi Cartridge	After Pump	Sieves sediment
Activated Charcoal	At Tap	Removes chlorine and other contaminants*
Reverse Osmosis	At Tap	Removes contaminants
Mixed Media	Separate Tank	Traps particulate matter
Slow Sand	Separate Tank	Traps particulate matter
DISINFECTING		
Boiling/Distilling	Before use	Kills microorganisms
Chemical Treatments(Chlorine or Iodine)	Within Tank or At Pump (liquid, tablet or granule)	Kills microorganisms
Ultraviolet Light	Ultraviolet light systems should be located after the activated carbon filter before tap	Kills microorganisms
Ozonation	Before Tap	Kills microorganisms

*Note: *Should only be used after chlorine or iodine has been used as a disinfectant. Ultrviolet light and ozone systems should be located after the activated carbon filter but before the tap.*

Source: Department of Health

Tank and rainwater catchment systems require maintenance. If there is a perceived decline in quality, or a more significant problem, water testing and advice can be sought from the Department of Health.

Water is expensive and people are understandably reluctant to empty their tanks and discard water but health requirements demand that water tanks are cleaned every six years. The bottom of the tank should be free of sludge build-up and the water should not be cloudy. It is the sludge that potentially harbours harmful chemicals and material and unless it is removed there is a greater risk of it being stirred up, delivered to the taps and consumed.

Ideally, Bermuda's tank and rainwater catchment systems should be designed and built to exclude contaminants and to facilitate cleaning and maintenance. More work can be done in this regard. Proprietary filters and roof washers are available and should be considered for new buildings. Methods for retrofitting existing structures should also be developed.

3.4 Summary

Fresh water is a limited resource that must be carefully managed in order to protect safety and quality and to ensure an adequate supply for Bermuda's residents, visitors and businesses.

Two main sources of water presently exist, rainwater that is harvested and groundwater that is extracted from underground lenses. Seawater is not presently utilised to any great extent for fresh water recovery.

The Department of Health regulates rainwater issues and the Department of Environmental Protection regulates groundwater resources. Both departments regulate different aspects of the water business including water abstraction, treatment processes such as reverse osmosis, micro filtration and disinfection, as well as storage and distribution pipes and truckers. The Ministry of Works and Engineering and Housing also has a responsibility for producing, distributing and selling fresh water.

All water is monitored for safety and quality purposes and microbiological and chemical tests are regularly performed for drinking water as well as groundwater.

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Chapter 4

Biodiversity and Habitats

4.1 Introduction

Bermuda's strong economy has brought about a huge loss of habitats as a result of development and an increase in population. Economic prosperity, and the fact that virtually everything (food, fuel, and consumer goods) is imported, has also brought about the introduction of new species to the Island. These are the biggest threats to Bermuda's natural environment.

Whilst development pressure has had a significantly high impact on the natural terrestrial environment, in contrast the marine environment has been much less affected. However, some marine species have declined through over-harvesting.

Biodiversity refers to the great variety of life forms on earth, encompassing the variations that occur both within and between species. This variety is critically important to preserving the quality of life on earth.

An ecosystem encompasses all the plants and animals in a given area together with their physical surroundings and all the interactions between them. The removal of one component can cause the system to crash or become permanently altered. A habitat is the locality where a species lives. Ecosystems usually comprise many habitats. Generally, the key to protecting a species is to protect its habitats. Careful biodiversity conservation planning must aim to protect an adequate representation of habitats to accommodate healthy populations of native species. Although this is especially important for Bermuda's terrestrial environment, it is also true of its marine environment.

The terrestrial environment has been drastically altered since human settlement such that there are few nature reserves today that resemble pre-settlement times. In spite of their protected designations, these areas are under threat from misuse and vandalism by users, illegal harvesting, invasive species and the lack of financial and human resources for their proper management.

Bermuda has 218 hectare (539 acres) of fragmented terrestrial areas that are protected as nature reserves under the Department of Planning's Bermuda Plan 1992. This equates to just over 4% of Bermuda's land area which is set aside strictly for the protection of flora and fauna. Other areas such as national parks and National Trust open spaces are also protected for their natural heritage, but they also cater to the recreational needs of the Island's residents and visitors.

Bermuda's marine platform covers some 780 sq. km (301 sq. miles) (see Figure 4.1) of which some 321 sq. km (124 sq. miles) or 41% has some form of marine protected area status assigned to it (see Chapter 9).

Figure 4.1 Aerial photograph showing the Bermuda platform

Source: Department of Planning

4

Bermuda possesses a variety of unique ecosystems that have been shaped by the following:

(a) The climate of the Island is sub-tropical because of the warm water from the Gulf of Mexico being carried north in the strong current of the Gulf Stream which passes to the west of Bermuda.

(b) Marine creatures, plants, larvae, spores and seeds from the West Indies and south-eastern North America are carried by the Gulf Stream and have been colonising the shores of Bermuda for several million years.

(c) The composition of Bermuda's flora and fauna, both marine and terrestrial, has been shaped by repeated sea level fluctuations of nearly 150 metres (500 ft) amplitude during the ice ages, which alternately submerged and dried up the shallow platform, respectively favouring shallow marine or terrestrial ecosystems. Bermuda's relative paucity of endemic species is a result of this habitat discontinuity and the continuing re-colonisation via the Gulf Stream (Sterrer 1998).

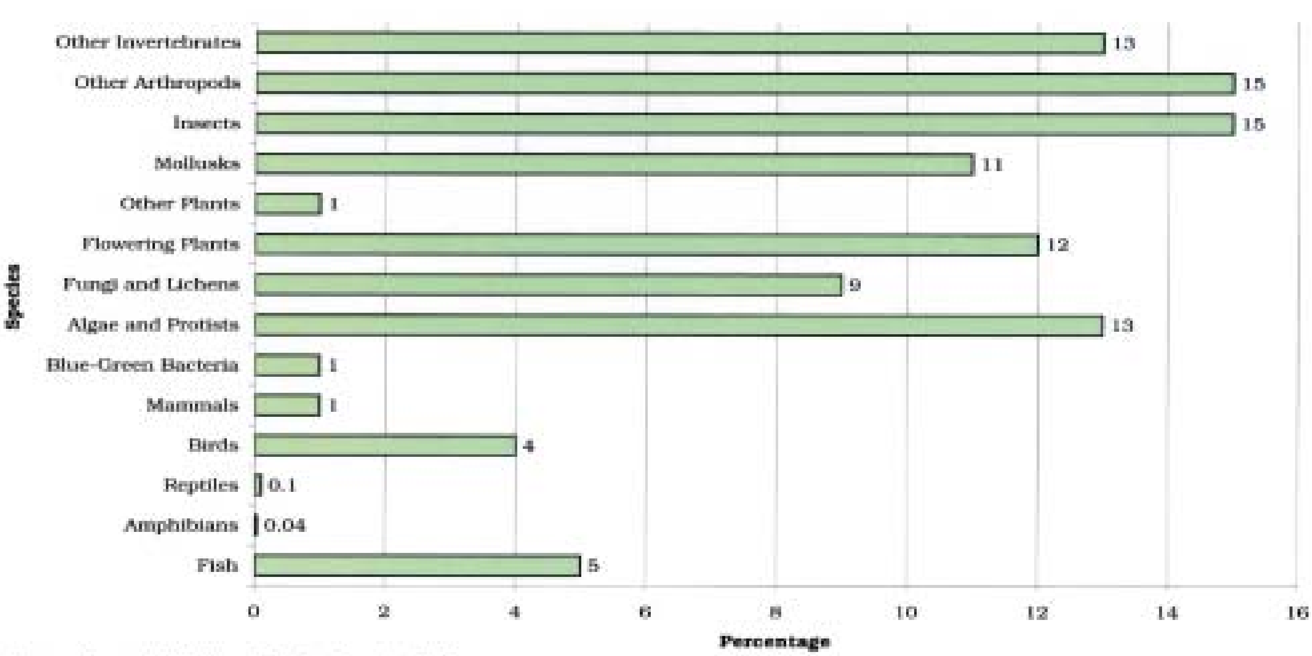
(d) The dune deposits which dominate the terrestrial landscape create sheltered and exposed areas with a very large length of coastline. They encompass some 290 km (180 miles) of land which compares to its small land area of only 53.7 sq. km. (21 sq. miles).

These factors make Bermuda home to the northern-most examples of tropical ecosystems such as coral reefs and mangroves. Relatively species-poor, fragmented, small in extent, and naturally stressed owing to their northern location, Bermuda's ecosystems are therefore unusually vulnerable to anthropogenic disturbance.

The term 'native species' describes those species that arrived in Bermuda naturally by means of currents, wind or transport by birds. An example of a native species is the white-tailed tropic bird or longtail (*Phaethon lepturus catesbyi*).

The term 'endemic' species refers to native species whose ancestors arrived in Bermuda on their own but adapted over time to become unique. An example is the Bermuda cedar (*Juniperus bermudiana*), closely related to but distinct from the Bahamian cedar. At least 8,301 species have been recorded in Bermuda of which 3 % are endemic. Of these species, 4,597 are marine and 3,702 are terrestrial (Sterrer 1998). Figure 4.2 classifies the types of organisms found in Bermuda.

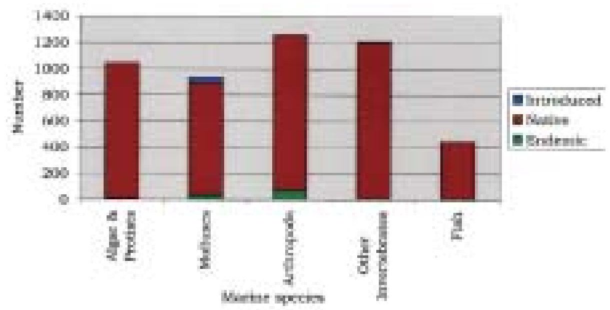
Figure 4.2 Composition of Bermuda's marine and terrestrial flora and fauna



Source: Bermuda Biodiversity Project Country Study

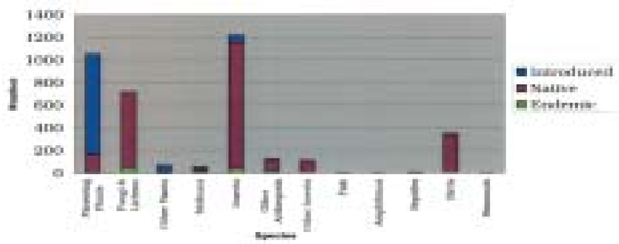
Most of Bermuda's terrestrial species were introduced by humans while the majority of marine species are native. Figures 4.3 and 4.4 show the number of marine and terrestrial species categorised according to the way in which they arrived in Bermuda.

Figure 4.3 The number of marine plants and animals that are endemic, native or introduced



Source: Bermuda Biodiversity Project Country Study

Figure 4.4 The number of terrestrial and fresh water plants and animals that are endemic, native or introduced



Source: Bermuda Biodiversity Project Country Study

There are three types of introduced (or alien) species: non-self propagating, naturalised (i.e., self-propagating) and invasive (which comprise species that self-propagate so aggressively that they threaten the survival of native and endemic species).

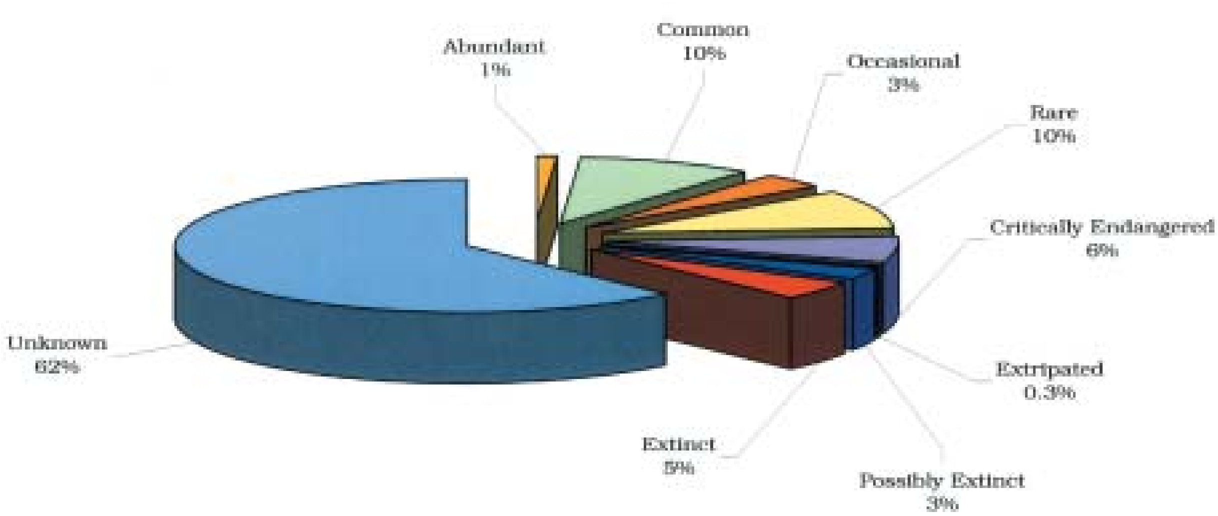
Figure 4.5 shows that the status of almost two-thirds of Bermuda's endemic species is unknown. Some two-thirds of these species inhabit marine caves that are difficult to access.

4.2 Marine Habitats

4.2.1 Introduction

Bermuda's marine environment consists of a narrow intertidal zone consisting of 786 sq. km. (301 sq. miles) of coastal waters on top of the Bermuda platform (see Figure 4.1) and an Exclusive Economic Zone (EEZ) with a radius of 200 miles which extends out over the surrounding oceanic region. Beyond the platform the Bermuda seamount drops steeply to the abyssal plain at depths greater than 4000 metres. Although the EEZ comprises mostly open ocean, it includes the two submerged platforms that rise to within 55 metres of the surface known as the Challenger and Plantagenet (locally called Argus) Banks. These banks are considered part of Bermuda's marine resources. Bermuda's coastal waters therefore have a pelagic (open-ocean) component as well as coral reefs and seagrass beds. The intertidal zone is

Figure 4.5 The status of Bermuda's endemic species



Source: Bermuda Biodiversity Project Country Study comprised of both rocky and sandy shorelines and includes mangrove swamps and fringing mangroves.

There is a considerable amount of interaction between the pelagic and benthic habitats in the coastal zone. For example, some reef fish feed on plankton and fry while some pelagic fish occasionally feed on the reefs or in the seagrass beds. Only a few species complete their entire life cycle in just one habitat and most actually utilise two or three different habitats at various stages of their life. Most larvae are pelagic and many juveniles utilise seagrass beds and mangrove swamps as nursery areas before migrating to the reefs as adults (Mumby *et al*., 2004). In addition, many fish and larger invertebrates use the coral reefs for shelter and migrate on a daily or nightly basis to nearby seagrass beds to forage. In this way the proximity of these different habitats combines them into a larger entity with greater diversity than they could support individually.

This connectivity has important management implications in that coastal marine ecosystems must be considered as a whole to ensure that all stages of the lifecycle are adequately managed and protected.

4.2.2 Coral Reefs

4.2.2.1 Introduction to coral reefs

Despite being a reduced version of the coral reefs in the Caribbean further to the south, Bermuda still supports a rich and diverse coral reef ecosystem that is unique and distinctive from any other Caribbean reef system (see Figure 4.6 and 4.7).

Figure 4.6 Aerial photo of Bermuda's coral reefs

Photo courtesy of the Department of Tourism

The most obvious difference between Bermudian reefs and those in the Caribbean is the reduced biodiversity of Bermuda's reefs. Of approximately 800 species of coral worldwide, 60 species of hard coral and 50 species of soft coral occur in the Caribbean. Bermuda, however, only has 34 hard coral species and 24 soft coral species. One entire group of Caribbean reef-building corals, the stag horn corals (*Acropora spp.*), are not present. Coral coverage of Bermuda's reefs is about 50% or less because Bermuda is located at a higher latitude than most coral reefs. However, coral coverage is higher in comparison to many Caribbean reefs that have experienced catastrophic losses of corals over the past 10–20 years due to diseases, coral bleaching, coastal development and over-fishing (Wilkinson, 2000).

There is a paucity of seaweeds (fleshy algae) on Bermudian reefs compared to other reefs of higher latitudes. This appears to be due in part to the increasing populations of parrot fish (*Scaridae*) and surgeon fish (*Acanthuridae*) since the fish pot ban in 1990. These groups of fish are effective at controlling the amount of algae on the shallow reefs.

Sponges, many types of worms, crustaceans, molluscs and echinoderms (sea stars and sea cucumbers) are also very important members of Bermuda's coral reef ecosystem. These species make up a great proportion of the biological diversity on a reef and their abundance and health may be good indicators of the state of the reef environment. Most of these species have not been well studied in Bermuda.

Figure 4.7 A Bermuda reef

Photo courtesy of Ian Murdoch

4.2.2.2 Reef types

There are a wide variety of reef types in Bermuda (see Figure 4.8). Starting at the northern extremity of the Bermuda platform, coral growth can be seen on the Fore Reef Slope but does not form a vertically structured reef until a depth of about 160 ft (50 m). From here to a depth of about 80 ft (25 m), 25% or less of the reef is covered by corals.

As the water shallows to less than 80 ft (25 m) on the Main Terrace reefs, the coverage of living corals rises to just over 50%. This is the only reef type in Bermuda where the majority of the bottom is coral covered. At depths of less than 30 ft (10 m), the northern reefs of Bermuda form the Rim Reefs, which shallow to 10 ft (3 m) or less to form emergent reefs like North Rock or isolated 'boiler' reefs. Living corals on the rim cover only just over 20% of the bottom. Here, encrusting coralline algae occupy about 2% to 5% cover but play an important role in cementing the reef structure together. In common with the fore Reef Slope and Main Terrace reefs, the Rim Reef has typically very clear water and provides an important habitat for a wide variety of fish and invertebrates.

To the landward of the Rim Reefs lies the North Lagoon. Up to 10 miles (16 km) across, this body of water has maximum depths of about 60 ft (20 m) and bottoms of sand and muddy sand with less clear waters than further out to sea. Within the North Lagoon lies a variety of Lagoonal Reefs all with a comparatively low (15%) cover of corals.

There are also several kinds of Lagoonal Reefs within Bermuda's sounds and harbours but the coverage of coral is less than 10%. These reefs, together with the elongated Fringing reefs that follow the shoreline in 3–6 ft (1–2 m) of water, form the Inshore Reefs. The best developed Inshore Reefs occur in Castle Harbour and may now be recovering somewhat following the destructive effects of the Kindley airbase construction between 1941 and 1943.

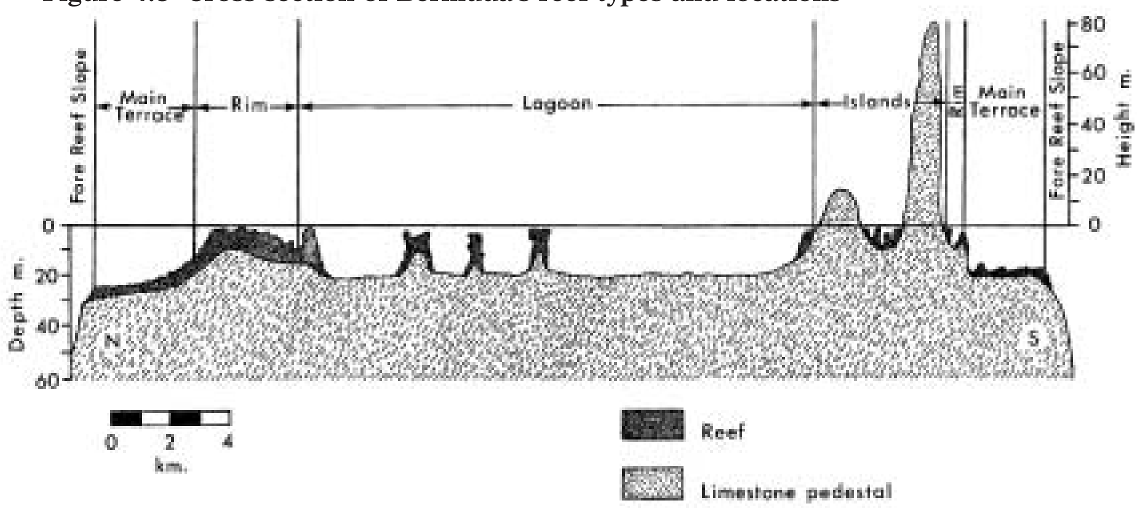
The reefs to the south of Bermuda differ significantly from those to the north. The most obvious reef type off the south shore is the boiler or cup reef, although there are some boilers to be found on the northern rim. These reefs resemble a wineglass in shape and rise from depths of 30 ft (10 m) or so to the level of low tide. Boilers have almost no coral at all in their structure but are composed of coralline algae and countless tiny shells of a sedentary worm snail.

Between the boilers and the south shore are the near-shore platform reefs that resemble the Northern Rim Reef with coverage of coral at about 15%-20%. Outside the boilers, the reefs range from 25–60ft (9–20 m) with high coral coverage at about 20% –50%.

4.2.2.3 Coral assemblages

The main reef-building corals in Bermuda are the brain corals (*Diploria labyrinthiformis* and *D. strigosa*), the great star coral (*Montastraea cavernosa*), the lesser star coral (*Montastraea annularis*) and the mustard coral (*Porites astreoides*). Together these account for about 80% or more of the coral coverage

Figure 4.8 Cross-section of Bermuda's reef types and locations



Source: Bermuda Aquarium, Museum and Zoo on all Bermuda's reef types except the Inshore Reefs and Boilers. These corals are all large, domed or platy in structure. This group of corals forms an assemblage called the *Diploria-Montastraea-Porites* Coral Assemblage.

The Inshore Reefs are characterised by smaller and more delicate branched corals including the ivory bush coral (*Oculina diffusa*) and the finger corals (*Madracis decactis* and *M. mirabilis*). This is the *Oculina-Madracis* Coral Assemblage. The Chinese hat coral (*Agaricia fragilis*) and the rose coral (*Isophyllia sinuosa*) also commonly occur on the inshore reefs.

4.2.2.4 Associated reef organisms

The reefs support a very broad array of other species of animals and plants. Coral reefs are built by the organisms inhabiting them, a process called bioconstruction. The bulk of the substance of Bermuda's reefs is made by corals and coralline algae, and seaweeds that deposit calcium carbonate in their tissues. Also important in reef construction are a wide variety of invertebrate animals that have stony shells which cement themselves to the reef.

Although the accumulation of limestone rock from biological activity is a dominant process on the reefs, the opposite pattern is also occurring. This is called bioerosion, an activity resulting in the removal of deposited rock. Bioerosion is vigorous on Bermuda's reefs but is more than balanced by bioconstruction. However, severe stress on reefs can reverse the roles and result in a net removal of material. Bioerosion takes place within the rock by burrowing creatures such as the date clam (*Lithophaga nigra*), barnacles (*Lithotrya dorsalis*), sponges such as the boring sponge (*Cliona lampa*) and various worms. At the surface most removal is accomplished by parrotfish (*Scaridae*) (see Figure 4.9) and by sea urchins (echinoids) such as the burrowing urchin (*Echinometra lucunter*) and the long-spined urchin (*Diadema antillarum*).

There are also a huge variety of plants and animals that use the reef as a habitat but do not alter its structure. Thus the reef supports a very large food web at the base of which are the seaweeds, plant plankton and the reef-building corals. Corals also culture plant cells (zooxanthellae) within their bodies. These plants grow and supply part of their production to the corals, which makes them grow quite rapidly. It is this symbiosis which is largely responsible for the very high biological productivity rates of coral reefs.

Figure 4.9 Parrotfish on Bermuda's reefs

Photo courtesy of the Department of Tourism

The reef fish resources of Bermuda are very diverse and resemble those of the Caribbean. As with corals, however, there is less diversity. The most important groups of reef fish are the morays (*Muraenidae*), the groupers (*Serranidae*), the grunts (*Haemulidae*), the angelfish (*Pomacanthidae*), the damselfish (*Pomacentridae*), the wrasses (*Labridae*), the parrotfish (*Scaridae*), (see Figure 4.9) the surgeonfish (*Acanthuridae*) and the triggerfish (*Balistidae*),

Herbivorous fish play an important role in the coral reef ecosystem in that their grazing clears patches of substrate on which coral larvae may settle and prevent the standing crop of algae from overgrowing corals. In this way, herbivorous fish and other reef herbivores such as sea urchins mediate the interaction between coral and algae on the reef.

Before the 1990 ban on using fish pots for fishing in Bermuda, many reef fish, particularly the groupers, were being over-fished (See chapter 9). The ban on pot fishing has not been in effect long enough to see all species that were caught returned to pre-depletion levels. However, populations of the ecologically important reef fish such as the parrotfish and surgeonfish have increased since 1990 and as a result grazing on the reefs may be slowly approaching reasonable levels.

Knowledge about the life spans of fish has important implications for fishery management in that long-lived species often take a long time to mature. Such species may require a greater degree of legal protection to ensure that enough individuals reach sexual maturity to sustain the population into the future.

4.2.2.5 Importance of coral reefs

Coral reefs provide structural protection from ocean surges and reduce the erosion of our coastline by wave action. Reefs and their inhabitants are a source of food and provide employment for fishermen. Bermuda's reefs also support recreational fishing. A prime economic benefit of coral reefs is the interest they generate from tourists, which translates into employment for environmentally-based tourism activities such as glass-bottom boats, snorkelling, helmet diving and SCUBA diving ((see Figure 4.10).

Figure 4.10 Coral reef ecosystem

Photo courtesy of Ian Murdoch

In addition, pharmaceutical companies have begun examining the huge array of different chemicals used by plants and animals to attack prey, protect themselves and attach themselves to surfaces, with the aim of finding novel and natural compounds that may be of use to humans. Ecosystems like coral reefs and rainforests are ideal places to start the search for such compounds. This is referred to as 'bioprospecting' and examples of products developed in this way include glues, painkillers and a potential anti-cancer drug.

4.2.2.6 The state of Bermuda's coral reefs

In 1993 a status report was produced by ReefBase. It focused largely on anecdotal information and suggested that 10% of the world's coral reefs were dead and that 30% were likely to die within 10 to 30 years. In light of recent, massive coral bleaching episodes, some scientists estimate that globally 25% of coral reefs are dead and that the remainder will die within the next 50 years. Coral bleaching is a physiological disorder which results in a pale, whitened appearance of the coral, the result of it expelling the symbiotic algae living within it.

In an effort to develop a more data-driven global assessment of coral reefs, the first map-based global analysis of the current condition and potential threats to coral reef ecosystems was produced in 1998. Entitled *Reefs At Risk: A Map-Based Indicator of Threats to the World's Coral Reefs*, the report indicates that almost two-thirds of the reefs in the Caribbean and Atlantic Ocean are at risk, one third of these being placed in the 'high risk' category. Bermuda's reefs fall into the 'high risk' category, apparently based on two main factors: 1) the Island's high population density (within 20 km of the coral reefs) which assumes a correlation between population density and overexploitation and 2) the shipping traffic and potential pollution threats from vessels. Despite this, Bermuda is nevertheless highlighted in the report as having reefs that show 'signs of promise.' This is attributed to local concern and interest in the reefs translating into local management action to protect and conserve these resources.

In a general sense Bermuda's reefs are considered relatively healthy as a result of effective management and the limited impacts from direct users including fisherman, snorkelers and divers.

Current long-term monitoring programmes show that the important reef-building corals in the different shallow reef zones have remained stable in terms of abundance and diversity over the past nine years. This is in contrast to many reefs in the Caribbean (CARICOMP, 2001). Many reef fish species are in a recovery phase from the effects of over-fishing in the 1980's. However, several species have not recovered, mostly groupers (*Serranidae*) and snappers (*Lutjanidae*), which may indicate that current fishing levels by commercial and recreational fishermen are still depletive, or that recruitment is failing. Other formerly harvested reef species such as the queen conch (*Strombus gigas*) are critically endangered.

4

4.2.3 Other Marine Habitats

4.2.3.1 Seagrass beds

Of the 50 species of seagrass worldwide, four are present in Bermuda. They are the only truly marine flowering plants. There are three common seagrasses in Bermuda: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*) and shoal grass (*Halodule bermudensis*). Seagrass beds are highly productive ecosystems supporting an invertebrate community of worms, crustaceans and molluscs living on and within the sediments. They form very large underwater beds on all but the very exposed sandy and muddy bottoms in water less than about 30 ft (10 m) deep around Bermuda (see Figure 4.11).

Figure 4.11 Bermuda seagrass bed

Photo courtesy of the Bermuda Biological Station for Research

Seagrass beds have a wide variety of important ecological features (Wood, Odum and Zieman, 1969). They have an important role to play in maintaining water quality in coastal areas by stabilising sediments and preventing erosion. They also form belts of shelter and act as nursery grounds for a host of marine creatures ranging from shrimp to juvenile fish and lobsters. Fish and invertebrates shelter from predators among the leaves and a huge variety of fish, lobster and shrimp spend their early lives in seagrass beds. Without seagrass beds the maintenance of important marine fish stocks and other creatures would suffer greatly.

Adults of numerous species also use the seagrass beds as feeding areas. These include green turtles (*Chelonia mydas*) (see Figure 4.12), herbivorous fish such as parrotfish and invertebrate feeders like snappers and grunts. Seagrass beds are also home to numerous shellfish.

Figure 4.12 A green turtle

Photo courtesy of the Department of Tourism

Particles of food arising from decaying seagrass leaves form the base of a food chain culminating in lobsters, crabs, conchs, commercially important species of fish, as well as seabirds.

There is no doubt that seagrass beds around Bermuda are changing. They are vulnerable to trampling by people and this has resulted in their disappearance in recent years from shallow bays such as Tobacco and Whalebone. Boat moorings also scour the seabed, causing loss of seagrasses.

Research on seagrass beds increased in the 1990s and ongoing studies are being conducted by the Benthic Ecology Research Programme at the Bermuda Biological Station for Research. Extensive studies have been conducted on the seagrass beds located off the Tynes Bay incinerator which appear to be unaffected by the thermal effluent (Smith *et al.*, 1998). Other long-term studies of seagrass beds within lagoonal patch reefs were initiated in 1991 and observed the complete and rapid disappearance of healthy turtle grass seagrass beds from 1996–1999. Additional studies in 1999 found other offshore beds in a state of decline but many others appeared healthy.

Elsewhere, larger shoreline beds are waxing in some locations and waning in others. For example, some large beds in Castle Harbour off Nonsuch Island have been greatly reduced, while others in the North Lagoon have extended their range (Ward, 1999).

At present it is possible to speculate about some of the causes for these changes including storm activity, scouring from moorings, anchoring and overgrazing by turtles. Further research is necessary to better understand the dynamics of these important ecological systems and the roles they play in Bermuda's reefs and inshore areas. As part of the Bermuda Biodiversity Project, a Bermuda Reef Ecosystem Assessment and Mapping Project is being undertaken which involves conducting extensive cross-platform surveys to map all marine habitats. This research will allow future changes to be monitored more closely.

4.2.3.2 Rocky and sandy intertidal areas

Bermuda's small tidal range (which is about 75 cm) means that our intertidal zone is very narrow, particularly on steeply sloping shores.

However, Bermuda has a very large extent of rocky shore and although deceivingly barren-looking these areas comprise a dynamic and productive marine ecosystem. Seaweeds growing in these areas are constantly grazed at times of high and low tide by a wide variety of marine creatures. Many of the rocky shore creatures are small and several live buried in the rock. Some fish that graze on the seashore come in from the sea at high tide, including parrotfish (*Scaridae*) and surgeonfish (*Acanthuridae*). Other grazers from the sea are important food for larger fish and lobsters. At low tide the shore is occupied by periwinkles and crabs which also feed on the rich seaweed turf. The lower shore in most places is inhabited by thousands of tiny snails cemented into the rock whose presence hardens the soft limestone rock rendering it less prone to erosion. The rocky shores are a vital and dynamic part of Bermuda's marine resources.

Because seashores intersect and filter the ocean's surface they are very vulnerable to floating pollutants. Oil is a particular problem here and sheets of it coat the shore in many places such as at Devonshire Bay and Spittal Pond. A rocky shore completely covered in oil loses all of its natural inhabitants. An additional problem on the rocky shorelines of Bermuda involves declining biodiversity which results from pollution and from the collection of attractive or edible shells by residents and tourists. This is, of course, a worldwide problem resulting from pressures created by man. The West Indian top shell (*Cittarium pica*) was possibly eradicated in this way and has had to be re-introduced in Bermuda. It is protected although poaching still occurs. The bleeding tooth (*Nerita peloronta*) shell and the rustic whelk (*Thais rustica*) were formerly common but are now quite rare. More steps need to be taken to adequately protect rocky seashore resources.

4.2.3.3 Sandy shores

One of Bermuda's most attractive features are the spectacular sandy beaches, particularly those along the south shore. Beaches here are famous for their pink hue derived from the crushed skeletal remains of the single-celled foraminiferan (*Homotrema rubrum*) (see Figure 4.13). The sand itself supports a wealth of organisms. Some are burrowing organisms whilst others are largely invisible to the naked eye, living between the sand grains. More easily visible examples are the ghost crab and land crab, shorebirds such as ruddy turnstone, various plovers and sandpipers as well as the tiger beetle, rove beetle and sand flea. The Bermuda skink and Jamaican anole may also scavenge on the beaches. The strandline that forms along the beach from organisms that have washed ashore is an important microhabitat.

Figure 4.13 Bermuda's pink sand

Photo courtesy of the Department of Tourism

Forming behind the beaches, above the strandline, are sand dunes, which support a number of specially adapted plants (Sterrer and Cavaliere, 1998). Behind the fore dunes the vegetation becomes more continuous, giving way to mature dunes that support both endemic and native species. In total, Bermuda's beaches and dunes cover an area of 77 ha (190 acres).

The major threat to the beaches and dunes is coastal erosion from storm surge. Intense storms may temporarily but significantly reduce the beaches and dunes around the Island. Other problems include trash, the raking of beaches, invasive species and camping (authorised and unauthorised).

4.2.3.4 Mangroves

Mangrove swamps are ecosystems dominated by trees that develop along sheltered coastlines and in bays. Like the coral reefs, Bermuda's mangrove swamps are not as species-rich as those in the Caribbean but they are unique in that they are the most northerly example in the Atlantic Ocean.

Mangroves are trees that are adapted to tolerate both salt and brackish water. Bermuda has two species of mangrove. The red mangrove (*Rhizophora mangle*) is found at the seaward edge of swamps and behind it lies the black mangrove (*Avicennia nitida*) trees. A landward species of this is the buttonwood (*Conocarpus erectus*) often forming a fringe at the back of the swamp. In recent years, the invasive Brazil or Mexican pepper (*Schinus terebinthifolius*) has been encroaching on the back of mangrove swamps and has become a serious menace (see Figure 4.14).

Figure 4.14 Bermuda's mangrove habitat

Photo courtesy of Bermuda Biological Station for Research

Mangroves are important for a number of reasons. They act as sediment traps, maintaining the structure of the coastline and the quality of the surrounding waters. Mangroves also act as natural breakwaters, protecting coastlines from erosion during storms. The dense tangled root masses trap sediments and hold them in place while the trees themselves slow wind velocities.

One of the greatest attributes of the mangrove swamps is that like sea grasses they provide a protected marine environment and a source of rich food. The roots of the trees are covered with a vigorous growth of marine animals and plants while the spaces among the roots are occupied by a wealth of small, juvenile marine creatures.

The structural complexity of mangrove forests provides many niches for both marine and terrestrial animals. The extensive root systems of mangrove trees support a rich community of epiphytic organisms ranging from algae to anemones. The sheltered nature of mangrove swamps along with their rich food supply makes them an ideal location for the juveniles of many marine organisms such as barracuda, snappers and grunts. The adults of many near-shore species including damselfish, bream, wrasses and parrotfish also make use of these areas.

Many intertidal species utilise both the sub-tidal areas and the above-water habitat of the trunks, prop roots and branches. The prop roots and lower branches of mangroves in Bermuda are home to a variety of crabs including marine and land hermit crabs, land crabs, the mangrove crab, the giant land crab (*Cardisoma guanhumi*) and the land hermit crab (*Coenobita clypeatus*). The coffee bean snail is another well-known resident found within the mangrove habitats.

The forest canopy provides a good habitat for many nesting birds including egrets and herons. As a result, mangroves are increasingly becoming of interest to the general public and as such are acquiring value as a resource for ecotourism, particularly among birdwatchers.

Falling leaves from mangrove trees decompose into a very rich food source for a wide variety of marine creatures. This natural broth carried to other coastal waters by tidal and wind-driven currents supports a whole food web of creatures which in time become the food of fish and lobsters. Research provides good evidence that without the mangrove swamps the productivity of Bermuda's fishery industry would decline substantially.

Hungry Bay supports the largest mangrove swamp in Bermuda and is 2.9 ha (7.2 acres) in size (see Figure 4.15). It has long been dubbed 'the Great Mangrove'. This is the only mangrove swamp with a well-developed system of drainage channels which are not characteristic of large swamps elsewhere. These channels are not natural and were created to secure boats during hurricanes and to allow access to docks at the eastern end of the swamp. The enhanced drainage of the forest by the channels has reduced peat formation and increased erosion at the seaward margin of the forest (Ellison, 1993). In addition, the sea level has risen significantly around Bermuda over the past century. These factors have combined to deepen the seaward edge of the forest while preventing new mangrove seedlings from establishing and replacing trees lost to storms. Thus the forest has retreated dramatically since the 19th Century.

Figure 4.15 Rising sea level at Hungry Bay

Photo courtesy of Heather DeSilva

The mangrove forest at Hungry Bay has been monitored by scientists at the Bermuda Biological Station for Research since 1991. Scientists have been examining forest biomass, mortality, recruitment and litterfall in permanent study plots (CARICOMP, 1997). The mangrove trees in Hungry Bay include some of the largest in Bermuda. In addition, the Hungry Bay mangrove swamp supports the Island's largest populations of two rare and endangered crabs, the giant land crab (*Cardisoma guanhumi*) and the land hermit crab (*Coenobita clypeatus*). Both of these crabs breed in the sea but spend their adult lives in marine swamps and marshes. Recent population surveys conducted by the Bermuda Biodiversity Project at the Bermuda Aquarium, Museum and Zoo (BAMZ) have revealed that both species are locally threatened.

Hungry Bay is extensively polluted by floating debris, which in some locations forms a continuous layer on the surface of the ground among the trees. Additionally, the severe erosion of a seaward section of the peninsula that encloses Hungry Bay has permitted stronger storm wave energy from entering the bay and impacting the forest edge by toppling trees. The effects of Hurricane Fabian in 2003 caused the most recent and severe damage. The entire area including the peninsula between the bay and the South Shore is in need of regular clean-up, restoration and an increased measure of protection.

At the other extreme are thin lines of fringing mangroves along the shores at such locations as Mullet Bay and Ferry Reach.

Mangrove swamps are fairly resilient to pollution and as such continue to grow well in locations such as Mill's Creek which has significant levels of pollution. Additionally, the diverse bacterial populations fostered in the mangrove environment serve to detoxify many toxic wastes. However, pollution does reduce biodiversity in mangroves and in extreme cases can result in the death of trees themselves.

Mangrove swamps tend to occur in very sheltered locations. These sheltered areas are also favoured sites for the construction of wharves, harbours, jetties and other marine structures. Development has resulted in mangroves being steadily removed since the arrival of man in Bermuda with the largest example totalling 5.7 ha (14 acres) of mangrove forest being removed during the construction of the Kindley airbase between 1941 and 1943 (see Table 4.1 in section 4.3).

The importance of mangrove swamps warrants strict protection and if removal of mangroves is absolutely necessary, it should be balanced by careful reforestation of mangrove trees in other suitable locations. In 1989, the International Union for the Conservation of Nature (IUCN) declared that mangrove forests are the most threatened ecosystem in the world. In Bermuda most mangroves are now protected by law under the Tree Preservation Order Regulations, 1976 subject to section 27 the Development and Planning Act, 1974. In 1999, Bermuda's largest coastal mangrove as well as some inland mangroves were designated as 'Ramsar' sites. 'Ramsar' sites are wetland areas that were protected for conservation under the Convention on Wetlands which was adopted in the Iranian city of Ramsar in 1971.

4.2.3.5 Salt marshes

Salt marshes occupy relatively sheltered coastlines and like mangrove swamps, they offer a great deal of protection to coastal environments in times of stormy weather. At present, salt marshes in Bermuda are limited to a few small areas such as the ones at Spittal Pond and at Hungry Bay, although the latter has all but disappeared as a result of storm erosion. Other small marshes appear to the rear of several mangrove swamps. However, there is evidence to show that before man colonised the Island extensive salt marshes existed in the area of Pembroke Marsh West. This area is now filled and heavily industrialised.

Occupying only a very small ecosystem in Bermuda, salt marshes are still very important in that they support an unusual number of rare and endangered plants and animals. Additionally, they raise the biodiversity of Bermuda's flora and fauna. Examples of uncommon animals and plants found in the salt marshes are sea lavender (*Limonium carolinianum*), seaside heliotrope (*Heliotropum curassavicum*), sea rush (*Juncus maritimus*) and the extremely rare and locally endangered land hermit crab (*Coenobita clypeatus*). The adults spend most of their time in mangrove swamps, salt marshes and coastal forests foraging for food. Bermuda's land hermit crab population is no more than a few hundred at most. They are continually threatened both by habitat destruction and a shortage of suitable host shells (West Indian top shells).

Salt marshes have steadily decreased in size since the Island was colonised and now occupy only tiny areas that total approximately one hectare. They require strengthened protection.

4.2.3.6 Marine ponds

The inland marine ponds of Bermuda should be considered one of the Island's national treasures because they support a very high biodiversity of marine and brackish-water organisms and because on a worldwide basis they are rare. Walsingham Pond with its high diversity of life has been termed 'a sort of sponge metropolis of the world' by Dr. de Laubenfels, a world-renowned sponge expert (de Laubenfels, 1950).

Marine ponds are ecologically special for a number of reasons. First, they offer the most sheltered marine habitats in Bermuda which means that very delicate animals and plants can survive there. Second, most are surrounded by mangrove trees whose decaying leaves make a rich food source. Third, the roots of the fringing mangrove trees form an intricate shoreline zone with plentiful submerged, clean, hard surfaces on which marine organisms can settle. This is especially important as the bottoms of the ponds are very muddy and are home to a very rich mix of sponges, tube worms, moss animals, anemones, sea squirts and delicate seaweeds.

Most marine ponds support large populations of fish including the endemic Bermuda killifish (*Fundulus bermudae*). Some ponds across the Island are home to rare species of plants and animals. For example, the very rare diamondback terrapin (*Malaclemys terrapin*) occurs in two of the ponds (Mangrove Lake and Trott's Pond) while the green turtle (*Chelonia mydas*) is often seen in Walsingham Pond. The endemic seaweed, Bermuda sargassum (*Sargassum bermudense*) has also been found at a few pond locations. One shellfish, the flat mangrove oyster (*Isognomon alatus*) is abundant in Trott's Pond and Mangrove Lake.

The ponds are very vulnerable to pollution run off from the land and they have traditionally been used as trash dumps. Although mass mortalities of fish have occurred in several ponds, notably Trott's Pond and Mangrove Lake, most of the species found in ponds are quite tough and can survive in remarkably poor environmental conditions. However, further additions of organic pollutants could result in the already low oxygen content of the water declining to zero, particularly in hot weather. This may cause conditions to deteriorate further, eradicating many rare and uncommon species. The important marine ponds, namely Mangrove Lake, Trott's Pond and Evans Pond warrant protection, particularly from further run-off from fertilisers and organic pollutants.

Walsingham Pond is the best example of an inland marine pond in Bermuda (see figure 4.16). It supports exceptionally high biodiversity and has by far the richest fish and marine invertebrate assemblages of any of the Island's marine ponds. Additionally, it is the most stable of the ponds and is deeper than any of the others. Its origin as a partly collapsed cave and part depression is also unique. It supports at least two endemic species, the Bermuda sargassum (*Sargassum bermudense*) and the Bermuda killifish (*Fundulus bermudae*) while supporting resident populations of the green turtle (*Chelonia mydas*).

Walsingham Pond lies within a protected nature reserve area and is therefore not subject to a great deal of disturbance from development. However, Hurricane Fabian deposited much sediment and marine debris which killed off some organisms. The pond is making a good recovery and should continue to do so although the possibility of pollution entering the pond from nearby properties should be investigated and controlled as required.

Figure 4.16 Walsingham Pond

Photo courtesy of Martin Thomas

4.2.3.7 Marine caves

Many of Bermuda's caves share characteristics of the inland saltwater ponds in that they can extend below sea level and are consequently filled with seawater (see figure 4.17). The largest, almost entirely submerged and connected network of cave passageways that has been discovered is the Green Bay Cave system, which opens into Harrington Sound. In several cases, for example at Walsingham Pond, submerged caves connect marine ponds to the sea. The well-lighted outer ends of seawater-filled caves support animals and plants very similar to those in marine ponds. The inner dark parts of caves, however, are very specialised marine habitats and support a sparse group of rare and highly adapted animals. Most of these are shrimp-like crustaceans that have been found nowhere else in the world. Examples are the shrimps *Procaris chacei, Typhlatya iliffei* and *Bermudacaris harti,* the ostracod *Spelaeoecia bermudensis*, the new crustacean order Mictacea represented by *Mictocaris halope* and the isopod *Atlantasellus cavernicolus*.

Stygobitic (cave-adapted) shrimp-like creatures, ranging in size from 1500µm to 10 cm, have been found to exist deep in the waters of Bermuda's cave pools. Most have no eyes or body pigmentation and are believed to feed on plankton and organic detritus carried by tidal currents through the caves. All of Bermuda's currently known 84 marine cave species are native and of these 73 species (mostly crustaceans) are endemic to Bermuda. This means that marine cave habitats hold some 43% of Bermuda's 169 known living, endemic animals and this percentage is likely to increase as research and discoveries in the caves continue.

Some species belong to the same genus as organisms living in distant deep-sea environments and cave systems in other oceanic islands. Due to their rarity and existing environmental threats to the cave habitat in Bermuda, 25 of these organisms have been placed on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Animals. Assuming that current environmental trends in Bermuda continue, scientists predict that approximately 50% of these species may become extinct within the next decade. Marine caves are threatened by pollution run-off, quarrying and dumping of trash.

Figure 4.17 SCUBA divers in a Bermuda marine cave

Photo courtesy of C. Lascu

4.2.3.8 Harrington Sound

Harrington Sound is an inland saltwater sound that has ecological characteristics that make it unique in the world. Harrington Sound's only obvious connection to the sea is by a very narrow channel at Flatts Bridge where seawater alternately enters and leaves the Sound with the tides (see figure 4.18). However, only about half the tidal water exchange between the sea and the Sound takes place through this surface channel. An equally large component enters via caves such as Green Bay Cave and through numerous cracks and fissures around the shoreline. Nevertheless, the tidal range in Harrington Sound is reduced to about 20 cm compared to 75 cm along the adjacent coast.

Harrington Sound supports several unique marine habitats and additionally has a very high biodiversity of marine life. Sponges are especially well represented. Perhaps the most unusual habitat in Harrington Sound is a deep notch cut into the cliffs of the shoreline, just below low tide level, that has been produced by very large populations of the date clam (*Lithophaga nigra*), a burrowing bivalve mollusc which bores into the rock using both chemical and mechanical means (Thomas, 1996). The notch supports a very diverse array of marine animals and plants.

A second unique habitat, now virtually eradicated, was the Oculina zone (Barnes and Bodungen, 1978) that existed on muddy sediments between 30 to 50 ft (9 to 17 m). This community was created by dense aggregations of colonies of the ivory bush corals (*Oculina valenciennesi*) and (*Oculina diffusa*) whose branches were encrusted with turkey wing mussels (*Arca zebra*). Many other corals, bivalves, sponges, fish and algae lived within this zone, creating a unique species-rich community. Unfortunately, dredging and pole methods used to harvest mussels destroyed the corals, reducing suitable substratum for most of the species to attach themselves to resulting in the community collapsing (Thomas, 1996).

In addition to these two habitats the near-shore sandy bottoms of Harrington Sound from about 6 to 30 ft (2 to 10m) deep support three bivalve molluscs of potential commercial importance. These are the Bermuda scallop (*Pecten ziczac*), the calico scallop (*Argopecten gibbus*) and the calico clam (*Macrocallista maculata*). Currently scallop populations are very low but clam populations are rising after a fall to very low levels in the late 1970s and 1980s. Efforts have been made over the past 10 years to increase scallop populations through research and mariculture at the Bermuda Biological Station for Research and the Department of Conservation Services. A fourth mollusc with commercial potential, the Harbour Conch (*Strombus costatus*), currently a protected species, has become quite common again.

Nutrients leaching from cesspits via the groundwaters that enter the Sound pose a threat to this unique inland water body. Mass blooms of the benthic algae (*Cladophora prolifera*) in the 1970s benefited from the nutrients and accumulated in thick mats up to 3 ft (1 m) deep (Bodungen, *et al.* 1982). These mats smothered seagrass beds and displaced many organisms (clams, sponges etc.) that lived in or on the sediment. The mats gradually disappeared in the 1980s partly due to large increases in the population of the sea urchin, (*Lytechinus variegates*) that consumed the algae. However, some small Cladophora mats still exist in Harrington Sound.

Harrington Sound has not been afforded the protected status that its unique characteristics demand. Continued housing development will add to the increase in nutrient levels in the Sound and this will potentially destabilise its ecological system. The loss of the Oculina zone represents a great reduction in the capacity to process planktonic material through filter-feeding by corals, bivalves and sponges. This loss may make the Sound more vulnerable to the effects of nutrients stimulating plankton blooms that may be detrimental.

Restoration of filter feeding communities, even through the mariculture of bivalves, may be a practical step in mitigating the effects of nutrient loading.However, more research and monitoring is required.

Figure 4.18 Harrington Sound

Photo courtesy of the Department of Planning

4.2.3.9 Mill's Creek

Mill's Creek and the lower part of Pembroke Canal form the only estuarine system in Bermuda since Pembroke Canal is the sole freshwater stream within Bermuda (see Figure 4.19). When Bermuda was first settled this area supported extensive mangrove swamps that graded into salt marshes in Pembroke Marsh West. Unfortunately, the area's proximity to the City of Hamilton meant that the swamps and marshes were steadily filled to provide space for industry, generating plants and many other businesses. The original stream was channelled and a tidal control structure (sluice gate) was built where it discharges into Mill's Creek. The salt marshes were totally eradicated and the mangrove swamps were reduced to the area below the sluice gate. Pembroke Canal carries heavy loads of run-off and sewage polluted water. It is feared that up to half a dozen of Bermuda's endemic freshwater mollusks, including a pea clam (*Pisidium volutabundum*), may have become extinct when the upper parts of Pembroke Canal were turned into a dump (Sterrer, 1998).

The mangrove swamp in Mill's Creek is in remarkably good condition considering the high level of pollution. It does, however, show reduced biodiversity compared to cleaner swamps across the Island. If improvements were made to the Canal, however, it would make an excellent site for an educational boardwalk.

Figure 4.19 Mill's Creek

Photo courtesy of the Department of Planning

4.3 Terrestrial Habitats and Biodiversity

4.3.1 Introduction

Like most island ecosystems, prior to human settlement Bermuda's terrestrial habitats supported a limited diversity of plants, probably no more than 167 species (Junos and Wingate, 1995). The Island's early floral biodiversity comprised a dense forest, largely dominated by the endemic Bermuda cedar (*Juniperus bermudiana*) and Bermuda palmetto (*Sabal bermudana*). The early forest also included natives such as yellow-wood (*Zanthoxxylum flavum*) and hackberry (*Celtis laevigata*). Emerging under the sheltered canopy of these forests were Bermuda's endemic understorey species including the Bermuda sedge (*Carex bermudiana*), Bermuda maidenhair fern (*Adiantum bellum*) and Bermuda snowberry (*Chicocca bermudiana*) as well as a variety of native species.

Bermuda's isolation prohibited colonisation by amphibians, mammals (except bats) and most reptiles except for one species of lizard. However, birds, snails and insects were abundant.

Human colonisation resulted in an immediate and dramatic change to Bermuda's flora and fauna (Sterrer *et al.*, 2004). Hogs were perhaps the earliest introduced animal species but rats, cats and dogs quickly followed. The accidental introduction of a scale insect, which resulted in the loss of 96% of the endemic cedars in the 1940s, highlighted the threat of introduced pests and was followed by a wave of further introductions, some accidental and some intentional. As a result of these and other human activities, the Island's natural history has changed dramatically since its colonisation in the early 1600s. Introduced or 'alien' species, many of which have become invasive, have out-competed many native species (see Chapter 15). Therefore, many of the habitats that remain comprise mostly introduced species with some natives struggling to survive. Only nature reserves that are continually managed, such as Nonsuch Island and Paget Marsh, have the highest incidences of native fauna and flora.

The habitats and their measured sizes are set out in Table 4.1 and can be compared with estimates of the sizes of habitats before human settlement.

Before people settled in Bermuda, the Island comprised some 11 habitats with three-quarters of the total land area of 5,100 ha comprising Upland Hillsides and Upland Coastal Hillside. The third largest area was the Upland Valleys totalling an estimated 18% of the land area. The distribution of Bermuda's terrestrial habitats is shown in Figures 4.20(a) and 4.20(b).

Development now occupies what were formerly areas of Upland Forest, Upland Coastal forests and Upland Valley habitats. Just over one-third of the original Upland Forests remain. Only one-quarter of the

Table 4.1 Size of habitats before and after human settlement

Habitat	1600 A.D.		2000 A.D.*		% change between AD 1600 & AD 2000
	Ha	%	ha	%	
Beach & Dune	76	1.5	76	1.4	-7
Mangrove Swamp	24	0.5	18	0.3	-40
Salt Marsh	4	0.1	1	0	-75
Marine Pond	17	0.3	17	0.3	0
Rocky Coastal Shoreline	162	3.2	90	1.7	-47
Upland Coastal Hillside	1,382	27	348	6.5	-76
Upland Hillside	2,303	45	903	17	-63
Brackish/Fresh Pond	8	0.1	10	0.2	20
Peat Marsh	119	2.3	45	0.8	-65
Upland Valley	921	18	0	0	-100
Limestone Sink	125	2.4	67	1.2	-50
Arable Field/Pasture	0	0	178**	3.3	
Landscaped Gardens, lawns & playing fields	0	0	669	13	
Golf Course	0	0	260	4.8	
Developed land, including hedgerows, walls, wayside. Road verges	0	0	2,689	50	
Total	**5,141**	**100**	**5,371*** **	**100**	

Notes:

*These figures from Bermuda Biodiversity Project are a 2003 revision from the 2001 figures presented in the Country Study.

**A discrepancy exists between figures given in this table and arable land coverage in Chapter 8.0 because of differing methodology.

***Reclaimed land was created in the 1940's increasing the land area from pre-settlement times.

Source: Bermuda Biodiversity Project Country Study 2001

original Upland Coastal Hillside areas survived and practically no Upland Valleys remain. Upland Valleys with their deep, fertile soil were originally converted to agricultural land but in recent years, as a result of land scarcity more fields have been given over for development as the profitability to develop land is greater than keeping it in cultivation. Therefore, the Upland Valleys, which once comprised an estimated 900 ha have almost completely disappeared.

Now over 50% of Bermuda's land area is developed, while a further 17% comprises anthropogenic habitats including golf courses, residential and public gardens, lawns and playing fields. This has left some 10 habitats comprising some 1,500 ha, few of which are in pristine condition, containing the original native vegetation and fauna. The hardy, native plants on the coasts tend to survive as they are better adapted to the salt and wind than the introduced species that have established themselves in the more

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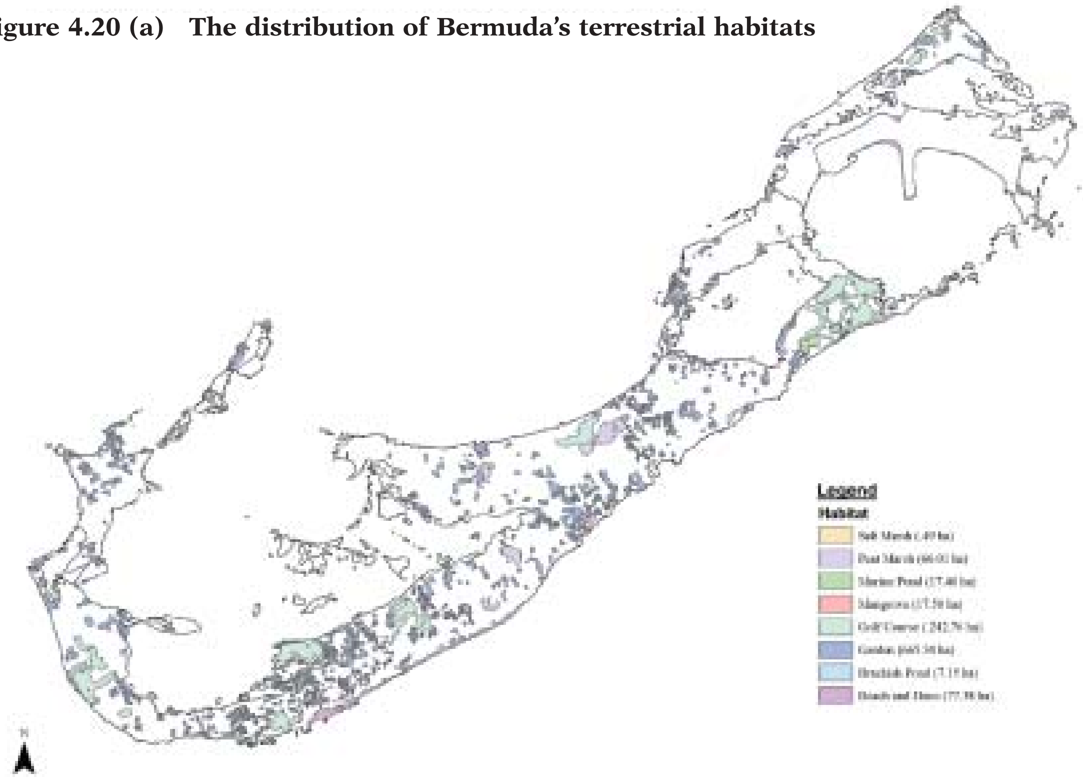
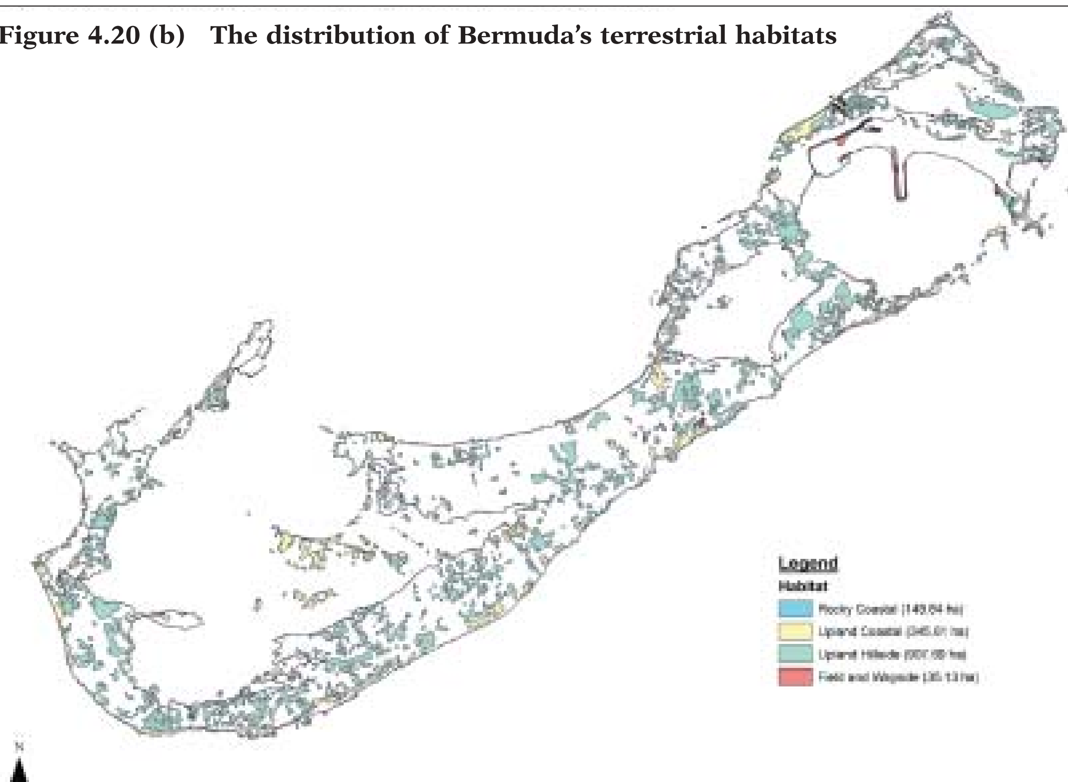
Figure 4.20 (a) The distribution of Bermuda's terrestrial habitats



Source: Bermuda Biodiversity Project Country Study 2001

Figure 4.20 (b) The distribution of Bermuda's terrestrial habitats



Source: Bermuda Biodiversity Project Country Study 2001 sheltered inland areas. The coastal habitats of Beach and Dune and Rocky Coastal areas remain less undiminished because they are unsuitable for development and are protected by legislation. Peat marshes have been used in the past as garbage dumps and for industrial uses and have been reduced in size to one-third of what they were in pre-settlement times.

4.3.2 The Status of Bermuda's Terrestrial Habitats

4.3.2.1 Rocky Coastal

In between the beaches and dunes, the Rocky Coastal habitat extends along most of Bermuda's shoreline from the high water tide mark inland up to 15 m (49 ft) and totals an area of approximately 90 ha (222 acres). Only the most salt-tolerant species such as buttonwood (*Conocarpus erectus*) and bay grape (*Coccoloba uvifera*) flourish in this habitat. Despite perhaps being the most resistant of all Bermuda's terrestrial habitats to invasive species, the native and endemic species of the Rocky Coast are nevertheless threatened by the casuarina (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*).

Two good examples of Rocky Coastal habitat with a high native biodiversity are Spittal Pond (see Figure 4.21) and the area north of the Railway Trail, west of Shelly Bay. Sightings of the Sally Lightfoot crab (*Grapsus grapsus*) as well as several heron species, longtails (*Phaethon lapturus catesbyi*), common terns (*Sterna hirundo*), cranes, double-crested cormorants (*Phalacrocorax auritus*) and belted kingfishers (*Megaceryle alcyon*) are common in these areas.

Figure 4.21 Spittal Pond, a Rocky Coastal habitat

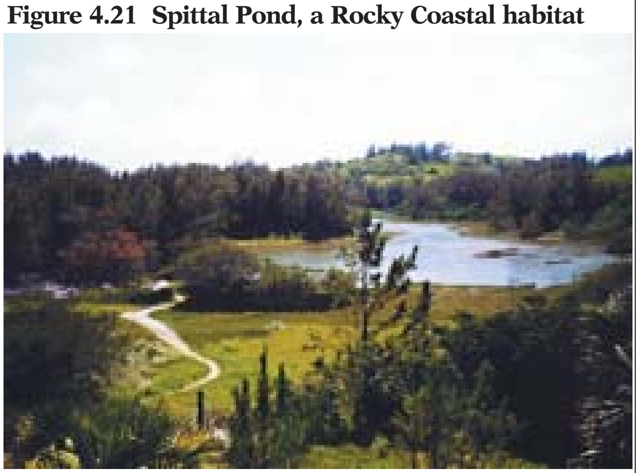


Photo courtesy of the Bermuda Biological Station for Research

The major threat to this habitat is pollution, particularly from oil and destruction (for the development of boathouses and docks). Given the porous nature of the rock, coastal erosion from storm surge and hurricanes is also a problem.

4.3.2.2 Upland Coastal

The Upland Coastal habitat extends inland from the rocky coastal habitat to the top of the old foredune and consists of an area of about 348 ha (860 acres). This habitat also supports vegetation well adapted to salt spray and capable of rooting in shallow soil. There are some differences between sheltered and exposed areas.

Pre-settlement species would have included endemics such as Bermuda cedar and Bermuda palmetto as well as natives such as bay grape (see Figure 4.22), forestiera, and buttonwood. Many of the same understorey species would have been present as in the Rocky Coastal but with the addition of Darrell's fleabane (*Erigeron darrellianus*), Spanish bayonet (*Yucca aloifolia*), poison ivy (*Rhus radicans*), cape weed (*Lippia nodiflora*), ink berry (*Passiflora suberosa*), and seven year apple (*Cassasia clusiifolia*).

One of the best examples of the Upland Coastal habitat with a high endemic and native biodiversity is High Point in Southampton Parish. Unfortunately, the Brazil pepper and the casuarina tree have taken hold in most areas. There is increasing concern over the presence of Surinam cherry (*Eugenia uniflora*) and allspice seedlings (*Pimenta dioica*), both of which threaten the endemic Bermuda palmetto, Darrell's fleabane, native forestiera, coast sophora (*Sophora tomentosa*) and ink berry.

Figure 4.22 A baygrape tree

Photo courtesy of the Department of Planning

Animals such as the land crab (*Gecarcinus lateralis*), yellow-crowned night heron (*Nyctanassa violacea*), the endangered native land hermit crab (*Coenobita clypeatus*) and the endemic skink (see Figure 4.23), as well as orb web spiders (*Gasteracantha cancriformis*), leaf-scarring beetles (*Chaetocnema sp*.) and leaf-cutting bee (*Megachile sp.*) are often associated with the upland coastal habitat.

Ongoing development, invasive species and hurricanes threaten coastal hillsides.

Figure 4.23: Bermuda's endemic skink

Photo courtesy of the Department of Tourism

4.3.2.3 Upland Hillside

Occupying a total area of 903 ha (2,231 acres), only a few pristine upland hillside habitats still survive, the best example being Abbott's Cliff (see Figure 4.24). Most have been cleared for agricultural or residential use. Characterised by deeper soil and fairly sheltered locations, pre-settlement species would have included trees such as the endemic Bermuda cedar, Bermuda palmetto, Bermuda olivewood, as well as forestiera, white stopper (*Eugenia monticola* (syn. *Eugenia axillaris*) and Jamaica dogwood (*Dodonaea viscosa*).

Understorey species such as endemic Bermuda snowberry (*Chiococca bemudiana*) (see Figure 4.25), shrubby fleabane (*Pluchea symphytifolia*), doc-bush (*Baccharis glomeruliflora*), Bermuda bedstraw (*Galium bermudense*), poison ivy (*Rhus radicans*), Virginia creeper (*Parthenocissus quinquefolia*), turnera (*Turnera ulmifolia*), St. Andrew's cross (*Ascyrum macrosepalum*), sword fern (*Nephrolepsis exaltata*) and paspalum grasses (*Paspalum species*) would have prevailed.

The deep soil and protection from wind and salt spray in these areas has enabled faster, taller-growing, introduced, invasive plants such as Brazil pepper, allspice and Surinam cherry to take a foothold while displacing and strangling the existing native and endemic species.

Figure 4.24 Abbott's Cliff, an Upland Hillside habitat

Photo courtesy of Bermuda Biodiversity Project

Figure 4.25 Bermuda snowberry

Note: This endemic understorey plant which is 'holding its own' in Upland Hillside and other habitats.
Photo courtesy of the Department of Planning

The Upland Hillside habitat is one of Bermuda's most threatened habitats. It is heavily impacted by habitat loss through development and is particularly susceptible to invasive species.

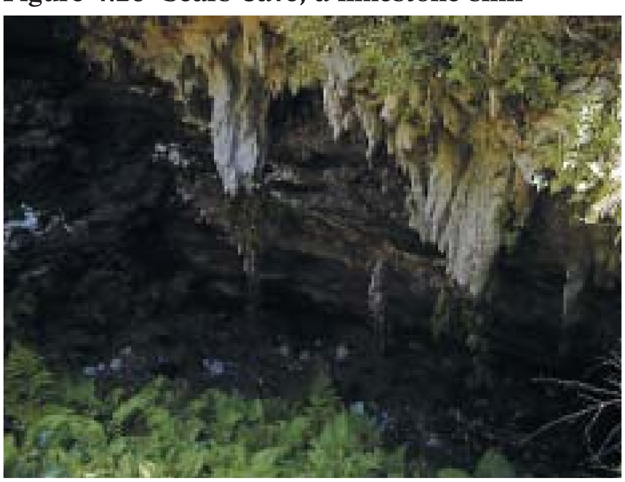
4.3.2.4 Upland Valley

Upland Valley areas comprise the sheltered valleys and depressions with deep soil along the central axis of the Island. They have become completely developed for arable, residential and garden use. However, an upland valley area on Nonsuch Island has been restored. In pre-colonial times the endemic Bermuda cedar, olivewood, palmetto, native yellow-wood and southern hackberry would have dominated this habitat. The dense canopy would have supported native and endemic ferns and mosses.

4.3.2.5 Limestone sinks

A limestone sink is a depression, sometimes with a steep-sided rock face, that is the site of a collapsed cave (see Figure 4.26). This is a very localised habitat and most are found in the areas of oldest limestone within the Walsingham Formation in Hamilton Parish. Because of their rugged topography, which historically has been difficult to develop, many sinkholes have served as a refuge for endemic and native species that have disappeared from other locations. Coupled with their moist environment they provide ideal conditions for ferns, including the endemic Bermuda shield fern, mosses and liverworts such as long spleenwort and toothed spleen-wort, as well as the endemic wild Bermuda bean and wild Bermuda pepper.

Figure 4.26 Sears Cave, a limestone sink



Note: This limestone sink is owned by the Bermuda Audubon Society. Once filled with dumped waste, it has been restored with native vegetation.
Photo courtesy of the Bermuda Biodiversity Project

The major threats to these limestone sinkholes are dumping of trash and development.

4.3.2.6 Caves

Caves are some of the most beautiful natural features of Bermuda and are considered national treasures. About 180 caves have been officially identified on the Island (see Figure 4.27). They range in size from small cracks and crevasses to large well developed chambers, some above sea level, some below and some intermediate and partially filled with water.

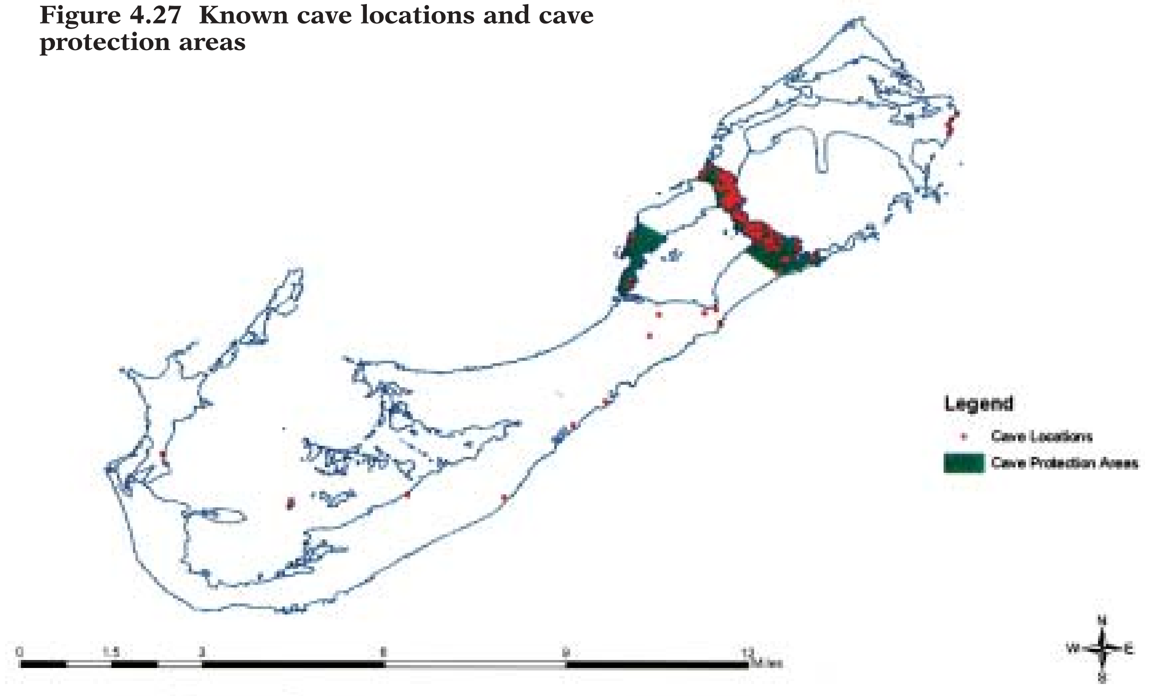
By far the greatest number of caves are located along a narrow strip of land between Harrington Sound and Castle Harbour in Bermuda's oldest limestone rock, the Walsingham Formation, which is one or more million years old. It is only because this formation happens to be exposed at the surface that this is where most cave entrances are found. Caves have been discovered in other parts of the Island but the majority of Bermuda's caves remain inaccessible due to entombment by younger limestone deposits, both above and below sea level.

A number of caves are very well decorated with karst features including stalactites, stalagmites and a variety of spectacular flowstones (see Figure 4.28). Cave formation is a process that is measured in terms of geological rather than historical time. With the growth of a stalactite estimated at approximately one inch per thousand years, it is easy to glean that most of Bermuda's caves are tens of thousands of years old.

It is widely thought that many of Bermuda's caves originated from the groundwater dissolution of the limestones in contact with the volcanic rock during periods of low sea level. Later stages of development saw the collapse of large blocks from the ceilings of caves as they developed towards the land surface. The apparently deep layers of large fallen blocks, which now form the floors in many of Bermuda's caves, provide evidence of such collapse.

Other Bermuda caves, such as the submerged Green Bay system, were created during high sea levels in zones where the mixing of fresh and saline groundwater produced a chemistry that was chemically aggressive towards limestones. These caves of sub-aqueous origin have smooth walls and floors and are 'primary' features, contrasting to Bermuda's better-known 'secondary' collapse caves, as described above. They tend to develop within the coastal margins of limestone islands and are accordingly known as 'flank margin' caves.

Figure 4.27 Known cave locations and cave protection areas



Source: The Bermuda Plan 1992, Department of Planning

Some of the most interesting Bermuda caves are those that are full or partially filled with water. Stalagmites, stalactites and other features in these caves were formed during periods of low sea level stands since they are solution/precipitation in origin and cannot form underwater. They provide irrefutable evidence of substantial sea level fluctuations.

In cave pools the surface, one to six inches deep, is typically fresh water derived from rainfall which reaches the pool surface through percolation and then as drip water. Just below this surface layer the waters become brackish as the fresh water mixes with the seawater below.

Two of the most notable features of pool waters are their quiescence and clarity. The clarity is due to the lack of suspended particulates and planktonic algae, which are unable to grow in the absence of sunlight. It is common to be able to see through some 20 to 30 m (60 to 100 ft) of water to a cave bottom. In addition to cave formations, lichens, fungi and other flora exist in and around cave entrances.

Whilst the highest density of discovered caves is located in the Walsingham rock area between Harrington Sound and Castle Harbour, other important caves are located throughout the Island.

Figure 4.28 Helictite diagonally-growing upwards off soda straw with 'bacon rind' formation in upper left

Photo courtesy of Dr. Thomas Illiffe

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Crystal Cave is probably the best known of the Bermuda caves and is a part of the Walsingham cave system. It appears connected to a number of other cave areas and comprises a spectacular representation of a partially submerged Bermuda cave with crystal clear water and magnificent exhibits of stalactites, stalagmites and flowstones (see Figure 4.29). It was discovered in 1907 and remains a popular tourist attraction today. Preservation of the cave and its features has been a priority and it is one of only a few local caves in which the water quality is routinely monitored. Wonderland, an adjacent cave, has been periodically open to visitors and in July 2001 was once again reopened as a visitor attraction.

Figure 4.29 Crystal Cave

Photo courtesy of the Crystal Caves of Bermuda

Church and Bitumen are two caves located near to each other on the Tucker's Point Club (formerly Castle Harbour Hotel) property in Hamilton Parish. As many as 16 other limestone caverns are also known to be located on that property. Bitumen Cave derives its historic use as a disposal waste site for bitumen barrels, believed to have been used as a part of the original hotel construction. The old barrels, together with various other refuse and debris, litter the floor of the cave.

Features of Church Cave include a pool extending some 50 m by 50 m (150 ft by 150 ft) and water depths which may extend to some 25 m (75 ft). Both caves were the subject of environmental threats by development in the late 1990s. However, through a combination of planning restrictions and public pressure, strict guidelines were enacted to ensure preservation of the cave structures and water quality. These include site management, together with routine geologic, photographic and water quality monitoring.

Quarry Caves are a group of caves located or formerly located at the site of the Bermuda Government quarry in Hamilton Parish. The Walsingham rock is the hardest of Bermuda limestones and subsequently makes the best gravel for roads and other industrial works. Over the past four decades, there has been much blasting and excavation of the rock and its associated caves, and a number of caves have been destroyed by the quarrying.

Since 1995, Bassett's Cave has attracted the greatest attention from an environmental perspective. Bassett's Cave is located in Sandys Parish on what is now called King's Point, the former U.S. Naval Annex. Historical accounts have described the cave as a great splendour and estimated it as being up to a mile in length. In the 1940s during World War II the British Colonial Government leased some 250 acres of land in this area to the U.S. Government for the development of a military base. This land together with the coastal waters saw an unprecedented re-sculpturing of the site with the installation of fuel storage tanks and other naval supply facilities. It was during this period and the following 40 years that hundreds of thousands of gallons of sewage and waste fuel was deposited in Bassett's Cave. In addition, leaking underground storage tanks contaminated the surrounding groundwater with jet fuel and other petroleum hydrocarbons. A clean-up plan for the cave and associated groundwater is proposed. However, the financing of the clean-up is uncertain. Despite any attempted clean-up efforts, it is unlikely that Bassett's Cave will ever return to its former pristine beauty.

Speleologists consider Bermuda to have some of the most spectacular crystal formations anywhere in the world. In caves with public access, such as Crystal Cave, the submerged marine parts seem to be in excellent condition. There are cases, however, where marine caves have been used as depositories for toxic wastes. Care must be taken to ensure that Bermuda's caves remain well protected.

The Bermuda limestone caves that we see today developed and existed in Bermuda tens of thousands of years before the first human settlers arrived on the Island in 1609. Whilst we know that they have undergone natural changes in morphology and water chemistry over time, it is the more recent changes resulting from the impacts of human development that threaten their existence.

In the past, caves have been sites for garbage dumping, disposal of sewage, waste oils, trash and a variety of other discarded materials. Cave entrances have been filled simply to meet other developmental objectives or demolished so that the associated gravel could be used in road works. In a number of instances, vandalism and theft of stalactites and other karst features have damaged caves.

Quarrying activities have destroyed caves in the Government Quarry. Admiral's Cave (see Figure 4.30), south of Wilkinson's Quarry, is monitored to ensure blasting from quarry works is carried out in accordance with the conditions set out in the Minister of the Environment's appeal decisions granting approval for the quarry's expansion in the early 1990s.

Figure 4.30 Admiral's Cave

Photo courtesy of Dr. Thomas Illiffe

The introduction of excess organic matter to cave waters poses a major threat to cave water quality. 'Excess organic matter' includes natural or anthropogenic debris introduced at a level that overtaxes the dissolved oxygen capacity of the waters. Decomposing organic matter combines with dissolved oxygen resulting in the waters becoming depleted of oxygen. These anoxic conditions produce foul odours, a loss of water clarity and staining of stalactites, stalagmites and cave walls with black sulphide deposits. Under extreme conditions cave air may become toxic from gases such as hydrogen sulphide (rotten egg gas). In addition, concern is raised for those microscopic creatures living in the deep recesses of the caves which cannot survive in the absence of oxygen.

Evidence of sewage pollution has been identified through the presence of elevated nitrate and faecal coliform bacteria in a few of Bermuda's caves and also in Bermuda's groundwater. With most houses on the Island disposing of sewage through unlined cesspits, cave waters are at risk of contamination from sewage because the fissures, passageways and caves themselves can provide direct groundwater connections to sources of contamination.

So significant are the threats to Bermuda's caves that the Department of Planning has formal regulations to protect caves and cave entrances from development. Caves are protected under the Development and Planning Act, 1974 and the planning provisions in Section 12.CAV of the Bermuda Plan 1992 Planning Statement. These provisions recognise the unique flora and fauna, geological features and water quality associated with caves, and place restrictions on development in cave protection areas and near known cave locations (see Figure 4.29). There is also a provision within the Bermuda Plan 1992 Planning Statement which requires a cave survey to be undertaken prior to development (paragraph CAV.3, Section 12.CAV refers).

Without the presence of a robust system of monitoring Bermuda's caves it is difficult to assess their state other than through the observations made by cave experts. Baseline data needs to be collected from caves and this data needs to be updated with the implementation of a monitoring system.

The main threat to Bermuda's caves was, and in many cases still is, ignorance resulting in indiscriminate waste disposal and landfilling, direct discharges of sewage and oil, quarrying, specimen collection and other wilful damage. In addition, less direct impacts such as contamination from cesspit seepage and other surface and subsurface leachates have negative impacts on caves. Despite increased public awareness regarding the environmental sensitivity of the Island's caves, Bermuda's growing population and the increased pressures for development pose current and future threats.

Special attention will need to be paid to the issue of geological integrity of cave structures, cesspits, underground storage tanks and other surface seepage. Where development is proposed, environmental concerns will need to be identified. Plans will need to be introduced to minimise the impacts and monitoring programmes should be put in place to maintain the unique cave environment.

Better information about Bermuda's caves is needed. In the future, technology will allow for improvements to the mapping of caves and will aid in the assessment of their condition. In January 2002, the Bermuda Cave and Karst Information System (BeCKIS) was formed as part of the Bermuda Biodiversity Project (see Section 4.1 and 4.3) with the mission of increasing awareness and promoting a scientific study about Bermuda's caves, cave lifeforms and the negative impacts on the caves. BeCKIS is led by the Marine Biospeleology Lab of Texas A & M University at Galveston.

4.3.2.7 Peat-filled marshes

Peat marshes, which are confined to low-lying inland areas, form the most extensive freshwater habitat in Bermuda. Their area has declined dramatically since colonisation. In 1900 there were about 121 ha (298 acres) of peat marsh, which by 1997 had been reduced to approximately 45 ha (111 acres). Of these, Paget Marsh (see Figure 4.31) is the largest at 9.25 ha (22.8 acres).

Figure 4.31 Palmetto forest in Paget Marsh

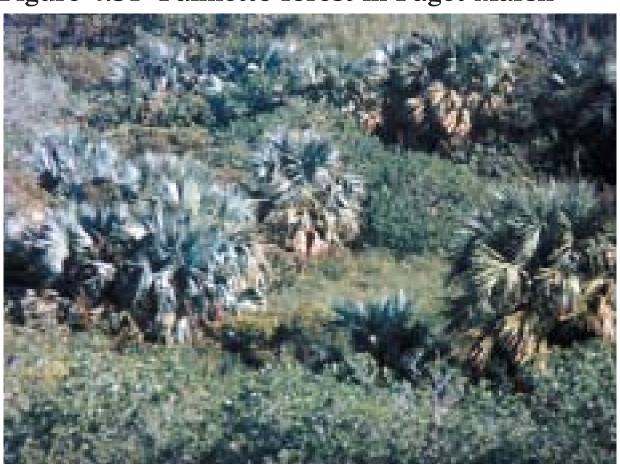

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

Marshes were historically used as areas to dump garbage, which provided an efficient way to eliminate mosquito breeding grounds. They were also cleared for lowland agricultural areas. Some marshes, or parts thereof, such as Mill's Creek, have been filled to allow development, whilst others such as The Pampas, Smith's Parish and the Lagoon Estate in Paget have been grassed over after being filled with waste and rubble to form lawns or wayside habitats.

Peat marshes have a high diversity of native and endemic species. Dominating the canopy in areas above the water table are the Bermuda palmetto (*Sabal bermudiana*), Bermuda cedar (*Juniperus bermudiana*), and wax myrtle (*Myrica cerifera*). The invasive Brazil pepper and in some areas Surinam cherry and guava (*Psidium guajava*) are also dominant species.

Wildlife in the peat marshes includes the barn owl (*Tyto alba*), migratory bats, the yellow-rumped warbler (*Dendroica coronata*), other migratory warblers, the giant toad (*Bufo marinus*), one species of whistling frog (*Eleutherodactylus gossei*), the grey catbird (*Dumetella carolinensis*), chick-of-the-village (*Vireo griseus bermudianus*), great blue heron (*Ardea herodias*), as well as ducks, herons, egrets, rails, other waterfowl and a wide variety of insects.

Expanded industrial development poses a potential threat to Devonshire Marsh whilst the impact of various introduced animals such as the giant ram's-horn snail (*Marisa cornuarietis*) and red-eared slider turtles (*Trachemys scripta elegans*), which have been discarded by local pet owners, warrant study.

4.3.2.8 Fresh-brackish pond

There are about a dozen freshwater and brackish water ponds in Bermuda, totalling an area of 10 ha (25 acres). Warwick Pond is the largest. Natural freshwater ponds have thick peat deposits on the bottom and around the edges, which prevent water from draining away. Several ponds such as David's Pond at Paget Marsh, Bartrum's Pond at Stokes Point Nature Reserve and one at Nonsuch Island have been artificially created. There are also ponds on golf courses and many residential properties.

Freshwater ponds are important for a diversity of resident and migrant waterfowl as well as mosquito fish (*Gambusia affinis*), giant toads (*Bufo marinus*), whistling frogs and aquatic insects such as dragonflies, midges and water snails.

Pollution from run-off of animal wastes from live-stock, dairy farming, fertilisers and pesticides from vegetable farming all threaten the freshwater pond habitat.

Field investigations of Bermuda's freshwater ponds have been undertaken locally and laboratory studies were conducted in 2002 and 2003 at Fort Environmental Laboratories in Stillwater, Oklahoma USA. Tissue and sediment analyses were subcontracted to a lab in Oklahoma.

Water and sediment extracts from the five ponds tested induced severe malformations in developing larvae of four different amphibian species. The studies (Bacon, 2003) revealed the following:

(a) The malformations seen in the laboratory were consistent with those found in larvae and newly metamorphosed toads collected from Bermuda's ponds.

(b) Sediment samples from all four ponds tested contained significant levels of total petroleum hydrocarbons and heavy metals.

(c) Toxicological analyses indicated that these two classes of toxicants are primarily responsible for the malformations observed in Bermuda's toads.

(d) Mixture analyses suggested that the two classes of contaminants interact synergistically, thus making the sediment significantly more toxic than one would expect based upon toxicant concentrations alone.

Four of the six ponds with the highest malformation rates are located in nature reserves. This data suggests that contaminants in Bermuda's ponds could pose a threat to wildlife and may potentially threaten human health as well (see Figure 4.32).

Table 4.2 shows the overall island-wide abnormality rates by year for two age classes of toads, the juvenile and adults (grouped together because they are found during the night time surveys) and the metamorphs (newly transformed toadlets from tadpoles) collected from ponds. Table 4.2 shows the number of sites surveyed each year, the total number of individuals examined (N), the % of the total number examined that exhibited abnormalities and the range of percent abnormal for each survey (adults) or cohort (collection of metamorphs). For example in 2003, the abnormality rates for each adult survey ranged from 15-55% and from 0-64% for each cohort of metamorphs examined.

Figure 4.32 Freddie the frog

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

4.3.2.9 Garden

Residential gardens, playing fields and public parks total approximately 669 ha (1,653 ac) of land. Invasive trees predominate in this habitat; however, the planting of ornamentals in gardens has actually helped increase the numbers of native and endemic species by providing more space for them to grow.

Gardens provide an important habitat for many animals including the Eastern Bluebird (see Figure 4.33), European goldfinch, common ground-dove (*Columbina passerina*), mourning dove (*Zenaida macroura*) as well as a wide variety of migratory warblers and other songbirds. Common insects include the field cricket (*Gryllus firmus bermudensis*), long-horn grasshopper (*Orchelimum vulgare*), short-

Table 4.2 Amphibian abnormality rates 2000 – 2003

MATURE AND JUVENILE TOADS					METAMORPHS				
YEAR	# SITES	N	% ABNORMAL	RANGE PER SURVEY	YEAR	# SITES	N	% ABNORMAL	RANGE PER COHORT
99-2000	27	726	19	0 - 29%	2000	18	2223	16	0 - 47%
2001	10	545	26	12 - 38%	2001	17	3687	19	0 - 61%
2002	11	521	30	6 - 43%	2002	24	3520	21	0 - 81%
2003	11	682	28	15 - 55%	2003	18	1952	24	0 - 64%

Source: Bacon et al.*, 2003*

horn grasshopper (*Orphulella olivacea*), Surinam and American roaches (*Pycnoscellus surinamensis* and *Periplaneta americana*), monarch butterfly (*Danaus plexippus*), buckeye butterfly (*Precis coenia* syn. *Junonia coenia*), cloudless sulphur butterfly (*Phoebis sennae*) and the cabbage white moth (*Pieris rapae*). Huntsman spiders (*Heteropoda venatoria*), giant toads and whistling frogs are also common.

Figure 4.33 The Eastern bluebird

Photo courtesy of the Department of Planning

4.3.2.10 Golf courses

Golf courses cover an extensive area (260 ha or 642 acres) and serve as important habitats for many bird species including migratory warblers, swallows, eastern bluebirds, the European goldfinch (see Figure 4.34), common ground-dove, mourning dove and other songbirds. Water hazards often support waterfowl and shorebirds.

Golf courses are a valuable habitat for encouraging bluebirds and most golf courses on the Island have bluebird boxes that have been erected and are monitored from early spring to mid-summer.

The liberal use of fertilisers and pesticides is probably the major threat to the wildlife supported on Bermuda's golf courses.

Figure 4.34 The European goldfinch

Photo courtesy of the Department of Tourism

4.3.2.11 Field and wayside

Field and wayside areas include those pieces of land at the edges of main roads such as unmown grassy areas, sites where building demolition has occurred and land which was formerly used for dumping. This category of habitat amounts to about 34 ha (84 acres) and provides a surprisingly diverse species assemblage with over 120 species in total recorded in the understorey. However, 75% of these are self-propagating introduced species, which threaten the few natives and endemics found in this habitat. They are nevertheless important areas as they often serve as corridors for various fauna.

4.3.2.12 Hedgerow

Comprising the hedges bordered by roads or footpaths, hedgerows are dominated by attractive ornamental plants such as oleander and hibiscus. Many hedgerow species are self-seeding invasives for example the Surinam cherry, Chinese fan palm (*Livistonis chinensis*), allspice, fiddlewood, Brazil pepper, giant pothos vine, locally called 'elephant's ear' (*Epipremnum aureum*) and fern asparagus (*Asparagus densiflorus*). These species threaten endemics such as the Bermuda cedar and palmetto as well as natives including Joseph's coat (*Euphorbia heterophylla*), morning glory (*Ipomoea indica*) and cape weed (*Lippia nodiflora*). Other introduced species in the hedgerows include wire weed (*Sida carpinifolia*), sow thistle (*Sonchus oleraceus*), fumitory (*Fumaria muralis*), mock orange (*Murraya paniculata*), nasturtium (*Tropaeolum majus*) and flopper (*Bryphyllum pinnatum*). Hedgerows provide an important habitat for many species of birds including the European goldfinch (*Carduelis carduelis*), chick-of-the-village (*Vireo griseus bermudianus*), northern cardinal (*Cardinalis cardinalis*) as well as the American crow (*Corvus brachyrhynchos*), European starling (*Sturnus vulgaris*), great kiskadee (*Pitangus sulphuratus*) and numerous insect species.

4.3.3 New Legislation

The Protected Species Act, 2003 came into force in March 2004. Prior to this the only legislation that protected species at risk was the Protection of Birds Act, 1975 and Protected Species Orders made under the Fisheries Act, 1972. The Protected Species Act, 2003 improves upon the earlier legislation by requiring the protection of habitats that are critical for the survival of endangered species and the preparation and implementation of recovery plans for listed species.

This legislation gives powers to:

- make orders to declare species to be protected species;
- protect any habitat critical to the survival of a listed species;
- develop recovery plans that identify positive measures to be taken to ensure the survival of each protected species;
- issue licences to those involved in activities which aim to benefit protected species such as research, captive propagation and species restoration, or to zoos and aquaria to promote public awareness by placing protected species on exhibit; and
- any police officer or officer working under the Ministry of the Environment or any other person authorised by the Minister of the Environment to enforce the Act.

The International Union for the Conservation of Nature (IUCN) has developed several categories of classifying threatened species. Although many of Bermuda's species such as the endemic Bermuda skink (*Eumeces longirostris*) and the native yellowwood tree (*Zanthoxylum flavumare*) are listed by the IUCN, they are not protected locally. The IUCN criteria for the categories 'critically endangered', 'endangered' and 'vulnerable' will be used under the Protected Species Act 2003, in declaring any species of plant or animal a protected species. These categories provide a way of highlighting those species that are under higher extinction risk to help prioritise conservation measures.

A preliminary list of 50 species that may warrant listing have been prepared. Critical habitats to be protected are being identified and recovery plans will be prepared for those species that will be listed as protected. This will necessitate some legislative amendments to improve the coordination and protection of existing terrestrial protected areas under the Development and Planning Act, 1974 and the National Parks Act 1986. Regulations will be introduced to ensure their proper support and management. However, the success of the implementation of this Act will require significant community support and commitment.

In spite of the recent introduction of the Protected Species Act a few species have had management plans to encourage increases in their populations for many years. An example is the cahow or Bermuda petrel (*Pterodroma cahow*) (see Figure 4.35) which was thought to be extinct for almost 300 years but was rediscovered on islets around Castle Harbour in 1951. Vigorous but successful efforts have been made since then to increase the breeding population of the cahow. However, the preparation of a formal recovery plan under the Protected Species Act will strengthen these restoration efforts.

Figure 4.35 A cahow chick

Photo courtesy of Jeremy Madeiros

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4.3.4 Projects and Initiatives

4.3.4.1 The Bermuda Biodiversity Project

The Bermuda Biodiversity Project (BBP) began in February 1997 in an effort to promote more effective management of the Island's natural resources. It was begun by the Bermuda Zoological Society (BZS) in partnership with the Bermuda Aquarium, Natural History Museum and Zoo (BAMZ).

The BBP's initial work focused on collating and disseminating information and promoting its importance and use. The BBP also identified information gaps. An emphasis to address these gaps was given to identifying the types, boundaries and extent of terrestrial habitats along with a survey of the vegetation within these areas. Marine habitats, particularly coral reefs and seagrass beds, are also being surveyed and mapped.

In 2003 the BBP coordinated the production of the Bermuda Biodiversity Strategy and Action Plan (BSAP), which was developed with input from key cross-sectoral stakeholders. The plan is a framework for prioritised conservation action, with the following 12 objectives:

- **Objective A**

  To ensure effective coordination, improved collaboration and ongoing communication in support of efficient biodiversity conservation such that key stakeholders are engaged throughout the implementation of this Plan.

- **Objective B**

  To ensure that biodiversity conservation is integrated into all Government programmes, policies and plans by 2007.

- **Objective C**

  To improve and strengthen biodiversity education and training programmes for every age group by 35% over the next five years.

- **Objective D**

  To increase public awareness of biodiversity, its inherent values and conservation activities throughout the community by 100% over the next five years.

- **Objective E**

  To increase the active participation of the community and the private sector in ecologically responsible behaviours by 25% by 2007.

- **Objective F**

  To provide appropriate economic and other incentives to effectively encourage people to protect and enhance biodiversity.

- **Objective G**

  To revise and develop laws that address all key identified gaps in existing environmental legislation for implementation by 2005.

- **Objective H**

  To ensure that enforcement effectively deters infractions against biodiversity such that violations decline by 50% by 2007.

- **Objective I**

  To strengthen the level of protection, where appropriate, through the re-designation of existing protected areas, and to increase the area of fully protected nature reserves and marine protected areas through land acquisition or re-designation by 25% and 10% respectively; and to ensure the effective management of the protected areas network by 2007.

- **Objective J**

  To develop new, and revise existing management plans for all key species and habitats and to ensure their implementation by 2007.

- **Objective K**

  To increase management-oriented biodiversity research and monitoring by 25% by 2007 as demonstrated by outputs.

- **Objective L**

  To secure from both public and private sources the financial commitment and other investment necessary for full implementation of the BSAP.

4.3.4.2 Environmental awards

In 2003 the Bermuda Government's Ministry of the Environment started to issue environmental awards to individuals and groups to undertake environmental improvements. Successful applicants can receive a grant of up to $10,000 for each project. The grant is offered twice a year and so far grants have been issued for a variety of projects including woodland restoration work, teaching organic gardening to prisoners and publishing written information on the endangered Bermuda rock lizard or skink.

4.3.5 Education Programmes

The BZS, a supporting charity of the BAMZ, has enabled numerous environmental education initiatives to help protect species and habitats. Its mission 'to inspire appreciation and care for island environments' reflects emphasis on education and action. BZS holds camps for children in the summer, gives lectures and carries out environmental field trips for adults such as nature walks, whale watches and snorkeling trips. It also holds training lectures for those involved in the tourism industry such as taxi, bus drivers and tour boat operators to encourage dissemination of information on Bermuda's natural heritage.

The Learning Through Landscapes programme, another initiative of BZS, works with schools to assist in landscaping school grounds as well as creating and restoring natural habitats.

In 2003 a renovated, state-of-the-art Natural History Museum opened at BAMZ. It walks the visitor through the creation of Bermuda and its habitats and educates visitors on the impacts of the arrival of humans to Bermuda. It is already proving an invaluable educational tool for students and the general public.

In 2000 the Bermuda National Trust established an education department and holds an annual nature walk for children. The Trust has erected interpretive signs for the boardwalk at Paget Marsh and Warwick Pond and has plans to develop more interpretive signs for other nature reserves around the Island. It collaborates with BZS to develop teacher resource packages on these reserves. It also works with BZS to plan and implement the biennial Youth Environment Conference. The Bermuda National Trust also holds the long-running Palm Sunday Walk and many other activities to educate the general public and youth.

The Bermuda Biological Station for Research (BBSR) works to promote environmental education by holding public lectures, continuing its Elderhostel programme, organising habitat restoration work and broadcasting the annual JASON Project. The JASON Project was founded in 1989 by Dr. Robert D. Ballard following his discovery of the wreck of the R.M.S. *Titanic*.

The Bermuda Underwater Exploration Institute (BUEI) has educational exhibits focusing on conservation issues concerning the oceans and holds camps for students on a regular basis.

The Bermuda Audubon Society holds birdwatching camp for adults, gives regular lectures, nature walks and trains students in habitat restoration.

The Bermuda Botanical Society, in conjunction with the Department of Parks, holds Botany Camps for children each summer. It also provides a lecture series and organises botanical and nature tours.

In addition to these initiatives, the Bermuda Government's Ministry of Education works closely with the BAMZ, especially at the primary and middle school levels, ensuring the integration and linking of curriculum objectives with Bermuda's environmental context and concerns.

4.4 Summary

Bermuda's population growth and economic prosperity have brought about significant losses of terrestrial habitats through land development. In addition, alien species introduced to the Island have drastically altered the original ecosystems. In contrast, the marine environment has been much less affected. However, some marine species have declined by over-harvesting and inshore marine habitats have been damaged by dredging and moorings, and the construction of docks and jetties.

Bermuda has 218 ha (539 acres) of terrestrial areas that are protected as nature reserves. This equates to just over 4% of Bermuda's land area which have been set aside strictly for the protection of flora and fauna. In spite of their protected designation, these areas are far from pristine and are affected by many types of threats. When protected open space areas such as public parks and other National Trust open spaces are added, this boosts the percentage of protected open spaces to just less than 10%.

The moderating influence of the warm Gulf Stream allows Bermuda to possess the most northerly coral reefs and mangroves. Since the plant and animal communities comprising these ecosystems live at their extreme limits, Bermuda is a very important location in which scientists can monitor global environmental trends.

At least 8,301 species have been recorded from Bermuda, of which only 3% are endemic. Of these, 4,597 are marine and 3,702 are terrestrial. Up to three-quarters of Bermuda's terrestrial species now are alien whereas the majority of marine species are native.

Most endemic species, particularly those in delicate habitats such as caves and ponds, are threatened, as are many native non-endemic species. The status of almost two-thirds of Bermuda's endemic species is unknown. Careful biodiversity conservation planning must aim to protect an adequate representation of habitats that accommodate healthy populations of native species.

Bermuda's marine environment consists of a narrow intertidal zone consisting of 786 sq. km of coastal waters on top of the Bermuda platform and an Exclusive Economic Zone (EEZ) with a radius of 200 miles which extends out over the surrounding oceanic region.

Bermuda has 34 hard coral species and 24 soft coral species. This compares to the 60 species of hard coral species and 50 species of soft coral found in the Caribbean. However, Bermuda's coral coverage is higher in comparison to many Caribbean reefs that have experienced significant losses of corals over the past 10 to 20 years due to diseases, coral bleaching, coastal development and over-fishing.

The reef fish resources of Bermuda are very diverse and resemble those of the Caribbean. As with corals, however, there is less diversity. The most important groups of reef fish are the morays (*Muraenidae*), the groupers (*Serranidae*), the grunts (*Haemulidae*), the angelfish (*Pomacanthidae*), the damselfish (*Pomacentridae*), the wrasses (*Labridae*), the parrotfish (*Scaridae*), the surgeonfish (*Acanthuridae*) and the triggerfish (*Balistidae*). Before the 1990 ban on using fish pots for fishing in Bermuda, many reef fish, particularly the groupers, were being over-fished.

Bermuda's coral reefs are thought to be at 'high risk' due mainly to the Island's high population density and potential pollution threats from vessels. Despite this, Bermuda's reefs are nevertheless thought to show 'signs of promise' and are generally considered to be relatively healthy as a result of effective management and the limited impacts from direct users including fisherman, snorkellers and divers.

Of the 50 species of seagrass worldwide, four are present in Bermuda, the most common being the turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*) and shoal grass (*Halodule bermudensis*).

Research on seagrass beds increased in the 1990s and ongoing studies are being conducted by the Benthic Ecology Research Programme at the Bermuda Biological Station for Research.

Bermuda's small tidal range (which is about 75 cm) means that our intertidal zone is very narrow, particularly on steeply sloping shores. However, Bermuda has a very large extent of rocky shore which supports a dynamic and productive marine ecosystem. Bermuda's seashores are vulnerable to floating pollutants especially oil and the collection of attractive or edible shells by residents and tourists.

One of Bermuda's most attractive features is its spectacular sandy beaches and dunes, particularly those of the south shore. Bermuda's beaches are famous for their pink hue derived from the crushed skeletal remains of the single-celled foraminiferan (*Homotrema rubrum*). The major threat to the Island's beaches and dunes is coastal erosion from storm surge.

Bermuda has two species of mangrove, the red mangrove (*Rhizophora mangle*) and the black mangrove (*Avicennia nitida*). Hungry Bay supports the largest mangrove swamp in Bermuda and is 2.9 ha (7.2 acres) in size. It has long been dubbed 'the Great Mangrove'. Hungry Bay is extensively polluted by floating debris and suffers from severe coastal erosion. In recent years, the invasive Brazil or Mexican pepper (*Schinus terebinthifolius*) has been encroaching on the back of mangrove swamps and has become a serious menace. Development for the construction of wharves, harbours, jetties and other marine structures has also resulted in the destruction of mangroves.

Salt marshes occupy relatively sheltered coastlines and offer a great deal of protection to coastal environments in times of stormy weather. At present, salt marshes in Bermuda are limited to a few small areas such as the ones at Spittal Pond and at Hungry Bay. Salt marshes are very important in that they support an unusual number of rare and endangered plants and animals. They have steadily decreased in size since Bermuda was first colonised and now occupy only tiny areas that total approximately one hectare.

The inland marine ponds of Bermuda are one of the Island's national treasures because they support a very high biodiversity of marine and brackish-water organisms and because on a worldwide basis they are rare. The ponds are very vulnerable to pollution run-off from the land and they have traditionally been used as trash dumps. Walsingham Pond is the best example of an inland marine pond in Bermuda. Bermuda's other inland marine ponds include Mangrove Lake, Trott's Pond and Evans Pond.

Many of Bermuda's caves share characteristics of the inland saltwater ponds in that they can extend below sea level and are consequently filled with seawater. The largest, almost entirely submerged and connected network of cave passageways that has been discovered is the Green Bay Cave system, which opens into Harrington Sound. All of Bermuda's currently known 84 marine cave species are native, and of these 73 species (mostly crustaceans) are endemic to Bermuda. Due to their rarity and existing environmental threats to the cave habitat in Bermuda, 25 of these organisms have been placed on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Animals.

Harrington Sound is an inland saltwater sound that has ecological characteristics that make it unique in the world. It supports several unique marine habitats and has a very high biodiversity of marine life.

Mill's Creek and the lower part of Pembroke Canal form the only estuarine system in Bermuda since Pembroke Canal is the sole freshwater stream within Bermuda. Pembroke Canal carries heavy loads of run-off and sewage polluted water. The mangrove swamp in Mill's Creek is in remarkably good condition considering the high level of pollution.

It is estimated that over 50% of Bermuda's land area is developed, while a further 17% comprises areas such as golf courses, residential and public gardens, lawns and playing fields. Today, most development occupies what used to be Upland Forests, Coastal Upland Forests and Upland Valley habitats in pre-settlement times. Just over one-third of original Upland Forests remain whilst only one-quarter of original Upland Coastal areas survive and practically no Upland Valleys remain. Only one-third of peat marshes survive from pre-settlement times.

The major threat to the coastal habitats such as beach and dune, the rocky coast, the upland coast and mangroves is pollution, particularly from oil, destruction for development of boathouses and docks, coastal erosion and invasive species.

One of Bermuda's most threatened habitats, the Upland Forest is heavily impacted by habitat loss through development, as well as being particularly susceptible to invasive species.

About 180 caves have been officially identified on the Island. Limestone sinks and caves are primarily found in the areas of oldest limestone formation on the narrow strip of land between Harrington Sound and Castle Harbour. Many sinkholes are inhabited by endemic and native species that have disappeared from other locations.

Many of these caves are very well decorated with beautiful features including stalactites, stalagmites and a variety of spectacular flowstones which take thousands of years to form. Marine and terrestrial caves have been destroyed or damaged by toxic wastes, leaking underground fuel storage tanks and by the dumping of garbage and the deliberate disposal of sewage, waste oils, trash and a variety of other discarded materials. Cave entrances have also been filled simply to accommodate new development and entire caves have been destroyed to extract gravel and stone in quarrying operations. Vandalism and theft of stalactites and other cave formations have damaged caves.

The Department of Planning has formal regulations to protect caves and cave entrances from development. However, a robust monitoring programme for Bermuda's caves is needed to properly assess their state.

Inland wetlands such as peat marshes and fresh and brackish water ponds were historically used as areas to dump garbage, cleared to create agricultural land and filled to allow development, whilst others have been grassed over after being filled with waste and rubble. Today the main threats are from invasive plant species particularly Brazil Pepper, introduced animals, such as the giant ram's-horn snail (*Marisa cornuarietis*) and red-eared slider turtles (*Trachemys scripta elegans*) and development.

Pollution from run-off of animal wastes from livestock, and fertilisers and pesticides from vegetable farming all threaten the freshwater pond habitat. Laboratory studies and field investigations of Bermuda's fresh water ponds have revealed significant malformation rates in developing larvae of several amphibian species.

Residential gardens, playing fields, golf courses, hedgerows, wayside habitats and public parks

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support a great variety of birds and insects, including the threatened bluebird, the endemic chick-of-the-village and the endemic buckeye butterfly.

Prior to the Protected Species Act, 2003, the only legislation that helped species at risk was the Protection of Birds Act, 1975 and Protected Species Orders made under the Fisheries Act, 1972. The Protected Species Act, 2003 came into force in March 2004 and requires the protection of habitats that are critical for the survival of endangered species and the preparation and implementation of recovery plans for listed species.

Existing management plans for the critically endangered cahow or Bermuda petrel (*Pterodroma cahow*), will be continued and strengthened by the preparation of a formal recovery plan under the Protected Species Act, 2003.

There are a number of environmental initiatives underway to protect the Island's terrestrial and marine environment. These include the The Bermuda Biodiversity Project (BBP), the Bermuda Government's Ministry of the Environment's environmental award scheme, the Learning through Landscapes scheme and other initiatives organised by the Bermuda Zoological Society, Bermuda Aquarium, Museum and Zoo, Bermuda Biological Station for Research, Bermuda National Trust, Bermuda Audubon Society, Bermuda Underwater Exploration Institute and the Bermuda Government's Ministry of Education.

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Chapter 5

Energy

5

5.1 Current Energy Sources

5.1.1 Introduction

Bermuda is 100% dependent on the importation of fuel which is supplied by the companies Shell and Esso (Table 5.1). Bermuda has no petroleum resources of its own and relies almost entirely on petroleum in the form of fuel oil, gasoline, diesel, liquid petroleum gas (LPG) and kerosene to power its transport and electricity production requirements. (See Table 5.1)

Of the fuels imported, approximately 800,000 barrels of fuel are used annually by the Bermuda Electric Light Company (BELCO) to produce electricity for the Island. This equates to approximately 50% of the fuel imported to the Island. The remainder is consumed by local road vehicle transport (gasoline and diesel), air and marine transport (diesel and jet kerosene) and home energy use (propane or LPG).

5.1.2 Electricity Production

Until 1994, BELCO had been the sole producer and distributor of electrical energy for the Island. One hundred per cent of the energy produced by BELCO comes from the importation and combustion of petroleum products with an annual average output of approximately 61 MW/hour (2000 estimate). Esso is the sole supplier of fuel oil and diesel to BELCO at an average of $30 million/year.

In 1994, the Tynes Bay Waste Treatment Facility, which is a mass burn incinerator with energy recovery, was commissioned. It contributes approximately 2 MW/hour into the BELCO grid at an estimated 18 million kilowatt hours annually, accounting for approximately 3% of the total electrical energy produced.

BELCO, situated on a 23-acre site in Pembroke Parish, operates internal combustion diesel engines and combustion turbines. The diesel engines are separated into two classes, D Engines and E Engines, based on their respective locations. The combustion turbines are separated into categories based on their manufacturer, rated capacity and fuel type.

Table 5.1 Bermuda's fuel import summary 1990–2000

	In barrels of fuel (US, 42 Gallons)		
Fuel Type	**1990**	**1995**	**2000**
Gasoline	312026	320425	370381
Jet Kerosene	277000	167033	221027
Gas/diesel oil	788538	764683	453298
Residual Fuel oils (Bunker C)	316686	331432	579392
LPG	52000	54000	52000
Other Oils	1400	1400	1400
Total	**1747650**	**1638973**	**1677498**

Source: Green House Gas Report

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Efficiencies range from 23% (small gas turbines) up to 44% (base load diesels). The classes of engine are as follows:

(a) There are six D engines (D2, D3, D8, D10, D14, D15) located in the Old Power Station. All of the D-units operate on diesel. Engines D2, D3, D8 and D10 have individual and relatively short exhaust stacks. The more recently installed diesels, D14 and D15, exhaust via a 130-foot steel stack.

(b) There are six E engines (E1, E2, E3, E4, E5, E6) located in the East Power Station. All of the E-units operate on Heavy Fuel Oil (HFO). These include the newest and most efficient base load diesel generators. They exhaust through two concrete stacks and are 205 feet above mean sea level. Each has four exhaust flues inside which allows for the future addition of diesels E7 and E8.

(c) There are seven gas turbines (5 GT3's, GT4 and GT5) located northwest of the Old Power Station. All gas turbines operate on diesel and are all equipped with individual weatherproof enclosures.

For various economic and technical reasons, in October 2003, BELCO officially ceased using HAGO (Heavy Atmospheric Gas Oil) to produce energy.

5.1.3 Energy Consumption

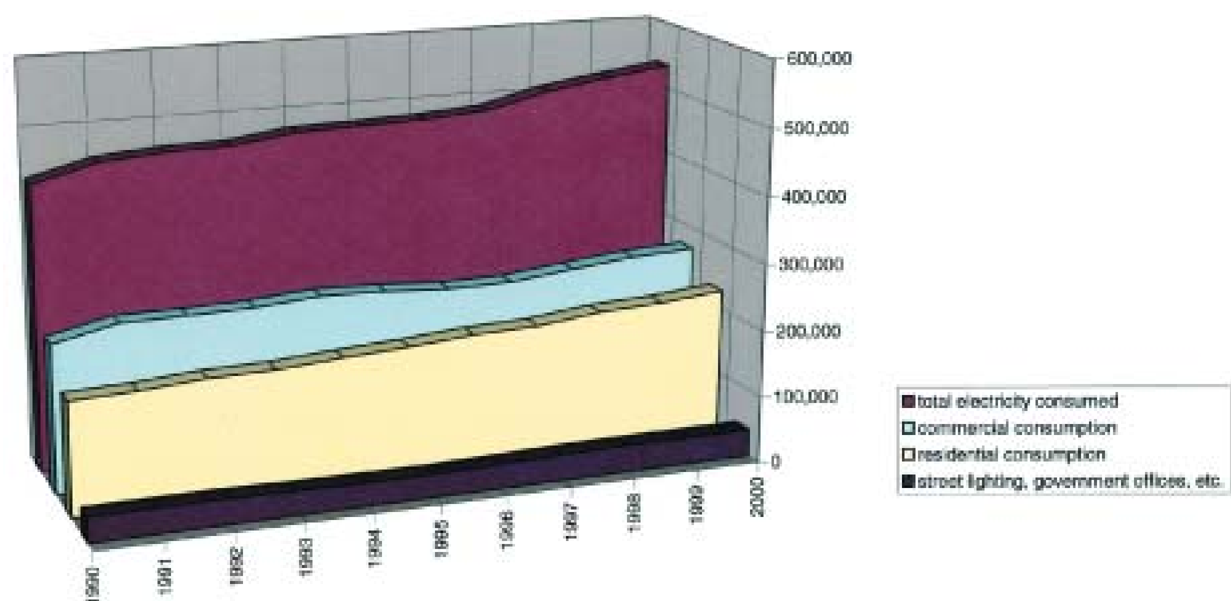
Approximately half of all energy consumption in Bermuda is attributed to commercial properties. Energy consumption has steadily increased from 429,367,000 kilowatt hours in 1990 to 535,335,000 kilowatt hours in 2000, as shown in Figure 5.1. Table 5.2 details the generation plant and the peak summer MW ratings.

Table 5.2 Generation plant and peak summer MW ratings

Generator	Summer Continuous Rating MW	Year Commissioned	Probable Retirement Year
E1	12	1984	2011
E2	12	1985	2012
E3	10	1989	Beyond 2015
E4	10	1989	Beyond 2015
E5	14	2000	Beyond 2015
E6	14	2000	Beyond 2015
D2	8	1976	2007
D3	8	1982	2008
D8	8	1979	2007
D10	8	1980	2007
D14	5.5	1995	Beyond 2015
D15	5.5	1995	Beyond 2015
GT3 (A-D)	10	1979	2006
GT3 (E&F)	5	1995	Beyond 2015
GT4	11.5	1988	2012
GT5	13	1995	Beyond 2015
Total Summer Capacity	**154.5**		

Source: Bermuda Electric Light Company

Figure 5.1 Bermuda's electricity consumption 1990–2000



Note: From 1995, Southside was included in commercial and total electricity consumption figures
Source: Bermuda Digest of Statistics 1992, 2002

In 2000, the average hourly load demand was 61 MW, with a summer peak demand of 103 MW. In order for BELCO to maintain reliable year-round supplies, the Bermuda Government legislates that BELCO be required to carry generation capacity of peak demand plus 40MW (to cover the outage of the two largest generators plus spinning reserve).

5.1.4 Generation Plant Changes and their impacts

Over the last 10 years, BELCO has focused on retiring old diesel and gas turbine generators, purchasing new ones and upgrading some of the existing generators. In addition, extensive computer-aided studies have been undertaken to develop enhanced generation operating regimes that minimise fuel consumption whilst still meeting system reliability and security criteria. Maintenance procedures have also been reviewed and new more efficient practices introduced. As a result of these changes, improvements have been made in fuel efficiency, system reliability, the price of electricity, as well as environmental improvements.

Between 1990 and 2000, the number of kilowatt-hours generated per barrel of fuel consumed increased by 11.4% to 664 kWh/Bbl. That value has marginally increased to 671 kWh/Bbl in 2001 and 673 kWh/Bbl in 2002. The price of electricity also remained within an average sale price of 19.4 to 20.7 cent/KWh (excluding fuel adjustment) over the last 12 years. Fuel adjustment costs are forwarded directly to the consumer and can contribute to increases in excess of 5 cent/kWh (2004 estimate).

With the passing of the Clean Air Act in 1991 and the introduction of air quality standards in 1993, BELCO undertook a programme of retiring older, less clean-burning engines and installing more efficient, cleaner-burning plant with exhausts being emitted into the atmosphere through higher smoke stacks. As a result, emissions now meet the Bermuda Air Quality Standards as defined in the Clean Air Regulations, 1993.

Significant improvements have also been made to reduce noise levels. These improvements include the lowering of radiator cooling fan decibel levels and specially designed and constructed buildings to contain noise. As the older plant continues to be retired, the situation will progressively improve.

Vibration levels from new diesel engines have been reduced with the installation of spring systems to isolate vibrations from the site base.

5.1.5 Global and Local Reasons for Change

Since the 1992 United Nations Conference on the Environment, climate change and global warming have been at the forefront of environmental issues and concerns both locally and globally.

Overwhelming scientific evidence suggests that the global climate is warming with accompanying sea level rise and increased stochastic weather patterns. The direct ramifications of these potential effects to Bermuda should be apparent insofar as the loss of coastal areas due to erosion and sea level rise as well as the increased threat of hurricane frequency and intensity. The cause for global warming and climate change has been attributed primarily to anthropogenic sources i.e., the production of greenhouse gases through the combustion of petroleum products.

In addition to the concerns regarding global warming and climate change, the United Nations in 1992 also introduced the hallmark concept of 'sustainable development'. Not only is the combustion of petroleum a concern for global warming and climate change, it is also a non-renewable resource.

With the global population increasing simultaneously with energy consumption, combined with a finite petroleum energy supply, energy costs will continue to escalate as the resource becomes more scarce.

Bermuda is 100% dependent on the combustion of fossil fuels for its electricity production and transport with no locally available petroleum resources. As such, it is 100% reliant on the importation of foreign fuel. Due to the finite nature of petroleum fuels and the increasing demand for energy both globally and locally, fuel prices will continue to increase.

Bermuda has a locally available renewable energy source in both offshore wind and wave energy as well as solar energy. It makes both economic and environmental sense to invest in these technologies since these energy sources are consistent and not subject to international supply and demand price pressures. It also allows for the reinvestment of millions of dollars back into the local economy rather than into foreign petroleum companies.

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There have been many studies conducted worldwide which demonstrate a direct link between the combustion of fossil fuels and respiratory related illnesses. Steps towards clean, renewable energy production and use would directly benefit these health related issues.

5.2 Potential Future Energy Sources

5.2.1 Bermuda's Potential for Alternative Energy Sources

When considering new energy supplies for a country, many factors such as location, energy sources and needs, and environmental constraints must be taken into account. Bermuda has many unique aspects, including the following:

- It is a small, remotely located landmass which is densely populated and developed with commercial and residential uses;
- It is extensively electrified with a highly reliable electricity system;
- It has an economy dependent on tourism and financial sectors that require reliable electricity for computing, telecommunications, lighting, and air-conditioning. There are no major industrial requirements for power;
- It has a high cost of energy (fuel prices, electricity) although these prices are heavily influenced by duties applied to fuels and transmission and distribution equipment as well as high labour costs;
- It has a growing vehicle population and has concerns about traffic congestion and air pollution from vehicles especially in the City during rush hours;
- It has a sensitive ecosystem with important fisheries and coral reefs. This may impose a constraint on the siting of new offshore facilities; and
- It has relied on the private sector to provide reliable, affordable energy services.

5.2.2 Renewable Energy Sources

5.2.2.1 Introduction

Worldwide, there is a growing interest in developing renewable and alternative energy sources, which convert primary energy sources (e.g., solar, hydrocarbons, wind) to useable forms of energy. This is being driven by many factors including the following:

- The desire to reduce carbon dioxide emissions from the combustion of fossil fuels;
- National renewable energy policies backed by subsidies and tax incentive schemes;
- Declining wind turbine installation costs due to more efficient machines;
- Maturity and economies of scale; and
- The recognition that huge wind resources are available offshore.

In almost all cases, the technologies have been proven as technically feasible but have only been able to establish themselves in limited markets. Success in these markets is either a function of a special geography (e.g., biomass), availability of a specific natural resource (e.g., natural gas for fuel cells) or a specific mandate from government (for example the Danish Government's goal of producing 30% of energy from renewable sources). Many of the renewable energy technologies are not yet to the point that they can compete economically on a widespread basis although many of their proponents are convinced that this will be changing in the near future.

5.2.2.2 Solar energy

'Solar energy' is the general term used for a variety of renewable energy technologies including (i) photovoltaic solar energy conversion (PV), (ii) high (HTSE) and low temperature thermal solar energy (LTSE), (iii) passive solar energy (PSE), and (iv) heat pumps.

(i) Photovoltaic solar energy conversion is the direct conversion of sunlight into electricity that can be accomplished by flat plate or concentrator systems.

(ii) High temperature thermal solar energy (solar thermal energy) is used to produce high temperature heat that is converted into electricity using a conventional cycle. It is always used in the form of concentrator systems. Low-temperature thermal solar energy is used for example to heat water or air for domestic or professional use.

(iii) Passive solar energy makes use of sunlight in buildings by design without the use of active elements. It may reduce energy consumption for space heating and lighting requirements.

(iv) Heat pumps are used to convert the energy available in (solar heated) ambient air into useful low-temperature heat.

Solar technologies are characterised by the fact that they do not cause emissions during operation. A substantial area is required in order to capture and convert significant amounts of solar energy to meet the energy needs of a developed country. If all of the BELCO site were used for this technology, the power capacity would only be 2MW.

In Bermuda, solar panels have been installed in some residences as well as in several hotels.

5.2.2.3 Biomass energy

Biomass can be classified into (i) plant biomass, (ii) animal biomass, and (iii) municipal solid waste.

The Tynes Bay incinerator uses municipal solid waste (a form of processed biomass) to produce electricity. Elsewhere, wastes from sawmills, sugarcane, cassava, banana, rice husks and pineapple wastes are commonly used in waste-to-energy plants. Biomass is often perceived as a fuel of the past because of its low efficiency and its association with air pollution and poverty. However the benefits of sustainably produced biomass energy in future energy supply have recently been acknowledged. Biomass fuels can substitute more or less directly for fossil fuels in the existing energy supply infrastructures without contributing to the build-up of greenhouse gases in the atmosphere. Whilst costs are not high, this technology is not feasible in Bermuda due to space limitations and the lack of plentiful agricultural wastes.

5.2.2.4 Biogas

Biogas is a combination of methane and carbon dioxide that is given off when bio-wastes disintegrate. Methane gas production systems, also known as biogas plants, use animal wastes of cattle, chickens, latrine waste, grasses and leaves to produce a clean and reliable source of energy that can be used for cooking, lighting, water heating or on a larger scale to produce electricity.

BELCO investigated the feasibility of harnessing the energy stored in the former Pembroke Marsh Landfill but determined that the reserves of biogas are too low for the economic production of energy.

5.2.2.5 Geothermal energy

This is the conversion of heat generated deep below the surface of the earth into useable energy. There is no perceived applicability of this for Bermuda.

5.2.2.6 Ocean energy technologies

The main ocean energy resources can be summarised in order of maturity and uses. They are:

(i) Tidal barrages i.e., the trapping of water at high tide behind a dam and releasing it through turbines. These have proved to be large and costly.

(ii) Wave energy conversion (WEC) technology. Potential wave energy is a direct function of the local wave climate of a region. Local wave climates are influenced by wind velocity, fetch, seabed conditions, and distant wave sources.

Within the past five to 10 years, this fledgling industry has experienced an extremely large increase in interest in many countries around the world. The European Union has invested in this technology within the past five years and there are now full-scale prototype units currently being installed and tested in different regions around the world from a variety of technology developers.

The first designs for WEC technologies can be seen as far back as the mid-1800s but very little happened in this field until the advent of socio-economic and environmental concerns. There are a variety of design philosophies that are being pursued which are all at the early stages of commercialisation yet deserve considerable attention as the projections for financially viable applications are within the next three to five years.

The major difference with types of WEC technologies is their location in the marine environment. They can be either onshore/near shore or offshore (see Figures 5.2 and 5.3). Offshore devices can be further categorised into floating or submerged systems. Thereafter, the classification continues based on the type of movement the system employs. Examples of this include heaving/pitching and rolling. Their power take off assemblies also differ. They can have gravity-fed water turbines, oscillating water columns (OWC) with air driven turbines or hydraulic systems that utilise fluid impellers. The primary function of these mechanisms is to convert linear mechanical energy into rotational mechanical energy that can be converted to electrical energy via electrical generators. Another system utilises direct drive

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sliding magnetic plates that may be a more efficient and more maintenance-free system.

Figure 5.2 An Ocean Power Delivery WEC system being towed out to the demonstration site in the north of Scotland

Photo courtesy of Ocean Power Delivery Ltd. www.oceanpd.com

Hawaii and Ireland have both conducted wave energy feasibility studies, assessing the local wave climate, electrical distribution system and energy legislation in order to determine the economic opportunities inherent in pursuing a wave energy development programme on a national scale. Both countries have determined that due to growth projections for the WEC industry and locally available resources, their respective territories were ideally suited to develop national wave energy programmes. Bermuda appears to have several similar characteristics to Hawaii and Ireland.

Figure 5.3 A prospective Pelamis wave energy platform

Photo courtesy of Ocean Power Delivery Ltd. www.oceanpd.com

(iii) Tidal marine currents (turbines mounted under water to use the flow of the sea). Only short-term demonstration projects have been developed to date. These systems require tidal currents with consistent velocity and suitable water depth. These conditions occur in areas with large, well-known currents like the Gulf Stream off the coast of Florida. Tidal and ocean current computer modelling studies conducted by the Bermuda Biological Station for Research (BBSR) for the Bermuda platform suggest that these conditions do not exist locally. Although the occasional Gulf Stream eddy does pass by the Island, there is not the suitable degree of consistency required to install an energy conversion system such as this.

(iv) Ocean Thermal Energy Conversion (OTEC). These are systems that can produce power from temperature differences between the warm surface waters and the colder deeper waters. These temperature differentials exist in Bermuda on a seasonal basis only. In addition, the technology is plagued with technical problems and challenges. This resource is potentially the largest source of renewable energy of all; however, it is still considered immature and not likely to make a major contribution in the short to medium term.

The ocean energy resource is vast. Estimations suggest that if the ocean wave energy resources alone were harnessed, more than twice the world's current electricity demands could be met. The experience of harnessing ocean energy to date is limited. Tidal energy requires substantial tidal ranges or currents, wave energy requires a relatively consistent wave climate, and ocean thermal conversion needs as large a temperature difference as possible between the surface waters and deep cold waters. Projections suggest that within the next five to 10 years, this industry will experience considerable growth and economic as well as environmental benefits will lie therein, very similar to the experience of the wind energy industry over the last two decades.

5.2.2.7 Fuel cells

Fuel cells operate like batteries except that unlike batteries, fuel cells do not run down or need recharging. Fuel cells consist of two electrodes and an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat. Fuel cells are clean and efficient and could significantly reduce air pollution and oil imports. Figure 5.4 shows a fuel cell bus.

Types of fuel cells include proton exchange membrane, molten carbonate, solid oxide and phosphoric acid, alkaline, direct methanol fuel cells and regenerative fuel cells.

Currently fuel cells have high costs and somewhat low power densities. In addition, a site area of around 1.25 acres would be required to accommodate a 5 MW fuel cell system in Bermuda.

Another limitation to fuel cells at this time is that they still require a hydrogen fuel source which is most commonly natural gas (methane). This would require the continued dependence on the importation of non-renewable petroleum products continuing Bermuda's reliance on foreign energy sources and prices.

A potential benefit to fuel cell technology is that it would lend itself seamlessly to distributed electricity production. Small generator units could be installed throughout the Island with no need for a central production facility as with BELCO's plant in Pembroke or for a connection to the central electrical grid. This could enable a choice of locations for fuel vehicles.

Figure 5.4 Fuel cell bus developed by Georgetown University

Photo courtesy of the Vehicle Development Department, Georgetown University, Washington, D. C.

Research on fuel cells is ongoing and future advances in technologies may make fuel cell technology a viable alternative energy source in Bermuda.

5.2.2.8 Micro gas turbines

Micro gas turbines are a new type of combustion turbine used for stationary energy generation applications. They are small, about the size of a refrigerator, with outputs of 25 kW to 500 kW and can be located on sites with space limitations. Waste heat recovery can be used in combined heat and power systems to achieve energy efficiencies of greater than 80%. These are becoming available for liquid fuel firing but the somewhat low plant efficiency results in high generation costs.

5.2.2.9 Advanced gas turbines

These are high-efficiency, low-emission gas turbines that run at high temperatures to produce electricity. Advanced gas turbine generators have ratings of 4.2 MW and above but are currently only available for natural gas firing, a fuel not available in Bermuda.

5.2.2.10 Distributed generation

Distributed energy resources are modular electric generation or storage located near the point of use. Distributed power systems can be grid-connected or operated independently of the grid. Distributed power systems can provide high value energy capacity and ancillary services such as voltage regulation, power quality improvement and emergency power.

The future introduction of several of the new technologies will require the availability of distributed generation sites in the east and west of the Island.

5.2.2.11 Wind power

During the last two decades enormous progress has been made in the development of wind turbines worldwide and wind power has emerged as one of the fastest growing renewable energy technologies. The worldwide installed capacity for grid-connected wind turbines increased from about 2,000 MW in 1990 to over 31,000 MW at the end of 2002.

In densely populated countries, offshore wind generation projects are being realised with Denmark, Norway, Sweden, the U.K., and the Netherlands leading the way. Currently the total global installed offshore wind capacity is around 170 MW. However, industry experts project that figure to increase to over 3,000 MW by 2010, due in large measure to the streamlined permitting process for offshore wind power in the U.K.

Wind power generation is not new to Bermuda. In 1978, the United States Navy installed two experimental 15 KW wind turbines at Tudor Hill in Southampton. Although these turbines no longer operate, it was demonstrated that wind power could be harnessed in Bermuda.

Due to the limited land mass of Bermuda and potential for conflicts with other uses, onshore sites are limited and environmental concerns would probably make this option unacceptable. Thus, the main area of investigation has been offshore wind energy.

In the late 1990s, BELCO and BBSR commenced a study to look into the feasibility of installing offshore wind turbines. The aims of the study were to research wind availability and characteristics in order to determine the wind energy potential as well as to assess the technical, economic and environmental challenges associated with wind power development. As part of the wind resource assessment, wind data was recorded for a one-year period in 2000/01 at the Warwick Tower in order to supplement historical wind data records from various sources. The long-term mean wind speed used for the energy production estimate was calculated at 7.32 m/s. Overall, the study concluded that offshore wind power development is technically feasible but presents significant economic, technical and environmental challenges.

The study indicated that the existing electrical system is capable of accepting the addition of up to 20 MW of wind generation at the western end of the Island, but can only accept a maximum of 14 MW of wind generation at the eastern end. However, in all cases, the capacity of wind generation must be limited to 10 MW if all load shedding due to loss of wind generation is to be avoided. For a wind farm with a total installed capacity of 20 MW, the average energy output would only be 6.0 MW. Similarly, for a 12 MW wind farm, the average energy output would be 3.6 MW. Based on the premise of avoided fuel costs, none of the wind power production options studied were economically viable. Wind power development would have very limited benefit in terms of capacity, since diesel plants would still be required to meet load demand during periods of low wind. Also, given the relatively low average energy output, the average fuel cost saving and reduction in sulphur dioxide emissions would be correspondingly small.

Estimated capital costs for offshore wind generation in Bermuda are $1,500 – $2,000 per kW. The capital cost of offshore wind farms is typically 50 % more than onshore installations primarily due to foundation requirements and undersea cable links. In addition, estimated wind turbine operation and maintenance costs are high compared with conventional generation.

Technical issues that would need to be resolved include: grid system instability due to variable wind conditions; designing appropriate turbine foundation structures for installation in limestone bedrock; designing turbine towers for hurricane wind loads, storm surge and wave action; and minimising salt corrosion on turbine structures.

Visual aesthetic impact would be an important environmental consideration associated with offshore wind turbines (see Figure 5.5). Visual intrusion could be related to the physical presence, number, size and layout of wind turbines. Detailed visualisation work would be required to determine an optimal wind farm configuration. Although it is commonly perceived that wind turbines are noisy, modern wind turbines have been designed to be very quiet, and any audible noise is attenuated within a short distance of turbine structures.

The risk of migratory birds, as well as the endangered cahow, colliding with rotating turbine blades would also need careful consideration. Another area of major environmental concern would be the potential damage to coral reefs during wind farm installation.

Figure 5.5 Photomontage of offshore wind turbines at differing distances from North Shore, Bermuda

Photo courtesy of the Bermuda Electric Light Company

It is not yet known whether the technical, environmental and economic challenges of exploiting offshore wind power in Bermuda can be overcome, but currently offshore wind power generation presents a potential renewable energy option for Bermuda in the foreseeable future.

Bermuda High School for Girls was the 2003 winner of the Eden Project Schools Environmental Competition. This winning entry depicted Bermuda using wind power for electricity generation and electric-powered vehicles and fuel cell buses for land transport. (see Figure 5.6)

Figure 5.6 The Bermuda High School's winning entry for the Eden Project School Competition

Photo courtesy of the Bermuda High School for Girls

5.3 Summary

More and more countries are embracing the principles of sustainable development and the need to develop more environmentally friendly practices. The development of renewable energy technologies that are both environmentally and economically viable is therefore a key issue for every country to address.

In order for renewable energy sources to become economically viable, the renewable energy industry requires substantial political support and financial investment. Bermuda is no exception.

The most viable renewable energy option for Bermuda utilising existing commercial technology appears to be offshore wind power generation and this may require new or amended legislation to address the many environmental, planning and construction issues that are unique to this type of marine development. However, there are still several key concerns with wind energy for Bermuda which need to be overcome.

Wave energy although not commercially available currently, appears to have substantial benefits over wind energy and serious consideration should be given to researching the feasibility of this technology in the near future.

Whilst the Bermuda Government is supportive of renewable energy development, currently, there is no renewable energy policy or national energy policy in place. Policy and legislative examples from Hawaii, Scotland, Ireland and Denmark should be reviewed as possible ways forward for Bermuda. Bermuda therefore needs to move towards establishing the necessary legislation and fiscal measures so that it is poised and ready to take full advantage of the opportunity of renewable energy technologies if and when they prove to be viable energy options for the Island.

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Ocean Power Delivery website: www.oceanpd.com

2 Resource Uses and Management

Chapter 6

Land Use and Open Space

6

6.1 Land Uses

6.1.1 Introduction

On a small island like Bermuda, which is densely populated and extensively developed, land is a precious commodity. Land is required to fulfil the development needs of its growing population as well as to meet the social and recreational needs of its residents and visitors. Bermuda's economic success has resulted in increasing development pressure on limited land resources particularly on those areas that are not yet developed. Set against this trend is the desire to retain sufficient open space to provide for the psychological well-being of residents, to preserve the amenity of the Island and to conserve biodiversity. The land use planning system in Bermuda tries to achieve a balance between the competing forces of development and conservation needs to ensure that land resources are used efficiently and valued open spaces are protected.

6.1.2 Land Use Distribution

Bermuda's total land resources amount to over 13,200 acres (5,370 ha). Over 30% of this land is owned by government, either directly or through various quangos.

With the return in the mid-1990s of the land occupied for military purposes by the U.K., U.S. and Canadian governments, all military land in Bermuda, with a few exceptions, came under the responsibility of the Bermuda Govern-ment. The former military land amounted to almost 10% of the Island's landmass although the airport comprises a large proportion of this land. Some 568 acres (230 ha) or 43% of this military land was created from land reclamation.

In 2000/2001, the Department of Planning undertook an analysis of existing land uses on the Island. The methodology utilised the Department's geographic information technology, aerial photographs of the Island and site visits (for verification and information-gathering purposes). The principal land use categories are set out in Table 6.1.

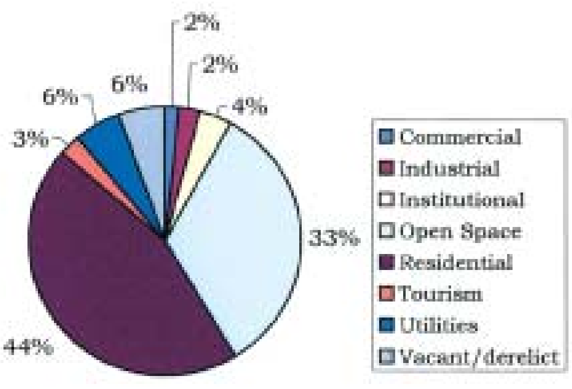
Table 6.1 Land use survey categories

Land Use Category	General Description
Commercial	Land used for commercial purposes including office use, retail, restaurant, entertainment, etc.
Industrial	Land in industrial use including warehousing and quarries.
Institutional	Land being used for educational, religious, health and social facilities or government services.
Open Space	Land generally open in character including rural areas, National Parks, nature reserves, golf courses and other recreational space etc.
Residential	Land used for housing including garden areas but excluding more extensive areas in natural state.
Tourism	Land occupied by functioning hotels, cottage colonies, guest-houses etc.
Utilities	Land used to provide the Island's basic infrastructure such as transport facilities (e.g. airport, docks etc), power generation, telecommunications, water, waste management etc.
Vacant/derelict	Previously developed land that is not currently being used and may include vacant buildings.

Source: Land Use Survey 2000/2001, Department of Planning

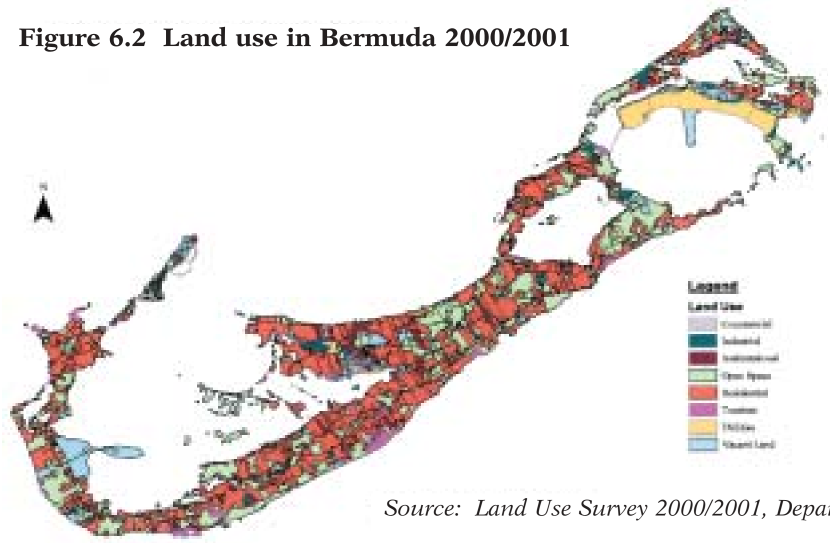
Figures 6.1 and 6.2 show the areas of land devoted to each of these uses and their distribution throughout Bermuda. Table 6.2 shows the distribution of land uses by Parish. Tables 6.3 and 6.4 show the proportional distribution of land (in percentage terms) by use and by parish respectively.

Figure 6.1 Land use in Bermuda 2000/2001



Source: Land Use Survey 2000/2001, Department of Planning

Figure 6.2 Land use in Bermuda 2000/2001



Source: Land Use Survey 2000/2001, Department of Planning

Two-thirds of Bermuda is covered by land uses that involve built development. Residential development consumes almost 6,000 acres (2,428 ha) or 45% of the Island and is by far the most extensive use. Residential land is distributed relatively evenly throughout the parishes with the percentage of total residential land for each parish being between 9% and 13%. The central parishes (such as Pembroke) have the highest acreages of land devoted to residential development with lower proportions of land in residential use in the east and west ends of the Island.

Employment uses including commercial, industrial and tourism consume a modest 7% of total land area. Over 40% of all commercial uses, including office and retail, are concentrated in the City of Hamilton, the Island's main employment centre. The distribution of remaining commercial uses reflects the other principal shopping locations of St. George's and Somerset/Dockyard. Much of the Island's industrial land is located in the east end with nearly 50% of it in the parishes of Hamilton and St. George's. A further 20% is located in Pembroke, mostly in the well-established industrial area of Mill's Creek. By contrast, almost 80% of land that is in active tourism use is located in the western half of the Island with a third of tourism land in Paget alone, including the large establishments of Elbow Beach Hotel and Coco Reef (the former Stonington) Hotel.

As might be expected, institutional uses, which mainly consist of government services, tend to be concentrated in the administrative centres of the city of Hamilton, St. George's and Somerset.

Two of the largest categories of developed land, excluding residential, are land in use for utilities and vacant/derelict land. Together these amount to about 12% of Bermuda's land area. Land used for utilities consists of land required for the Island's essential infrastructure. The airport comprises the vast majority of this land use (84%).

Table 6.2 Distribution of land use by parish (in acres) 2000/2001

	Commercial	Industrial	Institutional	Open Space	Residential	Tourism	Utilities	Vacant/ Derelict	Total
Sandys	27	14	61	383	670	45	20	219	1,439
Southampton	10	22	31	614	611	89	5	130	1,512
Warwick	10	18	55	585	708	9	0	31	1,416
Paget	16	4	66	297	804	112	0	3	1,302
Pembroke *	94	68	127	140	786	16	51	65	1,347
Devonshire	11	19	73	499	562	14	24	19	1,221
Smiths	3	21	16	433	710	15	7	12	1,217
Hamilton	11	47	13	611	585	19	11	14	1,311
St. George's	44	108	82	854	549	14	616	236	2,503
Total	226	321	524	4,416	5,985	333	734	729	13,268

*Note: *includes the City of Hamilton*
Source: Land Use Survey 2000/2001, Department of Planning

Vacant/derelict land is one of the most significant categories. These 'brownfield' sites are previously developed areas of land occupied or previously occupied by buildings, other permanent structures and associated fixed infrastructure which are not currently in beneficial use. The survey identified well over 700 acres (283 ha) of such land which could be available for redevelopment/re-use. Much of this land is on sites that were previously occupied as foreign military bases mostly in the east and west ends of the Island. However, it also includes former tourism sites such as the Banana Beach/Flamingo Beach and adjacent properties on South Shore in Warwick and the former Club Med site in St. George's.

Over 4,400 acres (1,780 ha) or 33% of Bermuda has been categorised as open space. This designation relates to the general character and appearance of the land and does not imply that the land is not being used for some purpose (see Table 6.1). For instance, while the category includes natural areas such as woodland, marshes, and beaches such as Horseshoe Bay (see Figure 6.3). It also includes golf courses, parks, and other areas in recreational use as well as land in cultivation. As a consequence, much of this land is protected from development pressure and is considered to be an essential part of the character and amenity of the Island.

There is a significant variation across the Parishes in the amount of open space. At over 850 acres (344 ha), St. George's parish has the largest amount of open space (see Figure 6.3). This, however, only comprises about one-third of the total land area of the parish (see Table 6.4). Hamilton Parish is the least developed parish with 47% of its land area falling within an open space category (see Table 6.4). By contrast, the central parishes of Paget and Pembroke are the most developed having only 10% of all open space between them (see Figure 6.3). The densely populated parish of Pembroke has only 140 acres (57ha) of open space.

Figure 6.3 Horseshoe Bay

Photo courtesy of the Department of Planning

6.2 Land Use Change

6.2.1 The 1970/71 and 2000/01 Land Use Surveys

To examine trends in land use over the years, the results of the land use survey 2000/01 were compared with a previous survey undertaken by the Department of Planning in 1970/71. The data was adjusted to take account of differences in category definitions and computational methods as well as the fact that the previous survey did not include land occupied by foreign military forces.

Table 6.3 Proportional distribution of land by use (percentage)

	Commercial	Industrial	Institutional	Open Space	Residential	Tourism	Utilities	Vacant/ Derelict	Total
Sandys	12	4	12	9	11	14	3	30	11
Southampton	4	7	6	14	10	27	1	18	11
Warwick	4	6	10	13	12	3	0	4	11
Paget	7	1	13	7	13	34	0	0	10
Pembroke*	42	21	24	3	13	5	7	9	10
Devonshire	5	6	14	11	9	4	3	3	9
Smith's	1	7	3	10	12	5	1	2	9
Hamilton	5	15	2	14	10	6	1	2	10
St George's	19	34	16	19	9	4	84	32	19
Total	100	100	100	100	100	100	100	100	100

*Note: *includes City of Hamilton*
Source: Land Use Survey 2000/2001, Department of Planning

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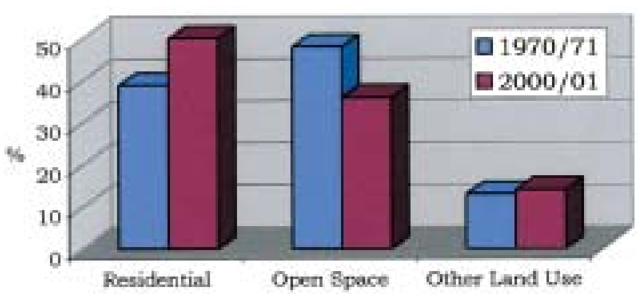
6.2.2 Changes in Residential Land and Open Space

The data highlights significant differences in the relative distribution of land in residential use and open space. However, there appears to have been limited change in the amount and distribution of land in 'other land uses' (i.e., not residential or open space). This is graphically illustrated in Figure 6.4, which shows that the increase in residential land over the last 30 years has been directly proportional to the decrease in open space over the same period. The data indicates that over the 30-year period an additional 1,558 acres (630 ha) of land has been used for residential purposes (an increase of 35% over the 1970/71 total) whereas the loss of open space amounts to 1,170 acres (473 ha), a 21% decrease. Some caution should be exercised in the use and interpretation of the data from the earlier survey as there are significant variations in the land area totals from that research as compared with the more recent calculations. However, the proportions illustrated in Figure 6.4 give a reasonably accurate picture of land use change over the period that accords with many people's intuitive response to the development of the Island since 1970.

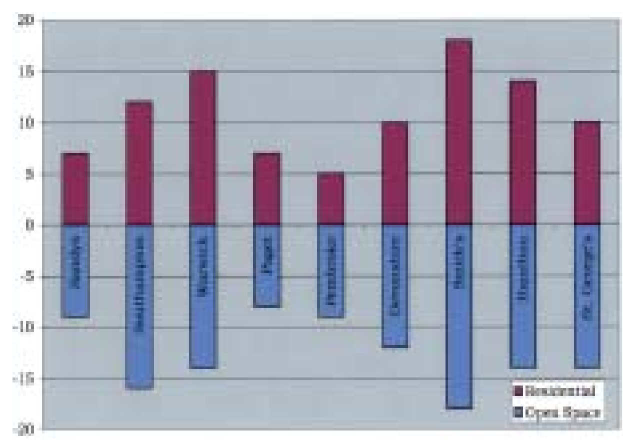
Figure 6.4 Land use change in Bermuda 1970/71 to 2000/01 (as a percentage)



Source: Land Use Surveys 1970/71 and 2000/01, Department of Planning

This trend is mirrored across the parishes, as illustrated in Figure 6.5, which shows the changes in the percentage of land in each parish used for residential or open space use in the 30 years between 1970/1 and 2000/1. There is a direct correlation between the increase in land used for residential purposes and the reduction in open space in each parish. For example, in Smith's Parish there was an 18% increase in the land used for residential purposes whilst there was a commensurate 18% loss of open space. The graph also clearly shows that the greatest increase in residential land and consequent loss of open space has occurred in those traditionally rural parishes between the more urban settlements in St. George's, Sandys and Pembroke. These comparisons provide evidence of the speed and extent of urbanisation in Bermuda over the last 30 years. Examples of large tracts of open space that have been subdivided into residential lots are Pokiok Farm (see Figure 6.6), the Pampas, and Saucos Hill on the South Shore in Smith's.

Figure 6.5 Differences in percentages of land used for residential and open space by parish between 1970/71 and 2000/01



Source: Land Use Surveys 1970/71 and 2000/01, Department of Planning

Table 6.4 Proportional distribution of land by parish (percentage)

	Commercial	Industrial	Institutional	Open Space	Residential	Tourism	Utilities	Vacant/ Derelict	Total**
Sandys	2	1	4	27	47	3	1	15	100
Southampton	1	1	2	41	40	6	0	9	100
Warwick	1	1	4	41	50	1	0	2	100
Paget	1	0	5	23	62	9	0	0	100
Pembroke*	7	5	10	10	58	1	4	5	100
Devonshire	1	2	6	41	46	1	2	2	100
Smith's	0	2	1	36	58	1	1	1	100
Hamilton	1	4	1	47	45	1	1	1	100
St George's	2	4	3	34	22	1	25	9	100
Total	2	2	4	33	45	3	6	6	100

*Note:*includes City of Hamilton*
***Totals may not equal 100 due to rounding*
Source: Land Use Survey 2000/2001, Department of Planning

The loss of open space can be attributed to Bermuda's growing population and number of households and the increased pressure to develop land, including open spaces, for residential purposes.

Figure 6.6 Pokiok Farm

Photo courtesy of the Minstry of Works and Engineering 1997

6.3 Open Space Provision

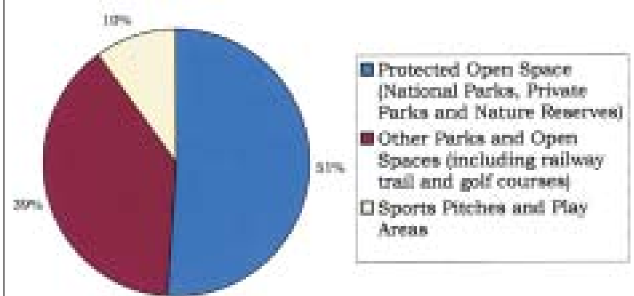
6.3.1 Inventory of Open Space Resources

The land use survey 2000/01 provides a broad measure of available open space in Bermuda. In 2001, the Department of Planning also prepared an inventory of all current open space resources in Bermuda. The inventory includes land used for active recreational purposes such as golf courses, sports pitches and school playing fields as well as areas used for more informal leisure including national parks, parks managed by other institutions, the Railway Trail and community play spaces.

Other areas which are protected as open space are generally those properties owned by such organisations as the Bermuda National Trust and the Bermuda Audubon Society or tracts of land held in trust at Heydon and Walsingham. They also include a variety of areas around Bermuda that are protected by planning agreements as designated under Section 34 of the Development and Planning Act, 1974. Section 34 (1): states that: *The Minister may enter into an agreement with any person interested in land for the purpose of restricting or regulating the development or use of the land, either permanently or during such period as may be specified in the agreement; and any such agreement may contain such incidental and consequential provisions (including provisions of a financial character) as appear to the Minister to be necessary or expedient for the purposes of the agreement.*

Open space resources amount to 2,543 acres or nearly 20% of Bermuda's land area. Half of this land is protected as national park or through ownership by a protective agency or an agreement. Other parks and open spaces amount to 1,000 acres (40% of open space resources) most of which is golf course whereas sports pitches and play spaces comprise less than 250 acres or 10% of open space (see Figure 6.7).

Figure 6.7 Open space resources in Bermuda 2000/2001



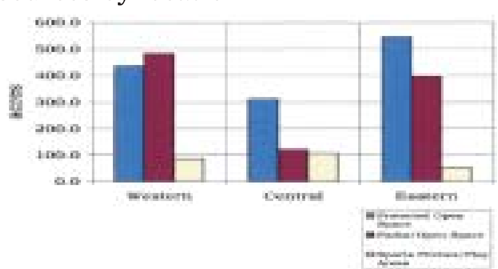
Source: Open Space Survey 2001, Department of Planning

By far the largest components of open space are national parks and golf courses with each contributing about 800 acres to the total (see Figure 6.8). This amounts to over 60% of all open space resources. Table 6.5 provides a detailed breakdown of open space resources by parish.

6.3.2 Open Space Distribution

Open space resources are not distributed evenly throughout Bermuda. The central parishes have only half of the open space resources enjoyed by the eastern and western parishes as shown in Figure 6.9.

Figure 6.9 Bermuda's open space resources by location



Source: Open Space Survey 2001, Department of Planning

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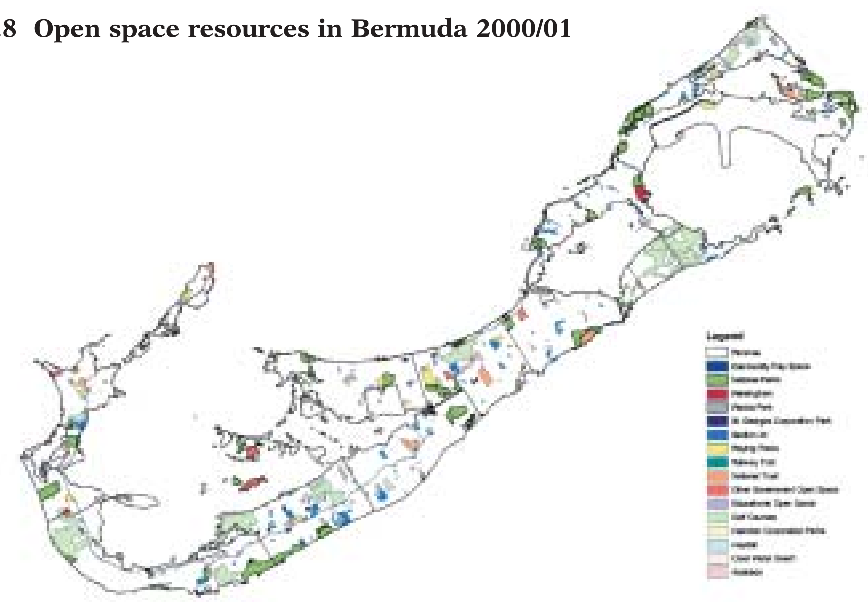
Table 6.5 Open space resources in Bermuda 2000/2001 by parish (in acres)

	Sandys	Southampton	Warwick	Paget	Pembroke	Devonshire	Smith's	Hamilton	St. George's	Total
PROTECTED OPEN SPACE										
National Parks - A	1.7	1.3	0.6	7.1	18.9	0.0	46.1	5.8	37.5	119.0
National Parks - B	74.5	92.7	79.3	40.4	31.8	57.1	26.5	54.4	216.5	673.2
National Trust	35.1	0.0	24.7	22.9	6.7	45.4	34.4	2.5	28.9	200.6
Audubon Society	2.7	2.5	1.6	8.7	0.0	17.9	0.4	0 0.2	2.4	36.2
Section 34	5.2	13.5	49.4	32.9	0.8	20.4	23.1	23.3	21.2	189.8
Heydon	50.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.8
Walsingham	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.2	0.0	23.2
Subtotal	**170.0**	**110.0**	**155.6**	**112.0**	**58.2**	**140.8**	**130.5**	**109.2**	**306.5**	**1292.8**
OTHER PARKS AND OPEN SPACE										
Clearwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	9.7
WEDCo	13.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3
City	0.0	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0	10.5
St. George's	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2
Other Govt OS	7.1	9.5	40.7	0.0	3.9	9.0	13.5	0.0	0.0	83.7
Railway Trail	11.8	17.0	9.0	6.4	0.0	3.9	3.0	11.6	13.2	75.9
Golf Courses	5.3	198.0	171.0	10.8	0.0	76.6	0.0	127.7	219.2	808.6
Subtotal	**37.5**	**224.5**	**220.7**	**17.2**	**14.4**	**89.5**	**16.5**	**139.3**	**243.3**	**1002.9**
SPORTS PITCHES AND PLAY AREAS										
Playing Fields	28.0	3.0	5.8	0.0	20.9	41.5	4.7	5.3	21.3	130.5
Educational OS	8.2	10.0	19.5	9.4	26.4	5.8	5.5	1.5	14.4	100.7
Community Playspace	2.9	0.3	8.5	0.0	2.9	0.3	0.0	0.0	1.1	16.0
Subtotal	**39.1**	**13.3**	**33.8**	**9.4**	**50.2**	**47.6**	**10.2**	**6.8**	**36.8**	**247.2**
TOTAL	**246.6**	**347.8**	**410.1**	**138.6**	**122.8**	**277.9**	**157.2**	**255.3**	**586.6**	**2542.9**

Source: Open Space Survey 2001, Department of Planning

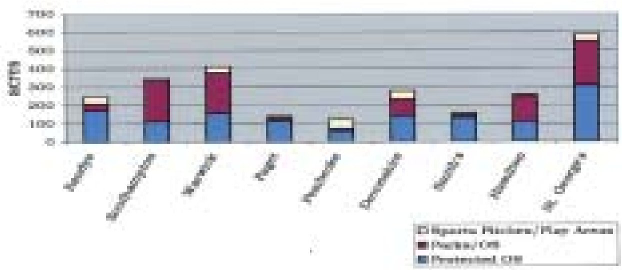
Figure 6.8 Open space resources in Bermuda 2000/01



Source: Department of Planning

These differences become more marked in the graph showing the distribution of open space on a parish by parish basis (see Figure 6.10). Nearly a quarter of all such land is located in St. George's which also has one third of all the land designated as national park. By contrast the densely developed parishes of Pembroke and Paget have the lowest amount of open space with each enjoying only about 5% of total open space resources (see Table 6.5).

Figure 6.10 Distribution of open space resources by parish



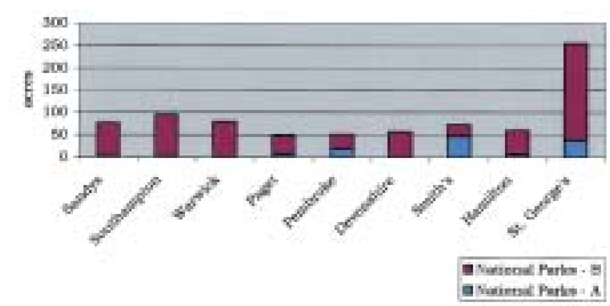
Source: Land Use Survey 2000/2001, The Department of Planning

6.3.3 Protected Open Space

6.3.3.1 National Parks

Over 60% of the land classified in the Open Space Survey 2001 as 'protected open space' falls in the national park system (see Table 6.5). This is mostly government-owned land designated as either Class A Protected Areas (Nature Reserves) or Class B Protected Areas (Parks) under the Bermuda National Parks Act, 1986.

Figure 6.11 National Parks by parish



Source: Open Space Survey 2001, The Department of Planning

As shown in Figure 6.11, nearly a third of all national park land is located in St. George's Parish (254 acres). The distribution of national park land through the rest of the parishes is more even. Pembroke, however, has significantly less protected open space or other parks and open areas compared to other parishes. This position should improve, however, when the proposed Pembroke Park on the site of the former waste disposal facility is complete. In addition, government has had an active programme for a number of years of acquiring land for open space purposes particularly for additions to the national park system.

6.3.3.2 National Trust parks

In total the Bermuda National Trust owns some 20 acres (81 ha) of land across the Island, comprising the next largest grouping of protected open space after government national parks. In addition to Smith's Island, National Trust properties include major elements of Bermuda's open spaces such as Warwick Pond, Paget Marsh, Locust Hall (Devonshire) and Spittal Pond.

One of the more recent acquisitions in 1999 was a joint arrangement by government to assist the National Trust in the purchase of 22 acres on the western part of Smith's Island in St. George's Parish. The National Trust was the major purchaser.

6.3.3.3 Section 34 protected land

Some 190 acres (77 ha) of land across the Island is protected by planning agreements between the Minister of the Environment and landowners as designated under Section 34 of the Development and Planning Act, 1974. There are currently 119 Section 34 agreements. These agreements have typically been used to protect important environmental features such as woodland or agricultural land whilst allowing built development on the remainder of the lot.

6.3.3.4 Audubon Society and Trust lands

The remaining 100 acres of open space comprises land protected by trust at Heydon and Walsingham or owned by the Bermuda Audubon Society. The Audubon Society owns a number of generally small sites around the Island, which have been acquired for their nature conservation interest. These include some 13 reserves ranging from Sears Cave in Smith's Parish which is 0.4 acres (0.2 ha) to Paget Marsh which is 8.9 acres (3.6 ha). The newsest acquisition in 2002 (which post dates the Open Space Survey 2001) is the Blackburn Smith Nature Reserve on South Shore in Paget which is 8.7 acres (3.5 ha) in size. This nature reserve has made a substantial contribution to protected open spaces in the central parishes.

6

6.3.4 Other Parks and Open Spaces

6.3.4.1 Golf courses

Golf courses comprise by far the largest proportion of land in the 'Other Parks and Open Space' category. The nine golf courses around Bermuda amount to over 800 acres of open space (see Table 6.5). Whilst this is land devoted to a particular form of recreational activity and general public access is not available, the importance of golf courses in providing large tracts of undeveloped land and open space should not be underestimated. With over 200 acres, St. George's Parish has the greatest amount land used for golf courses. The parishes of Southampton and Warwick also have a significant amount of land devoted to this use with lesser amounts in Hamilton Parish and Devonshire. With the exception of St. George's, each of these parishes has more land in golf course use than national park.

6.3.4.2 Other government open spaces

In addition to national parks, government owns a number of incidental open spaces that have restricted public access. These include Ports Island and Darrell's Island as well as several farms. Government also owns the Railway Trail which has the potential to become an extremely important recreational resource and 'green corridor' with its connections to Tribe Roads and links to a number of parks and other open areas. Management and development of the Railway Trail has recently been moved from the Ministry of Works and Engineering and Housing to the Ministry of the Environment's Department of Parks. Together, these smaller open spaces and the Railway Trail amount to about 160 acres.

The remainder of the land falling in this open space category consists of parks owned and maintained by the various municipal and development corporations.

6.3.5 Sports Pitches and Play Areas

Sports pitches and playing areas amount to only 10% or about 250 acres (101 ha) of the total amount of open space but they provide essential facilities for active recreation, contributing to the health and enjoyment of Bermuda residents. Playing fields comprise over 50% of this land and are those areas where active sports are played. They are generally government-owned or run by sports or community clubs and include the National Stadium. Educational open space, amounting to about 100 acres, are the playing areas and sports facilities in school and college grounds. Community play spaces are small neighbourhood playgrounds within easy walking distance of the local population. Play equipment may be provided in these areas and full or half-size basketball courts may also be available. They include such areas as Death Valley Field in Southampton and Pig's Field in Pembroke.

The distribution of all these facilities tends to be concentrated in the older established centres of population. Consequently, they are generally located in the centre of the Island, at the far east and far west ends, and in central Warwick.

6.4 Land Use Planning

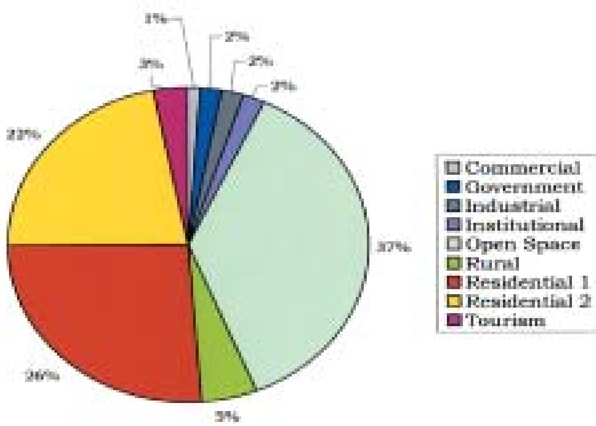
6.4.1 The Planning Framework

The mechanism for managing how Bermuda's land resources are used is provided through the planning system. The legal basis for this system is contained in the Development and Planning Act, 1974. This Act regulates the use and development of land in Bermuda and requires the Minister responsible for planning (the Minister of the Enviroment) to prepare a development plan for the Island. The development plan must be based on 'surveys and studies of land use, population growth, the economic base of the planning area, its transport and communication needs, public services, social services and such other factors as are relevant' (section 6(2)) and can designate any part of Bermuda as an environmental conservation area. The current development plan for the Island is the Bermuda Plan, 1992.

The Bermuda Plan, 1992, covers all of Bermuda except for the City of Hamilton and those areas formerly occupied by foreign military forces. The Bermuda Plan operates a two-tier zoning system. The basic layer identifies and seeks to protect a range of environmental conservation areas including agricultural land, nature reserves, woodland etc. This is overlain by a series of development zones that prescribe the type of development that is permitted in a certain area.

As shown in Figure 6.12, of the land covered by the Bermuda Plan 1992, 48% is zoned for residential purposes while 37% is zoned open space. A further 5% is zoned rural which seeks to protect the open character of the land whilst permitting some low density development. The remaining 10% is allocated to a range of other development uses including industrial, government and tourism. The distribution of the development zones across the parishes is shown in Figure 6.13.

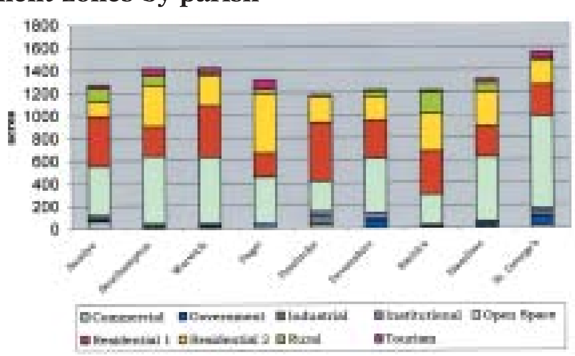
Figure 6.12 The Bermuda Plan 1992 development zones



Note: Figures do not include the former baselands or the City of Hamilton
Source: The Bermuda Plan, 1992, Department of Planning

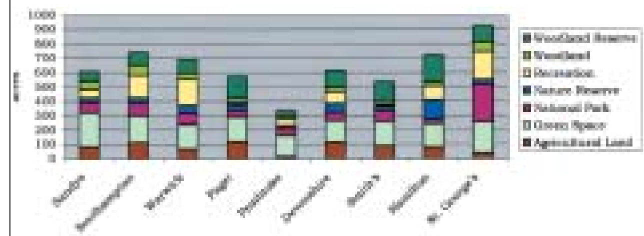
Figure 6.14 shows the distribution of conservation areas across the parishes. The Bermuda Plan, 1992 conservation areas cover 48% of the land subject to the Bermuda Plan 1992 (and 43% of the Island as a whole). The majority of this land is further protected by falling within an open space development zone.

Figure 6.13 The Bermuda Plan 1992 development zones by parish



Source: The Bermuda Plan 1992, Department of Planning

Figure 6.14 The Bermuda Plan 1992 conservation zones by parish



Source: The Bermuda Plan 1992, Department of Planning

Planning permission is required for any development of land (as defined in section 14 the Development and Planning Act, 1974). Planning applications are assessed in the Department of Planning for their conformity with the Bermuda Plan, 1992. Other relevant factors are also taken into account that may require consultation with other agencies. A recommendation is then made to the Development Applications Board (the Board) which makes decisions on such matters (as defined under section 3 of the Act). There is a right of appeal to the Minister of the Environment against decisions of the Board. This right extends to third parties. In addition, the Minister of the Environment has the power to grant planning permission in exceptional circumstances, where proposals do not comply with this statutory provisions, by means of a Special Development Order (as defined under section 15 of the Act).

6.4.2 The New Development Plan

The Department of Planning is currently in the process of reviewing the Bermuda Plan 1992. The new Development Plan will establish land use policies to guide development and the conservation of the Island's resources for the next 10 years. The former military baselands will be incorporated into the new plan but the City of Hamilton will retain its own plan.

The policies within the new Development Plan will seek to strike a suitable balance between accommodating the community's economic development and social needs and conserving the Island's most valuable land resources such as parkland, agricultural land and woodlands.

Key planning issues facing Bermuda concern how much development growth to provide for over the next 10 years and how to accommodate it. However, before decisions are made on the location and quantity of development, further forecasts of population growth and household projections need to be made. The requirement for new housing is also influenced by the investment decisions of firms, including the international business sector and tourism industry. There is a strong correlation between growth rates and development rates which all need to be taken into account as part of the Development Plan review process.

As the supply of land available for new housing continues to dwindle, there will be a need to focus on promoting higher density forms of residential development, in accessible locations, on previously developed sites such as parts of the former baselands. Residential development within and around the City of Hamilton will also be encouraged. With this in mind, a further part of the new Plan's strategy will be to provide stronger links between planning and transport policies. In this way, better use can be made of development opportunities at existing and new centres, which also serve as transport nodes, by increasing the mix of development and overall density. By influencing the type and location of development, more effective management of the environment can be achieved in a more desirable and sustainable way.

Policies within the new Plan will also seek to strengthen the protection of existing environmentally sensitive open spaces including coastal areas, which are both valuable for amenity reasons and vulnerable to coastal erosion. Striking the right balance by optimising development potential whilst protecting important environmental assets is key to achieving a sustainable future for Bermuda.

6.5 Coastal Development

6.5.1 Bermuda's Coastline

Bermuda has a comparatively large extent of coastline (290 km or 180 miles) in contrast to its small land area (21 sq. miles). As such, shoreline development must be regulated carefully to protect the visual amenity of the Island and to take into account factors such as coastal erosion from hurricanes and sea level changes.

6.5.2 Foreshore Development

Section 13.COA of the Bermuda Plan 1992 Planning Statement regulates coastline development including docks, jetties, boathouses, sea walls, reclamation projects and other structures extending into the water from the shore. It states that development proposals should protect the natural and scenic qualities of the coastline, protect the marine environment and minimise the physical and visual impact of coastline development.

Minor development proposals, including floating docks and mooring piles, are assessed by the Department of Marine and Ports Services. All other development proposals affecting the marine environment are overseen by the Department of Planning and referred to the Development Applications Board for its decision. The Marine Resources Board is also often consulted.

Department of Planning records show that there are on average between 40 to 50 planning applications received each year for some form of development on the foreshore whether this be a dock, jetty, marina, seawall, slip or boathouse.

6.5.3 Moorings and Marinas

The number of registered moorings totaled 4,920 in June 2000, an estimated increase of some 40% over the last 15 years. This figure includes walk-on moorings but excludes berths at Dockyard and the yacht clubs.

Preferred moorings sites are those that are protected from high winds and waves. However, these areas are not well flushed and are most prone to damage from bottom paint leachate, boat cleaning products and bilge water. The tremendous scouring impact of mooring weights and chains also tends to desecrate the marine environment in the vicinity of the mooring leaving behind a halo of bare sand encircling the buoy. For these reasons, the development of marinas is considered to be a better alternative to allowing more new moorings.

Figure 6.15 Halo effect of swing moorings, Mangrove Bay

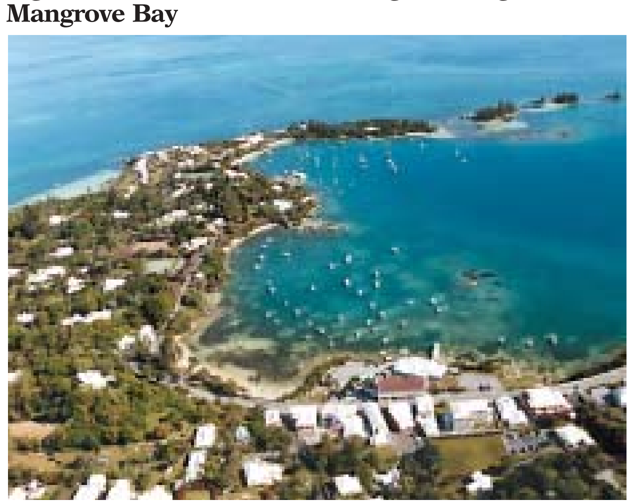


Photo courtesy of the Department of Planning

There are currently five marinas on the Island: Dockyard, the Royal Hamilton Amateur Dinghy Club (RHADC), the Royal Bermuda Yacht Club (RBYC), the St. George's Dinghy Club and the most recent Waterfront Development marina off Pitts Bay Road.

Figure 6.16 Dockyard Marina

Photo courtesy of the Department of Planning

The Department of Planning assesses planning applications for new marina developments and seeks advice from the Marine Resources Board.

Despite the growing preference for marinas over swing moorings, there are a number of potentially problematic issues relating to marina developments. In particular, issues of concern include the impact of structures on marine life, dredging, provision of adequate sewage pumping facilities, fuelling facilities, toilet facilities, means of preventing the discharge of waste and operational guidelines for the management of marinas. Other concerns include the scale of marinas and their aesthetic effect. Planning applications for marina developments are therefore, required to be accompanied by an environmental impact statement (paragraph 4.5 of the Bermuda Plan 1992 Planning Statement refers) in order for these issues to be thoroughly investigated.

6.5.4 Coastal Erosion

Bermuda's coastline has been experiencing significant erosion which is evident in a number of locations around the Island and became particularly noticeable after the passage of Hurricane Fabian in September 2003. Hurricane Fabian was a Category 3 hurricane according to the Saffir-Simpson scale. It caused major damage to Bermuda, and significant wave and wind action caused considerable damage to the Island's coastline.

The public's concern for the impact of coastal erosion is reflected in the increase, in recent years, of the number of planning applications received to carry out beach and shoreline protection works.

As part of the review of the Bermuda Plan 1992 and the desire for better information with regard to the implementation of coastal development and shoreline protection works, in July 2003 the Ministry of the Environment commissioned consultants Smith Warner International (SWI) to undertake a coastal erosion vulnerability assessment and to prepare coastal protection and development planning guidelines for Bermuda. The study was completed in November 2004 with the production of three reports: 'Assessment of Coastal Damages resulting from Hurricane Fabian' (October 2003); 'The Coastal Erosion Vulnerability Assessment Final Report' (November 2004); and 'Coastal Protection and Development Planning Guidelines for Bermuda' (November 2004).

The recommendations put forward by SWI are based on first-hand experience of observations made and lessons learned following the passage of Hurricane Fabian. SWI conducted an assessment by both land and sea of the shoreline damage caused by Hurricane Fabian. The results of the site surveys revealed damage to seawalls and other forms of shore protection, substantial structural damage to houses built too close to the sea, erosion of sand beaches, rockfalls along cliffs, damage to structures built on the cliffs and large numbers of uprooted casuarina (*Casuarina equisetifolia*) trees. Wave action also caused significant structural damage to the causeway and parts of South Shore Road.

Figure 6.17 Coastal damage, post Hurricane Fabian

Photo courtesy of the Department of Planning

As stated in the SWI report 'Assessment of Coastal Damages resulting from Hurricane Fabian' (October 2003), the main physical agent responsible for coastal erosion in Bermuda is wave action. Wave energy is strongly influenced by the angle of the wave's approach as well as the offshore and nearshore bathymetric conditions. SWI concluded that the main causes of coastline damage as a result of Hurricane Fabian were cliff erosion, beach and dune erosion and failure of shore protection structures. The 'Assessment of Coastal Damages resulting from Hurricane Fabian' report provided the following recommendations:

- Appropriate building setbacks from the coastline;

appropriate design and construction of seawalls (including steel reinforcing, stepped or sloped structures, and tying into adjacent structures or rock outcrops);

- An effective, well-designed drainage system to prevent the build-up of water behind structures; Consistency in shoreline defence systems;
- Public infrastructure (roads and bridges) armoured with sloping rock or concrete to help dissipate wave energy;
- 'Soft' protection measures (such as geosynthetic containers or fibre mesh packed with sand or stone) and vegetation for dune protection;
- Shoreline defence structures designed to be able withstand the one in 25 year or one in 50 year major storm, depending on the type of facility being protected and the structure's proximity to the coastline; and
- Attention to be paid to the aesthetics of coastal defence structures including facing with Bermuda stone or stepped structures.

'The Coastal Erosion Vulnerability Assessment Final Report' (November 2004) was guided by the following three main objectives:

- To synthesise the data that already exists in Bermuda about coastal erosion;
- To determine which coastal areas in Bermuda are prone to erosion and which structures and landforms are most at risk; and
- To make recommendations of best practices for coastal development and conservation.

The study involved a desk review and analysis as well as field investigations. During the tours an inventory was made of the shoreline types, shoreline structures and the forms of erosion found around the entire Island. The final analysis of the coastal erosion vulnerability involved the identification of the nature and extent of the significant forces of erosion and the geological make-up of the Island.

The study indicates that the day-to-day effects of wave action are minimal, but that the impacts of storm-induced waves on the shoreline are significant and result in the most severe erosion. Biological erosion is also an issue that is of secondary importance, the control of which will require further investigations into the biology and ecology of the boring organisms in Harrington Sound and immediate action to stop the proliferation of casuarina (*Casuarina equisetifolia*) trees.

The findings provide powerful tools that may be utilised in development planning. In particular, the depiction of zones of high wave energy gives a first indication to the Bermuda Government of the vulnerability of a proposed development or section of shoreline. When combined with information on static storm surge and wave run up levels, this provides a tool for regulation of development along the shoreline. Specifically, this information may be used to indicate appropriate 'step-up' requirements or set back distances required to avoid storm induced flooding.

SWI's report entitled 'Coastal Protection and Development Planning Guidelines for Bermuda' (November 2004) stresses the importance of establishing appropriate setbacks from the coast for development (based on wave height, storm surge and inundation level calculations), the adoption of a community approach to shoreline defence and the importance of achieving a balance between ensuring the functional integrity of a shoreline defence system and its aesthetics. The report examines the various types of shoreline protection structures including seawalls, revetments and breakwaters, and the design considerations for each. The report also emphasises the significant impact that ecological features including the casuarina (*Casuarina equisetifolia*) tree and certain marine organisms play in the erosion of Bermuda's coastline and the important role that the coral reefs play in protecting Bermuda's shoreline.

The recommendations provided in the three SWI reports will enable more informed policies and planning regulations with regard to coastal development to be established in the next Development Plan for the Island.

6.6 Summary

Bermuda's economic success has resulted in increasing development pressure on its limited land resources particularly on those areas that are not yet developed. Set against this trend is the desire to retain sufficient open space to provide for the psychological well-being of residents, to preserve the amenity of the Island and to conserve biodiversity.

The land use planning system in Bermuda tries to achieve a balance between the competing forces of development and conservation needs to ensure that land resources are used efficiently and valued open spaces are protected.

Bermuda's total land resources amount to over 13,200 acres (5,370 ha). Over 30% of this land is owned by government, either directly or through various quangos.

In 2000/01, the Bermuda Government's Department of Planning undertook a Land Use Survey to analyse existing land uses on the Island. The survey found that two-thirds of Bermuda is covered by land uses that involve some form of built development. Residential development consumes almost 45% of the Island and is by far the most extensive use. Employment uses including commercial, industrial and tourism account for 7% of total land area. Utilities amount to about 6% and vacant/derelict land together amount to about 12% of Bermuda's land area. Vacant/derelict land is one of the most significant categories as it comprises land that could be made available for redevelopment/re-use.

According to the 2000/01 Land Use Survey, one-third of Bermuda is categorised as open space. This includes natural areas such as woodland and marshes, golf courses, parks, and other areas in recreational use as well as land in cultivation.

The increase in residential land over the last 30 years (between 1970/71 and 2000/01) has been directly proportional to the decrease in open space over the same period. The loss of open space can be attributed to Bermuda's growing population and number of households and the increased pressure to develop land, including open spaces, for residential purposes.

In addition to the Land Use Survey 2000/01 which provides a broad measure of available open space, in 2001 the Department of Planning also prepared an inventory of all current open space resources in Bermuda. According to the Open Space Survey 2001, open space resources amount to 2,543 acres or nearly 20% of Bermuda's land area. Half of this land is protected as national park or through ownership by a protective agency or an agreement. Other parks and open space amount to 1,000 acres (40% of open space resources) most of which is golf course. Sports pitches and play spaces comprise less than 250 acres or 10% of open space.

Open space resources are not distributed evenly throughout Bermuda. The central parishes have only half of the open space resources enjoyed by the eastern and western parishes.

Bermuda's land resources are managed through the planning system, specifically the Development and Planning Act, 1974 and the Bermuda Plan, 1992, the current development plan for the Island.

Under the Bermuda Plan, 1992 planning zonings, 48% of the Island is zoned for residential purposes while 37% is zoned open space. A further 5% is zoned rural which seeks to protect the open character of the land whilst permitting some low density development. The remaining 10% is allocated to a range of other development uses including industrial, government and tourism.

Planning permission is required for any development of land (as defined in section 14 the Development and Planning Act, 1974) and planning applications are assessed by technical officers in the Department of Planning for their conformity with the Bermuda Plan, 1992.

The Department of Planning is currently in the process of reviewing the Bermuda Plan, 1992. The new Plan will establish land use policies to guide development and the conservation of the Island's resources for the next 10 years. The former military baselands will be incorporated into the new plan but the City of Hamilton will retain its own plan.

Bermuda has a comparatively large extent of coastline (290 km or 180 miles) in contrast to its small land area (21 sq. miles). As such, shoreline development is regulated carefully to protect the visual amenity of the Island and to control coastal erosion.

6

There are on average between 40 and 50 planning applications received each year for some form of foreshore development including docks, jetties, seawalls, slips, boathouses and marinas. Marinas are preferred to swing moorings which have a scouring effect on the seabed. However, marinas are major developments and their impacts on the marine environment need to be carefully considered.

In July 2003, the Ministry of the Environment commissioned consultants Smith Warner International (SWI) to undertake a coastal erosion vulnerability assessment and to prepare coastal protection and development planning guidelines for Bermuda. The study was completed in November 2004. The recommendations put forward by SWI are based on first hand experience of observations made and lessons learned following the passage of Hurricane Fabian in September 2003. ,The recommendations provided in the various SWI reports will enable more informed policies and planning regulations with regard to coastal development to be established in the next Development Plan for the Island.

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Chapter 7

Historic Sites and Buildings

7

7.1 Bermudian Architecture

7.1.1 Introduction

Bermuda's architecture is often referred to as the Island's only indigenous art form and public surveys have shown that Bermudians and visitors alike place a high value on the contribution that traditional architecture makes to their enjoyment of the Island. It is therefore important to retain Bermuda's distinctiveness and attractiveness both as a place to live and as a top visitor destination.

Bermuda's architecture, whilst aesthetically pleasing, originated in functionality. The eyebrows over windows were present to keep rain off the wood sashes (see Figure 7.1). The shutters protected the interiors from the sun and the rain. Chimneys at the ends of buildings acted as a lateral bracing to keep structures standing. The lime-washed white roofs cleansed and caught the rainwater which was used for drinking. Above-ground and barrel vaulted water tanks stored the water that was caught from the roofs.

Figure 7.1 Bridge House, Town of St. George

Photo courtesy of the Department of Planning

Whilst it may seem that incremental changes to these external details of Bermuda's traditional buildings are not significant, the cumulative effect of such alterations can have a material impact on the character and appearance of historic buildings. This can affect both individual properties as well as groups of historic buildings.

In order to identify and protect Bermuda's heritage as well as its special buildings and places, specific policy measures were introduced for historic buildings and areas as part of the Development and Planning Act 1974. The pace of change in Bermuda accelerated in the 1980s and as such the Government decided to implement the formal protection afforded by the Development and Planning Act, 1974 (the 1974 Act).

This chapter considers the state of Bermuda's historic environment and addresses current and future issues concerning all aspects of built heritage including listed buildings, historic areas, fortifications and archaeological resources. The progress of the heritage preservation movement in Bermuda over the last 30 years is also examined.

7.2 Listed Buildings and Historic Areas

7.2.1 Listed Buildings

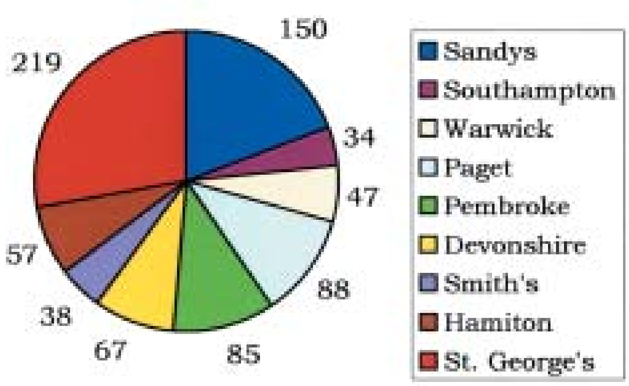
Section 30 of the 1974 Act affords protection to individual buildings which are considered to be of special architectural or historical interest. Under section 30 of the 1974 Act, the Minister has a statutory duty to compile a list of buildings of special architectural or historical interest. The statutory list of these 'listed buildings' provides protection for the best examples of the Island's built heritage.

The current list includes 785 buildings and structures, ranging from a wide variety of forts and churches to houses and gate posts Island-wide. The City of Hamilton currently has only one listed building, the Cathedral of the Most Holy Trinity.

Planning permission is required for any alterations and additions which affect the external appearance of a listed building as well as for any material change of use of a listed property. These protective measures will help to ensure that Bermuda's architectural heritage will be preserved for future generations to experience and enjoy.

The distribution of listed buildings across the Island is not even. Of the 785 listed buildings, St. George's Parish has by far the most totalling 219 (28%) of which 176 are located within the Historic Town of St. George. Sandys Parish has the second highest number of listed buildings totalling 150 (19%) of which 47 are located in the Royal Naval Dockyard. The parishes of Southampton and Smith's have the least number of listed buildings at 34 (4%) and 38 (5%) respectively (see Figure 7.2).

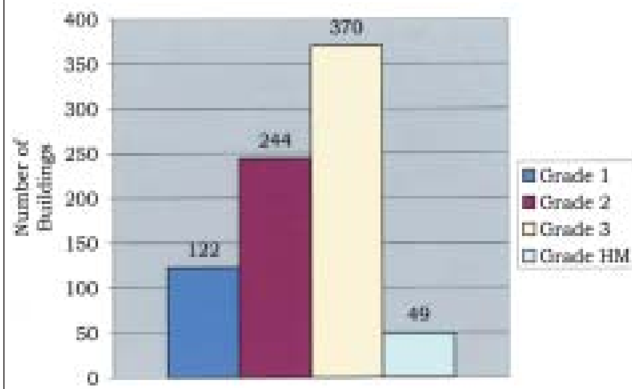
Figure 7.2 Number of listed buildings by parish



Source: Department of Planning

Of the 785 listed buildings, 122 (16%) are designated as Grade 1, 244 (31%) as Grade 2, 370 (47%) as Grade 3 and 49 (6%) as Grade HM (Historic Monuments) (see Figure 7.3). The definitions for each grade are as follows:

Figure 7.3 Number of listed buildings by grade



Source: Department of Planning

Grade 1 listed buildings are those which have survived in essentially their original condition and are of such exceptional interest and architectural or historical value that they should largely be preserved in their present form both structurally and decoratively (see Figure 7.4). Minor alterations or additions should normally be carried out in the same materials and in the same structural and decorative style as the original building.

Figure 7.4 Wellesley Lodge, Town of St. George, a grade 1 listed building

Photo courtesy of the Department of Planning

Grade 2 listed buildings are those which have survived in such condition and are of such special interest and architectural or historical value that alterations and additions should be limited to works that do not impinge on those parts of the building to be protected and preserved. Such works should normally be carried out in the structural and decorative style of the existing building.

Grade 3 listed buildings are those which serve Bermuda as an important visual amenity and are of such architectural or historical value that alterations or additions should normally be carried out in sympathy with the structural and decorative style dominant of the existing building.

Grade HM listed buildings are buildings, structures or groups of buildings not originally intended for residential, commercial or administrative purposes but built as defensive structures, monuments, outbuildings or other ancillary structures. This category also includes buildings that have become significant ruins.

The Minister of the Environment (the Minister) commenced the listing process in 1991. In April 1991, the Historic Buildings Advisory Committee (HBAC) was appointed by the Minister to advise on matters pertaining to the identification and protection of buildings, structures and areas of historical and/or architectural value. Criteria were formulated to be used in identifying buildings worthy of listing and to agree a grading classification. These were presented to Cabinet for information in June 1992.

It took the HBAC approximately seven years to complete the arduous task of surveying buildings across the Island. In 1998, the task was completed and the Minister mailed out the listing notices to homeowners in a first round of consultations. Out of the first round, 272 buildings were listed. In 2001, the Minister mailed out the second round of listing notices to the owners of the remaining buildings and subsequently listed all but seven of these buildings in October 2002.

The City of Hamilton was deliberately exempted from this listing exercise as the Department of Planning was in the process of preparing a new development plan for the City. To date there is only one building listed within the City of Hamilton, the Cathedral of the Most Holy Trinity, which was listed in 1983. The HBAC has identified 61 additional buildings within the City of Hamilton for inclusion on the list and it is anticipated that the formal listing of these structures will be pursued in the near future.

Since the Minister instituted the listing initiative in 1991, the Department of Planning has maintained a database and information management system to collect and store information on listed buildings. The Department has recently undertaken an initiative to build a listed building extension to the Department's Built Environment Information Management System (BEMIS). This extension will manage the information on listed buildings and historic areas and record new information such as interest-free loans, new proposals to list, development proposals, site visits to properties, criteria for listing and the condition of structures.

In order to promote the importance of protecting our heritage and to gain support from the public, the Department of Planning does not currently charge the owners of listed buildings planning or building application fees for work to these buildings.

In addition, since December 2000 the Department of Planning has offered owners of listed buildings access to interest-free loans from Butterfield's Bank for approved works to listed buildings. Since December 2000, the Department has approved and issued 10 loan certificates totaling $724,988.00. This amounted to $30,316.69 in interest paid by the Government from 1 April 2002 to 31 December 2003 (see Table 7.1).

The Department of Planning has also explored other incentives such as reduced land tax for listed buildings, the sale of transferable development rights and grants for listed buildings. The Department will continue to investigate these and other incentives in order to assist property owners in maintaining these valuable buildings.

In 2002, the Department of Planning, in partnership with the Bermuda National Trust, produced a book on traditional building methods called *The Bermuda Traditional Building Guide* which gives property owners, contractors and architects advice on how to maintain and preserve old buildings. *The Traditional Building Guide* explains traditional methods of building, many of which have never been written about before. Historically there had been no need to write about these methods because the knowledge was passed on to apprentices and assistants, and to sons and nephews. However, in an age of rapid change, the methods that elderly craftsmen have painstakingly learned from previous generations are now in danger of being lost forever. *The Traditional Building Guide* aims to keep practical knowledge of our built heritage alive.

In an effort to protect another of Bermuda's architectural features, in 2002 the Department of Planning, in consultation with HBAC, took on the task of surveying all dry stonewalls along Bermuda's main public roads. The aims of the survey were to locate, identify, record, photograph and classify

Table 7.1 Interest-free loans issued

Listed Building Ref No.	Loan Certificate Amount	Loan Certificate Date	Bank Note Date	Loan Maturity Date	Interest paid April 1 2002 to March 31 2003	Interest paid April 1 2003 to March 31 2004	Interest paid to date
HM 027	$107,500.00	November 14, 2001	April 1, 2002	April 1, 2007	$4,739.30	$2,873.09	$7,612.39
SM 035	$35,000.00	May 6, 2002	May 21, 2002	May 30, 2007	$1,399.07	$975.66	$2,374.73
PG 052	$25,000.00	May 6, 2002	May 30, 2002	May 15, 2007	$916.54	$660.74	$1,577.28
PM 105	$150,000.00	March 5, 2002	June 28, 2002	July 1, 2007	$5,318.84	$4,250.56	$9,569.40
CH 009	$150,000.00	March 1, 2002	July 30, 2002	July 30, 2007	$4,722.61	$4,345.49	$9,068.10
HM 052	$12,488.00	October 9, 2003	October 21, 2003	November 5, 2008	$0.00	$114.79	$114.79
SY 003	$20,300.00	October 2, 2003	n/a	n/a	$0.00	$0.00	$0.00
SY 093	$79,700.00	November 10, 2003	n/a	n/a	$0.00	$0.00	$0.00
SG 055	$55,000.00	September 25, 2003	n/a	n/a	$0.00	$0.00	$0.00
DV 004	$90,000.00	January 19, 2004	n/a	n/a	$0.00	$0.00	$0.00
Total	$724,988.00				$17,096.36	$13,220.33	$30,316.69

Source: Department of Planning

stonewalls, gates and other recognised boundary structures. The survey was completed in 2003. It is hoped that the data and images collected will lead to the production of a set of guidelines for homeowners, contractors, architects and those in the building trade to follow so that these structures can be preserved for future generations to enjoy.

7.2.2 Historic Areas

Areas which possess a certain group value in terms of having special architectural or historic attributes are designated as 'historic areas' under section 31 of the 1974 Act. The main objective of this designation is to protect the historic, architectural or cultural character of these areas, particularly when new development is proposed.

The current development plan for the Island, the Bermuda Plan 1992 has a specific protection area zoning for historic sites, of which there are 58 ranging from the Royal Naval Dockyard in the west end to the World Heritage Site (WHS) of the historic Town of St. George in the east end (see Figures 7.5(a),(b) and (c)).

The Town of St. George is additionally protected by the Town of St. George (Protection of Buildings of Special Interest) Act, 1950 which designates much of the Town as a preservation area and protects 21 individual buildings with preservation orders. (see Figures 7.6 and 7.7) The 1950 Act also requires that any alteration or external change to a building requires the grant of planning consent.

Figure 7.5 (a) Historic areas in the west

Source: Department of Planning

Figure 7.5 (b) Central historic areas

Source: Department of Planning

Figure 7.5 (c) Historic areas in the east

Source: Department of Planning

Figure 7.6 View of King's Square, Town of St. George

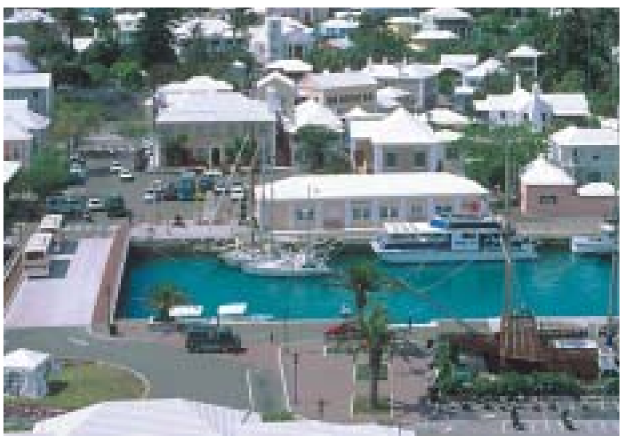


Photo courtesy of the Department of Planning

The City of Hamilton has its own development plan, the City of Hamilton Plan 2001, which designates four distinct areas as 'historic areas'. These are Front Street, Par-la-Ville Park, Princess Street and the Cabinet Office/House of Assembly.

Most of the 'historic areas' either surround historic fortifications, encompass sites of significant archaeological value or comprise districts with heavy concentrations of buildings and structures of special historical and architectural value. For example the Royal Naval Dockyard in the west of the Island and the World Heritage Site (WHS) of the historic Town of St. George in the east of the Island are two of the more heavily concentrated 'historic areas'.

Development in these areas is strictly controlled to conserve Bermuda's rich historical and architectural heritage. The HBAC is involved in reviewing and advising on all development applications within these areas.

On 2nd December 2000, the Historic Town of St. George, the most concentrated historic area on the Island, was recognised as one of the world's special places when the United Nations Educational, Scientific and Cultural Organisation (UNESCO) declared it a World Heritage Site (WHS).

Figure 7.7 Aerial photo of St. George's

Photo courtesy of the Ministry of Works and Engineering and Housing

Inscribed under UNESCO guidance (criteria c (iv)), the Historic Town of St. George with its related fortifications is an outstanding example of a continuously occupied, fortified, colonial town dating from the early 17th century as well as the oldest English town in the New World. Its associated fortifications graphically illustrate the development of English military engineering from the 17th to the 20th centuries, being adapted to take account of the development of artillery over this period. The certificate presented to Bermuda by UNESCO reads:

Inscription on this list confirms the exceptional and universal value of a cultural or natural site which requires protection for the benefit of humanity.

The World Heritage Site Committee for Bermuda was established in 2000 to implement the on-going Management Plan for the Town of St. George and related fortifications. The Plan highlights specific activities to be carried out by each of the Committee's member organisations including the Corporation of St. George's, the St. George's Foundation, the Departments of Planning, Parks, Tourism and Community and Cultural Affairs.

These activities are directed at preserving, and where necessary, restoring the site so that it will continue as a WHS into the future, as well as remaining a living town.

The Committee is also concerned with ensuring that St. George's and its history and cultural features are well presented and that Bermudians and visitors understand the significance of the Town and Bermuda in Western Atlantic events. The Committee meets monthly and reviews its action plans yearly. It is required to provide an update to UNESCO on the Management Plan and the WHS in 2006.

On 5 September 2003, Hurricane Fabian passed over Bermuda. Fabian was a Category 3 hurricane, which pounded the coast of Bermuda with significant wave and wind action resulting in major damage, particularly to the southern coastal areas of the Island. The hurricane caused extensive damage across Bermuda and significant damage in the WHS.

A survey of the damage to the buildings within the WHS was conducted by the Department of Planning a week after the hurricane. Of the 153 listed buildings within the WHS, 56 buildings or 37% sustained some visible form of damage consisting mostly of roof slate damage. Ninety-seven or 63% of the listed buildings remained intact including some of Bermuda's oldest buildings such as the Old Rectory built *circa* 1699 and the Globe Hotel built *circa* 1700.

Of the non-listed buildings located within the WHS, 25 sustained some form of damage (see Figure 7.8). Although not listed, these buildings nevertheless contribute to the character and setting of the historic area. The survey concluded that although a great amount of damage was sustained to the buildings, the vast majority did not involve structural damage and could be repaired relatively easily when resources (material and labour) were made available.

One of the main problems experienced following the hurricane was the lack of manpower and skills to provide the quarried limestone slate needed to repair the Island's unique roofs. With so many roofs damaged Island-wide there was a backlog for the required material and the labour (quarry cutters and contractors) needed to repair buildings as quickly as possible. Even the Government experienced the pinch in repairing its 850 damaged buildings and estimated that it needed 70,000 pieces of slate to repair them.

Figure 7.8 St. George's Preparatory School, damage after Hurricane Fabian

Photo courtesy of the Department of Planning

Some building suppliers imported alternative roofing materials but these materials had to be approved by the Department of Planning first and could not be used on Grade 1 listed buildings or within the WHS. The Department of Planning also expedited planning applications to re-open previously closed quarry sites in order to cut slate to repair the roofs. The Government is currently working on a plan to stockpile building materials in case similar widespread damage is caused by any future storms.

Another problem is that owners of buildings within 'historic areas' do not have the benefit of financial aid or incentives for maintenance of their buildings unless it is specifically listed. This lack of resources may have led to some neglect in these areas following the hurricane due to the expense associated with repairing and maintaining buildings.

In January 2004, four months after Hurricane Fabian, a survey revealed that the vast majority of buildings across the Island had been repaired. Within the WHS 37 (66%) of the 56 damaged listed buildings were repaired, 11 buildings (20%) had not had any repairs, two buildings (3%) were partially repaired and the remaining six buildings (11%) could not be determined. Of the 25 non-listed buildings which were damaged within the WHS, 13 (52%) had been repaired, 4 (16%) had not had any repairs, three buildings (12%) were partially repaired and the remaining five buildings (20%) could not be determined.

7.2.3 Challenges and Future Initiatives

Since 1991, the Department of Planning has made tremendous strides in highlighting the need to preserve and protect Bermuda's traditional architecture. However, there are some challenges and constraints that will need to be addressed in order to further the initiative.

Although the interest-free loan scheme is one way the Government assists in the maintenance of historic structures, for those who do not have the ability to qualify for a loan, there is no other financial assistance available for them to maintain a listed building. Government will therefore have to look at alternative means of assistance to make further progress on the preservation and enhancement of listed buildings.

The Department of Planning will also need to develop incentives to help with the maintenance of non-listed buildings located within historic areas to assist homeowners.

A lack of skills within the Bermudian community on how to maintain and repair historic buildings is another issue which is hampering the ability of homeowners to afford to preserve these buildings. The number of elder tradesmen who have these skills is diminishing and very few younger people are acquiring the skills. There is a need to provide apprenticeships, training programmes and incentives for getting young people involved.

There is an urgent need to secure suitably skilled personnel to advise on preservation and enhancement issues. The establishment of an experienced full-time heritage officer by the Department of Planning will help to fill this gap and provide much needed technical resources. In addition, the U.K. Department for Culture, Media and Sport has agreed to provide assistance in an advisory capacity through a six to 12 month secondment of a heritage officer. This officer will work with the Department of Planning staff to assist with training and the provision of advice on suitable repair and maintenance techniques for historic buildings.

The Department of Planning has undertaken an extensive public relations campaign to promote public awareness of the listing initiative. Since 1998, three information brochures have been produced: 'What Listing Means to You', 'Interest-free Loan Scheme' and 'The World Heritage Site'. These brochures were mailed directly to all owners and occupiers of listed buildings as well as occupants within the Town of St. George and are readily available to the general public.

In addition, in 2002, a 'Development Control Guidance Note on Listed Buildings and Historic Areas' was produced which provides advice on what type and scope of development may and may not be permitted for listed buildings and historic areas.

Greater efforts need to be made to ensure that Bermuda's traditional building techniques are not lost. The following are some recommended initiatives for the future:

- Establishing a traditional craftsman and skills course at the Bermuda College and adapting the *Traditional Building Guide* for coursework;
- The establishment of an apprentice programme in traditional building methods;
- Further financial assistance such as grants and transferable development rights;
- Establishing programmes to reuse historic buildings for other uses. This will bring about economic empowerment without impacting negatively upon the structures or the historic areas; and
- Continuing to increase public awareness about preserving Bermuda's architectural heritage.

7.3 Fortifications

A survey of Bermuda's forts commissioned by the Bermuda Government and prepared by Dr. Edward Harris in 2003 highlighted that 85 forts were used to defend Bermuda and its harbour for various periods over the three centuries from 1612 to 1957. Some of these forts exist now only as buried archaeological remains or as small relics and not accessible to the public.

Hurricane Fabian battered Bermuda's island fortifications which had to contend with storm surge, erosion and wave action some 20 to 30 ft high. The full extent of the damage caused to these forts has yet to be assessed.

The forts are distributed throughout the Island. However, the majority of forts, 42 (49%), are located at the eastern end of Bermuda in St. George's Parish. Pembroke Parish has the least number with only one, Fort Hamilton (see Figure 7.9 and Table 7.2)

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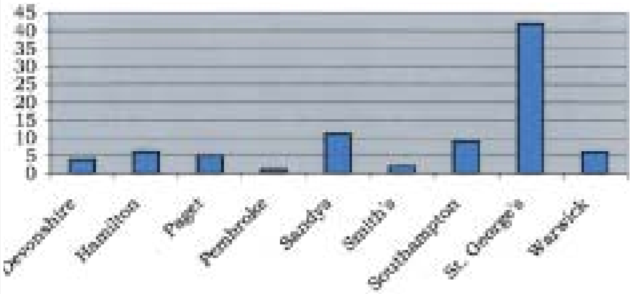
Figure 7.9 Distribution of forts by parish



Source: Fortifications Heritage at Bermuda, *2003*

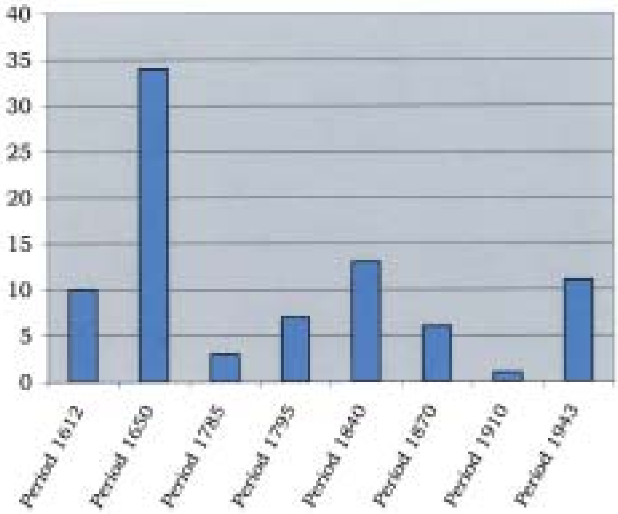
The majority of the Island's fortifications were built during the 1600s in the first decade or so after settlement. Another peak was during the mid 1800s with another during the Second World War in the 1940s (see Figure 7.10).

Table 7.2 List of Bermuda's fortifications

PARISH	FORT	PARISH	FORT
DEVONSHIRE	**Devonshire Bay Fort**	ST. GEORGE'S	**Alexandra Battery**
	Fort Langton		Amberfish Hole Fort
	Fort Prospect		Buildings Bay Battery
HAMILTON	Albuoy's Fort		Buildings Bay Fort
	Bailey's Bay Battery		**Burnt Point Fort**
	Charles Fort		**Coney Island Kiln**
	Fort Bruere		**Devonshire Redoubt**
	Newton's Bay Battery		Eastside Fort
	Paynter's Hill Base End Station		**Ferry Island Fort**
PAGET	Centre Bay Fort		**Ferry Reach Magazine**
	Crow Lane Battery		**Fort Albert**
	Crow Lane Fort		Fort Bell
	Hungry Bay Fort		Fort Clinton
	West Elbow Bay Fort		**Fort Cunningham**
PEMBROKE	Fort Hamilton		**Fort George**
SANDYS	**Daniel's Head Base End Station**		**Fort Popple**
	Daniel's Island Fort		**Fort St. Catherine**
	Dockyard Land Front		**Fort Victoria**
	Dockyard the Keep		**Gates Fort**
	Dockyard Western Rampart		**King's Castle**
	King's Point Redoubt		**Landward Fort**
	Mangrove Bay Fort		**Martello Tower**
	Maria Hill Fort		Moore's Fort
	Scaur Hill Fort		New Redoubt
	Gibbs Hill Base End Station		Paget Fascine Battery
	Wreck Hill Fort		**Paget Fort**
SMITHS	Harris's Bay Fort		Pembroke Fort
	Seur's Fort		**Penniston's Redoubt**
SOUTHAMPTON	Church Bay East Fort		**Smith's Fort**
	Church Bay West Fort		**Southampton Fort**
			St. David's Base End Station
	Fort Newbold		**St. David's Battery**
	Hunt's Fort		Tobacco Bay Fort
	Tudor Hill Battery		Town Redoubt #2
	Turtle Hill Battery		Town Redoubt #3
	Warwick Camp Battery		Town Redoubt #4
	West Side Fort		Tucker's Town Battery
	Whale Bay Battery		Upper Paget Fort
WARWICK	Common Land Battery		US Army, Cooper's Island
	Great Turtle Bay Battery		US Army, Fort Victoria
	Heron Bay Fort		Warwick Castle
	Jobson's Cove Fort		**Western Redoubt**
	Jobson's Fort		
	US Army, AATC		

Note: Forts in Survey in bold type, World Heritage Site forts in bold and underscored
Source: Fortifications Heritage at Bermuda *2003*

Figure 7.10 Distribution of forts by period



Source: Fortifications Heritage at Bermuda, *2003*

It is acknowledged that Bermuda's fortifications are a magnificent but underutilised resource with exceptional cultural tourism potential. Unfortunately, the condition of Bermuda's forts has deteriorated over the last 50 years. The Government recognised this problem and in 2003 the Ministry of the Environment commissioned a report by Dr. Edward Harris to examine the status of all Bermuda's forts.

Figure 7.11 Damage to Fort St. Catherine as a result of Hurricane Fabian

Photo courtesy of Smith Warner International

As described in the report entitled *Fortifications Heritage at Bermuda—A Conditions and Management Survey of he Historic Forts* 2003, in most cases the surroundings of the fortifications are in extremely poor condition partly due to the encroachment of vegetation, especially from casuarina, Mexican pepper and laurel trees. Most of the forts have also not been properly maintained. Common problems include leaking roofs, missing windows and doors, rotten floors, damaged masonry and vandalism. The recent damage caused by Hurricane Fabian has not helped the situation.

The majority of Bermuda's fortifications are protected from demolition or unsympathetic alteration by a range of legislative and policy measures. They are protected by one or more of the following measures:

- Designation as a listed building, grade HM (Historic Monument), under the Development and Planning Act, 1974 (section 30);
- Inclusion within an 'historic area', as designated in the Bermuda Plan, 1992 Planning Statement (the Development and Planning Act, 1974, section 31);
- Inclusion within a designated Nature Reserve or National Park (Bermuda National Parks Act, 1986); and
- An Open Space designation in section 11.OSP of the Bermuda Plan, 1992 Planning Statement.

Despite this legislation, the archaeology of the forts has not been fully protected. Sites are being re-landscaped with machinery while artefacts are being removed from the earth by amateur treasure-seekers with metal detectors. With the exception of only one site, the systematic collection and curation of artefacts has been non-existent. Only two sites have exhibits, and information signage at the forts is minimal.

In light of the past history of management of the forts, the report recommends that the curatorial management of the forts be delegated to a private organisation with cooperative relationships with the Department of Parks for landscaping matters and the Ministry of Works and Engineering and Housing for repair and maintenance issues. The recommended management system for the forts would include principles of curatorship, conservation, archaeology, historical research, exhibitions, publishing and marketing. The forts would be organised into a National Forts System and take full advantage of what the private sector has to offer by establishing a membership organisation. The Minister of the Environment is allowing the public the opportunity to comment on the report and give feedback and suggestions.

The Government has recognised the need to prepare a plan of action for the fortifications and the report by Dr. Harris will provide the foundation for a new and better management structure. A review is currently under way to investigate the best way to care for and manage the forts and the wider historic environment.

7.4 Archaeology

Bermuda has a long and rich history, much of which has been documented since 1615. Archaeological research will add to our understanding of Bermuda's history as well as the life and development of the Island.

There are 4,069 structures and many other ruins identified on the 1898 Savage Map. In 1988, the Bermuda National Trust started an in-depth study, the 'Old House Survey, to record details of all buildings built island-wide before 1898. The Bermuda Government Archives also houses a remarkable amount of historic information.

There are two organisations dedicated to advancing and promoting archaeological research in Bermuda, the Bermuda National Trust and the Bermuda Maritime Museum.

In the last decade, the Bermuda National Trust (the Trust) has concentrated on advancing and promoting archaeological research through the excavation of numerous sites Island-wide.

The Trust has its own Archaeological Research Committee (ARC) made up of active volunteers. It undertakes archaeological excavations of historic houses and properties throughout the Island and undertakes a major dig once every two years. The Trust has concentrated on conducting excavations on Trust-owned sites but has also worked on privately-owned sites. It carries out emergency rescue digs on properties before they are developed but home owners and developers can also request that the ARC undertake an excavation prior to renovation or construction. These assessments can take an hour or a couple of weekends to complete, depending on the importance of the site, the nature and the extent of the proposed development or renovations, and the archaeology that is uncovered. Artefacts recovered from privately-owned sites are the property of the owners and the Trust usually enters into a deposit agreement with them.

Locally, the Trust works closely with the Bermuda Maritime Museum and the St. George's Corporation but it also often works in partnership with internationally recognised institutions.

Table 7.3 details the arhaeological digs conducted by the ARC of the Trust and those planned for the near future. Digs carried out on privately-owned sites prior to development are highlighted in bold italics.

At the Archaeology Lab in Reeve Court, St. George's, volunteers clean, document and catalogue all artefacts recovered from the digs. Some artefacts are then displayed on the ground floor of the Tucker House Museum. The volunteers also work at the summer archaeology camps teaching young people the skills and processes involved in archaeological digs.

Figure 7.12 Volunteers sorting through archaeological artefacts

Photo courtesy of the Bermuda National Trust website www.bnt.bm

Figure 7.13 A volunteer digging for artefacts at the Unfinished Church site

Photo courtesy of the Bermuda National Trust website www.bnt.bm

Table 7.3 Archaelogical digs carried out by the Bermuda National Trust

1973	1989	1990/1991	1991	1991/1992	1993	1994
Tucker House, St. George's	Royal Naval Dockyard, Sandys	Reeve Court, St. George's	Stewart Hall, St. George's	Bailey's Bay Fort, Hamilton	Old Rectory, St. George's	Bridge House, St. George's
	Tucker House, St. George's		Stanley House, Flatts	Fort Cunningham, St. George's		Unfinished Church, St. George's
						Mitchell House Kitchen, St. George's
1997	**1998**	**1999**	**2001**	**2002**	**2003**	**2004 (July)**
Paget Island, St. George's	Manilla Wreck	Digby Project	Springfield, Sandys	***Long House, Hamilton***	***Long House,*** **St. George's**	State House, St. George's
Springfield, Sandys				***One Gun Alley, St. George's***	***Honey Hill, Paget***	
Tucker House, St. George's				Bank of Bermuda Car Park,	Reeve Court, St. George's	
				Hillcrest, St. George's		
				Harbour View, St. George's		
				Unfinished Church, St. George's		

Source: Bermuda National Trust

More land-based archaeology has been conducted in St. George's Parish than any other parish in Bermuda. The first dig at Tucker House occurred in 1973. Digs at Stewart Hall in 1990/91 and at the St. George's Historical Society in 1994 produced artefacts that illustrated life in the 17th Century.

The ARC of the Bermuda National Trust, began an Island-wide survey and assessment of historic sites, buildings and ruins in 2004 using Geographic Information System (GIS) technology and funded in part by a grant from the Ministry of the Environment. The project aims to locate, identify and catalogue sites of archaeological and historical importance using cartographic, photographic, archival and oral historical sources. The information is being used to help develop a strategy to properly manage and protect the Island's archaeological and cultural heritage by highlighting areas that may benefit from an archaeological assessment/excavation prior to development and proposing additions to the Island's protected Historic Preservation Areas. All research is shared with Government and other heritage stakeholders.

As an alternative to excavation, the Trust also hopes to test other methods that are quicker and less invasive to determine what lies beneath the ground, such as geophysics surveys with a proton magnetometer. The Trust is liaising with the Departments of Planning, The Ministry of Works and Engineering and Housing and the Department of Conservation Services regarding this initiative.

The Bermuda Maritime Museum (the Museum) conducts archaeological digs on and around Bermuda's forts and has set up a yearly schedule of digs. Between 1998 and 2003, the Museum carried out 10 archaeological digs around fortifications (see Table 7.4). The Museum works locally with the Bermuda

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Table 7.4 Archaelogical digs carried out on forts by the Bermuda Maritime Museum

1988	1989	1991	1991/1992	1992	1993-1995
Scaur Hill Fort, Sandys	West Elbow Bay Fort	Bailey's Bay Fort, Hamilton	Fort Cunningham, St. George's	Daniel's Head Fort, Sandys	King's Castle, St. George's
1997-1998	**1998-2001**	**2002**	**2003**	**2004**	**2005**
Paget Fort, St. George's	Smith's Fort, St. George's	Peniston's Redoubt, St. George's	Devonshire Redoubt, St. George's	Port Royal	Southampton Fort, St. George's
				Devonshire Redoubt, St. George's	

Source: Bermuda Maritime Museum

National Trust and with international organisations. It currently collaborates with Brown University and has an overseas expert as well as students who come to the Island each year.

In addition to the digs conducted around forts, the Museum has participated in some non-fort excavations and collaborated with the Bermuda National Trust on digs at: Tucker House, St. George's; Stanley House, Flatts; Springfield, Sandys; Digby Project; and Long House, Hamilton Parish. Other land-based digs undertaken include: Dockyard Hulk, Sandys; Hill House, Sandys; St. James' Church Vault, Sandys; Old Elliott School, Devonshire; and Dockyard Keep, Sandys.

The Museum also conducts all underwater projects in Bermuda and actively conserves, catalogues and displays artefacts found during these digs at the museum located at the Royal Naval Dockyard,

Table 7.5 Underwater archaelogical projects carried out by the Bermuda Maritime Museum

Underwater Archaeological Project	Date Of Project	Underwater Archaeological Project	Date Of Project
Sea Venture	1982-1983	Royal Naval Dockyard	1985-1988
Nola	1985-1988; 1993	H.M.S. Vixen	1986-1988
H.M. Floating Dock Bermuda	1986-1993	NOS Shipwreck	1987-1988
San Pedro	1987-1989	Western Ledge Wreck / Santa Licia	1988-1991
HMS Irresistible	1991	El Galgo	1991-1992
18th Century Collier	1992-1993	Stonewall Wreck	1992; 1994-1996
H.M.S. Cerberus	1993	L'Herminie	1994-1995
Constellation	1996	Coral Beach Cannon	1998
Ready	1998	Hunter Galley	1998
Manilla Wreck	1998-1999	Pollockshields	1999
North Carolina	1999-2000	18th Century Wreck	1999-2001

Source: Bermuda Maritime Museum

Sandys. The institution is fortunate in that it has a number of in-house staff and experts to help carry out archaeological initiatives. The Museum carried out 24 underwater projects between 1982 and 2001 (see Table 7.5)

Although nearly 800 buildings have been added to the statutory list of buildings of special architectural or historical interest, there is little statutory protection for Bermuda's archaeological resources.

There are over 1,200 development applications submitted to the Department of Planning each year and approximately 200 new dwelling units are built annually. New developments can and do cause irreparable harm to Bermuda's cultural heritage.

There is little regulation of land-based archaeology unlike underwater archaeology. However, undertaking an archaeological excavation in a national park, a nature reserve or a bird sanctuary does require a permit under the relevant legislation. Furthermore, undertaking an excavation in an environmentally sensitive area requires the submission of a management plan to the Ministry of the Environment's Department of Planning. However, better management agreements are needed for dig sites involving authorisation from a number of different government departments and particularly where forts are located within nature reserve areas.

The Bermuda National Trust is constrained by the fact that it is a part-time, volunteer-based organisation with limited resources. It usually has to limit its activities to the weekends. In addition, it is not informed about every development, renovation or construction project, whether private or public, so a significant part of the Island's archaeological heritage may get either lost or remain unrecorded. The recent cases of Hill House in Hog Bay Park and Ridgeway in Pembroke indicate that even 'safe' sites can fall victim to the bulldozer.

Often there is confusion as to who is responsible for archaeological work. The Bermuda National Trust and the Bermuda Maritime Museum have archaeological programmes but neither organisation has the staff or the mandate to undertake this work full-time. Similarly there is not a single focal institution to manage and display all archaeological artefacts found on dig sites. In addition, the legal status of archaeological artefacts needs to be addressed.

In an effort to uncover more of Bermuda's history, opportunities to undertake archaeological investigation should be taken when sites become available for redevelopment. There is a need to assess the impact of new development on sites of archaeological importance and if necessary conduct an archaeological excavation before work commences. It has been suggested that this could be achieved as part of the planning process.

It has also been recommended that an Archaeological Resource Protection Plan be prepared to create a blueprint for the identification, dating, classification, management and protection of sites.

7.5 Summary

Bermuda has made good progress over the last 12 years in highlighting the need to protect and preserve its heritage. There are nearly 800 listed buildings, 58 historic areas and the Town of St. George has been designated as a World Heritage Site.

Interest-free loans are available for listed building owners for up to $100,000 per property per year and public information on heritage matters is readily available.

The Government's commitment to heritage preservation is further reflected by the proposed establishment of a full-time heritage officer and the six to 12 month secondment of a technical officer from the U.K. Department for Culture, Media and Sport.

Damage caused by Hurricane Fabian highlighted that a lack of building materials and skilled labour in Bermuda can create backlogs in repairing historic buildings particularly during times of disaster. A concerted effort must therefore be made to train Bermuda's young people in the trades of quarrying, stone cutting, masonry and carpentry. In addition, stockpiling building materials, in anticipation of short term demand brought about by natural disasters, will help to ameliorate future delays in repairs.

A recent survey of Bermuda's fortifications found that 85 forts defended Bermuda and its harbour for various periods over the three centuries from 1612 to 1957. The forts are distributed throughout the Island, although the greatest numbers lie at the eastern end of Bermuda in St. George’s Parish. Some fortifications remain relatively intact, whilst others are now buried archaeological resources. Bermuda's fortifications are a significant but under-utilised resource with exceptional cultural tourism potential. Unfortunately, the condition of many of these structures has continued to deteriorate and the damage caused by Hurricane Fabian has exacerbated the situation. A review is currently underway to investigate the best way to care for and manage the forts and the wider historic environment.

A number of archaeological excavations have been undertaken by the Bermuda National Trust and the Bermuda Maritime Museum, often in partnership with other organisations. The pace and scale of development poses a threat to the Island’s archaeological resources. Tighter controls over the location and type of development would help to conserve this important historic asset and also ensure that improved recording and monitoring programmes are secured. Some of these changes could be achieved through the planning process.

Further collaboration between Government departments and private organisations concerned with Bermuda’s heritage is required. The World Heritage Site Committee, comprised of stakeholders from inside and outside of Government, provides a collaborative co-ordination and management role for the WHS of St. George’s and this model could be emulated in other areas.

A great deal has been accomplished over the last 20 years in preserving Bermuda’s heritage but there is still much work to be done.

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Chapter 8

Agriculture and Plant Protection

8

8.1 Agriculture

8.1.1 Agricultural Land Uses

The term 'agricultural land' includes arable land that is capable of cultivation and land that is capable of supporting a wider range of farming activities, such as grazing, dairy farming and the breeding of livestock. Agriculture does not have to be limited to arable land. Egg production and dairy farming utilises some non-arable land, as do greenhouse and hydroponics operations. However, with rising land costs and the overall scarcity of land in general, land reserved for agricultural use should be used for that purpose when possible. Today, however, an increasing amount of agricultural land is being used for a variety of purposes that are not agricultural in nature.

Table 8.1 details the number of parcels and acreage in each agricultural land use. It should be noted, however, that some pieces of land are used for more than one agricultural use. The many different uses for agricultural land, observed in the 2001 Arable Land Audit, include those listed below.

Table 8.1 Uses of agricultural land

Type of agricultural use	Arable Audit 2001 Categories	Number of parcels	Number of acres
Lawn	Lawn	291	108.25
Fruit	Bananas	87	36.45
	Citrus	26	8.10
Horticulture	Horticulture	22	12.30
Home garden	Garden	20	4.80
Paddock	Paddock	42	23.75
Dairy/Forage	Dairy/Forage	22	19.56
Recreation	Playing field/recreation	5	3.45
	School	1	0.40
Commercial vegetable production	Vegetables	455	283.88
Fallow	Weeds/Fallow	45	21.05
	Overgrown	164	64.45
Development	Construction/Parking/House	32	17.35
Land used for more than one use	2 uses	228	104.82
	3 uses	56	22.96
	4 uses	7	3.40
	5 uses	1	0.60
TOTALS		**1,504**	**735.57**

Source: Arable Audit 2001, Department of Conservation Services

- **Lawns**: Fallow agricultural land that was once in commercial production is now used as a formal grass area, usually attached to a residence. These can evolve into more intensive recreational spaces such as a tennis court or putting green.
- **Fruit:** Agricultural land planted with a banana crop or citrus trees.
- **Horticulture:** Agricultural land used for the production of trees, shrubs, ground covers and cut flowers. The use of agricultural land for growing flowers and trees in containers poses no threat to the land in terms of agricultural productivity potential. However, the trend in recent years has been to grow trees on agricultural land such as palms. During transplanting to other locations, large amounts of soil are removed, often resulting in severe degradation of agricultural fields.
- **Home garden:** Agricultural land used for home vegetable growing.
- **Paddocks:** Agricultural land used for keeping horses and livestock.
- **Dairy/Forage:** Agricultural land used for dairy farming or to grow feed for livestock.
- **Recreation:** Agricultural land used for active recreation such as playing fields and pitch and putting greens.
- **Commercial vegetable production:** Agricultural land used for the production of vegetables for sale.
- **Fallow:** Agricultural land that is temporarily not in production and has weeds growing on it.
- **Development:** Agricultural land taken out of production, which has some form of development on it, legal or otherwise.
- **Overgrown:** Agricultural land that was allowed to lie fallow to the point where it has become overgrown with trees and shrubs.

8.1.2 Agriculture Production

8.1.2.1 Vegetable production

Agriculture has long been a part of Bermudian life. Apart from wild pigs, cahows, prickly pear, cedar berries and palmetto hearts and berries, there was very little food at first available on the Island. In the 17th Century, the first colonists brought with them a wide variety of plant material, such as grapevines, oranges, lemons, bananas, carrots, turnips and beets, which were all grown successfully. In later years, potato, cassava, sweet potato, hemp, flax, cotton and indigo (planted for its dye) were imported and grown.

The development of agricultural products as exports occurred early in Bermuda's history with the growing of tobacco, potatoes, corn and citrus. Agriculture declined in the late 1600s, with the decline in tobacco exports and a long period of low vegetable productivity. By the mid 1800s, the Island experienced a revival of the agricultural industry, with profits from the export of arrowroot, lily bulbs, potatoes and onions to New York. By 1912, agriculture was at its peak with approximately 3,000 acres being farmed. At this time, fresh vegetables could be delivered to the East Coast faster from Bermuda than from Florida or California. Soon after, however, with the introduction of refrigerated rail containers, fresh produce could be transported very quickly from all parts of the United States. The introduction of high U.S. tariffs and increased competition from American farmers gradually forced Bermuda produce out of U.S. markets.

After 1942, farmers concentrated on growing solely for local consumption. However at this time, following the end of World War II, Bermuda's economy was changing to become more dependent on tourism and international business and support for agriculture as an industry was diminishing. Rising land values tempted many landowners to sell off their agricultural land to builders for golf course construction and housing developments. This meant that less land was available for cultivation and agricultural production began to dwindle.

Unfortunately, the decline in agriculture continues to this day. Before 1930 Bermuda was a major exporter of vegetables to the U.S. Today, however, over 90% of our fresh produce is imported. In 1987, 73 farmers farming a total of 660 acres of land were registered with the former Department of Agriculture and Fisheries. In comparison, in 2001, 46 farmers were registered and the total acres of land farmed commercially had decreased to approximately 380 acres.

Bermuda's proximity to the U.S. and the relative ease and cheapness of importing produce as opposed to growing its produce has meant that Bermuda has had to rely heavily on imported produce.

Figure 8.1 An agricultural field off Middle Road

Photo courtesy of the Department of Communication and Information

Figure 8.2 An orchard

Photo courtesy of Frances Eddy

8.1.2.2 Fruit culture

Historically orchards, particularly citrus groves, were a popular feature on most farming estates. Bermuda citrus was not only very popular locally but was also desired overseas. It was an important export to Europe during the 17th and 18th Centuries when the local tobacco industry was failing. Although citrus groves began to decline in the 1800s due to pests, diseases and wind exposure (as a result of cutting down Bermuda cedars around the Island), exports of Bermuda-grown citrus continued up until the 20th century. Today, there is still a strong demand for local citrus when supplies become available but disease and lack of proper care are two major issues which continue to result in an inconsistent supply. According to the Arable Land Audit 2001, a mere 8.1 acres were used solely in the cultivation of citrus. An additional 30.2 acres showed citrus being cultivated in combination with other uses. This is a stark contrast to the 148 acres used for citrus cultivation as reported in 'A Survey of the Agricultural Industry in Bermuda', 1971.

The relatively small amount of labour required to maintain plantings together with good market opportunities have traditionally made bananas a popular fruit to cultivate. However, the Bermuda banana struggles to compete against the low-priced imported banana that is always available in adequate supply.

The climate and soils in Bermuda are well suited to the cultivation of a wide range of sub-tropical fruits. More than 100 different fruits could be grown locally. Peaches, nectarines, plums, avocados, pawpaw, loquat, apples, strawberries, and blackberries are some of the many fruits which have been planted successfully.

8.1.3 Apiculture

The honeybee was introduced in 1616. By 1622 honey and beeswax were being exported to the West Indies and the new American colonies.

The Bermuda Beekeepers Association (BAA) boasts some 30 members, who maintain 319 hives around the Island. Each hive can contain from 60,000 to 80,000 bees. Most of the BAA members are hobbyists. There is only one commercial beekeeper on the Island. In addition, about three beekeepers sell any excess honey they produce but they do not consider themselves full-time commercial beekeepers.

Figure 8.3 A beehive

Photo courtesy of the Department of Planning

On average, a beekeeper can expect to harvest between 125–150 lbs of honey per hive per year. However, this figure can dramatically fluctuate depending on the quality and duration of nectar flows. The first major nectar flow occurs in June and July and the second major nectar flow in September and October, which follow the blooming of the fiddlewood and the Mexican pepper, respectively. Nectar flows are largely influenced by weather. Drought, excess of rain, hurricanes and high winds all have an adverse effect on nectar flows.

The Bermuda honey industry is fortunate to be relatively free from serious pests. Although there are wax moths and a low percentage (2.2%) of American foulbrood disease, there are presently no small hive beetles, varroa and tracheal mites or Africanised bees in Bermuda.

Honey continues to be 'exported' and it is a popular souvenir for tourists. With more Bermudians trying to eat healthily, honey has been in high demand in health food stores and supermarkets.

8.1.4 Animal Agriculture

8.1.4.1 The decline in animal agriculture

Besides planting material, the first colonists also brought pigs, cattle, goats, and chickens with them from England. Animal agriculture or livestock farming (which mainly comprises rearing cows for milk and chickens for eggs) has declined in recent years. In 1970 there were 11 dairy farms, 13 commercially operated poultry farms and several piggery farms. In 2000, there were a total of six dairy farms, one poultry farm and one piggery. There are 25 individuals employed in animal agriculture or livestock farming. There is also one slaughterhouse on the Island which provides fresh meat and in 2003, one farmer began producing fresh free-range chicken meat.

8.1.4.2 Dairy production

Dairy production has always played an important role in providing for the domestic population. There are currently 202 milking cows on a total of six dairy farms that are all operated by Bermudians. Some farm labourers are imported from overseas. These farms sell their milk to the only milk processing facility on the Island, Dunkley's Dairy. The volume of milk tends to vary with the time of year. The highest yields are obtained between March and May, and the lowest yields occur from June to September, possibly due to heat stress.

Figure 8.4 A dairy farm at Spittal Pond

Photo courtesy of the Department of Communication and Information

Bermuda's dairy farmers provide the Island with 100% of its fresh milk requirement. Raw milk sales for the year 2000 were recorded at approximately 1.6 million dollars, which translates into more than 3.2 million dollars in retail sales. The industry provides employment directly from dairying and also indirectly in milk processing, distribution and retail. Fresh milk is supplemented with imported milk products including 'filled milk' and reconstituted skimmed milk.

8.1.4.3 Egg production

The poultry industry has been very successful and is considered a valuable part of local agriculture. Even when faced with competition from low-priced imported eggs beginning in the 1970s, Bermuda's 13 poultry farms continued to thrive because of locals' preference for Bermuda eggs. However, the prolonged competition from imported eggs and the escalating value of land motivated landowners to develop their land rather than rent it to egg farmers.

Today only one poultry farm remains in business, due in part to the continued preference for fresh local eggs by consumers and also the demand for chicken manure by local farmers and home growers. The one egg farm on the Island houses approximately 7,000 laying hens. However, whereas local egg production met approximately 95% of the Island's fresh egg requirement in 1971, it presently represents less than 15% of the local fresh egg requirement.

8.1.4.4 Pig production

Up until the 1960s, it was common for families to have at least one pig. Eventually there became less

Table 8.2 The estimated dollar value of agricultural production from 1967–2000

Agricultural Product	1967	1977	1987	1997	2000
Vegetables	$353,043	$1,840,600	$3,900,000	$3,000,000	$3,000,000
Fruit	269,323	540,000	500,000	800,000	825,000
Milk	839,129	551,500	1,209,571	2,000,000	1,632,438
Eggs	945,736	740,000	390,000	N/A	312,000
Meat	98,596	252,000	100,000	N/A	32,893
Honey	N/A	80,000	54,000	181,000	210,000
Flowers	22,672	31,000	300,000	345,000	350,000
TOTAL	**$2,528,499**	**$3,672,100**	**$6,453,571**	**$5,800,000**	**$5,769,438**

Note: N/A means that records were not available for that period.
Source: Department of Agriculture and Fisheries annual reports.

tolerance of offensive odours associated with pig farming with increased urbanisation and the loss of rural land. Nowadays pigs are kept by only a handful of private individuals. The last 25 years has seen a decrease in the number of commercial piggeries on the Island. Whereas in the mid 1940s, there were some 3,500 pigs, today there is only one piggery left on the Island with only 20 pigs.

In addition to the growing intolerance to pigs, other factors thought to have played a role in the decline of the industry are refrigeration and the ease of importing meat. Today, although the industry is much smaller, it still provides meat for those who prefer fresh local pork, for sausage making and for those preparing pork for ethnic dishes and delicacies.

8.1.5 Floriculture and Ornamental Horticulture

8.1.5.1 Floriculture

Easter lily exports were once the basis of the floriculture industry. The Easter lily trade reached a peak in 1928, dwindled thereafter and then peaked again in 1941. After this, there was a drift from Easter lily bulb sales to that of cut Easter lilies. Although no longer exported commercially, cut Easter lilies remain popular with the majority of sales between Easter and Mother's Day.

The cultivation of other types of flowers include poinsettias, chrysanthemums, freesias, snapdragons and gladioli whose cultivation and sale has recently evolved into a mini floriculture industry.

8.1.5.2 Ornamental horticulture

In 1970, two main commercial plant nurseries supplied ornamental plants and gardening products to the public. They used more than 30 acres of agricultural land and employed approximately 40 individuals. Today, there are approximately half a dozen commercial nurseries on the Island, employing 54 individuals. Most of the nurseries own the land they use although the amount of agricultural land used for horticultural purposes has declined over the years to only 12.3 acres (see Table 8.1).

In 2000, there were over 56 landscaping and gardening companies. The Ministry of Works and Engineering and Housing and the Department of Parks undertake most of the landscaping on Government properties and in national parks.

Tourists and residents delight in seeing beautiful gardens and well-maintained lawns and hedges. This is quite evident by the number of visitors to the Botanical Gardens every year (just under 30,000 individuals per year in recent years).

Figure 8.5 Easter lilies

Photo courtesy of the Bermuda Aquarium, Museum and Zoo collection

8

8.1.6 The Value of Agriculture

As shown in Table 8.2, efforts have been made to put a dollar value on agriculture production in Bermuda.

However, the true value of agriculture and agricultural products to Bermuda goes beyond this dollar estimate. When determining the value of agriculture in Bermuda there are a number of factors, other than the direct financial return, that should be considered:

- Agriculture and related services provided employment for over 200 individuals in the year 2000;
- Agriculture is a therapeutic, rewarding, and recreational activity to many. Members of the public who are interested in gardening but have no access to agricultural land can rent a plot at Paget Community Garden (see Figure 8.6);
- Agriculture is part of our heritage. Many residents enjoy and prefer the taste of Bermudian produce such as potatoes, onions, oranges, and honey, to imports;
- In times of international crises, Bermuda agriculture could be an important source of agricultural products; and
- Reserving land for agricultural use also creates a rural impression which contrasts with the urban Bermuda landscape and contributes to our Island's natural beauty.

Figure 8.6 Paget community garden

Photo courtesy of the Department of Communication and Information

8.1.7 Government Support for Agriculture

The Bermuda Government supports the agricultural industry in a number of ways. These include the following:

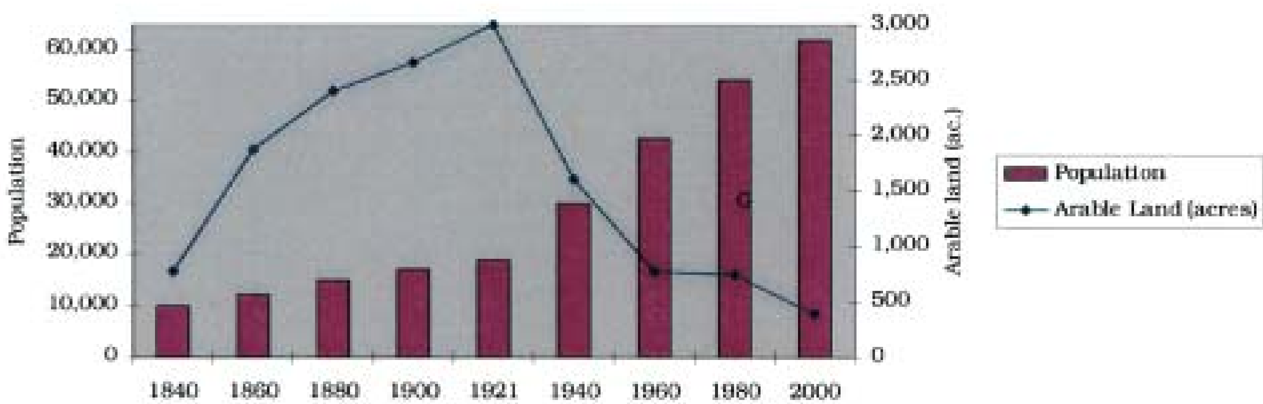
(a) Land

Government acts as 'landlord' by leasing Government owned land to farmers for periods of three to 10 years.

(b) Technical support

Government provides technical support to growers through the Department of Environmental

Figure 8.7 Arable land and population



Note: Data for years 1834–1931 represent land in cultivation. For years 1941–1970 the data is based on total arable land whether cultivated or not. The 1977 figure includes small plots as small as 0.1 acre.

Source: Adapted and updated (Census 2000 and Dept. of Conservation Services) from Bermuda's Delicate Balance, *1981*

Protection's Plant Protection Laboratory, which offers services such as soil and water testing and disease identification. The Department of Environmental Protection is also responsible for issuing permits for the importation of plant materials and for controlling the importation of chemicals used for agricultural and horticultural purposes.

Government's role in the dairy industry involves providing services to ensure the health of their livestock, carrying out sanitation inspections, and performing artificial insemination procedures. These services are carried out by the Animal Husbandry Section of the Department of Environmental Protection and by the Department of Health.

(c) Exemption from certain tariffs

Government allows for the duty free importation of seed, fertiliser, cardboard containers (for local produce), animal feed, milking and dairy equipment, queen bees, bee-keeping machinery and selected agricultural and horticultural machinery.

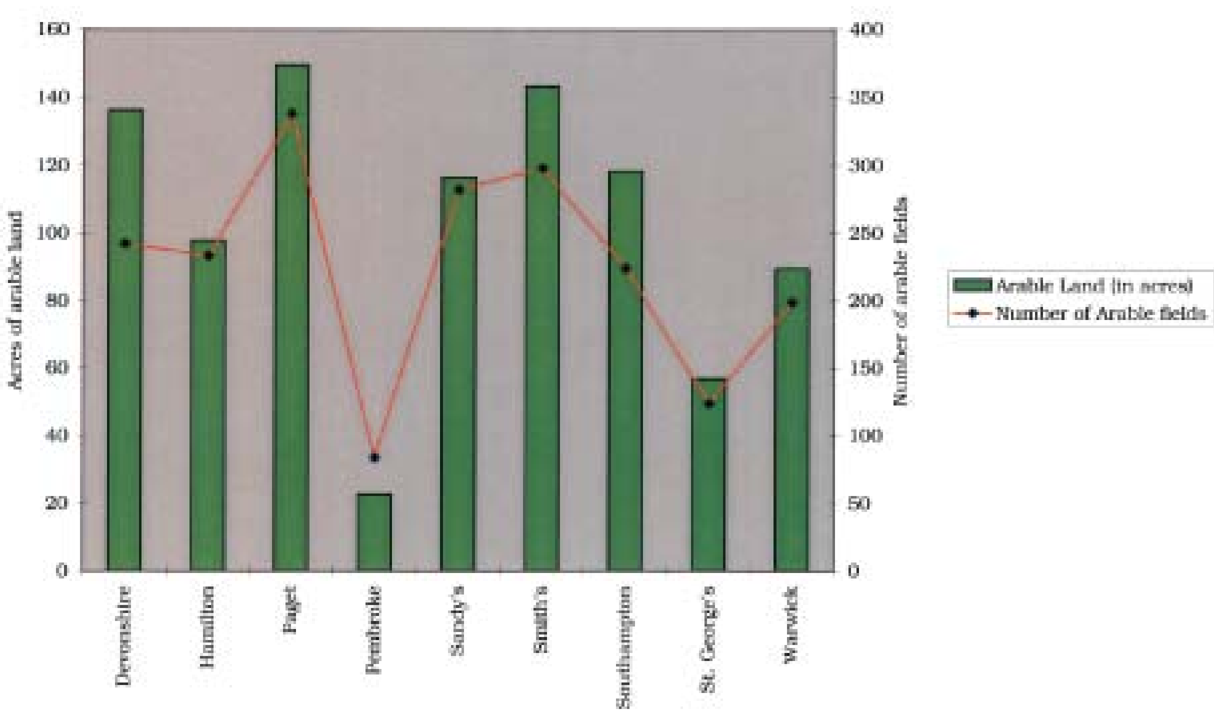
(d) The Government Marketing Centre

Government also provides support for agriculture through the Marketing Centre, a division of the Department of Conservation Services which is the department responsible for agricultural policy. Established in 1943, the Marketing Centre's main objectives include the following:

- To encourage fruit and vegetable production on the Island;
- To ensure farmers an orderly market for their crops at prices that result in a reasonable return on their investment and labour; and
- To ensure the supply of local quality produce to consumers at prices competitive with imports.

The Marketing Centre serves as a purchasing and wholesale distribution centre for local produce. Grocery stores, restaurants and wholesale distributors may order produce through the Marketing Centre when available locally which the Marketing Centre in turn purchases from the local farmers. When certain items of produce are available locally and in sufficient quantities to meet the needs of the domestic population, the Government

Figure 8.8 Distribution of agricultural land by parish in 2001



Source: Arable Audit 2001, Department of Conservation Services

Marketing Centre has the authority to impose embargoes on the importation of these items. The embargo system relies on good communication between the Government Agricultural Officer, commercial farmers and produce importers to ensure sufficient quantity and quality of the items on embargo.

The Marketing Centre meets the needs of local growers in many other ways. The Centre features two state-of-the-art banana ripening rooms and two ice machines that can produce over 3,000 lbs of ice per day for farmers and fishermen. It contains approximately 5,400 sq. ft of chill room storage space that is rented out to local farmers. It provides containers, seed and pesticides for sale to registered farmers. Although it is a non-profit establishment, a modest mark-up is added to the cost of goods sold and services provided to partially cover operation costs.

8.1.8 Trends in Agricultural Production

8.1.8.1 Loss and fragmentation of agricultural land

Since the peak in 1921, there has been a gradual decline in the amount of agricultural land in commercial cultivation. Whereas in 1921, there were some 3,000 acres of agricultural land, by 2000 this figure had dropped to 380 acres. This decline in agricultural land has been accompanied by a concomitant increase in Bermuda's population which has put pressure on the agriculture industry, as landowners have sought to develop their agricultural land for other purposes, particularly new dwellings and private lawns (see Figure 8.7).

Whilst there are areas of agricultural land in all of the parishes, there are imbalances in the amount of agricultural land within each parish. Paget has the largest total amount of agricultural land with 338 fields totalling approximately 150 acres. Pembroke has the least amount of agricultural land (84 fields) and less than 23 acres (see Figure 8.8)

Not only is the amount of agricultural land decreasing but so is the average size of the individual agricultural parcels of land. These parcels have become fragmented over time, particularly over the last 50 years due to development pressures. In 1987, just under 66% of agricultural fields were less than one acre in size and 36% of all fields were 0.5 acres or less. In 2001, 90% of agricultural fields were less than one acre while the number of fields 0.5 acres or less had increased to 74%.

Fragmentation not only occurs with individual fields but also within field units when they are subdivided. A field unit is defined as a group of agricultural fields, located in the same geographical area but not necessarily physically linked. Many farm units have barns or storage facilities and irrigation or wells. Because of fragmentation of farm units and the loss of farm units in general, farmers now have to cultivate several individual fields located in different parishes around the Island. This in turn has led to a decreased capacity to cultivate, increased transport costs, increased pesticide applications costs, increased harvesting and increased security costs.

8.1.8.2 Preserving soil

Bermuda soil is a precious resource. Soil on the Island was regarded as extremely fertile during the early history of Bermuda and during the export years because the land was able to crop 'soil-exhaustive produce', such as tobacco and potatoes, year after year, without the addition of commercial fertilisers. Even today the soil remains relatively fertile.

However, Bermuda soil is very scarce. The average soil depth around the Island is about four inches and varies in texture according to location. Sandy, light coloured soil tends to occur in the western parishes, loamy soils towards the centre of the Island and clay soils in the eastern parishes.

Because it is such an important resource, efforts have been made to preserve Bermuda soil. It is now policy that owners seeking to develop agricultural land be required to remove and conserve the soil for re-use elsewhere. Farmers are also playing their part in maintaining this resource by utilising cover crops. Not only do these crops, such as cowpeas, block sunlight so that weeds do not grow, they also prevent erosion and add nutrients and organic matter to the soil once ploughed.

8.1.8.3 Ownership of land

The increased demand for housing has caused land values to spiral upward. Financial returns from land in agricultural use are small in comparison to what could be obtained if the land was developed. On average, landlords of agricultural land receive $1,000 per year per acre.

In 2001, most farmers relied on the rental of Government and privately-owned land to carry out their farming operations. Dairy farming is a prime example, as most of the land used in this industry nowadays is government-owned.

It has been estimated that less than 10% of the total agricultural land used for commercial agricultural production is actually owned by the farmers themselves. As tenants, the majority of farmers are vulnerable to eviction and lease termination, as increasing land values and demand for land make agriculture a relatively unattractive economic use.

8.1.8.4 Diversification of crops

Factors such as globalisation of markets have also had an effect on agriculture production on the Island. Today's consumer is more sophisticated and therefore local restaurants, hotels, wholesalers and supermarkets have to keep up with current food and eating trends. In order for the local grower to remain competitive, he has had to diversify his crops from the staples such as carrots, onions and potatoes to crops such as herbs, daikon, radicchio, arugula, salad mixes and other specialty vegetables. Bermuda's farmers now grow over 120 different kinds of fruits and vegetables.

8.1.9 The Threats, Problems and Pressures

8.1.9.1 'Night time farming' (theft)

'Night time farming' is a problem that has become pervasive Island-wide and affects every farmer. Instances have occurred where entire fields have been stripped of produce. The insecurity of fields is due in part to the fragmented location of agricultural fields. However it also reflects a societal problem.

8.1.9.2 Weather

Extreme weather conditions, although uncontrollable, are one of the biggest threats facing local growers. Hurricanes, windstorms, hail, excessive rain, drought and searing temperatures play significant roles in causing various degrees of crop failure. Most farmers depend on rainfall for water crops as the majority of agricultural fields are not irrigated. It is not commercially viable to install irrigation systems into the majority of fields due to their dispersed location throughout the Island.

There is a lull in vegetable production during the summer months due to high temperatures and the unpredictability of rain. Usually during this period the fields lie fallow or are planted in cover crops, such as cowpeas. The cowpeas are ploughed into the soil at the beginning of the next growing season, usually in September.

8.1.9.3 Import duties

The new Bermuda Customs Tariff now places duty on agricultural items that were previously duty free. New duties put on farming equipment, such as tractor spare parts, plastic mulch, drip-lines and other innovative agricultural technologies impact on the farmer's bottom line and ultimately the consumer. Produce bags and containers are other items similarly affected by the tariff system.

For the local beekeepers, all equipment and supplies, except machinery, used in honey production is dutiable. This tariff, in addition to high freight charges, makes it virtually impossible for beekeepers to keep their prices of honey below that of imported honey.

8.1.9.4 Loss of agricultural labourers

Finding labourers for the agricultural industry is difficult since few Bermudians have expressed an interest in pursuing a career in agriculture and with each new generation, there are fewer persons committed to carrying on the agriculture tradition. This is especially a problem in dairy and pig farming. Local farmers also experience delays securing work permits for non-Bermudians who are interested in working here as farm labourers.

8.1.9.5 Competition

Given Bermuda's limited supply of available agricultural land, self-sufficiency seems impossible to achieve. Yet, at times farmers do produce sufficient produce to meet local demands, thus invoking embargoes on those specific items. However, when embargoes are not in effect and local produce is available, farmers have to compete with less expensive imported produce. Despite the fact that many Bermudians prefer local produce, price is a significant factor that prevents many from supporting Bermuda agriculture. Local vegetable production and egg production are two segments that continue to view competition from imports as a major problem.

8.1.9.6 Crows, pigeons, feral chickens

Feral chickens continue to be a major problem with the majority of growers reporting damage in many fields throughout the Island. The feral chickens pick at the tender leaves of newly planted seedlings and pick or scratch at the heads of mature cauliflower, broccoli, and cabbage. Damage to individual fields has been estimated to be between hundreds to thousands of dollars.

Currently, the only way to control this problem is by trapping. One company that specialises in trapping feral chickens has estimated that they have caught and disposed of over 50,000 chickens in two years.

Crows are a pest to farmers, especially in known roosting areas such as the Peak and Zuill's Farm, in Smith's Parish. The culling of crows occurs when population levels are high and when significant crop damage is seen in the fields. Pigeons, to a lesser extent, are also an agricultural pest and at times feed on newly seeded fields.

8.1.9.7 Overgrown

Many agricultural parcels have been allowed to lie uncultivated for extremely long periods. During this time they have become overgrown with scrub and invasive species. Whilst these fields remain protected areas and can be converted back into agricultural fields, it becomes extremely costly to clear and return these fields to a condition in which they can be planted.

8.1.9.8 Increased development

Increased development has led to the destruction of open space and problems for those agricultural businesses struggling to survive. For example, there has been a decrease in both the number of suitable locations to place beehives and the size of their foraging areas. In addition, without enough land to grow fodder for cattle, the dairy farmers are more dependent on imported feed which adds to the cost of the dairy operation. The land used for dairy farming is also not large enough to support the existing herds. This results in compaction of soil, erosion and at times extremely muddy conditions following periods of extended rain.

The cost of renting or purchasing agricultural land for horse paddocks and stables has been found to be disproportionate to paddock and stable rents which are typically very high. This has led to an increase in the construction of these structures on agricultural land. Prolonged use of agricultural land as a horse paddock can lead to the compaction of topsoil, erosion and degradation in the quality of the field.

Registered farmers find it difficult to expand their operations while new farmers find it difficult to break into the industry due to the decreased availability of agricultural land. At times, farmers are evicted from agricultural land due to the development pressures.

8.1.10 Home Gardening and the Farmers Market

8.1.10.1 Home gardening

As open space continues to be lost to development, the importance of backyard gardening increases as a significant contributor to the overall proportion of agricultural land.

The Ministry of the Environment's 2002 review of the Island's agricultural industry indicates that there is currently an estimated 140 acres of home gardens in Bermuda. The report states that this could represent some 27% of the land currently used for the production of fruit and vegetables.

The report suggests a number of reasons for the growth in home gardening. They include:

- Increased residential and commercial development on the Island which has compelled people to gardening as a source of psychological or spiritual comfort;
- Food safety concerns, particularly with regard to the use of pesticides;
- Interest in organic gardening; and
- The re-emergence of the Farmers Market as an opportunity for backyard gardeners to make commercial sales.

Figure 8.9 A home garden

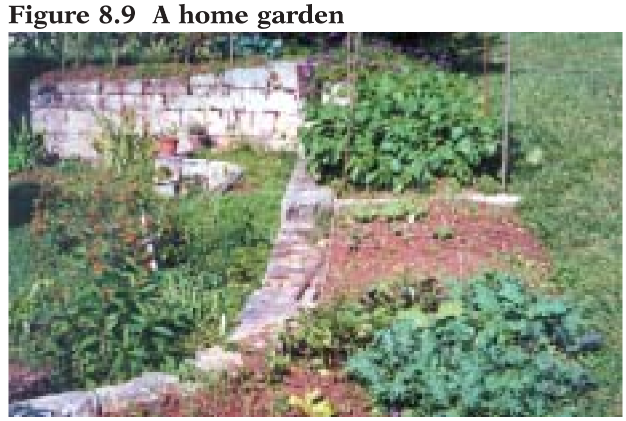


Photo courtesy of Frances Eddy

8.1.10.2 The Farmers Market

The Bermuda Farmers Market opened on 2 February 2002. It had not been in operation for four decades prior to this date. The market is located at Bulls Head car park and open from 8 a.m. to 1 p.m. every Saturday. Vendors can sell Bermuda-grown produce for a space fee of $20. Produce sold at the Farmers Market includes an array of vegetables, fruits, honey and plants.

The objective of the market is to support local agriculture and to provide an opportunity to smaller growers to sell their produce (Spreen et al, 2002).

Figure 8.10 The Farmers Market

Photo courtesy of the Department of Communication and Information

8.1.11 Planning Policy

Planning policies to protect agricultural land have existed since the first development plan for the Island was implemented in 1968. The development plan currently in effect, the Bermuda Plan 1992, provides for the protection of agricultural land through the conservation designation 'agricultural land', the provisions for which are set out in Section 11.AGR of the Bermuda Plan 1992 Planning Statement.

Some 696 acres of land are zoned agricultural land in the Bermuda Plan 1992. However, it is estimated that half of this 696 acres has both an agricultural land conservation zone overlay and a development zone overlay which makes the agricultural land vulnerable to the risk of development for other uses. This is partly reflected in the fact that in 2000, only 55% (380 acres) of all zoned agricultural land was actually in commercial cultivation. However, there are also areas of agricultural land that are zoned as national park rather than agriculture, such as at Astwood Park and Spittal Pond.

8.1.12 Future Initiatives

8.1.12.1 Legislation

Although there is much legislation in place relating to agriculture, as well as the importation of products and animal care, there is a need for the legislation to be more effectively enforced. Existing legislation includes the following:

- The Agriculture Act, 1930;
- The Agriculture (Importation and Sale of Potatoes) Regulations, 1936;
- The Agriculture (Sale of Vegetable Seeds) Regulations, 1937;
- The Agriculture (Control of Plant Disease and Pests) Regulations, 1970;
- The Agriculture (Inspection and Exportation of Produce) Regulations, 1931;
- The Agriculture (Inspection and Exportation of Nursery Stock) Regulations, 1931;
- The Agriculture (Soil Erosion) Regulations, 1967;
- The Agriculture (Improvement of Livestock) Regulations, 1947;
- The Agriculture (Control of Animal Diseases) Regulations, 1947;
- The Importation of Fruits, Vegetables and Flowers Act of 1961;
- The Importation of Eggs and Dairy Products (Protection) Act, 1964;
- The Importation of Milk (Prohibition) Act, 1997;
- The Care and Protection of Animals Act, 1975;
- The Care and Protection of Animals (Commercial Horse Stables) Regulations, 1984;
- The Endangered Animals and Plants Act, 1976; and
- The Dogs Act, 1978;

8.1.12.2 Education

Many educational projects, programmes and initiatives are in place to provide awareness and information to the general public about Bermuda's agricultural policy. These include the following:

- Agricultural Camp – held every summer to expose children to all aspects of agriculture;
- Agricultural/Horticultural Programme at the Prison Farm, provided by the National Training Board in conjunction with Government and other organisations;
- The Annual (Agricultural) Exhibition – fun-filled education is provided to thousands of people every year who visit the Botanical Gardens to see the best in agriculture, horticulture and home-made baked goods and crafts displayed;
- Bot Camp – Government, along with the Bermuda Botanical Society operates a summer camp to introduce children of all ages to botany;
- Farmers' registration – this programme seeks to

gather information on farmers. Registered farmers in turn are permitted to use the Marketing Centre facilities and benefit from services at the Marketing Centre;

- Marketing project 1998 – to encourage purchasing Bermuda-grown produce through special promotion with educational pamphlets and special 'Bermuda produce' labels;
- The Ministry of the Environment's monthly publication *Envirotalk* (formerly known as the Department of Agriculture and Fisheries *Bulletin*) includes articles on agriculture. It also provides general information on planting, weather and temperature, plant diseases, pests and the chemical treatment of pests; and
- Paget Community Garden – an initiative that began at the Department of Agriculture and Fisheries. Now the Paget Community Garden is run by its own committee. The Departments of Conservation Services and Environmental Protection provide technical advice and are responsible for general maintenance of the field.

8.1.12.3 Potential government initiatives

In addition to greater enforcement of legislation and more environmental awareness, government could also undertake the following initiatives to help the agricultural industry:

- Provide an incentive to landowners who keep land in production. For instance, government could reward those who keep this agricultural land in production by offering the landowners a reduction on the land tax required for the developed portion of the land;
- Raise awareness that agricultural land is desperately needed. There may be individuals who would like to have their agricultural land properly maintained but who cannot do it themselves and do not know that there are farmers who would be willing to do it for them;
- Aid farmers in purchasing farmland from landowners;
- Continue to purchase prime agricultural land, especially farm units, and make it available to farmers;
- Allow registered farmers exemption from customs duty for all agricultural equipment; and
- Assist farmers to better promote local agricultural products.

8.2 Plant Protection

To prevent the introduction and dissemination of potentially damaging pests and diseases, the movement of plants into and out of Bermuda is regulated by the Department of Conservation Services Plant Protection Laboratory under the authority of the Agriculture Act 1930 and the Agriculture (Control of Plant Disease and Pest) Regulations 1970.

To facilitate the proper importation of plant material into Bermuda, import permits stipulating the conditions that must be met for the entry of each plant shipment are issued by the Plant Protection Laboratory. Upon arrival into Bermuda, all incoming nursery stock is inspected for the presence of pests and diseases. Foreign pests and diseases are routinely intercepted on incoming plant material in both commercial and private imports.

Some pests and diseases of plants are considered to be 'quarantine pests'. These are pests that could cause detrimental economic impacts to an area. Some plants are prohibited entry due to the associated high risk of quarantine pest and disease introductions.

Local surveys are conducted to detect the presence of pests and diseases of quarantine significance. Another function of the Plant Protection Laboratory is the inspection of plants that leave Bermuda.

There are currently 61 pests and diseases of quarantine significance that are under surveillance internationally. Only seven of these are reported to occur in Bermuda. Some quarantine pests are present in Bermuda, such as bacterial blight *(Xanthomanas campestris pv. dieffenbachiae)* and citrus leaf miner *(Phyllocnistis citrella)* but remain on the quarantine list. Even though these quarantine organisms occur locally, their importation is not permitted. These local populations should not be enhanced, nor should new bacterial pathovars, fungal races, viral strains and insect biotypes be introduced.

The majority of plant problems encountered locally are effectively managed. Although Bermuda has experienced some significant losses in vegetation such as the cedar blight during the 1940s and storm/hurricane damage, fortunately, it has not been affected by some of the devastating quarantine plant pests and diseases such as pink mealybug and lethal yellowing that have wreaked havoc in other countries.

Figure 8.11 A quarantined plant, the firecracker plant

Photo courtesy of the Department of Environmental Protection Plant Protection Lab

The Plant Protection Laboratory continues to inform the public on the possible consequences of trafficking plants and plant parts without following the necessary importation standards and procedures. It is thought that people (unintentionally and intentionally) are the primary means for disseminating plant pests and disease organisms from one country to another.

8.3 Summary

The central issue or threat to local agriculture is the lack of land and diminishing supply of land. This is compounded by increased competition from more economically advantageous land uses. Policies giving greater certainty through the protection of key areas of agricultural land and provision of more assistance to farmers should be further developed and their implementation strengthened. It is in the national interest that as many forms of agriculture and horticulture as possible continue in Bermuda.

Bermuda's laws regulating the import and export plant material in order to prevent the spread of plant pests and diseases is highly effective. One gap in these regulations, however, is the prohibition of certain plant species due to their ecologically damaging effects to terrestrial habitats. There are plans for future legislation to cover this issue.

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Chapter 9

Marine Resources

9

9.1 Threats to the Marine Environment

9.1.1 Introduction

Bermuda's marine environment is used for recreational purposes by local residents and tourists as well as for commercial fishing. Marine transport vessels including ferries, cruise ships, container ships, military vessels and other smaller water craft all impact on Bermuda's waters.

Bermuda supports a rich and varied array of marine organisms but these organisms are exposed to an unusual amount of stress from several factors. The Island's dense resident population, high number of tourists and boat traffic all place great stress on the shoreline and shallow-water marine environments, since these are prime recreational areas. Pollution from both land and sea also affect the marine environment. Floating materials such as oil and trash constantly wash up on the shores. Other pollutants which are island-generated materials such as sewage, run-off and trash also impinge heavily on the shoreline. In addition, the occasional impact of tropical storms and hurricanes can cause serious erosional problems around the shorelines.

9.1.2 Threats to Reefs

There are a number of factors which pose a threat to the Island's reefs and these include the following:-

(a) Shipwrecks and anchor damage

Shipwrecks can destroy significant areas of the reef, particularly on the rim. Boat operations can also damage reefs by dropping anchors onto the reef surface.

(b) Diseases

There are a number of diseases which affect the Island's reefs. Black line (band) disease is present mostly on brain and star corals (see figure 9.1). Up to 1% of these corals may be infected and some die. Other hard coral diseases include the white band disease that only affects a number of corals and the yellow band disease that affects *Montastraea franksii*. At present these diseases do not appear to be widespread or causing significant mortality in Bermuda. A number of soft coral species including seafans and searods are affected by *Aspergillosis* infections and mortality is common after infection.

Figure 9.1 Coral (in bottom corner) with black line disease

Photo courtesy of the Bermuda Biological Station for Research

(c) Coral bleaching

Coral bleaching occurs globally as well as in Bermuda and is the result of abnormally high summer seawater temperatures. Corals become stressed and expel their symbiotic algae (zooxanthellae) turning the colonies pale white. The brain and star coral as well as the fire coral are affected but this stress does not generally result in mortality. The first bleaching episode was reported

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in 1988 (Cook *et al*., 1990) and other episodes have been observed in the 1990s. It has been suggested that bleaching episodes are increasing as a result of global warming but there is also evidence that corals are adapting to the stress.

(d) Overfishing

Overfishing of reef fishes and other animals that inhabit the reef can occur. Their exploitation must be carefully monitored to ensure a large and stable population.

(e) Dredging

The dredging work associated with the construction of the airport during the last world war showed the vulnerability of brain and platy corals to increased sediment load in the water. This activity increased suspended sediment loads in Castle Harbour which continue to remain high to this day resulting in most of the brain corals on the fringing reef dying.

(f) Invasive species

Bermuda's marine environment has so far been remarkably resilient to invasive alien species. However, the threat of invasive species to the marine environment is still significant.

(g) Climate change

A new threat is related to climate change effects and in particular the rising levels of carbon dioxide in the atmosphere. Current research indicates that the levels of carbon dioxide in seawater have risen as well. Current theory predicts that corals in Bermuda will be unable to build their carbonate skeletons at the same rate under predicted higher levels of carbon dioxide. In this scenario, reef growth (net accumulation of coral skeletons as a reef structure) may not balance erosional processes. This could result in the gradual degradation of the reef structure and result in a less effective buffer from storm waves, as well as reduced reef productivity and biological diversity.

(h) Continued human activity

Some future threats to reefs are similar to the current ones and include siltation stress on nearshore reefs, unsustainable fishing practices by commercial and recreational fishermen and the effects of chemical pollutants. Most of these threats are derived from human activity and are therefore subject to management and control.

9.1.3 Threats to Inshore Water Bodies

Bermuda's inshore environment is at potential risk from several stressors, which in combination may impact the inshore habitat and water quality, posing threats to both the marine ecosystem and public health. These include the following:-

(a) inputs of contaminants—industrial agrochemical and boat hull antifouling contaminants with known toxicological effects;

(b) inputs of sewage;

(c) inputs of nutrients leading to eutrophication and harmful algal blooms; and

(d) suspension of sediments associated with dredging and shipping activity.

Figure 9.2 The impact of sedimentation from cruise ship activity

Photo courtesy of the Department of Planning

Several important factors must be considered which in total allow an assessment to be made of the risk to Bermuda's marine habitats and public health posed by these stressors in the inshore environment. Factors governing the distribution of stressors within Bermuda's coastal ecosystem include the following: -

(a) sources, inputs and fluxes of stressors into the marine environment;

(b) the volume of water receiving these stressors and the water residence time; and

(c) the proximity of vulnerable marine habitats susceptible to specific stressors.

Ecosystems at risk are generally those with vulnerable marine habitats or coastal communities that are dependent on the marine ecosystem, lying within or adjacent to enclosed bodies of water that receive significant inputs of stressors.

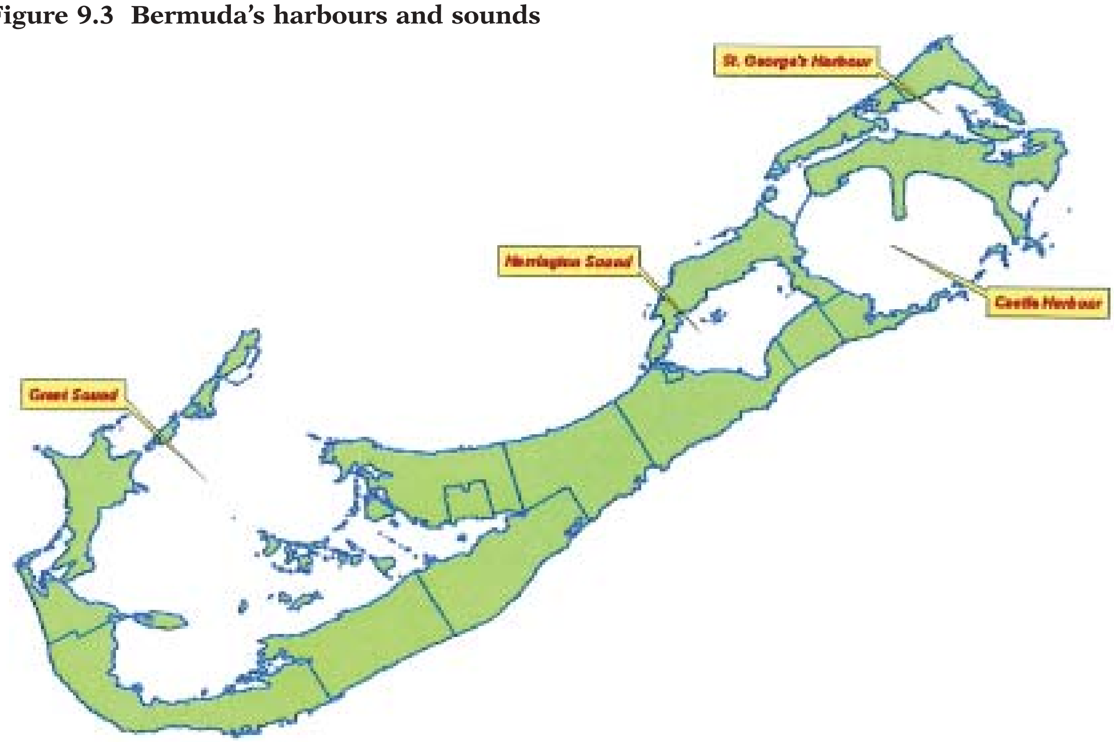
Within the Bermuda inshore water system, there are several bodies of water which have reduced flushing times with the open ocean (the primary mode of dispersal of stressors). The reduced depth of these water bodies, most of which are below 30m, additionally decreases the receiving volume for these stressors.

The Great Sound (see Figure 9.3) has a flushing time of 22 days during which time a direct exchange occurs with the waters of the lagoon to the north. This semi-enclosed body of water may receive inputs of several stressors which may then impact the lagoon habitat and which may directly or indirectly impact the surrounding coastal community. The main shipping channel transects the Great Sound stretching from the northern opening to the lagoon, to the City of Hamilton at its eastern most end. This results in resuspension of sediments particularly from April to November during the cruise ship season but also from channel dredging and leaching of antifouling paint constituents.

The only industries located on Bermuda are the diesel powered electricity generator plant and the mass burn waste incinerator. The former is located to the west of the City of Hamilton and effluent drains via the Pembroke Canal and through Mill's Creek, making its way into the Great Sound on its northern edge. Run-off of contaminants and nutrients from the City of Hamilton may also lead to local habitat damage and eutrophication where the eastern end of the Sound becomes Hamilton Harbour. The loss of aesthetic water quality within the Harbour area, a prime tourist location, may impact tourism in the long run. Additionally, the large amount of shipping and local boating activity may result in inputs of toxic antifouling agents into the enclosed waters of the Sound.

Harrington Sound (see Figure 9.3) is one of the most enclosed coastal areas in Bermuda with a mean depth of 20 m and contains one of the most unique biological habitats. Flushing time within the Sound has been estimated at 140 days or more. Harrington Sound receives about 50% of its input via a narrow tidal inlet at Flatts Village while the remainder results from groundwater recharging from the surrounding

Figure 9.3 Bermuda's harbours and sounds



Source: Department of Planning

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limestone caves. Due to this recharge and its extremely enclosed nature, Harrington Sound is extremely susceptible to diffuse, land-based sources of contaminants that may impact the delicate habitat. Of primary concern are the potential impacts of nutrients, pesticides and hull antifouling agents on the marine communities within Harrington Sound. Golf courses and agricultural fields are areas of high pesticide and fertiliser application which may contribute to the input of toxic organic contaminants and nutrients into adjacent water bodies. This is a concern, especially because Bermuda contains the highest density of golf courses per square kilometre for any one country, a large number being located in close proximity to Harrington Sound. Boating activity in Harrington Sound and Flatts Inlet may also contribute antifouling agents in these areas.

Castle Harbour (see Figure 9.3) is a shallow, semi-enclosed area with an average depth of 7.8 m. It is relatively well-flushed by waters from both the north lagoon and the open ocean to the south, reflected by a water residence time of 23 days. Whilst there is limited development around Castle Harbour, the airport and a metals dump to the east of the site potentially contribute to the influx of contaminants into the local marine ecosystem. Since 1995, Castle Harbour has also been a depository for concrete ash from the mass burn incinerator.

St. George's Harbour (see Figure 9.3) is a semi-enclosed water body partly created by artificial landfill during construction of the airport. St. George's Harbour is adjacent to the second largest urban region on the Island and as such potentially receives anthropogenic inputs. There is an active boatyard on the northern side of the Harbour and the Town of St. George's is one of Bermuda's three cruise ship ports. Water residence time is about 20 days with direct exchange with the open ocean through a narrow channel that is dredged for boat traffic.

9.1.4 Marine debris

Marine debris is a serious concern. Litter is either intentionally dumped, accidentally dropped, or indirectly deposited from the land and depending on its composition, it may sink to the seafloor, drift in the water column or bob on the surface of the sea. Floating debris poses unique hazards to wildlife, recreation, tourism, fisheries and humans.

Figure 9.4 A green turtle found dead in fishing line

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

Thousands of marine animals die every year from entanglement in fishing line, discarded ropes, nets and plastic six-pack rings (see Figures 9.4 and 9.5). Many marine animals also accidentally ingest marine debris confusing plastic items such as bags and helium balloons for food which cause internal injury, intestinal blockage or starvation. Some birds even feed debris to their young. Endangered species like sea turtles often mistake plastic bags for jellyfish, their favourite meal. Marine debris can also cause damage to vessels and equipment by getting caught in propellers and clogging the water intake ports that cause engines to overheat.

Figure 9.5 A green turtle found dead in fishing net

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

Once the debris washes up on shore it also mars the attractiveness and safety of the beaches and shorelines. Bermuda's Keep Bermuda Beautiful (KBB), a registered charity, organises annual marine clean-ups along Bermuda's shorelines.

Data from KBB clean-ups over the last few years indicate that the most common piece of trash found on the beaches and shorelines is plastic and glass (either bottles or glass pieces) (see Figure 9.7).

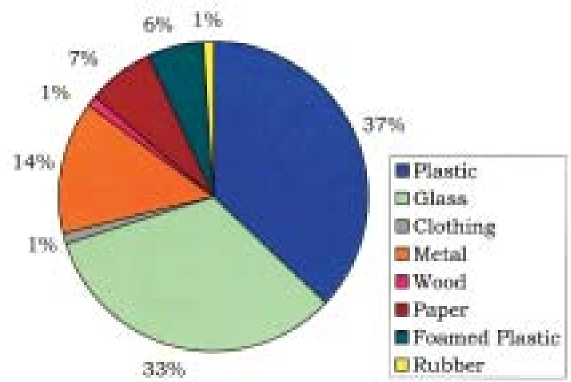
Figure 9.6 Keep Bermuda Beautiful marine clean-up

Photo courtesy of Keep Bermuda Beautiful

A number of local environmental organisations such as the Bermuda Audubon Society, Bermuda Zoological Society, Bermuda National Trust and Keep Bermuda Beautiful have campaigned against the use of helium balloons and as a result today a number of venues and events on the Island now ban the use of helium balloons.

The Waste and Litter Control Act 1987 states that it is an offence to release helium balloons and that anyone doing so could be prosecuted. The Marine Board Act 1962, which is administered by the Department of Marine and Ports Services, provides for the establishment of a Ports Authority, and addresses navigational safety in Bermuda's waters and the dumping of waste into local waters. In addition, the Marine and Ports Authority (Berthing and Anchoring) Regulations 1967 state that it is an offence to deposit or throw any ballast, rubbish or filthy water into the waters of the harbours of Bermuda. Unfortunately, this legislation is difficult to enforce. The focus instead has been on educating the public as to the dangers of marine debris and helium balloons.

Figure 9.7 Marine clean-up data 2001



Source: Keep Bermuda Beautiful

9.2 Fisheries

9.2.1 Historical Overview of Legislation and Management

A report conducted by the Bermuda Government Ministry of the Environment in 2000 entitled *Marine Resources and the Fishing Industry in Bermuda, a Discussion Paper* gives an historical overview of Bermuda's fishing legislation and fishery management.

In Bermuda, laws protecting species and restricting the use of specific types of fishing gear have been variously enacted over the centuries since the first piece of marine legislation was introduced in 1620 to protect marine turtles.

During the 1700s, there were 14 individual Acts passed to regulate the use of nets in certain areas around the Island and in 1791 to ban the use of fish pots. During the 19th Century only one Act was passed to restrict the use of fishing nets.

In 1911, the Harrington Sound Fishing Act was passed to establish a nursery area within this enclosed body of water. In 1921, the Board of Trade Act was passed and fishery matters were delegated to this Government Board. Under the Board of Trade Act, the Fishery by-laws were passed in 1925. These established minimum mesh sizes for nets and the wire mesh sizes that could be used for fish pots.

In the early 1950s, responsibility for fishery management was transferred to the Trade Development Board, which later became the Ministry of Tourism, and in 1952 a comprehensive set of

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Fisheries Regulations were passed which specified the minimum sizes of fish and lobster that could be taken. It also established protected areas where fish pots could not be used.

In 1961, responsibility for the fisheries transferred to the Board of Agriculture and the Department of Agriculture became the Department of Agriculture and Fisheries.

In 1963, another new set of principle regulations was created. The regulations defined the various types of fishing nets to be used, specified additional areas where pots could not be used and restricted the use of spears to one nautical mile from the shoreline. The use of aqualungs or any other type of breathing apparatus for taking fish of any kind was prohibited and all persons who fished commercially were required to register with the Department of Agriculture and Fisheries.

With the formation of the Commercial Fishermen's Association in the early 1970s came a degree of commitment by genuine full-time fishermen to protect and enhance the Island's healthy fish and lobster stocks for future generations to enjoy (see Figure 9.8). This came in the form of a document known as the 'Twenty-Six Points' which the Commercial Fishermen's Association forwarded to Government in April 1971. Most of the ideas which were put forward became law by way of the 1972 Fisheries Act. Commercial fishermen, having had a direct input into the Fisheries Act started to take a keen interest in ensuring that many of the regulations that came under the Act were adhered to and enforced.

Figure 9.8 A spiny lobster

Photo courtesy of the Department of Tourism

In 1972, Parliament passed the Fisheries Act and in the same year extended the jurisdiction over fisheries to a distance of 12 miles from the baseline of the territorial sea. The Fisheries Act provided for control of foreign fishing and made provision for orders to be made to protect selected species and areas of the exclusive fishing zone. The Act provided wider powers of enforcement, controlled the importation and exportation of fish and gave powers to the Minister to make regulations to control the fishing industry and to protect Bermuda's marine resources. These Regulations included requirements for commercial fishermen to be licensed and for the compulsory reporting of all catch and effort statistics by licensed commercial fishermen.

In 1978, the Fisheries Protected Species Order was created to afford protection to a number of vulnerable or over-exploited species. The taking of all hard and soft corals was prohibited as was the harvesting of queen and harbour conchs as well as various species of molluscs. Marine turtles and marine mammals including dolphins and whales (see figure 9.9) were also afforded protection.

Figure 9.9 A humpback whale

Photo courtesy of Michael Williamson/Whalenet

Historically, the major fishery for reef fish in Bermuda, as throughout much of the Caribbean, was based on the use of wire mesh fish pots. In general, these fisheries can be described as multi-species, non-selective fisheries frequently with high exploitation rates. These characteristics limited the options for the management of any designated species or group of species.

During the 1970s, restrictions were placed on the use of fish pots by commercial fishermen and a processing and marketing project (Sargasso

Seafoods) was initiated to develop markets for tuna, wahoo, shark and Bermuda chub, so called 'under-utilised species'.

From the 1950s onward, there were significant technological advances in the production of fibreglass vessels, diesel engines for small vessels, electric, gasoline and hydraulic winches, depth sounders, loran (a navigation aid which was a precursor to GPS) and ready access to refrigeration.

The maximum size of fish pots that could be handled by the industry increased from 1.3 m to 3 m in 1984. This represented a doubling of linear measurements but an exponential increase in volume that greatly increased fishing power. As such, these large pots were encouraged as a means of increasing yield. Live wells were replaced by ice boxes and the average size of vessels increased from 6 m in 1945 to just over 9 m in 1985.

9.2.2 Fisheries Management

Fisheries management in Bermuda has traditionally concentrated on managing the fishermen rather than the resource. In the past, there have been several unpopular management decisions that have been intended to conserve the fish stocks by cutting back on the number of fishermen and, more importantly, restrictions on the type of the gear which limit the efficiency of the fishery. This has been directed almost solely at the commercial fishing industry and has not taken into account any impact that the recreational fishery may have had on the fish stocks.

Most modern resource management, however, shies away from managing the fishermen and concentrates instead on managing the resource. The simplest form of this type of management starts with setting a total allowable catch (TAC). This is the amount of fish that fisheries managers believe can be taken without compromising long term sustainability. The TAC may then be divided amongst the fishermen, effectively giving each an individual quota. This may be done formally as in allowing each licence holder a fixed number of lobsters or weight of fish per season. As with other forms of regulation, this must be carefully monitored and is usually expensive to enforce.

It may be a less formal arrangement, as in the case of the present commercial spiny lobster fishery where the total catch is monitored and the amount of gear is fixed. Roughly speaking, knowing the efficiency of the gear allows an approximation of how many lobsters will be caught, on average, over the course of a season. Because the management authority has a responsibility to ensure that the fishermen can profit from their respective shares of the fishery, it is necessary to limit the number of licences so that each fisherman will be able to work with a reasonable amount of gear.

The concept of a TAC must also take into account the share which should be granted to the recreational fisheries and for this reason bag limits and minimum sizes are often set in other jurisdictions. This basic principle has been implemented in Bermuda for the lane snapper but may be expanded to encompass more important species.

9.2.3 Pelagic Fish Stocks

For the most part, Bermuda has little control over pelagic fish stocks as they comprise highly migratory species. Local peaks of abundance or declines may not be reflective of the global (Atlantic) population but may be indicative of inter-annual variations in oceanographic conditions that affect migration routes or timing.

Most of the pelagic species of interest to Bermuda (including wahoo, tuna, marlin and swordfish) fall under the management umbrella of the International Commission for the Conservation of Atlantic Tunas (ICCAT). This organisation has a number of scientific working groups that use the best available data on a collective basis to assess the state of these stocks. This information is then used for management purposes. Bermuda became a full member of ICCAT in 1995.

9.2.4 State of Fish Stocks prior to 1990

In the late 1960s, the grouper ground to the southeast of the Island was no longer productive and this was generally thought to be due to overfishing. It was also thought that the other grouper stocks were diminishing.

The dramatic decline in grouper landings from 1975 into the early 1980s was confirmed anecdotally by field observations of divers who reported that sighting a large grouper had become an increasingly rare event. A scientific assessment of the status of Bermuda's reef fish communities was not conducted during the 1980s because the basic biological

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information necessary was not available. Instead the status was inferred from the trends in the fishery statistical landings and from anecdotal evidence in the market in which bags of mixed white meat fillets dominated.

As a result of the severe decline in the preferred target species (groupers), there was a shift away from catches consisting mainly of grouper and snapper to catches where herbivorous reef fish, such as parrotfish (see Figure 9.10) and surgeonfish, were the mainstay of the fishery. An increase in fishing effort with fish pots coupled with new innovations in gear improved the effective effort in the early 1980s and populations of reef fishes were heavily impacted. This rang many alarm bells for the Government.

Figure 9.10 A blue parrotfish

Photo courtesy of the Bermuda Biological Station for Research

Commercial dive operators received an increasing number of complaints from visitors that there were too few fish on Bermuda's reefs and the Chamber of Commerce expressed concern to government about the deteriorating condition of the Island's reef fish populations.

9.2.5 The 1984 Fisheries Management Plan

In 1980, attempts were made to limit the number of fishermen and the fishpots they could use to prevent the reef fish stocks from collapsing in the same way as the groupers had. This programme was not very effective and it soon became obvious that fishing effort needed to be further reduced.

The 1984 Fisheries Management Plan regulated the number of pots that each fisherman could legally use. Part-time fishermen were barred from the pot fishery and the allocation of pots to full-time fishermen was based on their previous usage. There was a policy instituted in 1982, sometimes referred to as the 'moratorium' on licences, which allowed the transfer of fishing vessel licences but prevented the issue of any new licences. This was adopted in the hope that by limiting entry into the industry, the number of pots could be controlled.

Between 1985 and 1990 the number of pots used by fishermen was reduced on an annual basis from a total of 3,200 pots to 1,600 pots according to a sliding scale.

There were numerous reports of widespread abuse of the regulations governing the use of fish pots, particularly with regard to exceeding allotments, unlawful failure to use surface buoys (to avoid detection) and the use of unidentified pots (to avoid potential prosecution). The most distressing illegal activities within the pot fishery were the theft of pots or their catch and the use of pots identified with another fisherman's numbers. Those fishermen who complied with the conditions complained of being unable to compete with illegal operators.

Attempts at the enforcement of pot numbers were not effective because:

(a) they could be set on the platform without surface floats;

(b) it was difficult and time consuming to collect evidence of illegal use that would stand up in a court of law; and

(c) penalties handed down by the courts were not severe enough compared with the profits that were realised each time an illegal pot was hauled to dissuade fishermen from setting extra gear.

9.2.6 The 1990 Fisheries Management Programme

Based on the evidence from catch and effort statistics that were gathered after the 1984 Plan was initiated, it appeared likely that even if the necessary level of control over the pot fishery had been obtained, this fishery management scheme would not have been effective in protecting the stocks to allow for recovery.

There was concern for the total collapse of the reef fishery and its subsequent effect on the complex reef ecosystem. This would not only have an impact on the future of the fishing industry but also on Bermuda's tourism industry and quality of life for residents.

The Bermuda Government recognised that it was not only important to strike a balance between various industries competing for the finite reef fish as a resource but that it was also essential that the species and populations making up the resource be sustained. It was important to ensure that sustainable levels of harvest were not exceeded and that the marine habitats were not compromised.

In 1990, the Government of Bermuda passed into law the 1990 Fisheries Management Plan which included a ban of fish pots (traps) (see figure 9.11). The main reason for this ban was to protect the Island's reef fish species, particularly those herbivores (such as parrotfish) that helped to graze algae on the reef and which were valuable attractions to divers and tourists.

Figure 9.11 A fishpot

Photo courtesy of the Bermuda Biological Station for Research

A closure of the pot fishery raised two major areas of concern:

(a) spillover of displaced fishing effort into other established fisheries (longline fishing, charter fishing, net fishing); and

(b) the development and control of alternate fishing activities that would enable displaced fishermen to continue to harvest the reef fish resources, including grouper.

9.2.7 The 1990 Commission of Inquiry

The implementation of the 1990 Fisheries Management Programme caused considerable political unrest and debate. The reaction to the ban on the use of fish pots varied tremendously depending on the interest of the individual users. Line and net fishermen, commercial and sport divers and glass bottom boat operators endorsed the scheme and generally said it was long overdue.

Not surprisingly most commercial pot fishermen were opposed to the scheme, although a minority agreed it was inevitable but, nevertheless, would have liked to have used pots for a few more years. A group of pot fishermen (about one-third of the total) were so incensed by the ban that they formed a Fishermen's Division of the main trades union on the Island. Backed by the Union, the fishermen demonstrated in front of the Ministry Headquarters and at Parliament. The Union eventually threatened a general strike unless an inquiry was held into the banning of pots. This resulted in the Governor appointing a commission to inquire into the state of the marine environment and the fishing industry.

The Commission of Inquiry began on 19th November 1990 and conducted hearings for three weeks. The primary objectives of the Commission were to evaluate the extent to which the requirements for marine environmental protection and fishery resource management in Bermuda were being addressed. It included an evaluation of past performance by government and the fishery sector in regard to the sustainable utilisation of these resources.

Table 9.1 sets out the recommendations made by the Commission of Inquiry in 1991 for the future of the fishing industry and for the future protection of the marine environment in Bermuda.

9.2.8 Post Fish Pot Ban (1990 – Present)

Following the Commission of Inquiry, displaced pot fishermen took various courses of action. Some became part-time fishermen engaging in construction or other trades, others became charter fishermen or turned to full-time line fishing and others left the industry altogether.

Over time, annual landings have averaged out at something in excess of 800,000 pounds of foodfish, comprising predominantly (50%) of wahoo, tuna and other pelagic species. The re-establishment of a commercial lobster fishery starting in 1996 has seen landings of spiny lobster return, in some years, to pre-pot ban levels.

The fish pot debate continues although it is less heated than it was previously. It has, however, given rise to criticisms concerning the enforcement of fisheries legislation and the role of the Government,

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Table 9.1 Recommendations of the 1991 Commission of Inquiry for the future of the fishing industry and for the future protection of the marine environment in Bermuda

Recommendations:-
1. The establishment of a Department of the Environment placed directly under the Permanent Secretary for the Environment and that the Department be charged with environmental planning, regulation as supported by law, monitoring of the environment, and transfer of technical information to the policy makers.
2. That the Ministry of the Environment formulate a multi-user plan for marine resources and begin to assess and anticipate the public needs for, and the magnitude of threat to, the marine environment.
3. That the Government consider the establishment of a marine environmental advisory body to co-ordinate the activities of the various Government units with responsibility for the environment and to assure the best technical input into policy decisions.
4. That the Ministry of the Environment undertake a program of data compilation and concept synthesis embracing the entire Bermuda platform and the offshore banks.
5. That the Government increase the level of public awareness of marine environmental issues through formal and non-formal education programs, through the development and use of parks, including marine parks, and by seeking the co-operation of non-governmental organisations.
6. That the Government of Bermuda formulate clear policy statements for the management of fisheries, which recognise the multi-user nature of most of the resources, and the need for management to address potential user conflicts.
7. That in view of possibility of unpredictable permanent damage to Bermuda's marine ecosystems which could result from extreme overexploitation, the government adopt a conservative approach which minimises the risk to the ecosystems.
8. That the Fishery Division prepare fishery specific management plans which identify management objectives, options and action.
9. That every possible attempt should be made to include public hearings in the process of implementation of new regulations.
10. That future surveillance and enforcement of fishery regulations should be more prosecution oriented.
11. That training in law enforcement, preparation of court cases, etc. for Fishery Wardens.
12. That the surveillance/enforcement and extension/research/development functions in fishery management be separated both functionally and physically, possibly by transferring this function to the Marine Police.
13. That the voluntary catch and effort reporting system be validated, on an ongoing basis.
14. That the Fisheries Division initiate a small, regular survey, perhaps quarterly or half yearly, to estimate the extent and composition of recreational fish landings.
15. That the Fisheries Department assist fishermen with the establishment of co-operatives.
16. That the Government of Bermuda consider a system of temporary full tax rebate of fuel for periods of up to one year, for fishermen actively involved in pursuing innovative fishing arrangements.
17. That the Fisheries Division proceed with the increased level of activity on Fishing Aggregate Device (FAD) research which is projected in its research plan.
18. A comprehensive analysis of the current catch and effort database.
19. That the fish-pot ban remain in place indefinitely.
20. That each fishermen who has been compensated under the program described above be provided with a detailed calculation of his payment, and that the Minister appoint a group of 2-3 officials to hear appeals relating to the catch and effort numbers used in calculating the payment.
21. That the Government expand the *ex-gratia* payment to include lobster catches, for those individuals who were not included in the experimental lobster fishery program.
22. That the Government provide professional counselling service on request to fishermen affected by the pot ban.
23. That the Government investigate the extent of the alleged practice of using fishery licences to import duty free boats which are used primarily for recreational fishing.

Source: Marine Resources and the Fishery Industry in Bermuda, a Discussion Paper, *Ministry of the Environment* especially that of the Ministry of the Environment and the now disbanded Department of Agriculture and Fisheries.

9.2.9 Bermuda Government Advisory Bodies

From 1968 until 1991, the Fisheries Advisory Committee served as an advisory body to the Minister of the Environment and provided suggestions for new legislation relating to the fishing industry and desirable management measures. This Committee also had a sub-committee that screened would-be fishermen. Within this period, the Fisheries Commission (October 1985 through December 1991) dealt primarily with licensing matters and the determination of full-time fisherman status. This latter body resulted from the implementation of the 1984 Fisheries Management Plan. The screening sub-committee was replaced with an examination that was administered by the Division of Fisheries technical officers. At the start of 1992, the Marine Resources Board (MRB) came into being by virtue of section 3 of the Fisheries Act, 1972 (as amended). The formation of this body was an attempt to address the recommendations of the Commission of Inquiry. The MRB is bound to advise the Minister of the Environment on matters relating to The Fisheries Act and to the protection and use of marine natural resources and the marine environment.

The MRB comprises commercial fishermen, a representative from the Bermuda Biological Station for Research and various members of the public having interest in recreational fisheries, diving or environmental education. Although not required to by statute, the Bermuda National Trust has also had some level of representation on this Board.

In recent years, much of the work of the MRB has been as a consultant to the Department of Planning (for example on planning applications for foreshore developments) and the Ministry of Works and Engineering and Housing (on issues of dredging). The MRB has also been involved in the development of the spiny lobster fishery, the experimental guinea chick fishery and the creation of designated marine protected areas.

9.2.10 State of Fish Stocks since 1990

Following the fish pot ban in 1990, a fishery-independent visual census programme was started by the Division of Fisheries to monitor the recovery of the coral reef fish assemblages. To date, over 1,600 visual samples have been taken at a total of four study sites. This programme, which has been running for over 10 years, has demonstrated significant increases in estimates of the abundance of the four most important species of parrotfish.

Most commercial dive operators report that there appear to be more parrotfish and small colourful reef fish on the reefs since the pot ban but there has been no general increase in the number of groupers (see Figure 9.12) with the exception of the apparent increase and abundance of black grouper (rockfish). This tallies well with the findings of the research conducted by the Division of Fisheries and by the levels of reported grouper landings which show the red hind and coney landings remaining fairly stable.

Figure 9.12 A small grouper

Photo courtesy of the Bermuda Biological Station for Research

Although there is little in the way of definitive information on the state of the stocks of reef fish, the anecdotal evidence (for example from divers' observations) and the relatively steady landings of fish by the commercial fleet over the last few years, suggest that some level of equilibrium has been achieved.

9.2.11 Marine Fishery Reserves

Since the late 1980s, the concept of establishing Marine Fishery Reserves (MFR) has been under active discussion as a fisheries management tool because many other forms of classical fishery management appear to have failed.

The criteria for an MFR and its implementation have been the subject of a lengthy scientific debate but there is general agreement on some of the benefits. These include the following:

(a) they serve to protect spawning stock biomass;

(b) they help maintain the ecological integrity of the fish assemblages;

(c) they help ensure the maintenance of genetic diversity;

(d) they act as a kind of 'insurance policy' against the failure of traditional management; and

(e) they are relatively easy to enforce in comparison to other fisheries measures.

In Bermuda, the creation of an MFR has these benefits but is also problematic in terms of the Island's size and location. Bermuda's isolation makes it difficult to quantify the input of fish from offshore sources and therefore, in order to be effective, any MFR would have to reflect the diversity of habitat that most reef fish require. Most reef species have complex life cycles with varying ecological requirements throughout each stage of the cycle. It is very difficult to artificially create these stages, as is the case with mariculture, or to ensure that a given protected area has all the required attributes. In any event, if such a site can be identified, it is likely to be quite large encompassing a significant proportion of Bermuda's relatively small platform.

If an area of 30–40 square miles of reef platform were permanently closed to fishing there would be protests from those persons who traditionally fish in the area and from those who would be displaced. Furthermore, unless the number of fishermen is reduced, there would be crowding of fishermen into the remaining available area and an increase in competition. Before establishing an MFR, it is critical that all essential elements, both biological and socio-economic, be considered and evaluated. The likelihood of success will be greatly increased if the fishing community can be convinced of the long-term benefits of the creation of an MFR. However at the present time, there are few clear examples which support the concept and show the direct benefits of MFRs.

The concept of 'no go areas' has also been considered but there are legal difficulties with imposing such restrictions. In addition, the nature of the reef platform consisting of limited cuts and other access points, contribute to the problematic nature of this idea.

Accessible marine sites (such as reefs with a myriad of diverse species) while enhancing the range of tourism products available in a region, can become victims of their own success. Diverse interests of developers, operators and political parties need to be balanced with the conservation goals for each site. The success of a site invariably makes it attractive to increasing numbers of users, who collectively, may work to overwhelm the resource simply through the weight of numbers. At some point, the 'carrying capacity' threshold of a site, area or country is reached.

9.3 Marine Protected Areas

9.3.1 Introduction

In 1966, Bermuda created marine protected areas where it was illegal to remove any organism attached to the sea floor. This was done to protect the integrity of the coral reefs, although fishing and diving in these areas was permitted.

By 1971, the continuing depletion of the Island's 'grouper grounds' led fishermen to ask the Government to close off or protect certain areas at certain times of the year. These were the first seasonally protected areas. They were generally referred to as 'hind grounds' since this was the dominant species of grouper at the time and the sites in question were the areas where hinds aggregated. The term 'hind grounds' is still the vernacular for the seasonally protected areas.

In the 1984 Fisheries Management Plan, there was a proposal to designate a sizeable portion of the reef platform as a fishery reservoir. However, this component of the plan was never implemented.

Starting in the mid-1980s, popular diving sites were included under the Fisheries Protected Areas Order which made it illegal to conduct fishing of any kind on a permanent basis. This was done primarily to benefit the diving community and to provide a positive experience for visitors who wanted to see intact reef fish communities in a healthy coral reef setting.

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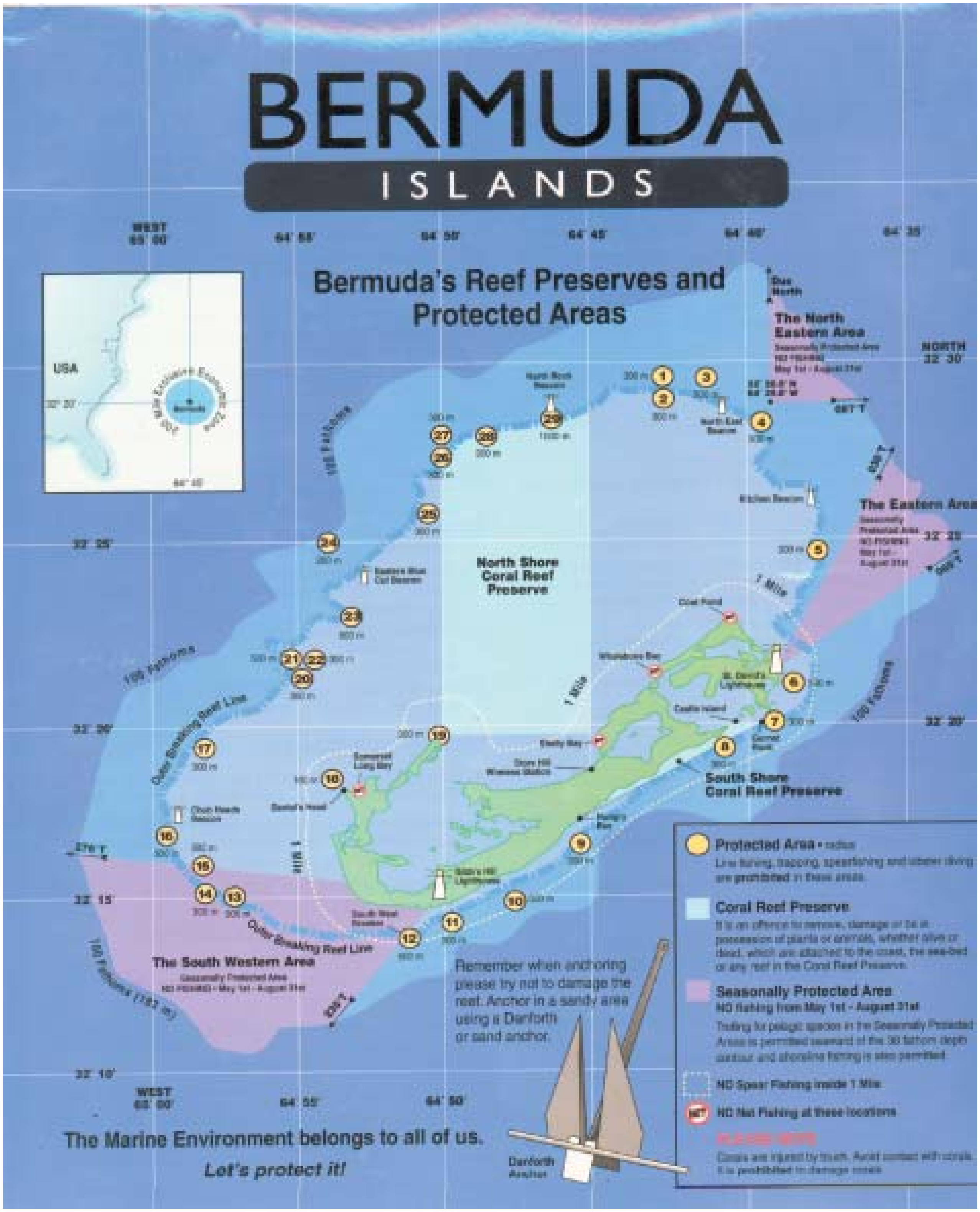
Figure 9.13 Map showing Bermuda's coral reef preserves, 32 permanently protected areas and three seasonally protected areas



Source: Bermuda Government

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At present there are 32 protected areas. They are divided into the three seasonally protected areas and 29 permanently protected areas (see Figure 9.13).

9.3.2 The Seasonally Protected Areas

There are three seasonally protected areas which are located to the southwest, northwest and off the eastern end of the Island (see Figure 9.13). Under the Prohibited Fisheries Order 1971 no fishing of any type was permitted in these areas from late May (various dates) until mid-August during both 1971 and 1972. In 1973, the number of protected areas was reduced to two (south-western and eastern) since the landmarks once used to locate the north-western hind ground had been demolished and because the number of hinds caught in that region had declined considerably. By the mid to late 1970s, the red hind, which had previously been scorned by many fisherman and either thrown away or used as lobster bait, became the 'number one fish' in terms of reported commercial landings.

In 1976, the Fisheries (Protected Areas) Order was promulgated to protect spawning aggregations of the hind. These enlarged, seasonally protected areas were defined in law as areas enclosed within certain co-ordinates that coincided with well-known landmarks, used for reference by vessels lacking navigational equipment.

Despite increased legislation and a growing public awareness of the need for conservation, these protected areas had problems. Since it was recognised that the resources available for active enforcement were inadequate, the main purpose for enlarging the areas was to prevent people from fishing on the edges of the actual spawning aggregations.

Although the establishment of the protected areas was promoted by the fishing industry and as such had a high level of initial compliance, this was eroded quickly due to poor enforcement and the inability to adequately punish offenders.

Table 9.2 Additional areas designated under the Fisheries (protected areas) Order 2000 as permanently protected areas (dive sites)

NAME OF DIVE SITE	RADIUS (metres)	DESCRIPTION
Montana	300m	Shipwreck
L'Herminie	300m	Shipwreck
Airplane	300m	Airplane wreck
Lartington	300m	Shipwreck
North Carolina	300m	Shipwreck
Blanche King	300m	Shipwreck
Darlington	300m	Shipwreck
Cristobol Colon	300m	Shipwreck
Caraquet	300m	Shipwreck
Aristo	300m	Shipwreck
Snake Pit	300m	Reef formation
North East Breaker	300m	Reef formation
Cathedral	300m	Reef formation
Tarpon Hole/ PollockShields	500m	Dive site and shipwreck
Hog Breaker	300m	Reef formation
Marie Celeste	300m	Shipwreck
Madiana	300m	Shipwreck
Taunton	300m	Shipwreck
Mills Breaker	300m	Reef Formation

Source: Bermuda Government

The implementation of the 1990 Fisheries Management Programme defined three new seasonally protected areas that replaced the hind grounds. These protected areas offer several advantages over the original 'hind ground' areas. Since they are based on bearings from a central origin, the process of observation is greatly simplified and there is also the potential for the utilisation of land or ship-based radar systems.

Apart from including the three major hind spawning sites, these enlarged protected areas also encompass previously known aggregation areas of other grouper species. Although it is acknowledged that these groupers exist in severely depleted numbers, it is hoped that the increased level of protection may allow these stocks an opportunity to recover to some extent. In addition large areas of a variety of bottom types are also covered by these seasonal closures. These areas may therefore also afford significant protection to other species of spawning reef fishes such as snappers and grunts. When fishing pressure is judged to be excessive, seasonal closures to protect spawning aggregations of groupers are a short-term management option that may give substantial protection.

9.3.3 The Permanently Protected Areas (Dive Sites)

These sites were first designated in the mid-1980s and have been added to from time to time. The one exception is the *Vixen* site which has been closed to fishing for many years for use by glass bottom boats. Whilst most sites are located offshore, on the reefs, (see Figure 9.14) the Commissioner's Point site abuts the shore and is the site of a snorkel operation.

The level of protection extended to these areas is a prohibition on all types of fishing and anchoring on the reef. However, the use of a sand anchor (Danforth) is allowed. The taking of corals and other organisms is further covered by the Fisheries (Protected Species) Order. It should, however, be noted that the existing fisheries legislation does not extend to affording protection to any artefacts or man-made physical structures (i.e., shipwrecks).

Figure 9.14 Glass bottom boat at a dive site

Photo courtesy of Tom Buchkoe

Just as charter fishing is important to tourism, so too are commercial dive operations. A great vacation in Bermuda must not only include land-based activities but also include the experience of seeing first-hand the breath-taking undersea world of multi-coloured fish and, for the most part, a healthy vibrant reef system. Several divers with international experience compared and contrasted the Bermuda reefs to those elsewhere. Although it was felt that Bermuda compared poorly in terms of fish to some jurisdictions, the reef itself was considered to be in a far better state. Support for the current use of specific areas as dive sites is paramount if we are to ensure that our visitors' expectations of an 'out of this world', undersea experience are to be fully realised.

In 2000, the Fisheries (Protected Areas) Order 2000 designated an additional 19 dive sites as marine protected areas to bring the total to 29 (see Table 9.2). For the most part these are shallow water wreck sites along the breaker line with the radii ranging from 300 to 500 metres. The size of the site varies because of the distance over which some wrecks may extend or because of physical features associated with the site. Many of these sites are routinely used by the commercial dive operators and are not in conflict with commercial fishing enterprises.

In order to facilitate the use of these sites and to reduce damage caused by anchoring, a co-operative effort has resulted in the deployment of mooring buoys at the sites. This was accomplished through private donations given to the Bermuda Zoological Society as well as the facilities of the former Department of Agriculture and Fisheries and the Department of Marine and Ports Services. Although traditional mooring weights (for example engines) have been utilised, consideration is being given to using more modern anchoring methods such as the Halas system as these are more environmentally friendly and aesthetically pleasing. During the summer of 2001, through a cooperative effort, some 50 such moorings were put down. Virtually all the legally protected areas had these moorings installed while a number of other popular dive sites also had moorings put in place to reduce the impact on the reef.

In 2001, the Bermuda Biological Station for Research initiated an assessment of the status of reef fish populations within several marine protection areas and adjacent reference areas. The results of this research were not available at the time of publication.

9.3.4 Marine Parks

The concept of marine parks or protected areas has been discussed by resource managers for many years and a small number of marine parks were established in Florida and the Caribbean in the 1960s and 1970s.

The creation of most of these parks followed the rationale used in the creation of terrestrial parks, i.e., the conservation and protection of habitats with their full complement of flora and fauna, which could be enjoyed by visitors.

In Bermuda, some feel that consideration should be given to creating marine national parks and that these areas should be set aside for recreational, educational and cultural purposes. At present one such park, Walsingham Marine Park, exists under the legislative protection of the Bermuda National Parks Act 1985. This protects valuable seagrass beds as well as some uncommon marine habitats. However, it may be argued that the existing dive sites protected by the Fisheries (Protected Areas) Order are tantamount to marine parks. The taking of any 'fish' (including corals, crustaceans and other marine animals) is prohibited and the prohibition of anchoring on the reef is designed to reduce impacts on the reef itself.

Perhaps the case may be made for additional shoreline parks with sections of water contiguous with parklands to be protected. The seagrass areas around Daniel's Head and Daniel's Head Park (see Figure 9.15), for example, might be a suitable site for a marine park. Fundamental to the 'park' concept, however, is the concept of usage. There is little point in designating marine parks if their proper use is not encouraged. This is particularly true of those sites that may provide valuable educational experiences.

Figure 9.15 Aerial photo of Daniel's Head and outlying seagrass beds

Photo courtesy of the Bermuda Government

It should also be acknowledged that as areas are closed to fishing, the options for both recreational and commercial fishermen are reduced. Some underwater wreck sites whilst having an aesthetic value to divers, partly because they serve as fish aggregating devices and often draw schools of amberjack and almaco jack, also constitute prime fishing locations.

There is a definite need to provide both for a capture fishery and for the ecotourism utilisation of the marine resource. The needs of both sectors should be balanced and careful attention paid to the capacity of the resource.

In 1997, the Bermuda Government sank the confiscated Chinese vessel, *Xing Da*, at a site north west of Bermuda, near Eastern Blue Cut. The sinking took place under strong protest from commercial fishermen who thought the site chosen would be a hazard to the marine environment. They were concerned that strong winter gales would, in short time, break up the *Xing Da*, thus destroying a large area of the Island's fragile reef and that the severe currents associated with the site would put divers at risk. By 2001, the *Xing Da* had largely broken up as predicted and although still used by some operators, is seldom spoken of as a dive site.

The unionised fishermen have recommended that no further ships be sunk to create dive sites and have asked that, when considering the establishment of any future dive sites, that the Ministers of Tourism and the Environment, properly and fairly vet the proposal with all relevant users of the marine environment.

9.4 Current Research Programmes

There are a number of current research activities concerning Bermuda's coral reefs. These are conducted by four main agencies including: Bermuda Biological Station for Research, (BBSR); the Department of Conservation Services which includes the Applied Ecology Unit; the Bermuda Aquarium, Museum and Zoo (BAMZ) and the Bermuda Zoological Society's Bermuda Biodiversity Project (BBP); and the Department of Environmental Protection's Division of Fisheries.

9.4.1 Research at Bermuda Biological Station for Research

9.4.1.1 Nutrients

Much of the research investigating distribution of stressors in the marine environment in Bermuda built upon the Bermuda Inshore Waters Investigation programme at the Bermuda Biological Station for Research. It was initiated in 1975 and continues in modified form to this day. It was a multi-interdisciplinary attempt to assess the environmental quality of Bermuda's coastal environment. Both physical parameters (for example, temperature and salinity) and chemical parameters (nutrients and dissolved organic matter) were studied.

Results of these investigations and further associated work showed the inshore waters to be divided into two nutrient regimes. The northern limits of the rim reef are characteristic of very low nutrient levels and the benthic activity of the reef community reduces nutrient levels to below that of the surrounding Sargasso Sea.

The four enclosed basins (the Great Sound, Harrington Sound, Castle Harbour and St. George's Harbour) where water exchange is limited and where there are increased land based inputs are characterised by increased levels of dissolved inorganic nitrogen leading to generally increased phytoplankton productivity. However, only the Great Sound exhibits seasonal eutrophication as a result of increased nutrient loading.

9.4.1.2 Suspended sediments

Evidence of the biological impacts of suspended sediments within the Bermuda coastal environment have been reported and are associated with the construction of Bermuda's airport in the 1940s. This introduced a heavy sediment load into Castle Harbour, changing the ecology of the coral reefs. The activity of the government quarry currently creates a fine sediment load that increases the turbidity within Castle Harbour. Turbidity resulting from dredging of shipping channels and daily passage of cruise ships is also documented for St. George's Harbour and the Great Sound.

9.4.1.3 Industrial, agrochemical and hull antifouling contaminants

Extensive studies of the distribution of trace metals have been undertaken in the inshore waters of Bermuda. In the 1980s, there was significant lead contamination due to the use of leaded gasoline. Atmospheric transport and deposition of lead into the marine environment has been reported and is a significant input pathway for this metal. A ban on lead additives has resulted in a rapid decrease in atmospheric lead levels and concentrations of lead in the marine environment are low, although concentrations of dissolved lead are relatively higher when compared to data from other coastal regions. This probably reflects the low concentration of suspended particulate material found in the Bermuda coastal zone.

In general, concentrations of other trace metals in the inshore waters of Bermuda are low. Exceptions to this are the waters in the immediate vicinity of harbours and marinas (notably Hamilton Harbour and St. George's Harbour) and the metals dump site in Castle Harbour which exhibits elevated levels of certain metals in sediments and/or sea water. Levels of cadmium in St. George's Harbour for example were similar to the North Sea which receives significant industrial discharge despite the absence of local industry and is possibly associated with contaminated landfill used in construction of the boatyard in the northeast part of the Harbour. Elevated levels of copper and lead in comparison with typical inshore waters were associated with the high boating activity and population density around the St. George's and Hamilton Harbour.

The most recent detailed studies of Hamilton Harbour showed that metals in sediments, whilst elevated in concentration, were below published remediation criteria.

Figure 9.16 Bermuda Biological Station for Research

Photo courtesy of the Department of Planning

Contamination of Bermuda's marine environment by organic contaminants is of potential concern particularly the threats to the marine environment posed by the leaching of constituents of antifouling paints from the considerable number of resident boats and visiting cruise ships. Organotin compounds such as TBT have been banned for boats under 25 m in length since legislation was passed in 1989. Work conducted at this time found extremely high levels of TBT in the coastal zone, (as high as 100ngl-1 in the water column and 236ngl-1 in the surface micro-layer). The concentration of TBT that produces deleterious environmental effects is extremely low, with for example widespread imposex in marine gastropods being reported at concentrations of less than 0.5ngl-1. Work conducted in Hamilton Harbour showed that the marine community structure was being adversely impacted by high TBT concentrations. In the U.K. an environmental quality standard (EQS) of 2ngl-1 has been set for this compound. The most recent surveys conducted by BBSR have shown that TBT concentrations have decreased from 220ngl-1 in 1990 to <20ng l-1 in 1995, although concentrations are still above the U.K. EQS. Elevated concentrations were found particularly in the vicinity of shipping lanes indicating that TBT inputs into these areas are from larger vessels like cruise ships and container vessels which are exempt from legislation. Due to the particularly toxic nature of this compound, TBT levels should be monitored in the future as the frequency of cruise ship visits and the size of vessels increase. Additionally, enclosed basins such as Harrington Sound which receive a component of water from the shipping channels (in this case from North Shore) should be monitored carefully.

Since the passing of legislation banning the use of TBT on small boats in 1989, new antifouling agents have been used. In particular has been the widespread use of triazine (algicide) based antifouling paints such as Irgarol 1051, which are formulated with copper. Irgarol 1051 is persistent in the marine environment and a study undertaken by BBSR has shown widespread contamination of Bermuda's coastal waters by this algaecide, with extremely high levels in the water column in the Island's harbours (up to 590 ngl-1in Hamilton harbour), comparable to levels found in congested marinas on the Mediterranean coast.

Little is known about the toxic effects of Irgarol 1051 in the marine environment although, one of the few studies has shown adverse effects on algal communities at concentrations of 250ngl-1. Of particular concern are the results of research conducted at BBSR showing photosynthesis of endosymbiotic microalgae (zooxanthellae) present in the tissues of one common inshore Bermudian coral to be inhibited at low levels of Irgarol 105. Further work at BBSR involves assessing seasonal distributions and biological impacts of Irgarol 1051 in Bermuda's coastal zone.

Of equal concern is the potential threat to the coastal zone posed by pesticides used in agriculture and on the considerable number of golf courses. Background research conducted at BBSR has shown that a number of organophosphate, carbonate and phenoxy acid pesticides (insecticides, herbicides, and fungicides) with known toxic effects in the marine environment are currently in heavy use on the Island.

A detailed study of pesticide distribution and biological impact of these compounds using biochemical biomarkers has been conducted at BBSR to address this issue and suggests that some seasonal contamination may occur in Harrington Sound and the Great Sound.

Two other non-locally derived inputs to the coastal environment have been documented which have been of concern in the past. Firstly, petroleum residues (pelagic tar) associated with Atlantic shipping were of great concern in the 1970s with reports of large tar lumps being washed up on the beaches. Such incidences have dramatically declined since the advent of newer operational methods of cleaning tankers and international pollution agreements. Secondly, long-range atmospheric transport has resulted in the transfer of many different types of contaminants to the local marine environment from the Americas.

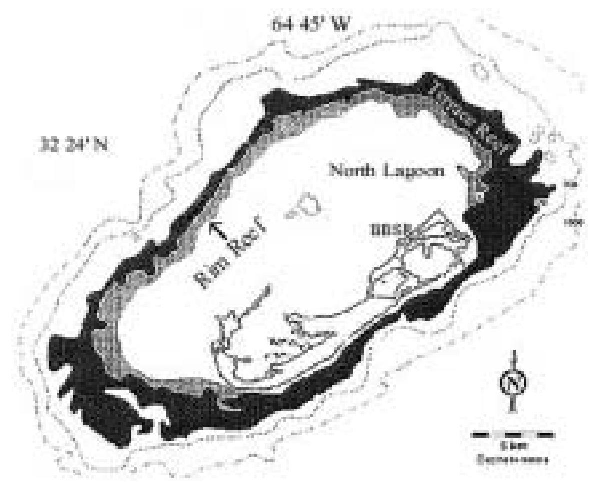
Persistent organochlorine compounds derived from atmospheric transport for example, chlorinated pesticides and polychlorinated biphenyls (PCB's) associated with industrial activities have been detected both in open ocean at about 100pg l-1 and in marine organisms. Highest concentrations have been detected in marine mammal blubber of 12-20mg g-1 and 8mg g-1 for DDT and PCB's respectively. Long range transport of trace metals such as copper, zinc, and lead have also been reported. Contamination by lead has decreased since the use of lead as an additive in gasoline ceased. Overall it is clear that the atmosphere above Bermuda is contaminated by emissions from North America and that these lead to contamination of the marine environment via rainfall.

9.4.1.4 Coral reefs

The projects conducted by BBSR include long-term monitoring of the health of corals and other attached reef organisms in three main shallow reef zones: near shore reefs, lagoon patch reefs and outer rim reefs (see Figure 9.17). Repetitive surveys are performed annually or biannually which assess the abundance and diversity of corals, invertebrates and algae as well as the extent of coral diseases and coral bleaching.

Long-term studies of adult fish populations have been made on two outer rim reef sites and indicate slow recovery of some fish species from the late 1980s to 2000. New projects include surveys for patterns of settlement of juvenile reef fish, many of which appear to utilise the nearshore reefs. Another project is evaluating fish populations in Bermuda's Marine Protected Areas (MPAs) in comparison to other reef sites. It has been predicted that the MPAs should show the strongest recovery of species that were previously over-harvested but other aspects such as the siting, size and effectiveness of MPAs are being considered. Nearly all the MPAs are located in the same outer rim reef zone and this may not protect critical habitats for juvenile or adult fish. Only two small areas of nearshore reef (Commissioner's Point and the wreck of the *Vixen*) are protected.

Figure 9.17 Bermuda's reef system



Source: Bermuda Biological Station for Research

Other focused studies have examined the impacts of the Seabright sewage outfall on the south shore. The impacts are very limited due to the rapid dilution and flushing of the effluent that occurs at the site. However, there does seem to be more algae on the reefs around the outfall and a slightly lower density of juvenile corals.

Nearshore reefs adjacent to the south shipping channel, off the north shore of Pembroke, have been monitored to assess the impact of siltation from cruise ships transiting the channel. These reefs have seen declines in soft corals and sponges since 1993. There is no clear evidence that the changes were related to siltation stress, as it was found to be relatively low on the reefs closest to the channel.

The reefs in Castle Harbour appear to be recovering from the destructive effects of airport construction in 1941–2. New species are colonising reefs and reef algae appears reduced, which facilitates the re-growth of coral. This might be related to the larger populations of parrotfish and surgeonfish on these reefs, following the fish pot ban in 1990. However, the expansion of the waste dump presents a potential new threat in terms of long-term exposure of chemical pollutants. Several reefs are monitored on a regular basis to assess coral health and fish population status.

9.4.1.5 Other research by BBSR

Other related areas of research include the long-term monitoring of nearshore and offshore seagrass beds, population genetic structure of marine species and molecular studies of the taxonomy of marine organisms. Currently there is an active bio-prospecting project which is investigating the potential bio-medical benefits of compounds produced by marine organisms in Bermuda.

Also, there are several projects evaluating the specific effects of pollutants on near-shore reef organisms. One of these projects used the commercially important Bermuda scallop (*Euvola (Pecten) ziczac*) (See Figure 9.18), to develop a rapid, non-invasive methodology to detect pesticide exposure. Many insecticides kill insects by inhibiting cholinesterases and scientists have found that measurements of enzyme activity in this species of scallop are a good biomarker for detecting these pesticides. Results of this research showed that the activity of the cholinesterase enzyme in the scallop is inhibited due to the presence of commonly used pesticides. A detailed study of scallops deployed in Harrington Sound and the Great Sound showed seasonal enzyme inhibition which suggests that the presence of pesticides in these areas vary at different times of the year.

In 2003, the Atlantis Mobile Laboratory, from Laval University, Quebec, visited Bermuda for two months. Techniques were used to measure the concentrations and effects of environmental contaminants, natural toxins and pathogens that may threaten the ecosystem and public health. The data collected will be compiled into an environmental health report that will be a useful tool in setting priorities for action. The Atlantis team is working in collaboration with the BBSR, the Bermuda Government Health Department and the King Edward VII Memorial Hospital. The Atlantis Project will collect data in such a way that comparisons can be made between different locations around the world.

Figure 9.18 Bermuda scallops

Photo courtesy of Samia Sarkis

9.4.2 Research by the Marine Resources Division, Department of Environmental Protection

The Government Marine Resources Division (MRD) has a long history of research on reef fish populations, including monitoring population abundance and biomass, studies of spawning aggregations, fishery biology of commercially important species and analysis of historical fisheries catch data. Research on pelagic species such as wahoo, tuna and billfish has been ongoing since 1995. Extensive research has also been done on the spiny lobster and guinea chick fisheries.

Contemporary research projects seek to broaden basic understanding of the biology of exploited fish species, particularly the commercially important groupers (*Serranidae*) and snappers (*Lutjanidae*). These studies have examined age, growth (otolith analysis), reproductive biology (size and age at sexual maturity) and movement patterns (tag-recapture studies). In addition, the MRD collates and analyses catch statistics of commercial fishermen to assess the status and trends within various fish stocks.

The MRD has made extensive use of mark-recapture studies of both reef and pelagic fish as well as lobsters in order to better understand habitat utilisation by key species. This information is essential in making management decisions, including the establishment of Fisheries Protected Areas for spawning aggregations of groupers and the development of

Marine Protected Areas for multiple resource management objectives. These studies have demonstrated that a number of Bermuda's commercial species can range widely over the reef platform.

In order to advance understanding of reef fish ecology and to monitor the recovery of reef fish stocks, the MRD and BBSR have been coordinating fish census research to link earlier, on-going studies by the MRD with current projects at BBSR.

Both the BBSR and MRD perform environmental impact assessments on habitats and carry out surveys on prospective Marine Protected Areas.

9.4.3 Research by the Department of Conservation Services

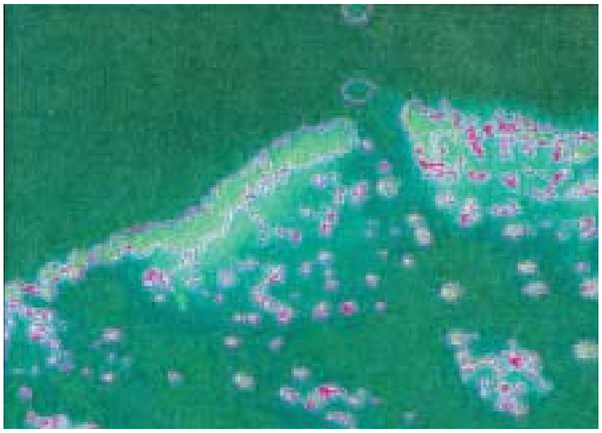
The assessment, monitoring and conservation of biological resources is a pressing issue and this work is being carried forward by the Bermuda Zoological Society's Bermuda Biodiversity Project (BBP) in partnership with the Applied Ecology Unit of the Department of Conservation Services (DCS). The scope of the project includes all of Bermuda's terrestrial and marine habitats.

9.4.3.1 Mapping of reefs and seagrass beds

With respect to Bermuda's coral reefs, the BBP has two linked areas of research that will ultimately produce a geographical information system (GIS) database that catalogues the biological resources of the reef system (see Figure 9.19). The foundation will be a digitised set of aerial photographs within which all reefs and seagrass beds will be mapped and used in the GIS. These maps will be geo-referenced (i.e., set to a geographical co-ordinates system according to the Global Positioning System). The second piece of research involves ground-truthing surveys, following a standardised procedure, to describe the biological communities (e.g., coral, fish) of specific reefs. The data is then entered into the GIS and will allow future changes in the marine environment to be monitored more closely.

The value of the GIS database is that other research information can be added over time (such as from BBSR and the Department of Environmental Protection) which expands the capacity of the database as a research tool. The ability to query a comprehensive database will prove invaluable for addressing management and research questions in the future.

Figure 9.19 Aerial photograph showing the digitised reefs



Source: Bermuda Biodiversity Project BREAM

9.4.3.2 The Collections of the Natural History Museum

The Natural History Museum is a critically important entity concerned with cataloguing all species in Bermuda, providing expert taxonomic advice and reference materials that ensure quality assurance for all other research on biological resources. The integration of the Museum's collection information on Bermuda's organisms with the GIS database will be an important step in the development of the database.

9.4.3.3 Bermuda Turtle Project

Early settlers of Bermuda harvested the abundant nesting and foraging green turtles (*Chelonia mydas*) to the point that in 1620 legislation was passed to protect juvenile turtles. By the early 1800s, Bermuda had decimated the nesting population and by the early 1900s it was extinct. All of the green turtles currently found in Bermuda's waters are immature animals from other nesting beach populations.

Dr. H. Clay Frick II (trustee of the Caribbean Conservation Corporation), in cooperation with the Bermuda Government, initiated the Bermuda Turtle Project in 1968. It began with the objective of studying the resident turtles of Bermuda. An earlier project involved the translocation of green turtle eggs from Costa Rica. During the 1960s and 1970s, thousands of turtle eggs were buried on beaches in Bermuda in an effort to re-establish a nesting population. More than 16,000 eggs hatched as a result of this project. Knowing that green turtles require 40 to 50 years to mature and that they return to the beach on which they were born to lay their eggs, it is hoped that some of these animals might still return to reproduce in Bermuda. As a result of this translocation work and further research, all sea turtle species in Bermuda's waters became protected by law in 1978 under the Fisheries (Protected Species) Order, 1978 in accordance with the section 5 of the Fisheries Act, 1972.

Since 1991 the Turtle Project has been a collaborative project of the Bermuda Aquarium, Museum and Zoo and the Caribbean Conservation Corporation. The primary aim of the project is to further the understanding of the biology of marine turtles in order to promote their conservation in Bermuda and worldwide. A major discovery has been that Bermuda serves as a nearshore or neritic developmental habitat, a place where immature green turtles, 25 – 75 cm in carapace length grow up in the absence of adults. The Bermuda Turtle Project research has therefore made a special contribution to the research on the biology of green turtles and their developmental habitats.

Most scientific studies of sea turtles take place on nesting beaches where females come ashore to lay their eggs. The Bermuda Turtle Project, however, gathers data by capturing sea turtles in an entrapment net that is 610 m long by 6.1 m deep (2000 ft x 20 ft) in a circle. Swimmers swim around the circumference and bring to the surface any entangled turtles (see Figure 9.20). These turtles are tagged, measured and weighed before being released. Blood samples are taken that allow the researchers to determine gender and genetic nesting beach origin (see Figure 9.21). This turtle-tagging work is one of the longest-running in-water projects in the world.

Researchers have used satellite transmitters attached to selected animals in order to gather information on sea turtle behaviour. The transmitters have provided data about the residency time of green turtles on the Bermuda platform as well as the identification of a single migratory route taken by a green turtle when leaving the Island's waters.

On 5 August 1998, a 76 cm (30 inch) carapace length green turtle, large enough for migration into the Caribbean where it would mature, was fitted with a satellite transmitter. After two more weeks in Bermuda waters it headed straight to the Caribbean. On 26 September 1998 the satellite data showed that she was positioned near shore on the eastern tip of Cuba where it is surmised she was taken for food. Her fate clearly shows the need for international cooperation in the protection of sea turtles.

Figure 9.20 Bermuda Turtle Project research

Photo courtesy of Marjo Vieros

Since 1968, the use of the netting method has resulted in the capture of approximately 2,974 green turtles, including approximately 729 recaptures. Some 67 tags have been returned from the Caribbean, mostly from Nicaraguan and the Cuban shores. Data shows that Caribbean fishermen harvested more than half of these Bermuda-tagged turtles.

In addition to research, some 19 signs have been erected to encourage boaters to change their speed in areas where turtles are frequently seen and there are plans to erect a further 20 signs around the Island. Flyers showing the locations of seagrass beds and the graphics used for the caution signs were inserted in all marine craft registration reminder notices in April 2000.

Figure 9.21 Bermuda Turtle Project Leader, Jennifer Gray, measures a young green turtle

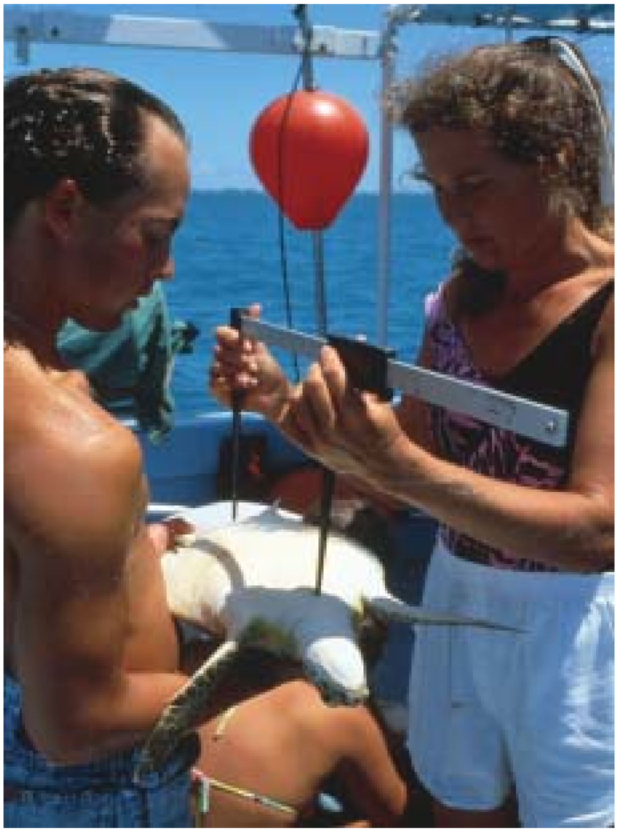


Photo courtesy of Jennifer Gray

9.5 Future Research and Legislation

There are several critical gaps of knowledge with respect to Bermuda's coral reefs. Very little research and monitoring has been done on the largest reef zone, the Main Terrace from 50 – 80 ft (17 – 25 m). There is only limited information on coral, invertebrate and fish populations and the spatial patterns that might exist in this zone around Bermuda. The limitations have included inadequate funding support, personnel and diving technology to work efficiently in this zone.

The Deep Reef zone from 80 – 150 ft (25 – 50 m) is also poorly known and it has been fished extensively in the past. The key questions that need to be investigated in these zones are their roles as potentially critical habitats for important shallower reef species, determination of the population structure of exploited fish species and the productivity of the reef zones.

Another gap of knowledge is determining critical habitats in the shallower rim reef as sites for spawning aggregations and lagoon patch reefs, as habitats for juvenile fish. Current projects at BBSR are beginning to examine some aspects of the latter topic but need to expand into non-reef habitats such as seagrass beds and inshore sub-tidal areas.

Further research is also needed on biodiversity patterns in the different reef zones to characterise species-rich or unusual habitats. Current efforts by BBSR, DCS and BBP need to be expanded to accomplish this goal.

In the context of fisheries management, more fishery-independent measures of reef fish and lobster populations are required. Current fish studies at BBSR will start to address this.

A mariculture facility exists at BBSR that could be useful in developing re-stocking programmes for conch, fish, and protected species.

More is also needed by way of legislation to protect the marine environment. Although, for instance, the Fisheries legislation can be used to cover damage to reefs, the maximum fines are negligible. Suggestions for new legislation include a Clean Water Act for Bermuda's inshore waters, a Coastal Zone Management Act and a Prevention of Physical Damage to Reefs Act.

It is recommended that cruise ships be charged an 'environment levy' as they are in the Caribbean. In addition, The Oil Pollution Act, 1973 addresses oil pollution offences in Bermuda's waters and provides for a system of fines but there is no provision in this Act to cover the cost of cleanup.

9.6 Summary

Bermuda's marine environment is used for a variety of purposes including fishing, recreational purposes and transport, all of which impact on Bermuda's waters and marine habitats.

The main threats to Bermuda's coral reefs include: shipwrecks and anchor damage; diseases; coral bleaching; overfishing; dredging; invasive species; climate change; human activity and pollution.

The main threats to Bermuda's inshore waters include: inputs of contaminants; inputs of sewage;

inputs of nutrients leading to eutrophication and harmful algal blooms; and suspension of sediments associated with dredging and shipping activity. These factors pose a threat not only to the marine ecosystem but also to public health.

Bermuda's main inshore water bodies are: the Great Sound, Harrington Sound, Castle Harbour and St. George's Harbour. These bodies of water have a depth below 30 m and reduced flushing times with the open ocean. As such, contaminants are less able to be dispersed and these areas are therefore more vulnerable to pollutants.

Marine debris is a serious concern in Bermuda and poses hazards to wildlife, recreation, tourism, fisheries and humans.

In Bermuda, laws protecting species and restricting the use of specific types of fishing gear have been variously enacted over the centuries since the first piece of marine legislation was introduced in 1620 to protect marine turtles.

There was a dramatic decline in grouper landings from the mid 1970s into the early 1980s which was generally thought to be due to overfishing. As a result of this, there was a shift away from catches consisting mainly of grouper and snapper to catches where herbivorous reef fish, such as parrotfish and surgeonfish, were the mainstay of the fishery. An increase in fishing effort with fish pots coupled with new innovations in gear improved the effective effort in the early 1980s and populations of reef fishes were heavily impacted. Attempts were made to limit the number of fishermen and the fishpots they could use to prevent the reef fish stocks from collapsing in the same way as the groupers had. However, this programme was not very effective and there were numerous reports of widespread abuse of the regulations governing the use of fish pots.

In 1990, the Government of Bermuda passed into law the 1990 Fisheries Management Plan which included a ban of fish pots (traps). Line and net fishermen, commercial and sport divers and glass bottom boat operators endorsed the ban and generally said it was long overdue. Most commercial pot fishermen, however, were opposed to it.

In 1990, a Commission of Inquiry was established to examine and make recommendations for the future of the fishing industry and for the future protection of the marine environment.

Since the fish pot ban, there has been a shift in the commercial fishery from the use of passive fishing gear (fish pots) to active fishing gear (line fishing). Over time, annual landings have averaged out at something in excess of 800,000 pounds of foodfish, comprising predominantly of wahoo, tuna and other pelagic species. The re-establishment of a commercial lobster fishery in 1996 has seen landings of spiny lobster return, in some years, to pre-pot ban levels. Most commercial dive operators report that there appear to be more parrotfish and small colourful reef fish on the reefs since the fish pot ban but there has been no general increase in the number of groupers with the exception of the apparent increase and abundance of black grouper (rockfish).

From 1968 until 1991, the Fisheries Advisory Committee served as an advisory body to the Minister of the Environment and provided suggestions for new legislation relating to the fishing industry and desirable management measures. In 1992, the Marine Resources Board (MRB) was established to advise the Minister of the Environment on matters relating to the Fisheries Act and to the protection and use of marine natural resources and the marine environment.

Since the late 1980s, the concept of establishing Marine Fishery Reserves (MFR) has been under active discussion as a fisheries management tool. In Bermuda, the creation of an MFR has benefits but is also problematic in terms of the Island's size and location.

In 1966, Bermuda created marine protected areas where it was illegal to remove any organism attached to the sea floor. This was done to protect the integrity of the coral reefs, although fishing and diving in these areas was permitted. The continuing depletion of the Island's 'grouper grounds' or 'hind grounds' in the 1970s led to the establishment of the Island's first seasonally protected areas. The implementation of the 1990 Fisheries Management Programme defined three new, larger seasonally protected areas that replaced the former 'hind grounds'.

In the mid 1980s, a series of popular diving sites were included under the Fisheries Protected Areas Order which made it illegal to conduct fishing of any kind in these areas.

At present there are 32 protected areas. They are divided into the three seasonally protected areas and 29 permanently protected areas.

Consideration is also being given to the creation of marine national parks for recreational, educational and cultural purposes. At present one such park, Walsingham Marine Park, exists under the legislative protection of the Bermuda National Parks Act, 1985. This protects valuable seagrass beds as well as some uncommon marine habitats.

Four main agencies conduct research studies of the marine environment and marine species. These agencies are: the Bermuda Biological Station for Research, (BBSR); the Department of Conservation Services which includes the Applied Ecology Unit; the Bermuda Aquarium, Museum and Zoo (BAMZ) and the Bermuda Zoological Society's Bermuda Biodiversity Project (BBP); and the Department of Environmental Protection's Division of Fisheries.

Recent and current research initiatives include: nutrient studies; the impacts of suspended sediments; industrial, agrochemical and hull antifouling contaminants; monitoring the health of coral reefs; monitoring seagrass beds; the effects of pollutants on specific marine organisms; reef fish populations; mapping of Bermuda's reefs and seagrass beds; and the Bermuda Turtle Project.

Research initiatives in the future should focus on filling in the gaps of knowledge with respect to Bermuda's coral reefs, specifically the Main Terrace from 50 – 80 ft (17 – 25 m) and the Deep Reef zone from 80 – 150 ft (25 – 50 m). Another gap of knowledge is determining critical habitats in the shallower rim reef as sites for spawning aggregations and lagoon patch reefs, as habitats for juvenile fish. Further research is also needed on biodiversity patterns in the different reef zones to characterise species-rich or unusual habitats.

More is also needed by way of legislation to protect the marine environment. Suggestions for new legislation include a Clean Water Act for Bermuda's inshore waters, a Coastal Zone Management Act and a Prevention of Physical Damage to Reefs Act.

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Chapter 10

Air and Land Transport

10

10.1 Air Traffic and the Airport

10.1.1 Introduction

Bermuda International Airport is a civil airport that is owned and operated by the Bermuda Governments' Department of Airport Operations (DAO). Bermuda's operational and safety standards are consistent with the recommended practices and standards of the International Civil Aviation Organisation (ICAO) and other recognised bodies such as the U.S. Federal Aviation Administration and the U.K. Civil Aviation Authority.

The airport is located in the eastern end of Bermuda in St. George's Parish (see Figure 10.1). The airport has been at this site since 1940 when the United States Government leased land from the United Kingdom Government for 99 years. The U.S. built a military airfield on the land and the airfield was operated by several branches of the U.S. armed forces up until June 1995 when the U.S. Navy withdrew from Bermuda. At this time, full responsibility for the control of the airport was handed over to the Bermuda Government.

Figure 10.1 Aerial photo of Bermuda International Airport

Photo courtesy of the Department of Communication and Information

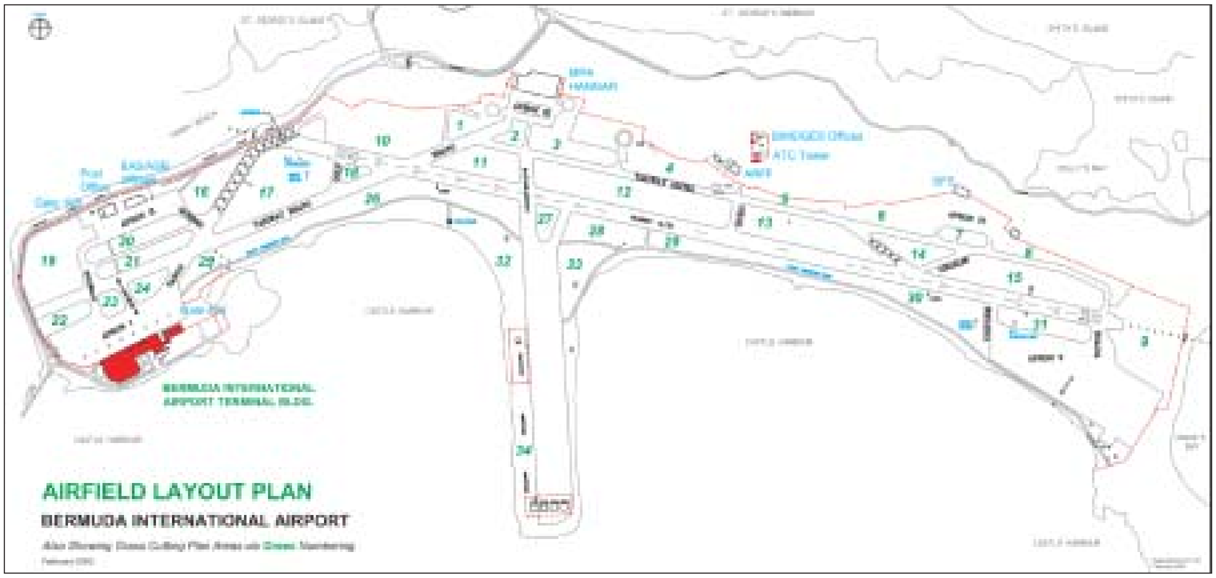
Whilst the Bermuda Government always operated and maintained the civil air terminal for commercial airline flights at the western end of the airport property, this was the first time it was responsible for the entire airport.

The DAO, under the Ministry of Transport, was set up to manage and operate the airport. Prior to this, the Department of Civil Aviation (DCA) had responsibility for the limited area for which the Government was responsible. Today the DCA's role is to regulate aviation, including airport operations, and to this end they work very closely with the DAO. The DCA also maintains the Bermuda register of aircraft and airmen.

Bermuda has one operational runway, 2,961m long and 46 m wide (9,713 ft x 150 ft), several taxiways and five aircraft parking aprons (see Figure 10.2). Most surfaces are asphalt. Apron I has concrete pads for air carrier aircraft parking. The remainder of the airfield is covered in grass. The entire airport occupies approximately 560 acres. This does not include the peninsula extending into Castle Harbour, which is a disused runway. This area is under the jurisdiction of the Bermuda Land Development Company.

Apron I is the designated area for air carrier aircraft and it is also known as the Passenger Terminal Apron. Apron II is leased to Bermuda Aviation Services (BAS) and it is the designated area for general aviation and military aircraft parking. There is also an executive jet passenger handling facility adjacent to Apron II. Apron III is adjacent to the airport hangar, which was originally built by the U.S. Navy and NATO for P3 Orion aircraft. The hangar (which is approximately 75,000 sq. ft in size) was handed over to the Government when the Navy withdrew from Bermuda. Several private aircraft park inside the hangar and a new company, Longtail Aviation, entered into a lease with DAO to use the hangar for an executive jet charter and air ambulance business in 1999. Aprons IV and V are seldom used.

Figure 10.2 Location plan of Bermuda International Airport



Source: Department of Airport Operations

10.1.2 Airport Zoning

An obstacle-free zone (OFZ) has been established around the runway in accordance with ICAO requirements. This zone, which did not exist when the airport was a military airfield, should be kept clear of all obstacles to ensure the safety of aircraft landing or taking off. DAO has removed most objects from the OFZ in the last six years, including the former Long Bird House and the former 'Pink' hangar at the airfield. The DAO, DCA and the Department of Planning continue to monitor the OFZ to ensure that no new development occurs that would infringe upon this zone. The OFZ will be incorporated into the next development plan for the Island.

10.1.3 Airport Statistics

There were just over 13,956 aircraft operations (arrivals and departures) in 2002. Scheduled airline operations accounted for 50% of the operations, whilst general aviation accounted for 38% and courier aircraft accouted for 10%, the remainder being charters, military flights and diversions.

Almost 850,000 passengers used the airport in 2002. Almost seven million kilograms of mail and cargo passed through the airport in 1999. Inbound mail and cargo volume is historically higher than outbound mail and cargo.

Figure 10.3 Bermuda International Airport

Photo courtesy of the Department of Communication and Informtation

10.1.4 Airport Environmental Management

10.1.4.1 Noise

Noise is traditionally one of the main environmental issues at airports. However, this is not the case at Bermuda International Airport. Noise, due to aircraft operations, decreased significantly in 1995 when the airport transitioned from a military airport to a civilian airport. Military aircraft are, for the most part, much noisier than civilian aircraft. In addition, the U.S. Navy P3 Orion aircraft that were based in Bermuda flew training and operational missions in the vicinity of the Island. They were also maintained and had their engines 'run-up' at the airport at any hour of the day. Presently, military aircraft operations make up a small part of all aircraft operations and no military aircraft are based at the airport.

Air carrier operations occur between 7.00 a.m. and 11.00 p.m. with the majority occurring between 11.30 a.m. and 5.00 p.m. Most airline jets that fly into Bermuda meet the highest engine noise environmental standards. This standard, known as the 'Chapter 3' or 'Stage 3' noise standard, has been imposed on aircraft operators and manufacturers by the United States, Canadian and European governments. There are no restrictions at the Bermuda Airport for aircraft not meeting the 'Chapter 3' standard. However, Bermuda has benefited from the actions of neighbouring countries, in that most of the aircraft visiting Bermuda are either built, registered or operated from the United States, Canada or Europe.

There are two aircraft noise abatement policies in place in Bermuda. Departing aircraft must refrain from making turns before reaching 3,000 feet or three nautical miles from the airport. This prevents aircraft from making departure turns over Ferry Reach or St. David's. In addition, jet-powered aircraft are not permitted to over-fly Bermuda below 5,000 feet (with the exception of arriving and departing aircraft).

10.1.4.2 Fuel management

Bermuda Refuelling Service, a joint operation between Esso and Shell, has an agreement with the Bermuda Government to supply fuel and oil products on the airport. A hydrant system is used on Apron I as well as a medium-sized refuelling tanker for smaller aircraft. Fuel spills occur on occasion and the fuel is contained with absorbent material before reaching the drains or before leaching into the ground. The cleanup materials are strategically located on Apron I. Esso, Shell and the DAO have contingency plans to handle a major fuel spill and these plans are practised and updated regularly.

Several hydrant systems installed by the U.S. Navy to service aircraft on Apron III have been mothballed. There are several other underground fuel storage tanks on the airport that are no longer in use. The Bermuda Government continues to have discussions with the United States Government on the environmental remediation of these tanks.

10.1.4.3 Storm water

All airport storm water drains into Castle Harbour. Most of the storm water originating at Southside, St. David's drains into the ground whilst some of the storm water flows through drains located on Apron I and through a system of drains running under the runway. The drains running under the runway were rehabilitated in 1996 when plastic pipes were installed within the existing pipes.

10.1.4.4 Rubber removal

Rubber deposits from aircraft tyres are removed annually with a high-powered water gun. Due to the relatively low volume of aircraft operations at Bermuda's Airport, the rubber amounts are minimal.

10.1.4.5 Wildlife management

Birds represent a potential safety threat to airplanes and to reduce this risk the DAO has an active bird control programme and BAS SERCo have a full time 'birdman'. One part of the programme is to manage the airfield habitat by eliminating standing water, food sources and by managing the grass height. The other part of the programme involves 'harassing' birds with noise making devices. This programme is conducted in consultation with the Department of Conservation Services Conservation Officer.

10.1.4.6 Litter control

Litter or foreign object debris (FOD) represents a potential threat to aircraft, specifically to jet engines. Small items can be ingested by jet engines resulting in engine failure or damage. The DAO's FOD control programme includes removing FOD from the airfield, regular FOD checks of the surfaces and aprons and FOD awareness. The DAO also removes FOD from the Castle Harbour shoreline. Most of these items are from the Airport Waste Disposal Facility.

10.1.4.7 Sewage and waste management

Aircraft sewage is deposited in a holding tank at the eastern end of Apron I. An environmental impact assessment was performed on this facility in 1997 and it was found to be acceptable due to the relatively low volume of sewage. Sewage from the terminal building is routed to standard septic tanks. Boreholes exist, having been approved by the issuance of licences by the Ministry of the Environment.

Other non-sewage waste or garbage is deposited in a trash compactor located at the eastern end of Apron I. The trash compactor is emptied twice a week and the contents are taken to the Tyne's Bay Waste Treatment Facility.

The Government's Airport Waste Management Facility is located adjacent to the airport. The Ministry of Works and Engineering and Housing is responsible for the management of the Waste Facility. Other than being unsightly, this facility has had little impact on the airport's operations. The other issues involve debris that occasionally escapes from the containment boom and ends up on the southern boundary of the airfield.

10.2 Land Transport

10.2.1 Introduction

Universally the growth in car ownership and private car use has led to increased traffic pollution, traffic congestion, fuel consumption, pressure on road space and increased road safety concerns. Consequently, traffic and transport issues probably generate more public debate than any other environmental issue.

Bermuda's 21 square mile land mass and limited road space mean that it cannot afford to accommodate the growth in traffic at the same pace in the future as it has done in the past, without it seriously threatening residents' quality of life and eroding the Island's fragile physical environment.

There have been a number of transport studies conducted in Bermuda over the last 30 years including:

- The Freeman Fox and Associates (1972) and Alaistair Dick and Associates (1989) studies of traffic problems on the Island and in the City of Hamilton,
- The Transport 2000 Planning for the New Millennium government study (1997);
- The Symonds Travers Morgan (1997) review of the City of Hamilton's traffic circulation pattern and traffic management system;
- The City of Hamilton Plan Transport Strategy (1999), Department of Planning and the Corporation of Hamilton; and
- The National Transportation Management Report (2002)

Despite the implementation of a number of recommendations contained in these reports, traffic still presents a major concern amongst the Island's residents and visitors. For instance, the results of a Ministry of Transport survey of 1,100 residents conducted in June 1999 indicated that 85% of respondents were very concerned about traffic congestion on the Island and 85% were very concerned about the increase in the number of motor vehicles. Similarly, the results from a Ministry of Transport survey of 1,784 visitors conducted in August 1999 indicated that 53% of respondents were concerned about drivers travelling too closely, 51% were concerned about pedestrian safety, and 37% were concerned about excessive vehicle speed. A disturbing statistic of 12% of visitors surveyed stated that their concern with regard to traffic and transport issues diminished the quality of their holiday experience in Bermuda.

In October 1998, a governmental Transportation Planning Team was established to review the Island's transport problems and to formulate a National Transportation Management Report (NTMR) recommending improvements to the Island's transport system. In addition, the Department of Planning, in collaboration with the Corporation of Hamilton, produced a transport strategy for the City of Hamilton in 1999 that forms an essential component of the new City of Hamilton Plan 2002. This strategy complements the recommendations arising from the National Transportation Management Report 2002 and details means of tackling the City's traffic, accessibility and parking problems.

Outlined below are the key land-based transport issues the Island is currently facing. The Island's transport infrastructure, the growth in vehicle traffic particularly car traffic, road safety, bus transport, traffic pollution and alternative vehicle technologies are examined.

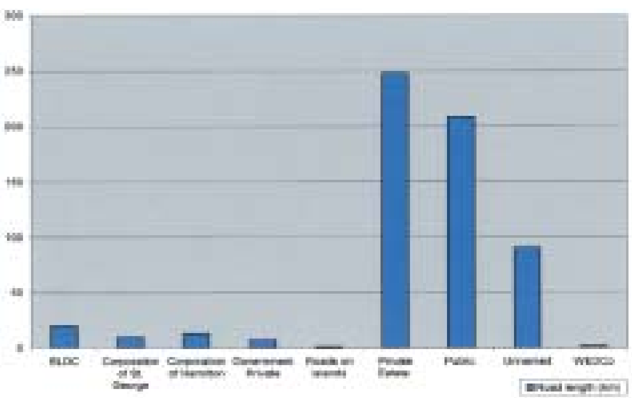
10.2.2 The Island's Transport Infrastructure

10.2.2.1 Roads

It is estimated that Bermuda has a total of 599 km (372 miles) of roads, of which 209 km (130 miles) are public roads (three main roads, secondary roads, lanes and tribe roads, bridges and causeways) and about 248 km (154 miles) are private estate roads. There are 90 km (56 miles) of unnamed roads. The Corporation of Hamilton and the Corporation of St. George's have 13 km (8 miles) and 9.5 km (6 miles) of roadway respectively (see Figures 10.4 & 10.5).

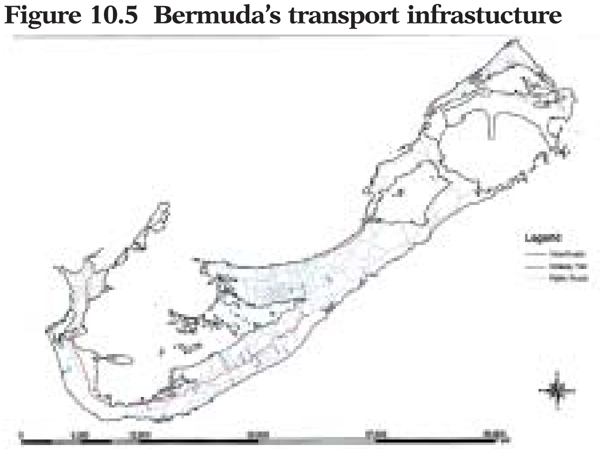
Whilst there are suggestions to build new bridges in key locations around the Island to ease traffic congestion, such as in Flatts Village, it is unlikely that there will be any major extensions to the public highway in the future. Instead, the emphasis of the Ministry of Works and Engineering and Housing's road programme has been on improving the safety of roads for vehicles through road widening schemes and protecting the character and charm of the Island's roads through sensitive design, road treatment and landscaping. (see Figure 10.6)

Figure 10.4 Bermuda's roads by length (km)



Source: Ministry of Works and Engineering and Housing

Figure 10.5 Bermuda's transport infrastucture



Source: Ministry of Works and Engineering and Housing

In recent years, major highway improvements have been undertaken in the following locations:

- Barker's Hill/North Shore Road/Palmetto Road roundabout (junction improvement to allow for safer movement of larger vehicles);
- Blue Hole Hill/Wilkinson Avenue near Swizzle Inn (junction improvements and provision of side-walks);
- St. John's Road/Langton Hill to Woodlands Road (road-widening and provision of sidewalks);
- St. David's Road near Gate No. 2 (new junction with new Southside Road);
- Wellington Slip Road, St. George's (realignment of road to accommodate increased size of cricket pitch);
- Verdmont/Sayle Road, Smith's (junction improve-ment);
- Tribe Road No. 5, Southampton (access to new fast ferry terminal); and
- Freeport Drive, Dockyard (implementation of one way system).

In addition, major construction works were completed on Somerset Bridge in 1998, Longbird Bridge in 2000, and the Causeway and South Road at John Smith's Bay in 2003 following Hurricane Fabian.

Figure 10.6 Road improvements

Photo courtesy of the Department of Communication and Information

10.2.2.2 Sidewalks and pedestrian spaces

The Ministry of Works and Engineering and Housing's road programme has also focused on improving the safety of roads for pedestrians through the provision of new sidewalks in areas of heavy pedestrian traffic. In recent years, new sidewalks have been constructed in the following locations:

- Rural Hill, Paget near Lover's Lane;
- St. David's Road, St. George's near Clearwater Beach Park;
- St. John's Road, Pembroke at Saltus School;
- No. 10, The Lane, Paget;
- The Lane, Paget at Crow Lane Park;
- South Road, Warwick at Astwood Park;
- North Shore Road, Deveonshire at Band Room Lane;

- Bob's Valley Road, Sandys at Sandys Primary School;
- Sound View Road, Sandys;
- North Shore Road, Hamilton Parish near BAMZ; and
- Mission Road, Paget.

Parts of the Island still have little or no sidewalk provision but it is hoped that this situation will improve over time.

In the last few years, the Corporation of Hamilton has also improved pedestrian safety in the City of Hamilton with the construction of speed bumps and footway buildouts at a number of pedestrian crossings. These help to reduce traffic speed and increase pedestrian visibility. The Corporation has also undertaken attractive sidewalk widening and improvement schemes along Reid Street and Church Street. The Corporation is currently investigating the feasibility of improving lower Reid Street for pedestrians to provide an attractive and safe environment in which people can walk leisurely between shops and dine alfresco on the street. The City's pedestrian environment is also gradually being improved to accommodate the needs of less mobile people through the provision of dropped kerbs, ramps into buildings and parking facilities for disabled persons.

Similarly, in the Town of St. George, pedestrian improvement schemes have been made along Water Street. There are also proposals to create a waterfront promenade from Hunter's Wharf to Davenport's Wharf.

10.2.2.3 The Railway Trail

Before motorised vehicles were introduced into Bermuda, the construction of a railway offered the only modern transport alternative to the horse and cart. The Bermuda Railway opened on 31 October 1931 but lasted only 17 years (see Figure 10.7). It was one of the slowest and most expensive railways ever built (costing one million pounds and progressing at two-and-a-half miles per year). With post-war disrepair and the arrival of motor cars, in 1946 the railway was closed and lay unused for nearly 40 years.

It was not until 1984, to coincide with the 375th anniversary of the discovery of Bermuda, that the Bermuda Government opened the Railway Trail for the public as a nature trail (see Figure10.8).

The Railway Trail is approximately 29 km (18 miles) in length and covers an area of some 90 acres of footpath. The Railway Trail provides a unique and scenic artery through the Island and a significant resource as a recreational venue for residents and visitors enjoying a walk, cycle, or horseback ride. Unfortunately, along much of the Trail's length, there is a conflict between those who use it for recreational purposes and motorists who use it as a vehicular route.

Figure 10.7 The Railway Trail at Bailey's Bay in the 1930s

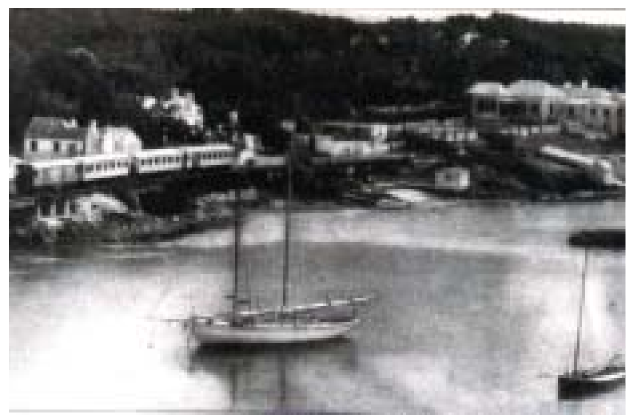


Photo courtesy of Tony Martin

In 2000, responsibility for management of the Railway Trail was transferred from the Ministry of Works and Engineering and Housing to the Department of Parks and the Trail was made into a Category B National Park. The Railway Trail Advisory Committee was re-established in January 2000 to assess the current state of the Trail, to propose recommendations for its enhancement and to monitor new developments that impact upon it.

As part of a review in 2001, a schedule of works was proposed. It was recommended that the mandate of the Railway Trail should be to create a linear national park that acts as an arterial connector to the Island's parks and nature reserves and is used as a major passive recreational greenspace. The main objectives for the Railway Trail are: to link the Trail wherever possible; to establish new habitats; to recognise the historical qualities of the Trail; and to minimise vehicular traffic along it.

Since 2001, the following physical improvements have been undertaken:

- Continued maintenance of the Trail;
- Opening up of the Trail;
- Shelly Bay boardwalk (400 km) (Department of Parks);
- New steps and surface water soakaways in different locations along the Trail e.g., Spicelands in Warwick and St. George's;
- Creation of various observation posts along the Trail with seating;
- Addition of gates along the western portion of the Trail; and
- New tunnel link in Southampton (Ministry of Works and Engineering and Housing).

In addition, the following improvements are planned for the near future:

- Management plan for the Railway Trail (2005);
- Review of ownership and legal boundaries (2006);
- Review of Highways Act;
- Integrated signage strategy for the Railway Trail;
- Store Hill bridge link;
- Possible Bailey's Bay link (2006); and
- Addition of gates to limit traffic (ongoing).

Figure 10.8 The Railway Trail as a nature trail

Photo courtesy of the Department of Communication and Information

10.2.2.4 Parking areas

It is within the City of Hamilton that parking is a particularly contentious issue. Whilst on the one hand, there is a perceived lack of car parking for shoppers and commuters, on the other hand if one examines the statistics, parking is actually a significant land use in the City.

In total, the City of Hamilton provides over 5,000 car parking spaces, the equivalent of a parking space for one in every four of the Island's cars. The City also accommodates over 2,500 cycle parking spaces, the equivalent of one space for every nine bikes on the Island. In addition, approximately 10% of the City's land area is occupied by car parks, approximately 16% of the City's land is consumed by road space and, with the exception of the container docks and cruise ship facilities, the City's prime waterfront is dominated by car and bike parking.

The Corporation of Hamilton is responsible for the provision of public car and bike parking. It is the City of Hamilton Plan, however, which sets out regulations for the provision of private parking (see Figure 10.9)

Figure 10.9 Bike parking on the City of Hamilton's waterfront

Photo courtesy of the Department of Communication and Information

One of the main goals of the City of Hamilton Plan 2002 is to make the most efficient use of the City's scarce land resources and to maximise pedestrian amenity. In terms of parking policy, this means controlling the supply of private parking and establishing a parking strategy that seeks to prioritise private parking provision according to the level of need of different City users. In this way, a higher priority is given to the parking needs of disabled people, City residents and the operational needs of businesses, and a lower priority is given to the parking needs of commuters who require long-term parking. It also means relocating parking space from areas of high pedestrian activity and utilising this space instead as pedestrian amenity areas such as on the waterfront and along lower Reid Street.

10

The Island's current development plan, the Bermuda Plan 1992, requires new developments outside the City to provide a minimum number of car and bike parking spaces according to the development's use and floorspace. Those establishments around the Island which have the largest areas of land devoted to parking are generally hotels, schools, churches, and supermarkets. In the future, as a means of reducing the amount of traffic on our roads as well as reducing the amount of land consumed by asphalt, private developments may be required to provide a maximum rather than a minimum number of parking spaces and to indicate that the parking space provided is absolutely necessary for the operational requirements of the land or building use to which it is associated.

10.2.3 Traffic Volumes

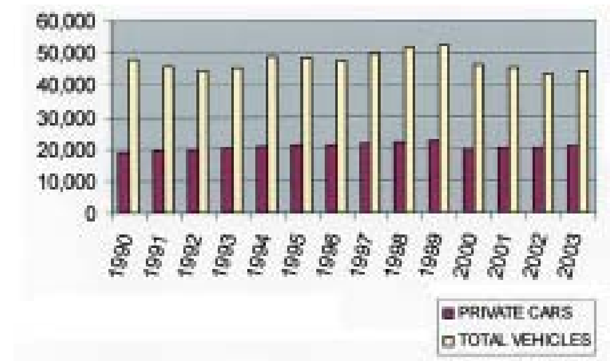
In 1999, there was almost one registered vehicle to every person on the Island whilst 50 years ago there was one registered vehicle to every five persons. Since 1949 the number of registered vehicles in Bermuda has increased from 6,326 to 52,432 in 1999. The increase in the number of registered private cars has been even more significant with a growth from 1,474 private cars in 1949 to 22,567 in 1999. In the last 20 years alone there has been a 71% increase in the number of registered private cars on the Island.

In 2000, a new system of reporting was introduced in the Transport Control Department. This new system involves reporting the number of licensed road vehicles as opposed to the number of registered road vehicles. In 2000, the number of licensed road vehicles was 46,041. The apparent decline in the number of vehicles between 1999 (52,432) and 2000 (46,041) is explained, therefore, by the fact that unregistered vehicles are not accounted for in the 2000 figures. In 2003, there were 44,112 licensed road vehicles (see Figure 10.10).

Island-wide traffic counts conducted by the Ministry of Works and Engineering and Housing indicate that traffic volumes have increased at an average rate of 4.5% a year during the 1990s compared to a 2% increase in traffic volumes experienced during the 1980s.

The parishes of Sandys, Southampton, and St. George's have seen the highest growth in traffic volumes during the last 10 years which reflects the high population growth in these areas. The Island's busiest junctions during the peak rush hours are Crow Lane roundabout, Paget traffic lights and Stowe Hill south end. The three busiest roads are East Broadway, Rural Hill (South Road) and Harbour Road (1999 Traffic Survey).

Figure 10.10 Registered vehicles 1990 to 2003



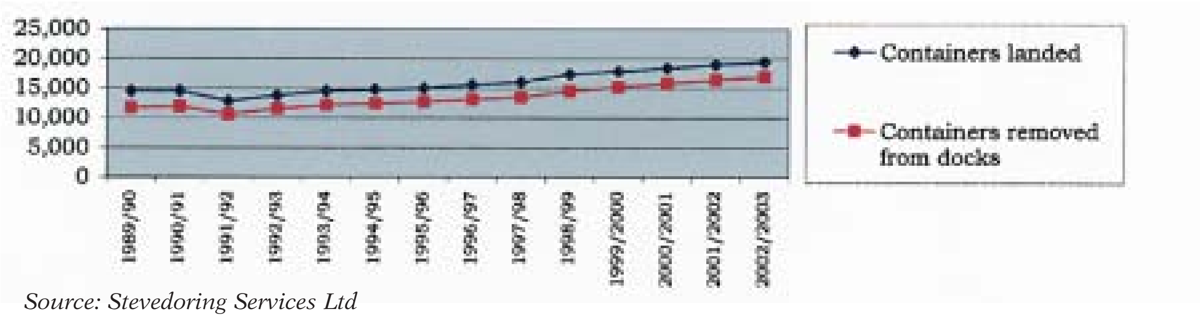
Source: Transport Control Department

The Symonds Travers Morgan (STM) traffic study (1997) indicated that while there was only a 2% growth in the number of vehicles entering the City in the morning peak between 1989 and 1997, there was a 14% growth in the number of cars entering the City during the peak hour. This growth in car traffic can be attributed to the increase in the number of cars Island-wide as well as the substantial increase in office floorspace built in and around the City of Hamilton in the past 10 to 15 years and the concomitant increase in the City's commuter traffic. In addition, more parking facilities have been provided for commuters including the construction of Bull's Head car park in 1995 which initially accommodated 720 cars. In 2004, this car park expanded to accommodate an additional 270 car parking spaces.

Traffic flow on the Island is seasonal with flows significantly lower during school holiday periods. The STM traffic study (1997) determined that the volume of traffic entering the City of Hamilton during the morning rush hour (8 to 9 a.m.) increases by some 15% during school term time. This amounts to approximately 1,500 additional vehicles.

The STM traffic study showed that the level of increase varies across the City with traffic levels highest at the City gateways closest to the three private schools of Bermuda High School for Girls, Saltus, and Mount St. Agnes. In November 1999, the Ministry of Transport's NTMR team started work on an Island-wide study to gather more specific

Figure 10.11 Containers landed at the City of Hamilton docks



Source: Stevedoring Services Ltd

information from schools on school-related transport. The first phase of this study focused on the private and public schools located in close proximity to the City. Working closely with school officials, the NTMR team conducted a school transport survey to ascertain the transport needs of students, parents and staff members and to identify alternative means of transporting students to school including the establishment of car pooling schemes, school bus services and minibus pick up services from bus and ferry stops. The results of this survey provide useful guidelines to the Ministry of Transport and school officials in establishing alternative, safe, efficient transport arrangements for school students and staff members.

The Ministry of Transport is currently seeking amendments to the Motor Car Act 1951 to allow more flexibility in the types of services vehicles can be used for. This could include using airport limousines for school transport.

10.2.4 Road Freight Traffic

Over the last 14 years, the number of containers that have landed at the Hamilton docks have increased by approximately 34% ((see Figure 10.11). On average, 80% to 87% of containers are removed from the docks and distributed around the Island with the rest remaining on dock for unpacking. In 2002/03, out of a total of 19,489 containers that landed, 16,958 were removed from the docks. Most containers are distributed in the City of Hamilton and Mill's Creek area. Other distribution points include Middle Road in Devonshire, Southampton, and Warwick.

Container traffic is most problematic in the City of Hamilton. Whilst container traffic is relatively light in the City during the morning rush hour and only constitutes approximately 3% of all vehicles entering the City at that time (STM Study 1997), the real problem comes with the routing of container traffic through the heart of the City. Since the container dock is located in the south eastern corner of the City and the Island's main industrial and warehousing hub is located north west of the City in the Mills Creek area, large container trucks must travel through the City either along the stretch of Front Street or along Court and Dundonald Streets.

10.2.5 Car Transport

In 1951, Bermuda introduced the Motor Car Act. This legislation established restrictions on vehicle weight, dimensions, and engine size, and restricted the rental of cars. More significantly, this Act put a limit on car ownership to one car per household. It was a revolutionary piece of legislation and is still one of very few pieces of legislation in the world that puts a restriction on the ownership of motor vehicles.

The premise behind this legislation was 'to preserve as far as possible the amenities of Bermuda'. It was forward-thinking and effective in controlling car ownership and its associated traffic congestion. It also necessitated the development of alternative modes of transport including motorised bikes and scooters, and bus transport.

Despite the positive controlling factors of the 1951 Motor Car Act, Bermuda has nevertheless experienced a phenomenal growth in the number of motor vehicles on its roads and, in particular, cars. With this growth has come increased traffic congestion, air and noise pollution, as well as

Table 10.1 Working population by mode of travel to work

Mode of Travel	Island-wide		City	
	Total	Percent	Total	Percent
Total	**36,878**	**100**	**14,995**	**100**
Alone in car	8,948	24.3	3,289	21.9
In car with others	6,740	18.2	3,686	24.6
Motorcycle	11,483	31.1	5,179	34.5
Bus	2,789	7.6	1,259	8.4
Mini bus	32	0.1	16	0.1
Van/truck	2,222	6	393	2.6
Taxi	562	1.5	58	0.4
Pedal cycle	199	0.5	65	0.4
Ferry	387	1	332	2.2
On foot	2,186	5.9	582	3.9
No usual mode of travel	464	1.3	111	0.7
Works at home	767	2.1	13	0.1
Not stated	99	0.3	12	0.1

Source: Census of Population and Housing 2000

increased pressure on the Island's scarce land resources to provide more road and parking space.

Cars dominate as the prime mode of transport to work Island-wide. The 2000 Census results show that 43% of the working population travel to work by car, 31% travel by motorcycle, 6% travel by van/truck, 8% travel by bus, 1% travel by ferry and 6% walk (see Table 10.1).

Similarly, car travel appears to have grown as the predominant mode of travel to work into the City. The 2000 Census figures show that 47% of city workers travel to work by car, 35% travel by motorcycle, 3% travel by van/truck, 8% travel by bus, 2% travel by ferry and 4% walk (see Table 10.1).

The car has remained the most popular mode of transport to work over the last decade with little difference between the 1991 and 2000 Census figures. However, there has been a slight increase (2%) in the number of people travelling alone in a car to work. There has been a 3% increase in the number of people travelling to work by motorcycle, a 1% decrease in the number travelling to work by van/truck and a 2% decrease in the number of people walking to work.

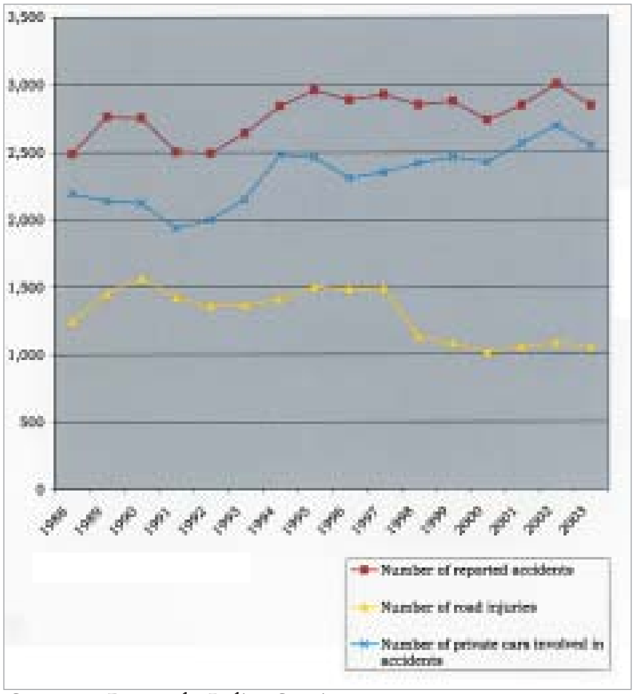
In 1960, 50% of residential valuation units (RVUs) had a car. This compares to 64% in 1980 and 83% in 2000. There is currently, therefore, the potential for 17% or 4,735 more RVUs to have a car. Factors which have contributed to the growth in the number of households that own a car include the introduction of the used car market in 1994 which made cars more affordable to many people and the increased popularity it had over the motorised bike for safety, comfort and status reasons. In addition to these factors, there are also on average approximately 200 new dwellings that are built every year and in the last three years, there has also been a growing trend in the conversion of tourism establishments to residential units. With these new residences and conversions to residences comes an increase in the number of RVUs and the potential for more households to own a car.

The economic importance of the car is also growing with Government collecting a total revenue in the region of $23 million for the financial year 2002/3, of which $15.2 million was from license fees from private cars. The introduction in the City of Hamilton of pay parking and the construction of Bull's Head car park has significantly boosted revenue of the Corporation of Hamilton which collected $3.3 million in parking fees in 2002.

10.2.6 Road Safety

In the last 16 years, there have been an average of 2,777 reported road accidents per year, an average of 1,297 road injuries per year and an average of eight road fatalities per year. (see Figure 10.12) The highest number of road fatalities in any one year was 17 in 1998.

Figure 10.12 Number of reported accidents and road injuries



Source: Bermuda Police Service

Approximately 90% of road accidents in Bermuda involve a private car. In 2003, 2,550 private cars were involved in accidents compared to 779 motor cycles/scooters, 594 trucks, 494 auxiliary cycles, 382 livery cycles, 161 taxis, 66 public service vehicles and 20 pedal cycles.

The Road Safety Council is appointed under the Motor Car Act, 1951. Working closely with the Ministry of Transport, its goals and objectives are:

- To formulate a National Road Safety Strategy that supports the efforts of the Ministry of Transport and enforcement agencies to minimise serious injuries, deaths, and property damage on Bermuda's roads;
- To collect, analyse, and review data with respect to all aspects of road safety (human behaviour, legislation, road engineering, motor vehicle trends);
- To facilitate injury surveillance activities within the community;
- To advise the Minister of Transport with respect to emerging trends that favourably and unfavourably impact on road users' behaviours;
- To facilitate the development of formal research plans that can determine injury mechanisms unique to Bermuda's roads; and
- To act as 'watch dogs' and as a resource to the Ministry of Transport and the community.

10.2.7 Bus Transport

The Public Transportation Board (PTB) operates a fleet of over 106 buses along 11 bus routes including regular commuter services, a school bus service, and charter and sightseeing tours. The Island's bus service is extensive with no areas more than half a mile from a bus route (see Figure 10.13a and b).

Figure 10.13 (a) East end bus routes

Figure 10.13 (b) West end bus routes

Source: Ministry of Transport

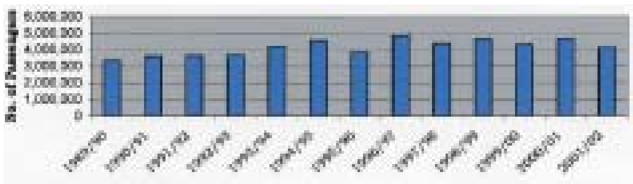
All the new buses have air conditioning and meet the strictest emission control standards. Emission controls are Euro 2 standard or better and this is checked three times a year.

Revenues peaked at $6,297,007 in 2000/01 but 2001/2 saw a drop to $5,556,010. The decline could be attributed to the loss of visitors following the terrorist attacks on the United States, in September 2001.

Approximately 92% of receipts come from the regular bus service including transporting school children, whilst 5% come from sightseeing services and 3% from charter bus services.

The public bus service attracted 4.6 million passengers during 2000/2001 but this number fell to 4.1 million in 2001/2. Figure 10.14 shows the trends in the number of passenger journeys over time

Figure 10.14 Number of bus passenger journeys



Source: Public Transportation Board

The 1991 and 2000 censuses, however, revealed that the percentage of bus commuter trips to the City and Island-wide remained fairly low at 9% and 8% respectively.

Buses are nevertheless a popular mode of transport amongst visitors. The results of a NTMR visitor transport survey of 1,784 air and cruise ship visitors conducted in August 1999 indicated that 57% of visitors use public buses compared to 35% who use mopeds/scooters, 42% who travel by ferry, 21% who ride minibuses and 78% who take taxis.

The Ministry of Works and Engineering and Housing has greatly improved the safety and comfort of bus users through the construction of new bus shelters. In addition, new bus lay-bys have been provided to allow for improved and safer traffic flow. In recent years, new bus shelters and lay-bys have been built at the following locations:

- South Road near The Reefs;
- St. David's Road near Clearwater School;
- Wilkinson Avenue;
- South Road, Devonshire near Devonshire Bay Road;
- Malabar Road, Sandys near Heydon Road;
- Verdmont Road, Smith's; and
- Middle Road, Sandys near George's Bay Road.

10.2.8 Taxi Services

The taxi industry is highly controlled with the number of taxis, the rates and the hours of operations all being regulated. There are currently 600 licensed taxis on the Island. Taxi operators act as transport providers as well as tour guides and tourism ambassadors for the Island. As such, taxi operators make a significant contribution to the Island's transport and tourism industries. Taxi operators have also had a significant influence on the Island's transport policy and legislation. Their influence is reflected in the following restrictions:

- A limit of 600 taxis;
- Formal limousine services are not permitted;
- Minibuses services cannot operate to the airport (drop-offs only) or to hotels;
- Hotels in close proximity to the airport are not permitted to have shuttles;
- No buses can be chartered during the low season (November to March) except in special circumstances; and
- No bus company other than the PTB can charter sightseeing buses at any part of the year.

Unfortunately these restrictions have limited competition within the transport industry and have reduced the potential transport options available to customers, particularly visitors to the Island.

Taxi utilisation is highly concentrated during the peak tourist season with demand high for cruise ship visitor tours from Mondays to Thursdays between the hours of 9.30 a.m. and 12.30 p.m. and for airport arrivals and departures between the hours of 11.30 a.m. and 2.30 p.m. There is also high demand during the evenings for transport to and from clubs and restaurants. Taxi usage is lowest during the peak commuter hours of 8 a.m. to 9 a.m. and 5 p.m. to 6 p.m.

The National Transportation Management Report (NTMR) 2002 makes a number of recommendations regarding improvements to the taxi industry. Proposals include the establishment of a well managed 'shared ride' taxi service as a more effective way of meeting the high demand caused by the clustered nature of visitor air arrivals and departures as well as a more efficient means of transporting more passengers in fewer vehicles. It also suggests that there may be some potential for taxis to become more involved in the transport of commuters to and from work.

10.2.9 Minibus Services

There are currently four minibus services on the Island. One operates in the east end, one in the west end (Sandys and Southampton) and a third in Pembroke. Most recently in February 2004, a minibus service started operating in the central Warwick area. These services supplement the PTB bus service by providing an 'on-demand' bus service. The vehicles are much smaller than PTB buses and generally carry no more than 20 passengers.

Whilst none of the minibus services can serve the airport for pick-ups, some take visitors to the beaches and on sightseeing tours. Residents use the services when the PTB ceases to operate, particularly in the evening and in more remote areas not served by the PTB buses.

In addition, a subsidised minibus feeder service is provided to take people in the Southampton and Somerset area to the Rockaway ferry stop. The minibus operates on a fixed route and provides a free service between Granaway Heights and Somerset Bridge. Minibuses are a valuable and complementary extension to the Island's public transport system and play a significant role in reducing the amount of car traffic on our roads.

Two companies have permits to operate airport shuttle service. Beeline and Bermuda Hosts transport pre-arranged passengers to and from the Bermuda International Airport. The enabling legislation restricts use of the buses, stipulating that at least one leg of the journey must be to or from the Airport. Consequently, the vehicles cannot be used for other transport uses.

10.2.10 Livery Cycles

The NTMR 2002 indicates that approximately 30% to 40% of hotel visitors and 10% to 15% of cruise ship visitors rent cycles. Exempt company rentals also constitute a significant 10% of cycle rentals at a number of bike rental companies.

The increase in the number of vehicles on Bermuda's roads and the subsequent growing concerns about road safety, however, have somewhat tarnished the quaint Bermuda holiday advertisement image of tourists riding scooters along the Island's picturesque rural roads. The Ministry of Transport visitor survey (August 1999) found that approximately 35% of visitors rent livery cycles while on holiday in Bermuda. Of the 65% of visitors who did not rent a cycle, 54% said the reason for not using one was because of safety concerns.

The NTMR 2002 recommends that cycle companies ensure proper training practices are followed and that better monitoring and presentation of safety related statistics to ensure that the cycle industry continues to provide a viable transport option for visitors.

10.2.11 Fuel and Emissions

Although not legislated, gasoline imported to Bermuda has a low sulphur content and meets U.S. specifications. Emissions from diesel engines contain a significant number of carcinogenic organic compounds that are harmful to human health. Diesel-fuelled public buses undergo an emissions test every quarter. Emission charts from July 1999 showed that of the 106 buses at the PTB depot, only four exceeded European standards of 3.2 ppm. These four buses require new engines and are used infrequently. The 1988 series buses emit the most smoke although they do generally meet emission standards. These buses are reserved on school bus routes at peak hours. Particulate emissions from diesel engines can be significantly improved with good maintenance but only slightly improved with an alteration in fuel quality.

The NTMR 2002 includes recommendations to require all new vehicles to meet U.S., Japanese Domestic and European emissions standards The team has also recommended that an emissions testing programme for existing vehicles be established. In 2001, the government passed legislation requiring all imported vehicles to meet the international vehicle emission standards. Additionally, legislation was also passed that permits four-stroke cycles to be imported into Bermuda, as long as they are under 150 cc. Two-stroke (50 cc) cycles will still be permitted for visitor rentals. This is intended to reduce harmful levels of emissions and noise originating from the inefficient two-stroke engine.

10.2.12 Vehicle Noise

The existing noise standard was established in the 1950s and was set at 93 decibels at 20 m.p.h. The results of recent tests conducted on newly imported bikes from Holmes William and Purvey Ltd showed the following noise levels (see table 10.2)

Table 10.2 Vehicle noise levels

Bike type	Noise at 20 mph	Noise at 40 mph
4-stroke Honda 90 cub	83 dB	90 dB
2-stroke Honda Scoopy	85 dB	89 dB
Honda Racing NSR 75	90 dB	90 dB

Source: Holmes William and Purvey Ltd.

Generally, vehicle noise increases with speed which indicates that the current noise standard should be amended to make provision for vehicles travelling at different speeds. Alternatively, this noise standard could be applied without regard to the speed at which the vehicle is travelling.

Many newly imported motorbikes actually have a noise level that is lower than the Bermuda 93-decibel standard. The problem is that many engines are tampered with after purchase to make them louder. Research is being commenced to see whether or not the noise limit of 93 decibels should be lowered for bikes.

The Transport Control Department (TCD) in the City of Hamilton has a device to test the noise levels of vehicles but the noise booth requires upgrading. There is no mobile device on the Island that could be used by the police. Consequently, if the police currently stop motorbikes for excessive noise, they must transport the bike to TCD for testing. This has resulted in a reluctance on the part of the police, particularly officers in the east and west divisions, to issue tickets for excessive noise. However, mobile noise testers do present problems in that factors such as wind, air pressure, rain, ambient noise and location affect noise readings. Research is underway to address the issue of noise originating from motor vehicles, particularly cycles. Figure 10.15 shows the traffic congestion along East Broadway, the Island's busiest and noisiest roadway.

Figure 10.15 Traffic congestion along East Broadway, City of Hamilton

Photo courtesy of the Department of Communication and Information

10.2.13 Alternative Vehicle Technologies

In June 1999, the Ministry of Transport tested the effectiveness of a mini electric car and an electric scooter on the Island (see Figure 10.16).

Figure 10.16 An electric vehicle

Photo courtesy of the Ministry of Transport

In addition, a study was conducted by BELCO in 1998/99 to ascertain the merits of introducing electric vehicles into Bermuda.

The advantages of the electric car were seen to be its low levels of noise and emissions and the increased safety it offers over bikes. No import duty on electric vehicles being brought into Bermuda also favours the development of the electric vehicle market.

The disadvantages included its limited speed which may disrupt the regular flow of traffic, its limited range, the high cost of batteries, battery disposal issues, luggage space being compromised for battery storage, parking issues, the time it takes to recharge the battery, and the need for recharging points to be installed around the Island. Cost is also a restrictive factor with electric vehicles having higher capital and running costs compared to vehicles with internal combustion engines.

The BELCO study concluded that if the electric vehicle market was to establish itself in Bermuda, the following will have to be in place:

- Government would need to establish inspection and safety standards and provide emergency response in accidents;
- The automotive dealerships would need to provide technical support and staff training;
- BELCO would need to install recharging infrastructure, have time-of-day recharging incentives and monitor electricity consumption;
- The private sector would need to invest in fleets of electric vehicles and undertake trial promotions;
- Parking and recharging facilities would have to

be provided for electric vehicle users; and

- Government, BELCO, dealerships, and the private sector would need to promote the electric vehicle market and provide incentives to the public.

On the other hand, it might be that hybrid vehicles, which have both an internal combustion engine for highway driving and an electric motor for stop/go driving, may be a viable alternative to electric vehicles. The NTMR 2002 includes a recommendation that Government consider reducing the duty for hybrid vehicles.

10.2.14 Sustainable Transport

Integral to the task of preserving Bermuda's high quality of life and fragile physical environment is the concept of 'sustainable development'. Sustainable development can generally be defined as striking a balance between economic growth and the conservation of land and natural resources. Transport systems are a key component of sustainable development because of their depen-dence on the use of natural resources and their potentially damaging effect on the physical environment.

The alleviation of many land traffic problems can to a great extent be achieved by encouraging a modal shift from the private car to more 'sustainable' modes of transport such as the bus or ferry that are more efficient in terms of passenger carrying capacity. Transport policies can utilise both 'carrot' and 'stick' measures to enhance the provision of public transport, cycling and pedestrian facilities and to make private car use less attractive. In addition, land use planning policies can encourage patterns of land use and urban form that reduce journey lengths and the need to travel, particularly by private car.

This 'sustainable approach' to resolving Bermuda's transport problems is at the forefront of the Island-wide National Transportation Management Report 2002, as well as the City of Hamilton Plan 2002. Collectively, the key objectives of these two initiatives are to:

- Use the waterways more effectively and modernise the ferry system (see Chapter 11.3 'Local Marine Transport').
- Integrate taxi, bus, minibus and ferry public transport services to provide a seamless and convenient journey for passengers.
- Research and recommend schemes to reduce vehicular traffic, including road pricing, parking fees, and vehicle ownership policies.
- Assess current planning standards for private parking provision Island-wide.
- Conduct further analysis of vehicle emissions, noise standards and the introduction of alternative vehicles (such as electric/hybrid vehicles).
- Analyse the economic contributions of transport to the Bermuda economy including potential economic opportunities and the economic implications of continued growth in traffic congestion.
- Examine the transport needs of the elderly and disabled.
- Conduct an analysis of alternative methods of transporting school children.
- Develop green travel plans for schools and businesses which promote the use of public transport, cycling and walking as alternatives to travelling by private car.

An effective process of monitoring and evaluation needs to be in place in order to identify changes in transport issues, to provide up-to-date information to aid sound decision making, and to evaluate the effectiveness of policies and initiatives aimed at resolving the Island's transport problems.

10.3 Summary

There are no major airport developments planned in the short-term that would have an impact on the environment. In the long term (15-20 years) it is possible that a new terminal will be built in the vicinity of Apron III. This is a logical location as it is near the centre of the runway. This major undertaking could have an impact on the environment and there will be full consultation with the appropriate agencies.

Passenger volume is not expected to increase significantly, as this growth will be consistent with the growth in tourism. Notwithstanding the low growth in passenger volume, growth in aircraft volume may increase as air carriers opt to replace existing aircraft with relatively smaller ones. This will enable the airlines to increase the frequency of flights to Bermuda and to offer more flight schedule options.

The Department of Airport Operations (DAO) has operated Bermuda International Airport since 1995. There have been a number of challenges including developing effective environmental programmes and making the necessary changes to the airport environment to ensure the safety of aircraft. The DAO will continue to make improvements to its environmental programmes by using the best practices consistent with the airport's size and air traffic volume.

There have been a number of transport studies conducted in Bermuda over the last 30 years but despite the implementation of a number of recommendations contained in these reports, traffic is still a major concern.

Bermuda has a total of 599 km (372 miles) of roads. Over the years, the emphasis of the Ministry of Works and Engineering and Housing's road programme has been on improving the safety of roads through road widening schemes and the provision of new sidewalks as well as protecting the character and charm of the Island's roads through sensitive design, road treatments and landscaping.

The Bermuda Railway opened in October 1931 but lasted only 17 years. It is 29 km (18 miles) in length. Today the railway provides a unique and scenic nature trail for walkers, cyclists and horseback riders. There have been a number of physical improvements to the trail in recent years and more improvements are planned for the near future.

In 1999 there was almost one registered vehicle to every person on the Island whilst 50 years ago there was one registered vehicle to every five persons. In 2003 there were 44,112 licensed road vehicles. Traffic congestion is particularly bad in and around the City and increases by some 15% during school term time. Cars dominate as the prime mode of transport to work Island-wide. Approximately 90% of all road accidents involve a private car.

The Island's bus service is extensive with no areas more than half-a-mile from a bus route. The Public Transportation Board operates a fleet of over 106 buses along 11 bus routes. In addition, there are four minibus services which provide a valuable and complementary extension to the Island's public transport system.

Bus transport is a popular mode of transport amongst visitors. Livery cycles are also popular amongst visitors with an estimated 30% to 40% of hotel visitors and 10% to 15% of cruise ship visitors renting cycles.

There are 600 licensed taxis on the Island. Taxi operators act as transport providers as well as tour guides and tourism ambassadors for the Island.

In 2001, the Bermuda Government passed legislation requiring all imported vehicles to meet the international vehicle emission standards.

Research is underway to address the issue of noise originating from motor vehicles, particularly cycles. In addition, the Bermuda Government and Bermuda Electric Light Company have been looking into the feasibility of introducing electric vehicles.

The alleviation of many of the Island's land traffic problems can be achieved by encouraging a modal shift from the private car to more sustainable modes of transport such as the bus or ferry. The Bermuda Government has been successful in modernising the ferry system and continues to work on various transport initiatives to enhance the Island's public transport services.

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Chapter 11

Marine Transport and the Marine Environment

11

11.1 Cruise Ships

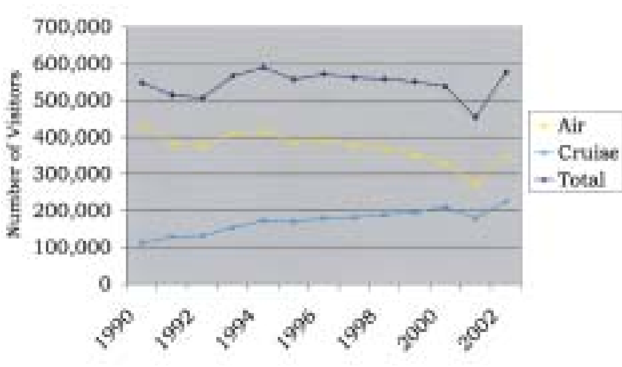
11.1.1 Introduction

Bermuda is a highly sought after cruise ship destination and offers the only Island destination in which a seven day cruise itinerary serving the markets of New York and Boston can be accommodated. It also offers unique berthing facilities that place cruise visitors in the very heart of the Island's three main commercial centres of Hamilton, St. George's, and Dockyard.

Bermuda was served by six contract cruise ships in 2002: the *Zenith*, the *Horizon*, the *Nordic Empress*, the Radisson *Seven Seas Navigator*, the *Norwegian Sea* and the *Norwegian Majesty*.

In 2002, a total of 225,000 cruise ship passengers visited Bermuda representing 39% of all visitors to the Island for the year. Twelve years ago, in 1990, cruise ship passengers only represented 21% of all visitors (see Figure 11.1).

Figure 11.1 Visitor arrivals 1990 to 2002

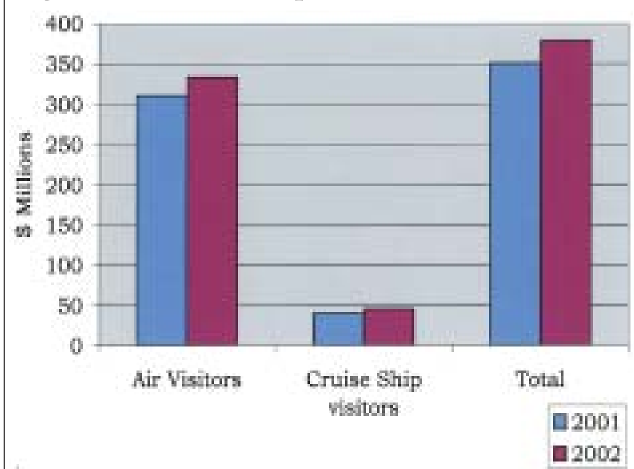


Source: Department of Tourism

The cruise ship industry makes a significant contribution to the Bermuda economy in terms of port dues, cabin and head taxes, shore excursions, water-sport activities, guest and crew members on-shore sales and related contributions.

However, in general, air passengers tend to outspend cruise ship passengers by a ratio of 7:1. In 2002, for example, the total cruise ship passenger expenditure was $45.3 million which apportioned to approximately $226 per person during their stay and included shopping, transport and restaurants. This compares to air visitor expenditure that amounted to $333.5 million in 2002 (or $1,174 per person). Whilst this latter figure includes expenditure on accommodation totaling $217 million or 65% of the total air visitor expenditure, it nevertheless leaves a comparative figure of $117 million expenditure on the same items as cruise visitor expenditure. Passenger expenditure for cruise ship visitors, excluding accommodation is, therefore, 39% of that spent by air visitors. Per person expenditures for both cruise and air visitors were slightly higher in 2002 compared to 2001 (see Figure 11.2).

Figure 11.2 Visitor expenditure 2001 and 2002



Source: Department of Tourism

Whilst the Island has the potential to generate much more cruise ship traffic, there is concern regarding the Island's visitor carrying capacity. The Island's small size and delicate infrastructure means that visitor numbers have to be carefully managed. In order to maintain a high quality visitor experience and not exceed the ability of the transport and attraction infrastructures to accommodate the visitors, it has been deemed necessary to have a policy which limits the number of cruise ship passengers on the Island to 7,500 per day.

At present, Tuesdays, Wednesdays and Thursdays are peak days for cruise ship visitors and the numbers of cruise ship passengers on the Island on these days often exceeds 7,500. Such a high number of cruise ship visitors on the Island at approximately the same time, coupled with the fact that the visitors also tend to travel around the Island at the same time of the day, has a significant impact on the Island's public transport system. The Public Transportation Board has to supplement the regular bus service with additional buses and the ferry system often experiences overload.

11.1.2 Cruise Ship Movements

Bermuda currently has three cruise ship ports and five cruise ship berths, two in Hamilton, two in St. George's and one in Dockyard.

Cruise ship policy has generally adopted a two port concept. In the 2002 season, five of the six cruise ships visited two ports with one ship only calling at one port.

The merits of a ship calling at more than one port include a higher quality visitor experience, less pressure on the Island's transport infrastructure and a greater distribution of visitor revenue around the Island. The disadvantage, however, is that of increased cruise ship movements and the potential detrimental impact on the marine environment including sedimentation on coral reefs.

11.1.3 Larger Cruise Ships

The cruise ships that currently service Bermuda are no more than 700 ft in length and have a passenger capacity of no more than 1,800. These are the smallest ships (in terms of their length, passenger capacity and gross tonnage) in the fleets of the cruise lines which call at Bermuda. They are also the oldest ships in the fleets. The six ships under contract with Bermuda in 2002 had an average age in excess of 10 years. These older cruise ships are gradually being replaced by newer, larger ships which have a length of 900 to 950 ft, a draft of 28 ft, a beam of approximately 106 ft., a passenger capacity of between 2,000 to 2,500 and a crew capacity of 800.

Dockyard is the only port that is currently physically capable of accommodating the larger cruise ships in operation. There has been some discussion with the cruise lines regarding the possibility of building a smaller cruise ship(s) to suit Bermuda's specifications but the cruise lines are not enthusiastic. The inflexibility of using a smaller ship in other destinations during the Bermuda off-season is cited as a major problem. In addition, cruise lines would expect the Bermuda Government to guarantee a long term commitment to the cruise line of at least 10 years.

Figure 11.3 Cruise ships in port, the City of Hamilton

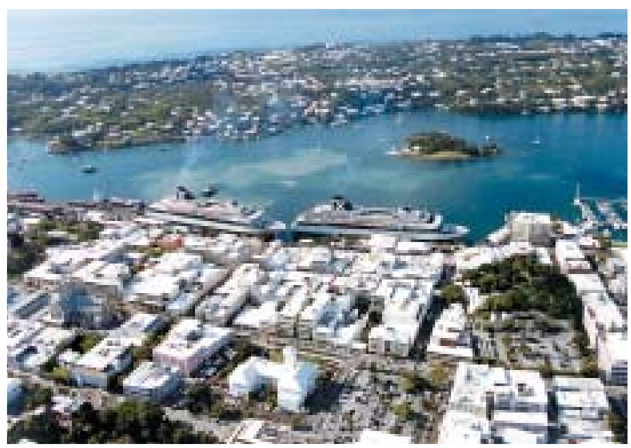


Photo courtesy of the Department of Communication and Information

If Bermuda decides that its three ports should be redesigned to accommodate the new larger cruise ships, some significant infrastructure developments would be required. Such developments may include land reclamation, erection of finger piers, dredging of the harbour and the widening of Town Cut, all of which would have potentially significant environmental impacts. An analysis of the future of the cruise ship industry is required to determine if and how Bermuda can accommodate larger cruise ships. In 2004, the Bermuda Government's Ministry of Transport commissioned consultants Bermello Ajamil and Partners to conduct a planning and design assesment associated with the improvement and expansion of Bermuda's cruise ports to accommodate larger cruise vessels, passenger flows and transport demands. This study will include an assesment of the viability of relocating the City of Hamilton cargo facilities to another location on the Island.

11.1.4 Sewage

In 1988, the International Convention for the Prevention of Pollution from Ships (MARPOL) was revised to include Annex IV which addresses sewage disposal. Annex IV is being further amended at the time of writing and will not come into effect until July 2005 at the earliest, following which existing ships will have five years to comply with the following conditions.

Every ship to which Annex IV applies (those certified to carry more than 15 persons) shall be equipped with either a sewage treatment plant or a sewage comminuting and disinfecting system or a sewage holding tank. The discharge of sewage into the sea is prohibited, except when the ship:

- has in operation an approved sewage treatment plant; or
- is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; or
- is discharging sewage which is not comminuted or disinfected at a distance of more than 12 nautical miles from the nearest land.

The sewage treatment plants at WEDCO and St. George's are heavily impacted by cruise ships, contributing to approximately 50% of the total daily flow of sewage at these plants during the cruise ship season. The Corporation of Hamilton's sewage treatment plant is less impacted as cruise ships only contribute approximately 14% of the total flow. The Corporation of Hamilton has just upgraded its sewage treatment plant to a preliminary treatment plant and St. George's may upgrade to a tertiary sewage treatment plant. Dockyard has no plans to upgrade its secondary treatment plant.

All data relating to the flow of sewage from cruise ships into the treatment plants are estimates and there are currently no controls or regulations concerning the type or amount of sewage disposed into the plants. A study commissioned in 1999 by the Bermuda National Trust entitled 'The Potential Impacts of Cruise Ships on Bermuda's Environment' recommends that in the future, the volume and type of sewage disposed of by cruise ships should be recorded. Regulations should be established and enforced with respect to monitoring the type of sewage disposed of in Bermuda's treatment plants. The report also proposes that scientific studies be conducted to assess the long-term impacts of sewage disposal at sewage outfall sites and that water quality criteria be set for Bermuda's inshore waters.

The Bermuda Government's *Discussion Paper on Marine Resources and the Fishing Industry in Bermuda* (2000) recommends that visiting yachts use onshore sanitary and trash facilities. It also states that boats and ships above a certain size which enter Bermuda's inshore waters are equipped with holding tanks which can be discharged offshore in deep waters. Under Annex IV of MARPOL, this will apply to vessels certified to carry more than 15 persons and 'offshore' i.e., at a distance of more than 12 nautical miles from the nearest land. Alternatively, vessels should be required to hook up to the disposal system at Hamilton or Dockyard or the pumpout stations at marine service stations.

11.1.5 Recycling

Materials that can be recycled are collected from some of the cruise ships visiting the Island. Whilst there is no accurate data on the total volume collected, it is thought to be significant enough to heavily impact the Island's recycling plant and yet there is no processing charge to the cruise ships.

The Bermuda National Trust study recommends that a thorough assessment of the volume of recyclable material collected from the cruise ships be conducted. This would establish the level of impact created by cruise ships on the Bermuda recycling plant and identify what alternative solutions for the disposal of recyclables by cruise ships should be investigated.

11.1.6 Coral Reef Sedimentation

There is some scientific data on the potential impact of sedimentation caused by cruise ship movements on adjacent coral reefs but this issue requires more research into the long term impacts. This issue is particularly important to investigate with regard to the new larger cruise ships since these are designed to have propellers that allow greater manoeuvrability. This, in turn, increases water column movement and turbulence that increases sediment re-suspension.

11.1.7 Dredging

In order to accommodate the new, larger cruise ships, dredging would be necessary for the modification of berths in St. George's and Hamilton as well as dredging associated with an expansion of Town Cut. It has been suggested that the dredge spoils could be used as landfill to create an expansion of the waterfront in the City of Hamilton.

The Bermuda National Trust study recommends that guidelines be developed for the assessment and remediation levels of trace metal concentration in the marine sediments of Bermuda's inshore waters. It also proposes that scientific data be obtained on the pollutant concentrations of heavy metals and organic compounds associated with sediments in the harbours prior to any proposed dredging work. It is recommended that guidelines be drawn up by the Bermuda Biological Station for Research for the Ministry of the Environment regarding the disposal of dredged material. Scientific studies should also be carried out to assess the transport of bed load and suspended load of sediment in Hamilton and St. George's harbours prior to proposed dredging.

11.1.8 Antifouling and Leaching of Contaminants

Tributylin (TBT) is an organotin added to paint used on ship hulls to prevent them from becoming encrusted with barnacles. In open water, TBT breaks down. In the 1980s, researchers found that TBT was severely contaminating many inshore waters and causing deformities in marine animals.

In 1989, Bermuda banned the importation and use of TBT antifouling paints, although there were exceptions. In 1999/2000, a total ban was imposed in Bermuda. There is a worldwide movement to ban TBT and a call from the International Maritime Organisation (IMO) for complete prohibition of TBT by 2008.

TBT is presently used as antifouling paint on boats larger than 25 metres, such as cruise ships. Detailed scientific data exists on TBT levels in Bermuda's inshore waters and indicate that large ships (container ships and cruise ships) are a potential source of TBT to Bermuda's coastal waters.

The use of two other chemicals, Irgarol 1051 and Diuron, will be prohibited under the proposed Fisheries (Anti-Fouling Paints Prohibition) Amendment Regulations, 2003.

There is no legislation regarding dockside cleaning of ships in Bermuda nor adequate regulations regarding the input of contaminants into Bermuda's inshore waters, for example from waste disposal, boat cleaning agents, and leaching from antifouling paints. The only available Act is the Water Resources Act, 1975 that does not provide any specific limits on contaminants entering the water column.

It has been recommended that guidelines and/or regulations be established to control the levels of contaminants entering the inshore waters.

11.1.9 Noise Emissions

Cruise ships generally provide onboard entertainment for their guests. At times, these events disturb residents living near the ports. Amplified noise pollution in Bermuda is controlled under the Summary Offences Act, 1926. This states that any amplified noise made beween midnight and 6 a.m. that is more than 100 ft from the source and annoys two or more people is an offence, as well as any amplified noise made between midnight and 6.00 a.m. that disturbs any resident in the vicinity. However cruise ships are not prosecuted under this law.

The Bermuda National Trust study recommends that the existing provision be enforced regardless of the source of noise and that the Ministry of Tourism work to reduce the level of noise emanating from cruise ships by helping in the provision of more land based entertainment.

In addition to entertainment related noise from cruise ships, some residents and businesses are adversely affected by cruise ship soot and engine noise.

11.1.10 Cruise Ship Policy

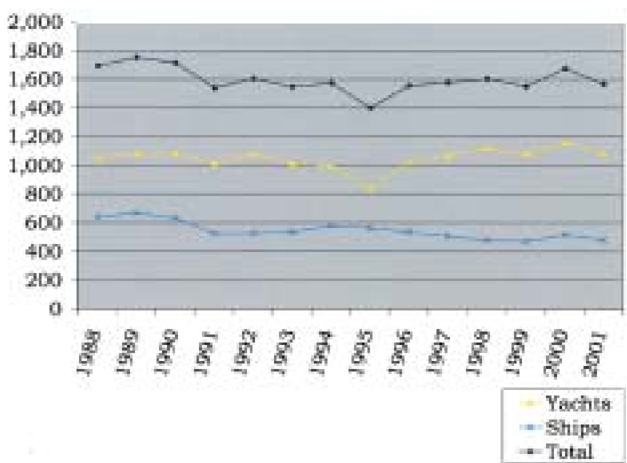
Cruise ship issues are complex. In developing a new cruise ship policy for Bermuda, the whole array of issues involving tourism, transport, infrastructure requirements, retail, revenue potential, and the marine environment need to be considered. In 2002, the Ministry of Tourism and the Cruise Ship Policy Committee prepared the Cruise Ship Policy 2002 Report. The 2002 Policy was adopted by Cabinet and it addresses many of the operational and environmental issues

11.2 Overseas Shipping

11.2.1 Introduction

In 2001, a total of 1,566 ships arrived in Bermuda, 69% of which were yachts and 31% of which were ships. Of the 481 ships that arrived in 2001, 71% were cargo and passenger ships. More than half of these berthed at Hamilton and just over one-quarter of them berthed at St. George's. As shown in Figure 11.4, the number of ships arriving in Bermuda from overseas has been fairly consistent over the years.

Figure 11.4 Arrival of overseas shipping



Source: Department of Marine and Ports Services

11.2.2 Ship Groundings

The impact of ship groundings on the marine environment is potentially significant. Not only do the ships themselves damage the reefs when grounding but the blasting that is at times employed to salvage them may further damage the reef. In addition, ships may spill potentially polluting cargo.

The vulnerability of Bermuda's coral reef system was dramatically demonstrated in 1984 with the grounding of the fully laden super tanker *Aguila Azteca* on the reefs to the north of Bermuda. Carrying 196,000 tons of heavy Maya crude oil, this quantity of oil on board was three times the amount carried on the *Exxon Valdez*. It was considered to be an environmental time bomb and its grounding could easily have created the largest oil spill in history were it not for the unseasonably mild weather. In addition, if the hull had ruptured, the combination of oncoming inclement weather and emulsified oil could have destroyed the reefs and affected Bermuda's potable water supply. Fortunately the tanker was refloated without incident.

The potentially catastrophic nature of the grounding of the *Aguila Azteca* forced the Bermuda Government to petition the International Maritime Organisation (IMO) to create an internationally recognisable 'Area to be Avoided' (ATBA) around the Island. This ATBA is published in navigation charts and publications and is repeated in notices to mariners together with the instruction that vessels not bound for Bermuda ports should pass at least 30 miles distant. In addition, the Bermuda Government invested several million dollars in (RACON) active radar responding beacons and navigation beacons on the fringing reef to indicate navigational hazards.

Figure 11.5 *Aguila Azteca*

Photo courtesy of Michael Dolding

The Bermuda Government's Rescue Co-ordination Centre (RCC) Bermuda/Bermuda Harbour Radio, operates on a 24-hour basis. The RCC uses a combination of scheduled radio broadcasts and a radar surveillance system to monitor and control shipping traffic within 30 miles of Bermuda for environmental protection and the prevention of maritime disasters. Vessels within 30 miles of Bermuda are required to maintain radio communications with the RCC. This work has been successfully undertaken since 1986.

11.2.3 Oil Spills and Oil Spill Contingency Planning

The density of shipping traffic, especially oil and chemical tankers, passing Bermuda and the number of visits made by cargo and passenger vessels to the Island presents a risk of marine pollution. Even a limited oil spill in coastal waters could temporarily ruin beaches, seriously affect marine life in the intertidal zones, foul pleasure craft and rocky shorelines and generally threaten the marine and coastal environment of Bermuda.

Since 1976, when there was an oil spill from the passenger liner *Statendam*, Bermuda's oil spill response has been very effective. More than 135 spills have occurred in local waters since then and of these 22 have been pursued in court, all of which have led to convictions.

A marine pollution contingency plan (MPCP) is in place to provide a formal response procedure in the event of oil spills and the spillage of other toxic substances in coastal waters. The objectives of the MPCP are to document the procedure for responding to spills of oil and other toxic substances in local waters, to make maximum use of the limited local resources, and to provide the means for acquiring assistance from overseas as required. The MPCP satisfies the requirements of Article 6 to the International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990.

No small island can expect or afford to develop and maintain a response capability to deal with major oil spills. The MPCP provides a system for reporting oil spills and provides for a command structure appropriate to the magnitude of the spill. For larger spills, for which local resources are found to be inadequate, the MPCP provides procedures for requesting and acquiring international assistance to aid in cleanup and containment of the spill.

The MPCP is administered by the On-Scene Co-ordinator (OSC) who is supported by the Command Team that is made up of leaders of various resource agencies. These agencies include the Bermuda Government Departments of Marine and Ports Services, Marine Police, Parks, Environmental Protection and Conservation Services; the Bermuda Regiment; and the Shell and Esso companies of Bermuda. Stockpiles of oil spill containment boom and cleanup equipment are on hand at various locations. The stockpiles are located at the Marine and Ports offices, Hamilton Harbour; Marginal Wharf, St. David's; Coney Island; the Shell depot at Dockyard; and the ESSO facility at Richardson Bay, Ferry Reach.

Maps of Bermuda's coastline showing priority areas that require maximum effort for protection, cleanup, and conservation are stored at Harbour Radio, Fort George. Fifteen coastal environments are ranked on a sensitivity scale to reflect the expected persistence of oil spills on the coastline. Also shown are water depths, current velocities and distances across inlets for deployment of containment or deflection booms.

One of the main objectives of an oil spill response is to minimise the impact of the spilled oil on marine life, the coastal and inshore waters and amenities. When there is an imminent threat to any of these coastal resources, the use of chemical dispersants may be approved on a site-specific basis by application to the Ministry of the Environment.

The use of chemical dispersants is becoming an increasingly accepted tool for marine oil spill response. When applied to a fresh oil spill, chemical dispersants accelerate the process of natural dispersion, transferring the oil from the surface of the water into the water column. In addition they decrease the 'coating' properties of the oil thus reducing the impact on shorelines and reducing the cleanup effort. Once dispersed, waves and currents rapidly dilute the oil. Dispersing spilled oil generally reduces the impact on marine birds, sensitive shoreline habitats and the potential for oil to be stranded on beaches or other shoreline areas. The effectiveness of chemical dispersants in oil spill response depends to some extent on the properties of the spilled product but also relies heavily on their prompt application, preferably within the first 24 to 36 hours of the spill.

Chemical dispersants remove spilled oil from the surface of the water and suspend it as tiny droplets in the water column. The concentrations of the dispersed oil are highest in the top several feet of surface water and concentrations decrease quickly with depth. Accordingly, dispersant use should be limited to areas where there is sufficient water depth to accommodate the oil and sufficient wave and current to mix the dispersed oil. The areas where the use of chemical dispersants is pre-approved are as follows:

- The area beyond the 10-fathom line around the Bermuda platform;
- Areas a minimum of 1,000 metres from shore;
- Areas a minimum of 500 metres from a shallow reef (less than 5.5 metres deep (3 fathoms));
- Areas within the Bermuda platform where the water is a minimum of 5.5 metres deep (3 fathoms); and
- The area a minimum of 100 metres from shore along the northwest coast of St. George's Island. This is a high-risk area due to the proximity of the shipping channel and oil terminal.

Annual exercises both on paper and in the field are staged to provide training for local responders to marine pollution incidents.

A major three-day exercise was conducted on 12–14 May 1998, code named 'Exercise Weatherbird'. Exercise Weatherbird was a co-operative oil spill response exercise co-sponsored by Esso Bermuda and the Bermuda Government. It was designed to test the effectiveness of the Bermuda Marine Pollution Contingency Plan and the readiness of the local and international response teams to be called upon in the event of a large oil spill. The exercise involved deployment of local (Tier 1 and 2) resources (booms, boats, vessel-based dispersant delivery systems), integration of the Bermuda Command Team with international advisors from the petroleum and shipping industries, and the mobilisation and deployment of international Tier 3 resources from the Clean Caribbean Co-operative (CCC) of Ft. Lauderdale, Florida.

Figure 11.6 Exercise Weatherbird

Photo courtesy of Esso Bermuda

Exercise Weatherbird was a significant undertaking involving over 100 people from the Government of Bermuda and other local organisations as well as over 50 offshore participants from the petroleum, shipping, oil spill response and insurance organisations.

Exercise Weatherbird was successful due to Bermuda having a well-developed contingency plan and short chains of command. It highlighted the need for improved communication systems, cost controls and comprehensive public relations support during an actual spill event.

11.2.4 Other Issues

As with cruise ships, sediment deposits on the coral reefs and dredging are significannt environmental concerns.

Another issue of concern, which has been a serious problem in many parts of the world, has been the introduction of invasive marine species through the discharge of ballast water that is used to stabilise ships when they have no cargo. Fortunately, in Bermuda, vessels usually arrive fully laden and leave empty. The RCC Bermuda/Harbour Radio directs vessels not to discharge ballast water inside the 100-fathom contour which reduces this risk.

There are additional issues relating to the visual impact of container ships and the contentious issue regarding the use of prime waterfront in the City of Hamilton for the container docks.

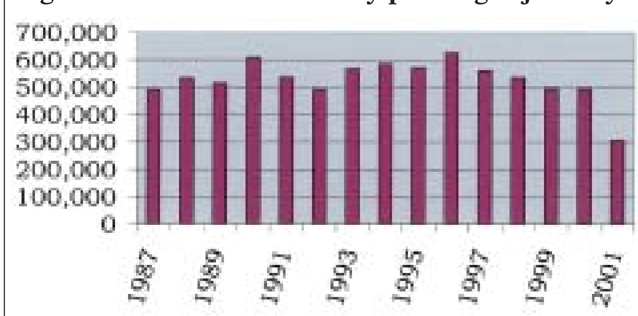
11.3 Local MarineTransport

11.3.1 Ferry Transport

In 2001, there were a total of 306,884 ferry passenger journeys, a significant drop of over 187,000 (38%) on the previous year (see Figure 11.7). This drop is also reflected in the lower visitor arrival figures for 2001 which were a result of the terrorist attacks in the United States.

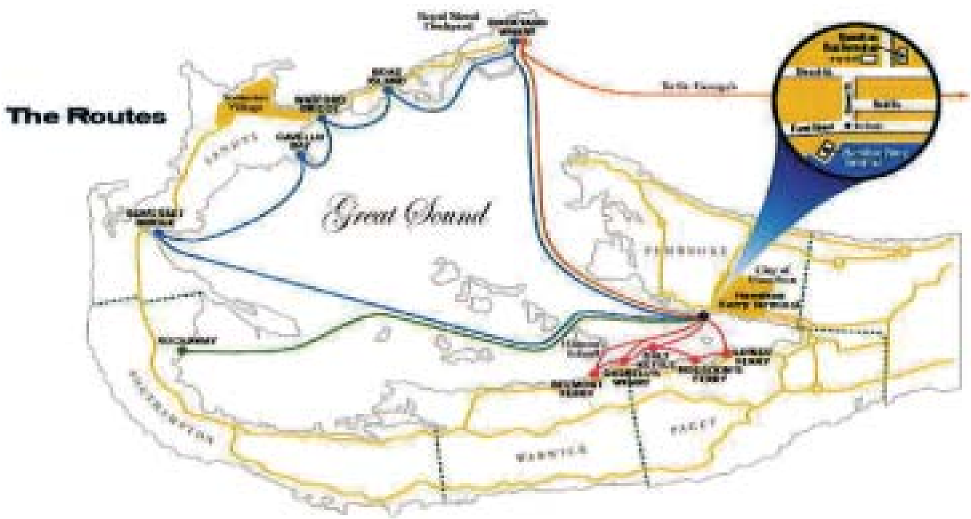
Bermuda's ferry service currently comprises 10 ferries. These include three small Paget/Warwick boats, three old Somerset ferries which to be phased out in 2005/6 and four new catamaran ferries (*Serenity*, *Resolute*, *Venturilla* and *Tempest*). There are four ferry routes, the Hamilton-Paget-Warwick route, the Hamilton-Somerset/Dockyard route, the Hamilton–St. George's route (summer only) and most recently the Hamilton-Rockaway, Southampton route.

Figure 11.7 Number of ferry passenger journeys



Source: Department of Marine and Ports Services

Figure 11.8 Ferry routes



Source: Ministry of Transport

The Hamilton-Paget-Warwick route accounted for just over 105,000 passenger journeys in 2001, a decrease of 58,304 on the previous year. Most of the passengers travelling on this route are commuters working in the City and visitors staying at hotels and guest houses in the Paget and Warwick areas. Over the last few years, the level of passenger journeys on this route has dropped due to some significant tourist properties having either closed completely or for renovations which has resulted in a lower patronage on this route.

The Hamilton-Somerset/Dockyard route accounted for approximately 201,000 passenger journeys in 2001. This route increased its patronage during the 1990s due to the redevelopment of Dockyard and increased visitor demand as well as the increased commuter demand within the Southampton and Sandys parishes.

The third route between Dockyard and St. George's operates during the May to September cruise ship season. This service started in 1996 and was initially intended to serve visitors. It has also proved popular with resident senior citizens.

The 2000 Census indicated that the ferry service only attracts about 2% of commuters to the City of Hamilton. Market research conducted by the Ministry of Transport in 1999/2000 as part of the National Transportation Management Report (NTMR) 2002, however, indicated strong public support from both residents and visitors for improvements to the ferry service. Residents, in particular, were keen to see improvements such as extended hours of service, provision of parking and drop-off areas at ferry stops and a minibus service to/from the ferry stop as a means of encouraging more people to use the ferry service. One of the main objectives in the NTMR was therefore to modernise the ferry system.

A 'sustainable approach' to resolving Bermuda's land transport problems is better utilisation of Bermuda's extensive waterways. The National Transportation Management Report (NTMR) 2002 details ways to achieve this through the establishment of a more effective and modern ferry system. The NTMR 2002 sets out to: replace the ageing Somerset/Dockyard ferries with new catamaran ferries which are faster and more comfortable; construct new docks and ferry stops to accommodate the new vessels; provide an improved ferry service in terms of scheduling, cost efficiency and convenience; provide additional amenities such as minibus feeder services, parking at ferry stops, more sidewalks and improved lighting; and integrate the fare structure and scheduling of the service with other public transport services.

The first phase of the ferry modernisation project started in 2002 with the construction of a new ferry stop at Rockaway in Southampton (see Figure 11.9) and improvements to the Hamilton Ferry Terminal and ferry docks at the Hamilton Depot, Dockyard and St. George's. In 2002, two new, higher speed, catamaran style ferries (*Serenity* and *Resolute*) started operation (see Figure 11.10). During the morning rush hours, the new ferries are used to provide a commuter service from the Rockaway ferry stop in Southampton to the City of Hamilton.

Figure 11.9 New ferry stop at Rockaway, Southampton

Photo courtesy of the Department of Planning

Out of rush hours, the new ferries are used on the Hamilton/Dockyard/St. George's routes and largely serve visitors, senior citizens and school groups. The addition of the new ferry boat service in Dockyard has significantly improved public transport provision from Dockyard by relieving pressure from the PTB buses. It has also been significant in attracting cruise ships to dock in the West End.

Figure 11.10 The new catamaran ferries *Serenity* and *Resolute*

Photo courtesy of the Ministry of Transport

According to the results of a survey undertaken during the week of 5 to 9 January 2004, 673 passenger trips were made per day on the Rockaway ferry. This is a 190% increase in daily ridership since the Rockaway ferry's first day of service on 2 April 2002.

It is estimated that 25% of the passengers using the Rockaway ferry use the subsidised minibus feeder service to get to the Rockaway ferry stop. The Rockaway ferry stop also provides free car parking and bike parking. The Rockaway ferry service has proved to be very successful in providing commuters in the West End with a viable alternative mode of transport to the car. It is expected that the percentage of commuters using the ferry to get to work will have increased significantly since the 2000 Census.

These recent enhancements to the ferry system have provided a much improved service to visitors and residents. In 2004, two additional ferries (*Venturilla* and *Tempest*) were delivered. These will enable the gradual replacement of the older ferry boats. In addition, they will provide backup for the two existing new ferries and will offer the potential for new ferry routes and ferry stops in the future, so further improving the ferry system.

Special attention has also been applied to the environmental elements of the new ferry boats including the following:

(i) Wake

The wake of the older ferry boats has been measured at four feet at 300 metres from the boats. The specifications for the new ferry boats specify a wake of three feet at 300 metres at full 22- knot speed. This results in less wake than the older boats and less shore erosion.

(ii) Noise

Exterior noise levels from the new boats are specified as 80dbA at 100 metres from the boat. This noise level is no worse than the older boats, which are considered to be very quiet. Interior noise on the older boats is relatively high with noise levels much less (72dbA) on the new boats.

(iii) Sewerage

The older Somerset ferry boats lack sewerage holding tanks. The new boats have sewerage tanks installed. Sewerage is pumped from the boats to a holding tank at the Hamilton Depot, located at Marine and Ports Services Headquarters at East Broadway, from where it is discharged into the Corporation of Hamilton sewer.

(iv) Emissions

The new ferry boats have the latest marine emission controls, meeting International Maritime Organisation (IMO) certifications. These comply with MARPOL (Marine Pollution Convention 1973-78, Annex V1) for NOx limits. This international requirement came into force in January 2000. Bermuda currently lacks marine emission controls; however, the Ministry of Transport has set a high standard for ferry vessels by meeting the latest international emission controls.

11

11.3.2 Water Taxis

There are very few water taxis currently operating in Bermuda despite the fact that anyone is permitted to operate a water taxi providing it does not run in direct competition with the ferry service. It is anticipated, however, that this form of transport will grow in importance. As indicated in a Ministry of Transport visitor survey conducted in August 1999, there is high demand for water taxis as an additional transport mode for visitors.

11.3.3 Other Watercraft

Table 11.1 shows the numbers and type of registered watercraft with engines for 2003/2004.

In addition to motorised boats, in 2003/2004, registered and unregistered private boats without engines totalled 3,621 while rental boats with no engine totalled 139.

Table 11.1 Registered watercraft (with engines) in 2003/04

Type of Vessel	Number
Commercial Fishing Boats	182
Charter Fishing Boats	32
Subtotal	**214**
Private boats	6,834
Charter boats (includes motor yachts and sailboats)	75
Rental boats	124
Private jet skis	517
Rental jet skis	52
Subtotal	**7,602**

Source: Department of Marine and Ports Services

The Department of Marine and Ports Services estimate that the number of watercraft on the Island has increased by approximately 30% over the last 10 years. In addition to locally registered boats, some 1,000 foreign pleasure boats visit Bermuda every year and stay on average three to five days.

There were 182 commercial fishing boats and 32 charter fishing boats registered until 31 March 2004. A wide variety of craft are used in Bermuda's fishing industry ranging in size from 10 ft dinghies to boats of 100 ft or more. Boats also vary in the power, electronics and equipment used.

The charter fishing boats vary in their operations. Some only operate in the tourist season from May to November while others operate as commercial fishing boats in the winter and take charters in the summer months.

Up to five U.S. registered sport fishing boats visit Bermuda each year. The majority come to participate in the Bermuda Big Game Classic in July. The activities of these boats probably have a minimal impact on local fish stocks. However, it is considered that the benefits the owners, guests and crew of these boats bring to the local economy in terms of use of hotel accommodation, restaurants and shops may encourage the growth of this sector of the tourism industry.

Figure 11.11 Fishing and pleasure boats at Jews Bay, Southampton

Photo courtesy of the Department of Communication and Information

Motor boats and accessory structures that are associated with their use pose serious potential threats to the marine environment. Environmental concerns include the increase in foreshore development, the impacts of anchor damage and pollution. There is also concern that boat drivers are not obliged to obtain a driver's licence unless they intend to use their boat for hire or charter. In addition, little guidance or training is given in terms of codes of conduct on the water and rules for protecting the marine environment.

The majority of outboards in use today are two stroke engines primarily because the two stroke design has a better power to weight ratio compared to the four stroke engine. The two stroke cycle is accomplished by having both the intake and exhaust ports at the bottom of the cylinder where they are both opened when the piston reaches the bottom of its downward travel. However with both ports opened at the same time, some of the incoming fuel and air mixture flows out of the exhaust unburnt and pollutes the environment. Approximately 25–30% of unburnt fuel is exhausted in the conventional two stroke engine which does not comply with the Environmental Protection Agency (EPA) emissions standards.

There is a noticeable proliferation in the four stroke outboards because the four stroke cycle is better at regulating the flow of fuel which results in less waste and polluting emissions. The four stroke is cleaner, however its cost, weight and durability are arguments against its use.

The new generation of two stroke engines has solved the lack of fuel control problem with direct fuel injection (DFI). Improved control of fuel is achieved by injecting the fuel into the cylinder as the piston is moving upward with both intake and exhaust ports closed. The new generation of two strokes has now matched the economy of a four stroke and most new models exceed the 2006 EPA emission standards.

With both two and four stroke engines complying with the EPA emission standards, the move to phase out two stroke outboard engines has ceased and the choice remains one of the consumer.

The Water Safety Council is appointed under the Bermuda Constitution Order, 1968, section 61. Its objectives are to identify issues with respect to water safety and to develop local strategies to prevent accidents and injuries on the water by means of relevant marine safety regulations, public education and the promotion of good water safety practices throughout the community. In 2001, the RCC (Rescue Coordination Centre) Bermuda, more commonly known as Bermuda Harbour Radio, handled 337 incidents where there was a threat to the safety of life, while a further 296 incidents of a non-life threatening nature were also handled.

11.4 Summary

Bermuda is a highly sought after cruise ship destination offering the only Island destination in which a seven day cruise itinerary serving the markets of New York and Boston can be accommodated as well as offering berthing facilities that place cruise visitors in the very heart of the Island's three main commercial centres of Hamilton, St. George's and Dockyard.

In 2002, a total of 225,000 cruise ship passengers visited Bermuda representing 39% of all visitors to the Island for the year. Twelve years ago, in 1990, cruise ship passengers only represented 21% of all visitors. The cruise ship industry makes a significant contribution to the Bermuda economy in terms of port dues, cabin and head taxes, shore excursions, water-sport activities, guest and crew members on-shore sales and related contributions. The Island's small size and delicate infrastructure, however, means that visitor numbers have to be carefully managed.

Cruise ship issues are complex. In developing a new cruise ship policy for Bermuda, the whole array of issues involving tourism, transport, infrastructure requirements, retail, revenue potential and the marine environment need to be considered.

The cruise ships that currently service Bermuda are some of the oldest and smallest in the fleets of cruise lines which call at Bermuda. These cruise ships are gradually being replaced by newer, larger ships. Dockyard is the only port that is currently physically capable of accommodating the larger cruise ships in operation. In 2004, the Bermuda Government's Ministry of Transport commissioned consultants to conduct a planning and design assessment associated with the improvement and expansion of Bermuda's cruise ports to accommodate larger cruise vessels, passenger flows and transport demands.

The main environmental issues associated with cruise ships include sewage disposal, recycling, the impact of coral reef sedimentation, dredging, antifouling, leaching of contaminants and noise emissions. Large ships also pose concerns with regard to ship groundings and pollution (including oil spills and fuel leakages). Bermuda has a marine pollution contingency plan (MPCP) in place to provide a formal response procedure in the event of oil spills and the spillage of other toxic substances in coastal waters.

The National Transportation Management Report (NTMR) 2002 details ways of establishing a more effective and modern ferry system. This includes replacement of the older ferries with new ferries which are faster and more comfortable, the construction of new docks and ferry stops to accommodate the new vessels, improvements to the ferry service (scheduling, cost efficiency and convenience) and the provision of additional amenities (minibus feeder services, and parking, sidewalks and lighting at ferry stops).

The first phase of the ferry modernisation project started in 2002 with the construction of a new ferry stop at Rockaway in Southampton and improvements to the Hamilton Ferry Terminal and ferry docks at the Hamilton Depot, Dockyard and St. George's. Bermuda's ferry service currently comprises 10 ferries of which four are new, higher speed ferries.

There are very few water taxis currently operating in Bermuda despite the fact that anyone is permitted to operate a water taxi providing it does not run in direct competition with the ferry service. It is anticipated, however, that this form of transport will grow in importance in the future.

The Department of Marine and Ports Services estimate that the number of watercraft on the Island has increased by approximately 30% over the last 10 years. Motor boats and accessory structures that are associated with their use pose serious potential threats to the marine environment. Environmental concerns include the increase in foreshore development, the impacts of anchor damage and pollution.

The Water Safety Council identifies issues with respect to water safety and develops local strategies to prevent accidents and injuries on the water by means of relevant marine safety regulations, public education and the promotion of good water safety practices throughout the community.

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3 Waste Management and Pollution

Chapter 12

Waste Management and Pollution

12.1 Solid Waste

12.1.1 Introduction

Waste is broadly defined as 'unwanted material or refuse from places of human or animal habitation' (www.epa.gov). Nearly everything we do leaves behind some kind of waste. Households create ordinary garbage and industrial and manufacturing processes create solid and hazardous waste. In Bermuda's case, waste is predominantly municipal solid waste from residential and commercial sources since there is very little industry and manufacturing on the Island.

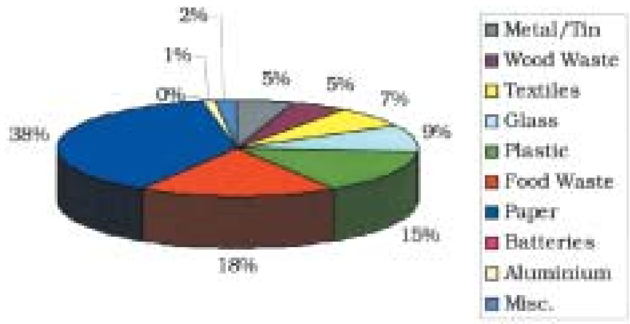
Bermuda has one of the highest garbage generation rates in the world in terms of per capita income. Every year approximately 100,000 tonnes of garbage is produced of which 68,000 tonnes is burnable waste while the remaining 32,000 is non-burnable. Of the 68,000 tonnes of burnable waste, 23,000 is collected from residences and 45,000 is generated by commercial sources.

Since 1975, waste quantities have increased by approximately 3 to 4% annually. Assuming these trends continue, by the year 2010 Bermuda will be generating about 125,000 tonnes of waste annually.

Solid wastes produced in Bermuda include municipal waste (both residential and commercial), hazardous waste, construction waste as well as dredge and spoil waste.

Figure 12.1 shows that from a sample of 349 kg (770 lbs) of residential waste collected and examined in February 2000, paper comprised the largest percentage (38%) followed by food waste (18%).

Figure 12.1 Composition of residential waste – February 2000 (sample size 770 lbs)



Source: Ministry of Works and Engineering and Housing

Household garbage is collected twice a week by the Ministry of Works and Engineering and Housing (MWEH) and recyclables are collected once a week by a private contractor. Residents are also able to call the MWEH to arrange a special collection of bulky waste. The MWEH does not provide any commercial collections.

The Corporation of Hamilton and the Corporation of St. George's collect commercial and residential garbage and recyclables within the City of Hamilton and the Town of St. George respectively. Private haulers provide waste collection services to hotels, guest houses, cruise ships, wholesalers and retailers who are not otherwise served.

For many years landfilling was the only means of waste disposal. Today, however, there is a comprehensive waste management system with incineration as the main method of disposal. This is also supported by recycling, windrow composting, hazardous waste programmes and a land reclamation project which involves the landfilling of scrap vehicles, metals, appliances, construction waste and demolition waste. The amount of waste disposed of at each location is shown in Table 12.1.

12.1.2 Landfill – The Pembroke Dump

From the 1930s until 1994 the Pembroke Dump was the Island's main waste disposal site, receiving approximately 80% of Bermuda's garbage during this period.

In 1975, in an effort to extend the life of the dump, a pulverisation plant, which shreds the waste to enhance compaction, was installed. However, it was apparent that the Pembroke Dump could not handle Bermuda's waste indefinitely. Pembroke Dump, the Island's only landfill site, was nearing its capacity and was beginning to cause unacceptable problems for local residents.

In 1977, investigations began to look for alternative disposal methods and the decision was taken to replace landfill with a mass burn incinerator.

Figure 12.2 Pembroke Dump as a landfill site

Photo courtesy of the Ministry of Works and Engineering and Housing

In 1994 the Pembroke dump was closed as a land fall site (see Figure 12.2). A portion of Pembroke Dump has been developed into a recreational park (see Figure 12.3). The majority of the remaining area is used for windrow composting and is known as the Marsh Folly Composting Facility.

Figure 12.3 Pembroke Dump as a recreational park

Photo courtesy of the Department of Planning

12.1.3 Incineration, Energy Recovery and the Tynes Bay Waste Treatment Facility

Incineration energy recovery was chosen as the solution for disposing of the portion of Bermuda's waste stream that is burnable but cannot be recycled or composted. The plant design was approved after being subjected to a thorough environmental impact assessment process including wind tunnel testing, two extensive public hearings, research programmes, and computer modelling.

The Tynes Bay Waste Treatment Facility (TBWTF) was officially opened in October 1994. It is a water wall, mass burn, two-stream plant. Its primary role is to reduce the volume of combustible waste by 80 to 90% through high temperature incineration and to thereby minimise the need to landfill. Its secondary role is to extract energy from the combustion gases to produce electricity for the facility and to export any excess energy to the local grid. (See Figure 12.4).

12.4 Tynes Bay Waste Treatment Facility

Photo courtesy of the Department of Planning

The facility is a 'controlled plant' as defined by the Clean Air Act 1991 and therefore has to be licensed annually. The operating licence, issued by the Environmental Authority, stipulates the operating conditions and emission limits under which the plant must operate.

Emissions from the incinerator are reduced to a minimum by controlled operating standards. This includes the removal of all toxic components within the waste stream (for example batteries and fluorescent tubes) prior to incineration as well as the use of air pollution control equipment thereafter. This equipment consists of efficient electrostatic precipitators which remove virtually all particulate matter. Combined with the height of the stack at 91 m above sea level (or 75 m above the surrounding ground level) the precipitators ensure that emissions from the TBWTF have little impact on the air quality of Bermuda. The ambient air is monitored for heavy metals, organics and particulate matter.

Burnable bulky wastes such as couches, mattresses and wooden planks are incinerated at the TBWTF after being chopped into smaller pieces using a hydraulically operated guillotine shear.

The facility is capable of burning 288 tonnes of refuse a day; however, during the summer the daily demand increases to over 300 tonnes. The plant has two main 'streams' and was designed for a third stream should the need arise. Stream 1 operated for 5,534 hours in 2002 (63% of the year) while stream 2 operated for 7,036 hours (80% of the year).

To accommodate the increasing generation of waste, a third stream will be needed by the end of 2007. In addition to a third stream, other options to assist in the management of waste are being considered. This includes improved waste reduction strategies, an increased recycling initiative and a programme to export electronic waste, white goods, vehicles and other scrap metals.

Figure 12.5 Concrete ash blocks

Photo courtesy of the Department of Communication and Information

Over the past five to six years, the plant has processed on average 60,000 tonnes of waste per year although in 2003 it was recorded to have processed 73,000 tonnes of combustible waste (see Table 12.1). The ash produced by the incineration process is mixed with concrete to form ash blocks 1m^3 in size and weighing about two tonnes. These blocks are placed into Castle Harbour as part of the land reclamation scheme at the airport waste facility (see Figures 12.5 and 12.6). In 2002 some 12,180 tonnes of ash were processed and 1,120 tonnes of metal were removed from the ash. This indicates that better waste separation and increased recycling needs to occur. The continual removal of metals produces better quality ash, which in turn is better for the environment. Studies by the Benthic Lab at the Bermuda Biological Station for Research (BBSR) have shown that the ash blocks remain relatively stable when placed in the marine environment with few or no adverse effects on marine organisms.

The TBWTF produces approximately 23 million kilowatt hours of electricity by efficiently using the heat recovered from the combustion of waste. The generated power supplies sufficient energy to run the entire plant as well as to export approximately 17.25 million kilowatt hours of electricity to BELCO annually. There is currently a proposal to utilise this electrical power to run a salt water reverse osmosis plant.

Figure 12.6 Concrete ash blocks submerged under water in Castle Harbour

Photo courtesy of Robbie Smith

In May 2001, a fee for the disposal of commercial waste was introduced at the TBWTF. The charge is presently $35 per tonne on weekdays and $45 per tonne on Saturdays. The revenue collected helps recoup a portion of the cost to run the facility.

The Ministry of Works and Engineering and Housing conducts tours of the Tynes Bay plant and some of the other waste disposal sites to school and community groups. An average of 20 to 25 tour groups visit Tynes Bay Waste Treatment Facility yearly, translating to about 200 to 300 people visiting the facility every year.

Table 12.1 Waste disposal by location

Waste Location or Type of Waste	Amount of Waste			
	2000	2001	2002	2003
Tynes Bay Incinerator	67,000 tonnes	N/A	68,081	73,000
Horticultural Waste - Composting	18,000 tonnes	18,000	18,000	18,000
Delivered to Airport Waste Disposal Facility - scrap cars, meals, appliances, construction rubble	650-700 truck loads per week	650-700	650-700	650-700
Hazardous Waste	306 tonnes			

Source: Ministry of Works and Engineering and Housing

12.1.4 Land Reclamation and the Airport Disposal Facility

A recommendation was adopted in 1971 that a land reclamation site should be found for the disposal of scrap vehicles and other bulky metal waste. As a result, the foreshore land reclamation project next to the Bermuda Air Terminal began and metals were diverted there from the Pembroke Dump.

Materials disposed of at the Airport Waste Disposal Facility (see Figure 12.7) include bulky non-burnable waste such as construction wastes, rubble, scrap metals, vehicles, appliances, electronic goods, PVC plastics and other large pieces of plastics, cement stabilised incinerator ash blocks and tyres. Seven acres have been added to the area since the site opened.

A programme to remove oil, gas and batteries from vehicles prior to disposal has been in place since 1999. Between 1999 and 2000 approximately 1,680 vehicles were drained of all fluids and processed for disposal. A weekly total of 650 to 700 trucks are presently using the airport facility to dispose of waste (see Table 12.1)

Table 12.2 shows the number of ash blocks that were cast with concrete and processed for disposal between 2001 and 2003.

The operation of the facility is regulated under the Clean Air Act, 1991. Stringent monitoring practices will soon be introduced to prevent unlawful dumping of prohibited wastes at the airport. On-the-spot investigations will take place and violators will be turned away or fined $300.

There are problems associated with present conditions at the airport site. Problems include birds which are attracted to the dump which present a hazard for airplanes; the negative visual impact of the site; and the threat to marine life and boating activities caused by debris washing into Castle Harbour when the retaining booms malfunction or when there is bad weather.

The feasibility of exporting scrap metal is under investigation. This would significantly reduce the amount of material requiring disposal thereby extending the life of the Airport site.

Figure 12.7 The Airport disposal facility

Photo courtesy of the Department of Communication and Information

Table 12.2 Number of ash blocks produced 2001 to 2003

Year	No. of Ash Blocks
2001	1,238
2002	1,811
2003	2,641

Note: In 1998, 6,591 ash blocks were cast. The lower figures in more recent years are due to difficulties with processing the blocks and a change in methodology in statistical collection. In reading this table, it is useful to remember that there is an annual increase in solid waste by 3% and thus an approximate commensurate increase in ash block production.

Source: Personal communication R. Wadden, MWEH, March 2004, Ministry of Works and Engineering and Housing

12.1.5 Backyard Burning

The Clean Air Act, 1991 prohibits low temperature burning of commercial and residential garbage but allows the burning of horticultural wastes providing it does not cause a nuisance to neighbours.

12.1.6 Composting and the Marsh Folly Facility

Composting is the recycling of organic matter through natural decomposition. Horticultural and food waste make up the bulk of this material in addition to smaller portions of compostable paper, sewage sludge and animal carcasses. The composting process produces a soil-like substance (compost) that enhances the physical properties of soil. Composting is practical on both a large and small scale.

Figure 12.8 Composting at the Marsh Folly facility

Photo courtesy of the Department of Planning

The Island produces approximately 18,000 tonnes of horticultural waste per year most of which is taken to the Marsh Folly facility (see Figure 12.8). It is mixed with food waste from cruise ships and local restaurants and then composted. Several times a year sewage sludge is also mixed in.

Animal carcasses are also composted at Marsh Folly using wood chippings. With the planned restoration of the former Pembroke Dump site as a park, the Marsh Folly facility will need to be relocated. Although a new site has not been finalised, it is likely to be on one of the former baselands, managed by the Bermuda Land Development Company (BLDC). Large-scale composting would be replaced with 'in vessel' composting, a highly mechanised controlled system which produces finished compost in 28 to 42 days rather than six months for the current system of windrow piles. Other advantages of 'in vessel' composting are the ability to process higher tonnages of waste using less space while allowing for odour control due to the rapid rate of compost production. In addition, it is possible to remediate contaminated soil using this technology (pers. comm. Hunt, 2004).

There is also a 'backyard composting programme' in operation and home composting is promoted on an on-going basis. The programme is partly subsidised by Government. Since 1996 over 1,500 composting units have been sold to residents and given to schools.

12.1.7 Recycling and the Devon Springs Facility

Recycling is the process by which waste materials are transformed into raw materials which are then used to make new products. In 1991, the MWEH started a non-mandatory recycling programme for glass bottles and jars, aluminium and steel cans. Initially, blue recycling bins were placed in supermarket parking lots for the public to drop off their recyclables. In November 1992, the residential recycling programme was started and recyclables are collected once a week at regular trash pick up locations within neighbourhoods.

Bermuda's recycling plant located at Devon Springs is currently running at full capacity (see Figure 12.9). In early 2004, plans began for a new state-of-the-art recycling plant at the Government Quarry in Bailey's Bay. Completion is scheduled for early 2006.

Figure 12.9 The Devon Springs recycling facility

Photo courtesy of the Ministry of Works and Engineering and Housing

Aluminium has been recycled in Bermuda since 1989 when the Bermuda Junior Chamber established a volunteer programme. There is a reliable overseas market for scrap aluminium, it is relatively easy to process and its revenues offset shipping expenses. However, markets for steel cans fluctuate.

The volume of aluminium cans is far less than those of steel cans but there are fluctuations between the summer and winter months. The aluminium is sorted by hand which is a labour intensive process.

Used aluminium and steel (tin) drink and food cans are shipped to the U.S. where they are recycled to make new aluminium and steel cans. Since the mid-1990s, on average approximately 176 tonnes of steel and 46 tonnes of aluminium have been recycled annually. Between 1992 and 2000, a total of 1,418 tonnes of steel and 412 tonnes of aluminium had been recycled. For the fiscal year 2003–2004, 38 tonnes of aluminium and 140 tonnes of steel were recycled.

Glass is crushed and reused locally as landfill and as land drainage material when needed, for example, for golf courses. Since the mid-1990s, on average approximately 1,125 tonnes of glass has been recycled annually and between 1992 and 2000, a total of 7,960 tonnes of glass was recycled.

Between 1992 and 1994, approximately 180 tonnes of old newspapers were recycled per year. In 1995, the newspaper recycling programme was stopped due to low revenues from overseas, limited markets as well as the declining demand locally. For these reasons, it became financially impractical to continue. Now only off-cuts from the daily newspaper and white office paper collected by the Corporation of Hamilton are shredded at the recycling centre. The paper is reused locally as animal bedding. Since 1995, an average of approximately 34 tonnes of newspaper has been recycled each year and a total of 754 tonnes has been recycled since 1992.

12.1.8 Hazardous Waste and the Sallyport Facility

Hazardous wastes are wastes which because of their quantity, concentration or characteristics may pose a hazard to human health and/or the environment when improperly treated, stored, transported, disposed of or otherwise managed. Some 'everyday' products found in homes and offices contain toxic chemicals for example batteries, cleaning agents and paints, and require special handling and disposal because of their potentially hazardous nature.

In 1992, the Bermuda Government implemented a local programme for the management of hazardous waste. All hazardous waste material with the exception of fluorescent tubes and asbestos is transported to, sorted and containerised for shipping at the Sallyport Transfer Storage Facility (TSF) or Hazardous Waste Operations Centre in Dockyard (see Figure 12.10). This facility opened in 1992 and is constantly being upgraded to meet ever-changing operational. Most hazardous waste material is difficult to dispose of in Bermuda in an environmentally acceptable way and is therefore shipped to special hazardous waste processing plants in the U.S. Fluorescent tubes are packaged separately at the Marsh Folly Facility for shipment overseas.

There is currently no legislation which defines or regulates hazardous waste in Bermuda. It is therefore proposed to either amend the existing legislation (the Waste and Litter Control Act, 1987) to add definitions for hazardous waste and regulations or to draft new legislation.

During the fiscal year 1 April 2002 to 31 March 2003, 39 ocean shipping containers containing various hazardous waste materials were shipped to the U.S. A breakdown of types and quantities of hazardous wastes is shown in Table 12.3.

Figure 12.10 Two workers bulking vapour and liquid from aerosol cans at the Sallyport facility

Photo courtesy of the Ministry of Works and Engineering and Housing

Household batteries, such as those used in watches, calculators, flashlights, electrical toys and appliances contain small concentrations of potentially harmful materials and therefore require appropriate disposal.

Battery buckets are located in most pharmacies and supermarkets for public drop-off. Currently there are 35 businesses that participate in this drop-off service. This programme started in 1995 as part of the overall Hazardous Waste Programme.

In 2003–2004, approximately seven to nine tonnes (15,000 to 20,000 lbs) of dry cell batteries were collected and shipped overseas for recycling or disposal.

Vehicle batteries are collected from service stations and garages. On average 11,500 vehicle batteries are collected each year. Collected batteries are shipped to the U.S. for recycling or disposal.

Waste oil tanks are located at participating service stations (currently there are 8) and at the Tynes Bay public drop-off facility. In 2003–2004 some 65,000 gallons of oil was collected and shipped for recycling or fuel blending. Disposal costs are approximately U.S. $0.50/gallon.

Waste paint can be dropped off at most paint and hardware stores as well as at the Tynes Bay public drop-off facility. Currently 15 businesses participate by allowing the MWEH to place paint receiving bins on their premises. Approximately 25,000 gallons of waste paint is collected annually. The paints collected are divided into two categories, water-based and oil-based. All paint is then shipped to the U.S. for recycling and used as fuel or it is landfilled. The disposal costs (which do not include transport or local costs) are approximately U.S. $6/gallon.

Fluorescent lamps and light ballasts can be dropped off at the Tynes Bay public drop-off facility or at the Marsh Folly Depot. Some 56,000 tubes were collected in 2003-2004 and shipped to the U.S. for recycling. Disposal costs are approximately US$ 0.06/ft.

Electronic monitors (CRTs) have recently been identified as a hazardous waste due to the lead content. Those generated by the public are currently disposed of at the Airport disposal facility. The MWEH has started a pilot programme whereby the Hazardous Waste Section keeps all government computers in sea containers awaiting the appropriate de-manufacturing or recycling systems to be implemented.

Biomedical waste from the hospital as well as from veterinary practices on the Island is incinerated in a bio-oxidiser at the King Edward VII Memorial Hospital. The Bermuda Hospitals Board runs this unit privately. Ash from the bio-oxidiser is currently being incorporated into the Tynes Bay Waste Treatment Facility's waste stream where it is re-burned and then added to the other incinerator ash.

Asbestos has been collected and stored at the government quarry for a number of years, awaiting an acceptable means of disposal. Approvals had been obtained for the disposal of asbestos in the deep sea surrounding Bermuda. However, political pressure exerted by local and overseas environmentalists caused the government to re-examine this disposal option.

Currently there are approximately 2,495 tonnes (5,500,000 lbs) of waste asbestos awaiting disposal and this amount increases by approximately 3-5% each year. The current requirements are that all asbestos waste be wrapped in 6-mil polyethylene and delivered to the government quarry by appointment. The asbestos is weighed and the generator is invoiced at that point of transaction. Current charges are $0.60 per lb for loose delivery or $6,000 for full 20 ft ocean container loads. These requirements may change once a disposal method has been decided upon.

In an effort to help reduce ozone depletion, the Ministry of the Environment made it unlawful (under the Clean Air Act, 1991) to vent refrigerants (CFCs) of any type to the atmosphere. Until recently, local refrigerant generators had the choice of storing waste refrigerants in appropriate containers anticipating local means of disposal or sending it off-Island for disposal themselves.

On 1 July 1999 the Hazardous Waste Section of the MWEH implemented the refrigerant recovery and reclamation programme. Commercial generators can now dispose of their waste refrigerants through the hazardous waste programme and have the option of having it cleaned for reuse, essentially recycling it locally. Since the year 2000, 0.23 tonnes or 227 kg (500 lbs) of waste refrigerant has been collected and 0.91 tonnes (2000 lbs) of refrigerant recycled. Current local charges for handling of refrigerants are $10.00 per 2.2 kg (or per lb).

The Hazardous Waste Section also manages a refrigerant recovery programme at the airport disposal facility. Appliances containing refrigerants (for example refrigerators, air conditioners and dehumidifiers) which are brought to the airport disposal facility by the general public are emptied by

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Table 12.3 Types and quantities of hazardous wastes collected 2002 to 2003

Type of Waste	No. of Containers	Volume/Weight
Waste Oil	13	295,500 litres (65,000 gallons)/236 tonnes
Fluorescent tubes	8	56,000 tubes
Waste Paint in Totes	7	70,239 litres (15,400 imperial gallons)
Waste Paint in Boxes	3	40,915 litres (9,000 imperial gallons)
Contaminated Materials	4	73 tonnes
Flammable liquids	2	16,366 litres (3,600 gallons)
Chemicals/poisons	2	13,638.3 litres (3,000 gallons)

Source: Ministry of Works and Engineering and Housing

staff prior to being buried. Approximately 100 units are handled weekly.

Occasionally, the need arises to treat and remove petroleum hydrocarbon contaminates from soils. These contaminated soils are the result of sand used on road spills, overflowing drums of stored waste oil and tank leakage of fuels. Currently these soils are being taken to the government quarry and stored in piles with the milled road asphalt.

For the short term, this process is sufficient but in the longer term a permanent programme dedicated to the remediation of contaminated soils will need to be in place. The MWEH has set up a pilot bioremediation treatment programme at the Sallyport Dockyard site to fulfil that need. In 2003–2004, 30 truckloads of contaminated soil were received at the bioremediation site and are currently being handled by a private contractor.

Other hazardous wastes such as pesticides, vehicle wastes and household hazardous wastes including fertilisers, pool chemicals, waxes, polishes and poisons are all shipped to the U.S. for disposal.

12.1.9 Illegal Dumping and Littering

Illegal dumping is large-scale littering and primarily results when people do not take their waste to a proper disposal site or plan for it to be collected. Whilst the Waste and Litter Control Act, 1987 allows for fines up to $1,000 to be imposed for littering offences, enforcement of dumping and general littering violations, it is difficult if the offender is not caught in the act.

It is intended that the Waste and Litter Control Act, 1987 be amended to include on the spot ticketing for litter and illegal dumping.

The problem of litter is evident. It is everywhere, in the hedges and bushes, on the roadsides, in parks, on beaches and even underwater. Litter is created both accidentally and deliberately. Most accidental litter comes from: residential and commercial refuse put out in inadequate containers and then scattered by wind, traffic and animals; construction and demolition sites; uncovered loads; and from loading docks. These sources of litter can be reduced through increased public awareness and by making minor operational changes such as requiring trucks to cover loads, specifying secure refuse containers and improving waste handling practices.

Deliberate litter is thrown down or left behind by people who lack awareness or do not care about the impact it has on the environment. Reducing deliberate littering requires educating the public about the detrimental impacts of littering (see Figure 12.11). Fines can also be used to deter litterers.

Figure 12.11 Illegal littering in Chalk Cave

Photo courtesy of Dr. Thomas Illiffe

To try and combat the litter problem many different campaigns and programmes have been tried over the years. One of the more innovative methods occurred in the early 1990s. The Comprehensive Litter Control Programme emerged as a result of a compromise reached between government, Keep Bermuda Beautiful (KBB) and a group of businesses known as 'Businesses for a Beautiful Bermuda' (primarily food and drink importers, distributors and retailers). It occurred at a time when the government of the day was proposing to implement beverage container deposit legislation. Beverage container deposit legislation requires a deposit usually between five to 25 cents to be placed on a beverage container that is refundable if the consumer returns the container to the retail outlet or to a redemption centre. After numerous discussions and negotiations, all parties agreed to a compromise in the form of the Comprehensive Litter Control Programme which targeted not only beverage litter but other types of litter as well.

The method and operation for this programme had several components. First, the businesses involved agreed to commit funds for anti-litter campaigns. Second, a litter survey was carried out by MWEH staff in 1991 which placed items into specific categories for example beer bottles, beer cans, soft drink bottles and cans, paper products and candy wrappers. Third, a levy was then placed on businesses who sold these littered items, the amount of the levy corresponding with the amount of the specific type of litter. The levy collected was forwarded to KBB for use in anti-litter campaigns. A follow-up litter survey was carried out in 1993 to determine what effects the campaign had on the amount of litter found.

The 1991 Island-wide survey showed that 37% of littered items were beverage-related including glass bottles, bottle caps, six-ring packs etc. The re-survey in 1993 using the same methods and the same randomly selected sites indicated that 33% of litter comprised beverage-related items. The 1991 and 1993 surveys have generally shown that secondary roads have far above the average amount of litter and just less than 50% of the litter items are beer bottles. Primary roads are also littered with beer bottles and candy/snack packaging. Park and coastal areas tend to have an abundance of plastic litter, much of which is water-borne. The 1993 litter survey identified 69% of litter being deliberate and 31% being accidental. Of the deliberate litter, snack and food-related items comprised the largest category of deliberate waste (19%) while take-out food containers were next highest with 16%. Beer bottles were specified as comprising a significant amount of deliberate litter (10%).

The Comprehensive Litter Control Programme was practised for a short period and then ceased upon the onset of the economic recession in the 1990s. The Ministry of Works and Engineering and Housing is considering beverage container deposit legislation for Bermuda once again.

Keep Bermuda Beautiful (KBB) is a registered Bermuda charity which acts to reduce the proliferation of litter and other unsightly conditions that negatively impact on the beauty of Bermuda. KBB also has environmental education programmes that aim to raise public awareness in the importance of keeping Bermuda beautiful. KBB organises approximately 60 assisted cleanups annually around the Island, which net about 50 tonnes of trash. This is a service provided to community groups, sports clubs and the general public who are interested in undertaking a clean up.

In 2001, KBB undertook a litter survey on two roads at the extreme east and west ends of the Island. Although the survey was not island-wide, it showed that litter continues to be a problem and found that beverage containers, paper and plastics comprise a significant proportion of litter (KBB 2001). Presently, KBB reports that 60 to 70% of litter collected by its volunteers comprise beverage containers.

Figure 12.12 Keep Bermuda Beautiful land clean-up

Photo courtesy of Keep Bermuda Beautiful

In addition to the annual land and marine cleanups (see Figure 12.12), KBB also organises the 'Rockwatchers' and 'Adopt a Park' programmes that involve individuals, communities and corporations dedicated to monitoring and cleaning a specific part of Bermuda.

12.1.10 Future Waste Management Programme

The magnitude of Bermuda's waste generation is expressed in the calculation by the MWEH that if Bermuda's annual production of approximately 70,000 tonnes of burnable garbage was spread across the Island, it would create a layer of one and a half to two garbage bags of refuse across the Island's entire land area.

The key elements of Bermuda's Waste Management Programme include incineration, land reclamation of metals, recycling, composting and improved disposal of potentially hazardous materials. This provides an environmentally sound and flexible disposal method for Bermuda's wastes.

However, the best option for the management of waste is to minimise it from the outset. It presently costs approximately $129 to collect and $95 to dispose of each tonne of residential waste. In addition to the economic costs of disposing of waste, there are also environmental issues associated with the disposal of waste, including consumption of open space, visual and odour impacts, health effects, harmful effects on birds and wildlife and the general deterioration of the environment. For these reasons, it is prudent to encourage the reduction of waste from the source, by limiting the amount of garbage that needs to be handled and by minimising the amounts of household and other hazardous wastes that must be processed.

An issue of concern is that there are indications that overseas recipients of the Island's hazardous waste and recyclables (tin and aluminium) may not wish to continue receiving such waste at some time between 2013 and 2018. In the interests of environmental justice for low-income people living near hazardous waste sites in North America and other countries, particularly developing countries, it is imperative to find local solutions to waste management.

Two main measures for reducing the waste stream include control factors such as legislation and persuasion measures such as education and awareness-raising. Under the Waste and Litter Control Act, 1987, the MWEH have the power to restrict excess packaging and containers. To date, these powers have not been exercised. In addition, publicity campaigns can aim to persuade consumers to buy fewer disposable items, to buy more durable goods and to make more environmentally sound purchasing choices.

The MWEH is reviewing its current Waste Management Programme (1992) and a new 10-year programme for 2004 to 2014 is being produced. This includes a thorough review of the existing waste processes and infrastructure and the requirements for the next 10 years. Included in this assessment is a review of the existing waste management legislation with a view towards possible amendments and new legislation.

12.2 Wastewater and Sewage

12.2.1 Sources of Wastewater

Of the 60 inches of rainwater that falls on average per year in Bermuda, an estimated 75% evaporates. The remainder has the potential for picking up contaminants of one form or another before entering the groundwater lens and ultimately the ocean. This is particularly true for rain that is intercepted by roofs and other water catchments for the purpose of water collection. Subsequently it is used for domestic purposes such as drinking, personal hygiene, toilet flushing, laundry and irrigation. Water that runs off other artificial surfaces such as roads, parking lots and industrial yards may sweep up pollutants from traffic exhaust fumes, rubber tyres, anti-fouling and other paints, solvents and oil. Heavy rain falling on bare ground can be expected to carry silt or topsoil when storm sewers discharge it into the sea. In addition, rain falling on heavily manured, fertilised or pesticide-treated grounds such as pastures, agricultural fields or golf courses may take these pollutants into the groundwater.

Any pollution to the freshwater lenses is of concern to human health as well as the health of nearshore marine communities into which groundwater percolates.

Cruise ships, boats and airplanes bring additional quantities of liquid wastes to Bermuda, and desalination plants produce high-salinity outflows.

In addition, many imports, liquid or solid, may find their way into the wastewater stream, from fuels, oils, solvents, bleach and detergents to pharmaceuticals, photo processing chemicals and pesticides.

Bermuda is fortunate in being able to rely on its geology and location when disposing of the estimated five million Imperial gallons of wastewater per day (Igpd) which it generates. It has the following advantages when faced with the task of disposing of liquid waste:

- Bermuda's sewage is almost exclusively of a benign domestic (rather than a toxic industrial) kind and therefore primarily a plant fertiliser;
- Historically, Bermuda's porous limestone has been acting as a filter, chemical sponge and natural treatment plant; and
- Bermuda is surrounded by a vast, nutrient-poor ocean which destroys most human pathogens and readily dilutes the small quantities of effluent produced.

12.2.2 Environmental Impacts

Local sources of biodegradable organic inputs include cesspit leaching, sewage outfalls, fertiliser runoff from lawns, farms and golf courses as well as farm and fishing wastes. These inputs are also known as oxygen-demanding wastes because whilst they may be readily broken down in the marine environment, the aerobic bacteria that degrade them consume oxygen in the process. Oxygen diffuses into water at a slow rate and it may therefore take some time to replenish oxygen levels after a major input of oxygen-demanding material, for example following significant rainfall that washes such material into coastal waters. If oxygen levels fall below a certain level (1.5 mg/l), anaerobic bacteria take over the degradation process. They are less efficient decomposers and produce by-products such as hydrogen sulphide, ammonia and methane, which may be toxic to other organisms. A good example of such a situation would be the rotten egg odour often associated with Warwick pond on calm days.

Biochemical oxygen demand (BOD) is a measure of how much oxygen is required for the decomposition of a given type of waste. BOD is affected by the type of product involved and its concentration, and can be reduced through dilution of the product.

Many of the degradable wastes entering the marine environment are plant nutrients. Decaying organic matter, fertiliser runoff and the nitrates and phosphates from sewage all enhance the growth of phytoplankton and benthic algae. Although a small amount of nutrient enrichment may enhance overall production levels, eutrophication (which is the supply of excessive amounts of nutrients to a system) results in rapid growth of plants and the subsequent decay of plant material may result in oxygen depletion. This in turn affects other organisms and may lead to an alteration of the community structure.

Population explosions of certain types of phytoplankton are known as 'red tides' because they produce a discolouration of the water column and may result in the death of many marine organisms, either from the toxins they produce or through oxygen depletion when they decompose.

Eutrophication can be particularly damaging in waters that are naturally nutrient-poor (oligotrophic) and there is increasing evidence that eutrophication is responsible for damage to coral reefs. Increased phytoplankton growth reduces light intensity, affecting photosynthesis by the corals' zooxanthellae. Greater abundances of benthic (bottom-dwelling) algae increase sedimentation. The algae compete with corals for space and may overgrow or smother them. The area around the Seabright sewage outfall (see Figure 12.13) is currently being monitored as part of the Benthic Ecology Research Programme at the Bermuda Biological Station for Research (BBSR).

Figure 12.13 Aerial photo showing the alignment of the Seabright sewage outfall between the reefs

Photo courtesy of the Department of Planning

12.2.3 Current Volumes and Treatments

Disposal of untreated sewage into the ground may seem primitive but is a common practice worldwide and not unsuitable for Bermuda. It relies on the natural capacity of the porous rock to temporarily retain, physically filter, and chemically and biologically break down organic matter into solubles that are relatively harmless when percolating into the groundwater. Wherever it is used, cesspit disposal must be adapted to local geology. Bermuda's calcareous sandstone, elevation and rainfall combine to provide an efficient natural treatment process similar to 'slow sand filtration', which is recognised in the water industry as one of the most effective means of cleaning wastewater. In addition, Bermuda's limestone is of calcium carbonate which appears selectively to remove phosphorus, one of several nutrients whose excess may lead to undesirable plant blooms called 'cultural eutrophication' ('over-feeding').

It is estimated that there are 21,000 cesspits in Bermuda which together dispose of 3.5 million Igpd.

Roughly one million Igpd is being disposed of by four major ocean outfalls, of which two also receive liquid wastes from cruise ships. The Corporation of Hamilton operates the largest, in terms of volume, with a flow rate of 550,000 to 1,100,000 Igpd. Sewage receives preliminary treatment consisting of maceration, screening for large solids and grit removal afterwhich it is pumped through 20-inch diameter polyethylene pipes to a place 2,060 feet off Hungry Bay, Seabright where it is diffused into the water column at a depth of 48 feet. The St. George's Corporation operates a similar outfall that disposes of 50,000 to 150,000 Igpd, 1,122 feet offshore, in 55 feet of water. Two smaller outfalls deal with sewage from the former Sonesta Beach Hotel (80,000 Igpd peak) and Elbow Beach Hotel (70,000 Igpd peak). Another two existing outfalls are the former Club Med Hotel site and Southside which are currently not in operation.

Sewage disposal by deep sealed boreholes is a comparatively new method that takes care of about 300,000 Igpd. At present there are 86 deep sealed boreholes. Originally designed for the salty discharge from desalination plants, sealed boreholes are now used for wastewater disposal from high-density developments or other producers of large quantities of effluent on relatively small properties, such as laundromats, especially close to the coastline or over freshwater resources (see 12.2.11 Boreholes), 40 feet or more below sea level, well below the freshwater lens. Sealing is achieved by placing PVC or steel casing to the required depth into the oversized drilled hole and filling the space around the casing with cement slurry. The hole is then extended 20 feet or more by drilling inside the casing into the limestone below. Wastewater which has undergone at least primary treatment, discharges at the bottom of the borehole into the surrounding saline groundwater.

Direct land runoff is difficult to quantify in terms of effluent volume and environmental impact and its effect is not well known. It is particularly visible where runoff from quarries is involved and especially after severe rainstorms. One area where this can be seen is where Lolly's Well Road runs into Harrington Sound. At this location, run off results in the spilling of vast plumes of sediment which is detrimental to corals and other sedentary sea life in the Harrington Sound. Runoff may also carry large quantities of organic debris such as branches, leaves and topsoil. Less visible but possibly more environmentally serious is land runoff which sweeps up hydrocarbons from asphalt and exhaust fumes, rubber tyre crumbs and other road surface deposits.

Of particular concern is the re-suspension of sediments as a result of prop wash or the movement of large vessels. The settling out of these materials has an impact on corals in as much as they use a considerable portion of their energy budget to cleanse themselves. Filter feeders may also be adversely affected by becoming clogged with sediment material.

12.2.4 What Is Sewage?

The vast bulk of Bermuda's sewage is biological derived from toilet flushing, bathing and washing. There is little chemical or industrial waste included in the effluent. Businesses such as photographic processing, dry cleaning and electroplating may discharge varying quantities of toxic substances into the sewage system. The hospital also contributes unknown quantities and varieties of chemical waste. Other wastes which find their way into sewage systems include grease, cleaning chemicals, cigarette butts, contraceptives, plastics, various kitchen scraps and other relatively biodegradable materials. About 85% to 95% of human waste is water. The remaining major constituents are nitrogen (0.6%), potassium (0.3%), phosphorus (0.2%) and solids of different types and sizes but mostly of organic origin.

Sewage in its untreated form carries suspended solids that may smother and suffocate marine life. It requires high amounts of oxygen for decomposition and may contain human pathogens . However, while sewage treatment does produce an ecologically less objectionable effluent, there is a price to pay in terms of the retained sludge which is a by-product of the treatment process. More treatment will produce more contaminated solids with which our present sludge treatment and disposal facilities could not cope. It is estimated that the cost of sludge treatment and disposal exceeds the cost of conventional sewage treatment. It is an energy intensive process and usually involves double handling and transport. Sludge is a large problem that is too frequently overlooked.

12.2.5 Sewage Treatment

Treatment of sewage is designed to make the resulting effluent safe for disposal or use at a chosen site. Increasing levels of treatment aim at removing or breaking down solids, organics, pathogens and nutrients. As outlined by Rowe (1996), there are four broad categories of treatment: (i) preliminary, (ii) primary, (iii) secondary and (iv) tertiary.

(i) Preliminary treatment

Preliminary treatment includes maceration (grinding up soft solids), screening (straining for solid trash) and grit removal (of sand and larger inorganic particles). All sewage discharged via ocean outfalls is currently receiving preliminary treatment.

(ii) Primary treatment

Primary treatment achieves the settlement of fine organic and inorganic solids by temporarily retaining or slowing the effluent in a sedimentation tank. One or more sedimentation tanks may also be used to remove floatable matter (scum) and serve as a reservoir to even out flow rates. Primary treatment typically removes 50% of suspended solids and reduces biological activity by 30%, as measured by biochemical oxygen demand (BOD). In essence, the Island's cesspits are primary treatment facilities. All wastewater disposed of via deep sealed boreholes receives at least primary treatment in septic tanks and often some secondary treatment in the form of a gravel bed that serves as a bacterial trickling filter.

(iii) Secondary treatment

Secondary treatment achieves a 90% or more reduction of gross pollutants by providing a suitable, controlled environment for microbial breakdown. This is done through aeration and circulation of primary treatment effluent in a series of tanks. Of the many different approaches to secondary treatment, the bacteria bed and the activated sludge (ASL) are the best known. Bacteria beds or trickling filters encourage bacterial degradation of organic wastes by letting them trickle through a permeable, aerated medium.

Because of space needs and associated odours, open bacteria beds are not a practicable solution for Bermuda, whereas an enclosed version such as the rotating biological contactor should be considered.

In the ASL process, sewage is circulated through various tanks and first vigorously aerated to encourage bacterial degradation and then allowed to settle. Bacteria-enriched sludge from a settling tank is then added back to the aerating stage. All plants operated in Bermuda, including those at Fairmont Southampton and Grotto Bay hotels, are ASL types. Several of the new plants under construction in Bermuda (for example the former Sonesta Beach Hotel and Palmetto Gardens Hotel) are a version of ASL known as a 'sequencing batch reactor'. This process incorporates duplicate tanks, one of which goes through an automated sequence of treatment processes while the other fills. The sequence can be designed to incorporate an anaerobic stage, which reduces nitrates by up to 80%.

(iv) Tertiary treatment

Tertiary treatment is applied when wastewater is destined for reuse such as flushing, irrigation, or groundwater recharge, or for disposal in an environment with low mixing or high sensitivity to nutrients. Tertiary treatment generally includes disinfection to eliminate harmful microorganisms and further reduces suspended solids and BOD. It may also aim at removing nutrients such as nitrates.

Tertiary treatment may be achieved by filtration through sand beds, flow through the root zone of grass or reeds or retention in 'stabilisation ponds'. For high-quality use such as irrigation of food crops, ultra filtration or reverse osmosis may be required. In Bermuda, the Fairmont Southampton Hotel channels effluent from secondary treatment into a 'polishing tank' for clearing and disinfection, after which it enters a stabilisation pond where algae and other aquatic organisms do the final cleanup job prior to use as irrigation on the golf course.

Whilst a new pumping station has recently come on-line in the City of Hamilton, there seem to be no immediate plans to upgrade the level of treatment beyond simple maceration (preliminary treatment) and screening. Tertiary treatment plants are now required for all resorts situated on islands associated with the Great Barrier Reef in Australia. Secondary treatment is an intermediate option and is being adopted for heavily populated areas in most developed countries.

12.2.6 Health Hazards

There are public health risks associated with sewage inputs into the marine environment. Human sewage contains intestinal bacteria, pathogens and viruses as well as the eggs of intestinal parasites. Contamination of coastal waters by sewage may therefore pose a health hazard to humans through contact with, or accidental ingestion of, pathogenic bacteria, viruses, yeasts and parasites, or through the consumption of contaminated seafood.

Bermuda's sewage outfalls are generally in areas with high rates of water exchange and are at a safe distance from bathing beaches. Occasionally exceedences of bacteriological standards have been recorded but these have not been persistent enough to warrant any action by the health authorities. Several of the major outfalls, including those of Hamilton and St. George's, have been extended further off shore to reduce the potential impact on public health and the environment.

Direct ingestion of sewage-infested waters or of fish that feed around these areas is thought to cause bouts of infectious hepatitis and gastroenteritis and in some countries has led to outbreaks of typhoid fever and cholera. Bermuda is notably free from the worst of sewage related health problems. Coliform bacteria (usually benign organisms that are often associated with pathogens) are an important indicator of water quality. High coliform counts suggest a greater likelihood of harmful bacteria. Faecal coliforms have been found in various Bermuda waters and may be the result of direct discharge of sewage, runoff or cesspit leakage. More recent research has suggested that faecal enterococci are more reliable indicators of sewage pollution in marine environments. Faecal coliforms were found concentrated in filter-feeding calico clams taken from Harrington Sound. The Department of Health includes tests for these bacteria in its routine analysis of seawater samples from many of Bermuda's harbours and beaches.

Sewage contaminated food or drinking water may transmit human parasites (such as round and tapeworms) and pathogens (such as viruses and bacteria). As an incident in 1998 in one of the Island's larger hotels shows, contamination of drinking water through faulty sewer pipes leaking into fresh water tanks, is also a concern.

Groundwater can be subject to contamination from sewage, household and industrial chemicals, agricultural applications, road run-off and dump sites. Industrial sites, through accidental, negligent or deliberate dumping of oil and other contaminants into the ground, may pollute groundwater in ways that are difficult to remediate. For these reasons, it is illegal to drink raw groundwater in Bermuda. Most water which goes into public supply is treated by microfiltration and/or reverse osmosis, which are the most efficient technologies for the removal or reduction to safe levels, of contaminants including sodium chloride, nitrates, pesticides, trace metals, bacteria and other micro-organisms.

More recently, attention has been drawn to the polluting impact of drugs. Although the human body tends to break down any medicine it uses, up to 90% of some drugs, including ibuprofen, chemotherapy drugs, antibiotics and hormones may leave the body through the excretion of urine and faeces. Scientists analysing wastewater in Las Vegas found for example, that despite high dilution rates, concentrations of estradiol, the major hormone in birth control pills, were high enough to cause male fish to produce an egg-making protein normally seen only in reproductive females.

Another impact on the marine environment is the volume of sewage from the cruise ships that must be handled by the local facilities. Recently, a fault in the system resulted in a stream of raw sewage pouring into St. George's Harbour. This is a serious hazard to human health and to the health of marine life in the area, and is particularly dangerous given the enclosed nature of the harbour.

12.2.7 Sewage as a Nutrient

As sewage is broken down into its inorganic components it releases nutrients. Sewage fertilises the sea just as manure fertilises a field. Nutrient enrichment has been blamed for blooms of 'red tides' and other toxic marine microbes, which Bermuda has fortunately been spared so far.

Initially, nutrient input may seem beneficial. An increase in phytoplankton, the microscopic plants that may give the water a 'pea soup' appearance, can lead to increases in desirable organisms such as shellfish and fish. However, if nutrient input continues to grow, this initial benefit may soon turn into disaster where organic production outruns the orderly breakdown resulting in the starvation of oxygen and finally the catastrophic callapse of the system. Termed 'cultural eutrophication', this process was first seen to occur in lakes but is now increasingly known to occur in tropical marine areas. Excessive growth of certain opportunistic seaweed species has been recorded in 25 countries all over the world. It occurs most often in estuaries and shallow or enclosed lagoons that receive effluents from sewage, agricultural fertiliser or other runoff.

Eutrophication from sewage seepage was suspected when, in the 1970s, the green seaweed, *Cladophora prolifera* began to blanket many of Bermuda's inshore waters (Bermuda Inshore Waters Investigations 1977–1982). While the final verdict is still out that seaweed mats have shrunk over the years and retreated to deeper water, it is likely that some of the bloom was fed by nutrients which, seeped into the sounds from below the sediment via groundwater and were intercepted by the weed (Sterrer, *et al.*, 1998).

12.2.8 Fish Kills

Sporadic mass mortalities of fish and shellfish in Harrington Sound have been linked with hydrographic peculiarities of this unique inshore water basin. Every summer water gets strongly stratified with a warmer, oxygen-rich layer near the surface and a cooler, anoxic layer near the bottom. Anoxia also promotes the growth of many bacteria, the accumulation of nutrients and the release of trace metals (especially manganese) from bottom sediments. When this stratification breaks down under storm conditions or early fall cooling, fish and shellfish may be abruptly surrounded and stunned by poor-quality bottom water. This is thought be the reason for the fish kill of a large number of pinfish (*Lagodon rhomboides*) in September 1997 (see Figure 12.14). Similarly, sudden mortality of caged scallop (*Pecten ziczac*) in late summer of 1996 appeared to be the result of ciliate protozoan infection promoted by the prevailing environmental conditions. The frequency of these recent mortality events is considered unusual and suggests that some critical, as yet unknown factor, may have changed.

Figure 12.14 Dead pinfish, September 1997

Photo courtesy of Sarah Manuel

12.2.9 Effects of Sewage

As with most pollutants, the effect of sewage on the environment depends largely on dilution. Bermuda's sewage at present is almost exclusively organic in origin and is not immediately toxic to marine life. Toxicity of effluent could change in the unlikely event that Bermuda was to host a major manufacturing industry without making adequate provision for sewage treatment. The varied and often unpredictable ecological effects of Bermuda's sewage are due to suspended solids, oxygen demand and nutrient content. All three components are usually present when sewage is piped into the sea whereas nutrient content is the main concern in disposal by cesspits or treatment plants.

The open ocean around Bermuda is poor in nutrients, hence its blue colour, clarity and relative paucity of fish. Bermuda's coastal marine life has evolved under this constraint. Any inordinate input of nutrients might, therefore, upset the balance, particularly in enclosed bays and lagoons where dilution through flushing is slow. Groundwater, which is markedly contaminated by nitrates from sewage, is probably the dominant source of nutrients to Bermuda's inshore waters. Nutrient levels in inshore waters appeared to be rising in the 1980s, reflecting the increase in population and housing development. However, over the past five years, nitrogen levels in groundwaters have stabilised and even decreased in some areas, probably due to lower population growth and increased annual rainfalls, which have diluted cesspit seepage (Rowe, 1999). In addition to nutrients from the breakdown of domestic sewage, Bermuda also imports and uses large quantities of plant fertiliser. Much of this is not taken up by plants but probably infiltrates directly into the groundwater and inshore waters.

12.2.10 Cesspits

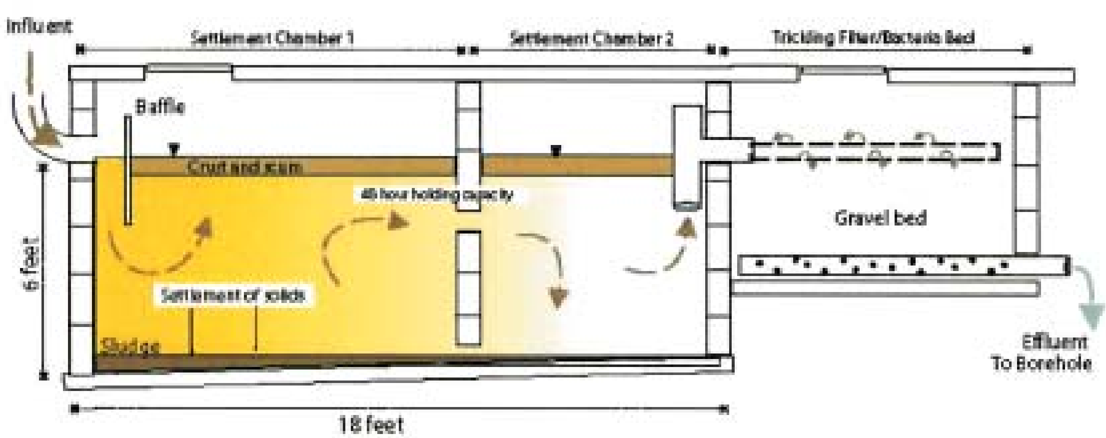
Bermuda's cesspits are similar to boreholes and outfalls in that the effluent eventually reaches the ocean but with a delay in time and with changes in quality as it passes through the rock and the groundwater. Little is known about what exactly happens to sewage during this passage, what proportion, if any, of its nutrient content is retained by the porous rocks, and how it finally mixes with seawater. Since the Island's rock formations are of various ages and permeability, some possibly acting like a sponge, others like a gutter, it is almost impossible to predict the flow path of effluents from a given cesspit.

While cesspit disposal seems to cope with most contaminants rather effectively, nutrients remain a problem in that they are highly soluble and are not removed even by conventional sewage treatments. As the Bermuda Inshore Waters Investigations (BIWI, 1977–1982) found out, even the simple process of drawing brackish groundwater for cooling purposes, and then discharging it slightly warmer yet otherwise unchanged, may increase nutrient levels in the enclosed bay that receives it. During the hot and calm summer months these inputs can cause the development of a warm, nutrient-rich surface layer, creating the perfect environment for plankton blooms, as described for Hamilton Harbour in 1978 (Ward, 1978). For this reason the direct discharge of cooling water through outfalls has been banned for many years.

12.2.11 Boreholes

Where there is a high-density development, which results in the production of large quantities of effluent on relatively small sites, cesspit disposal is not acceptable, particularly close to the coastline, over fresh groundwater resources or over cave systems. For such developments, which are not sufficiently large to make secondary treatment practical, primary treatment in a septic tank (see Figure 12.15) followed by disposal via a deep sealed borehole is an option, which is permitted. For developments up to 100 bedrooms, or equivalent, this type of system may be acceptable depending on the location. For larger developments, a higher level of treatment with borehole disposal may be acceptable.

Figure 12.15 Septic tank treatment prior to deep-sealed borehole disposal



Source: Department of Environmental Protection

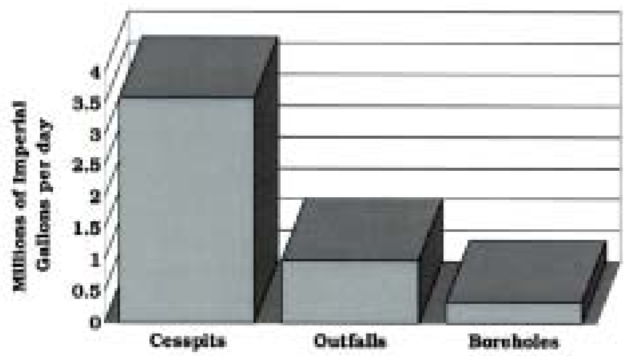
In many instances where there is insufficient land elevation for a cesspit to perform efficiently (and therefore health risks related to the lack of filtration), there is an increased likelihood of a cesspit backing-up or of direct seepage to the shoreline which means that a deep sealed borehole is required. For small developments, settlement of the solids in a septic tank and disposal of the clarified effluent into a sealed borehole is an alternative, which works very well in these circumstances.

Sealing of disposal boreholes is achieved by placing PVC or steel casing to the required depth (40 feet or more below sea level well below the fresh water lens) in an oversized drilled hole, and then filling the space around the casing with a suitable grout such as cement slurry. The hole is then extended 20 feet or more by drilling inside the PVC casing into the limestone below wastewater which has undergone at least primary treatment, discharges at the bottom of the borehole into the surrounding saline groundwater.

Deep sealed boreholes are required to solve very localised problems, which would result from other forms of disposal. They provide a longer flow path, and therefore more dispersion and dilution, to areas that would be adversely affected by concentrated input. Even though the effluent introduced into a borehole has undergone a minimum of a primary level of treatment, boreholes do not address any larger scale problems that might be related to input of sewage into groundwater and the sea. Borehole disposal of sewage effluent is not touted as a panacea. Any significant improvement that can be made over cesspits and outfalls will also apply to boreholes.

Large quantities of effluent disposed of into boreholes are treated to a secondary or tertiary level, and smaller quantities to a minimum of primary level. The total rate of effluent disposed of into boreholes is only a fraction of that disposed of into either cesspits or outfalls (see Figure 12.16). So, while there are concerns about the behaviour of borehole effluent, which are primarily related to density effects, its impact at its worst will only marginally add to that being caused by the alternative forms of sewage disposal.

Figure 12.16 Volume of sewage entering Bermuda's marine environment



Source: Department of Environmental Protection

12.2.12 Future Methods of Wastewater Disposal

In theory, Bermuda has three options to deal with its wastewater: (1) ocean disposal; (2) inshore disposal/reuse and (3) reduction of volumes generated.

Many would argue that, if properly controlled, disposing of some waste in the ocean is acceptable and will do no damage to marine life. The Seabright outfall, having been extended further seaward, with better maceration, screening, and improved diffusers, may be considered a step in the right direction. However, a study of the Seabright outfall carried out by the Bermuda Biological Station for Research in the summers of 1996 and 1997 found that both the abundance and diversity of the sediment infaunal community was lowest at a distance of 10 m from the outfall compared with 50 m sites, which were generally lower than the 400 m control sites. Similarly, trace metal analysis found elevated copper levels. Coral coverage and diversity showed no difference between years or between a site located 75 m from the outfall and a control site located at a distance of 3 km. Algal coverage was higher on the impact reefs and juvenile coral abundance in 1997 was lower than on control reefs. This short-term study concluded that there was an impact on the sediment community but 'of limited spatial extent' (Webster *et al.*, 2002). Metal concentrations were much lower than values found in inshore waters and did not represent gross levels of contamination. The study found that the organic content of the sediment indicated 'no persistent accumulation of sewage material in the sediment around the outfall' (Webster *et al.*, 2002).

It remains to be seen whether the limited impact which Bermuda's largest outfall seems to have also applies to other Bermuda outfalls, particularly those that discharge into shallow water such as those located around St. George's. The continued close and long-term monitoring of the ecology as well as any improvements to all installations are needed.

The main criticism that can be raised against ocean outfalls is that they waste rather than recycle valuable resources such as freshwater and nutrients thus wastewater treatment is theoretically the ideal solution to sewage disposal. A complete treatment system is designed to prevent nuisance, disease, hazards to groundwater as well as inshore ecology and retrieves water and nutrients for reuse. Under the direction of the Ministry of the Environment's Environmental Authority, several hotels are installing treatment plants with the aim to achieve a high quality effluent which will be re-used for toilet flushing and irrigation. This has long been a requirement for any major new development or re-development.

The more sophisticated a treatment system, the cleaner and the more useful the end product will be, and the higher is the cost of installation and maintenance. The comparatively small volume of Bermuda's sewage and the high land and construction costs make the capital investment seem prohibitive. However, standards imposed by the Environmental Authority along with greater environmental awareness and anticipated cost savings realised by the re-use of effluent have lead to the construction of increasingly sophisticated sewage treatment plants in Bermuda. The most recent of these will even be able to achieve significant nutrient reduction.

Where there are large treatment plants being considered (Hamilton and St. George's) any excess treated effluent could be discharged into a fresh groundwater lens either through the surface soil, by land irrigation (for example on a golf course), or directly into boreholes. The passage of the effluent through the limestone would provide natural filtration, prior to the water being drawn back into public supply by government wells. This practice of groundwater replenishment with treated effluent is employed in several countries including the United States. Alternatively, the effluent could be strategically injected to create a hydraulic barrier between the shoreline and a groundwater lens. Rather than being directly re-used, the effluent is beneficially employed to cut off the leakage of the natural fresh water resources to the sea.

In proximity to sensitive environments such as enclosed water bodies, marshes, or caves, elimination of on-site sewage disposal is sometimes considered prudent. This can be achieved by sewering, as was done at Ship's Hill, or use of holding tanks which have to be routinely emptied by tankers. Sewage treatment which incorporates nutrient removal may also be acceptable in these circumstances.

Ways to reduce wastewater volumes also need to be considered. Manufacturers claim that a dry toilet will store up to 10 years worth of wastes and conserve 50,000 gallons of water per year. Drawbacks to this system include the space that must be excavated below the house to accommodate the composting unit, the need for a regular supply of organic wastes (such as kitchen scraps) and the fact that no germicides, bleaches or other household chemicals may be disposed of via the system. In Bermuda, where topsoil is scarce, the composting of sludge and other solid organic wastes is wholly appropriate.

12.2.13 The Environmental Authority

The following objectives are being met as a result of Environmental Authority policies and these policies are strictly adhered to for new developments and major re-developments. The objectives are as follows:

(1) To end all direct discharges into inshore or shallow nearshore waters

The once common practice of direct discharge of sewage through short outfalls has been eradicated in Bermuda. New developments in areas that cannot be serviced by an ocean outfall because of distance must provide a septic tank treatment system, with final discharge via a cesspit or deep borehole. Ideally, all wastewater effluent in these environments should be directed into ocean outfalls or treatment plants.

(2) To require comprehensive disposal systems for redevelopment

New or proposed re-developments such as Southside, Castle Harbour, the former Club Med Hotel site and the Southampton Naval Annex have been, or will be, required to meet stringent new standards for effluent quality which necessitate tertiary level treatment, and in most cases the re-use of the effluent will follow logically on from that.

Improvement in existing facilities are warranted, such as those operated by the Corporations of Hamilton and St. George's, by adding treatment plants. Existing ocean outfalls could perhaps be consolidated and extended to discharge waste in deep water, far enough beyond the reefs to ensure rapid dilution and dispersal. Regular inspection and maintenance are required to ensure that all facilities are in good working condition.

(3) To set effluent standards

The Environmental Authority has applied standards for sewage effluent for major new developments or re-developments over many years. As a result, full sewage treatment was required at the Boaz Island housing development, at the Dockyard, Castle Harbour and Southside re-developments, and at all the major hotels which have undergone upgrades. The latest standards include limits for suspended solids, biological oxygen demand, chlorine residual, oil and grease, bacteria counts and nitrate reduction targets.

With regard to chemical wastes, public education could improve understanding of the cesspit system to prevent disposal of hazardous or harmful substances. Disposal of commercial and industrial liquid effluents could be improved to prevent accidental dumping of chemicals and other environmentally damaging materials into the sewers.

The following are future objectives:

(a) To minimise sewage discharge from vessels into inshore waters

Visiting yachts should use onshore sanitary and trash facilities. Boats and ships above a certain size, which enter Bermuda's inshore waters should be equipped with holding tanks that can only be discharged in deep waters offshore. Otherwise vessels should hook up to either the City of Hamilton or the Dockyard disposal systems or to purpose-built pump-out stations such as at marine service stations. This would require that existing facilities (especially WEDCO and the Corporations of Hamilton and St. George's) be prepared to handle large increases in sewage, as can be expected from larger ships, and at peak times. It also means that shore facilities must be adequate for big boating events such as the Newport-Bermuda Race.

(b) To research wastewater production and the effectiveness of existing disposal

More information is needed about the effects of further housing or commercial development, particularly around inshore waters. The quantity and types of wastewaters being discharged should be researched.

The organic (nutrient) and chemical content of cesspit, septic tank and treatment plant effluents should be determined, as well as the adequacy of existing facilities to deal with fluctuating and increasing volumes of wastewater from cruise ships and beach facilities.

(c) To research new disposal systems

Current and alternative treatment systems toward devising a more comprehensive sewage disposal plan should be researched. A standing task force could be set up which would regularly, perhaps once yearly, examine and evaluate latest technologies.

(d) To require environmental impact statements for proposed industries.

Proposals for any light or heavy industries should be accompanied by environmental impact assessments. Such a statement should identify the quantities and toxicity of non-organic liquid wastes as well as assess the nutrient content, suspended solids and BOD of any organic wastes and the dilution factor for all wastes.

(e) To monitor and research the effects of existing disposal systems on freshwater quality, human health and marine life

Scientific data on changing volumes and composition of Bermuda's sewage in light of changing inputs, pathways and fates of sewage components from cesspits, as influenced by pit construction, rock porosity and stratification, groundwater etc., and on the effect of outfalls and cesspit seepage on marine life and inshore water quality should be gathered. Such studies should be long-term and multi-disciplinary, including assessment of microbial pathogens and new contaminants such as drugs. An in-depth study of liquid waste disposal and other land run-off should be undertaken. Cesspits and deep sealed boreholes should be modelled and monitored in view of potential saturation points and impacts far from input location.

12.3 Summary

Bermuda currently has a comprehensive waste management system that processes and disposes of waste in a mostly environmentally sound manner. However, with most of the facilities approaching, or at, full capacity, the Ministry of Works and Engineering and Housing is planning for the future with a new 'stream' for the Tynes Bay incinerator and a new recycling plant at the Bailey's Bay government quarry. Other proposed facilities and plans include an 'in vessel' plant for composting horticultural waste and a plan for scrap metal to be shipped overseas for recycling. With these new facilities and processes in place, Bermuda's waste management programme will be well placed to handle the Island's waste disposal requirements for the next 10–20 years.

The majority of households in Bermuda continue to discharge their wastewater into cesspits. The towns of Hamilton and St. George's have sewer systems, which, following only 'preliminary' treatment of the effluent, discharge to the sea via outfalls. All of the large hotels now operate secondary or tertiary wastewater treatment plants. These are designed to meet effluent standards set by the Environmental Authority. A fourth method of dealing with sewage, which is applied for intermediate density developments such as condominiums or developments at low elevations, is to treat it to a primary level in a septic tank and then discharge the effluent to a deep sealed borehole. As compared to cesspits, this has less impact on fresh groundwater lenses and is also preferred in some coastal locations, due to health considerations.

Discharge of sewage to the ground is not uncommon, including in North America, in areas not served by sewer systems. It has been tolerable in Bermuda, because of the properties of the limestone and the land elevation, which, together, provide for reasonably effective filtration of contaminants, including bacteria, from infiltrating wastewater. Some dissolved wastewater constituents, such as nitrates, do persist and these must be removed by treatment processes, where groundwater is to be used for public supply. Nitrate concentrations in the groundwater lenses have not increased over the last decade.

The Water Resources Act, 1975 (Section 34) makes provisions for the prosecution of anyone polluting public water and seawater. This includes the discharge of any matter or substance likely to affect marine life, livestock, birds and other organisms. The penalties are provided for in Section 37 and this allows for fines up to $10,000. The same legislation also gives the Minister of the Environment the power to make regulations controlling the discharge of matter or substances capable of polluting seawater.

The relatively non–toxic nature of domestic sewage and the ocean's vast capacity for dilution makes ocean disposal Bermuda's most practicable option. Bermuda can probably continue to dispose of its non-hazardous liquid wastes via a mix of ocean outfalls, cesspits and septic tanks/boreholes provided it researches, monitors and when necessary upgrades existing facilities and practices. Ultimately the goal must be to increasingly deal with wastes in ways that recover resources, i.e., produce less wastewater, extract reusable components and dispose safely of the rest.

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Chapter 13

Noise Pollution

13

13.1 What is Noise Pollution?

More people are recognising that noise is becoming an environmental pollutant that threatens our quality of life. Barking dogs, lawn mowers, leaf blowers, power saws, church bells, jackhammers, motorcycles, airplanes, car stereo systems, boats, jet skis and traffic generally have combined to such a degree that noise-induced irritation, annoyance, discomfort and hearing impairment have become a significant public health issue in the United States and are of growing concern in Bermuda. In addition to impairing human health, noise is detrimental to wildlife, scaring away birds and other animals from their habitats.

As the Island's population continues to grow and housing densities increase, there will be a greater need for guidelines, policies and possibly revised and/or new legislation covering noise pollution in residential and other areas.

Noise is usually defined as 'unwanted sound' (World Health Organisation). Sound is a sensory perception and the complex pattern of sound waves is labelled music, speech and noise. Sound is the result of pressure changes in air, caused by vibration or turbulence. The amplitude of the pressure change, called the sound level, is measured in decibels (dB). The speed at which the changes occur (the frequency) is stated in terms of cycles per second, or Hertz (Hz). Examples of sound levels from various sources are shown in Table 13.1.

Humans can detect a wide range of sound pressures. These levels are measured on a logarithmic scale. The audible range for people is about 0 to 120 dB, with zero decibels being an arbitrary noise energy intensity approximately equal to the lower limit of hearing of a young adult. Above 120 dB, hearing damage will rapidly occur.

The effects of noise are determined mainly by the duration and level of the noise but they are also influenced by the frequency. Long-lasting, high-level sounds are the most damaging to hearing and are generally the most annoying. High-frequency sounds tend to be more hazardous to hearing and more annoying than low-frequency sounds. The way sounds are distributed in time is also important, in that intermittent sounds appear to be somewhat less damaging to hearing than continuous sounds because of the ear's ability to regenerate during the intervening quite periods. However, intermittent and impulsive sounds tend to be more annoying because of their unpredictability.

The adverse effects of noise can be cumulative with prolonged or repeated exposure. Noise is an intrusion on one's sense of privacy. It can take years for noise-induced hearing loss to develop. Noise-induced hearing loss can impact the quality of life, through a reduction in the ability to hear important sounds and to communicate with others. Some of the other effects of noise, such as sleep disruption, the masking of speech and television and the inability to enjoy one's property or leisure time also impair the quality of life. In addition, noise can interfere with the teaching and learning process, disrupt the performance of certain tasks and increase the incidence of antisocial behaviour. There is also some evidence that it can adversely affect general health and well being in the same manner as chronic stress.

Non-industrial noise is referred to as community noise, also known as environmental, residential or domestic noise. The main indoor sources are

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ventilation systems, office machines, home appliances and neighbours. Other typical sources of neighbourhood noise include the catering trade (including restaurants and cafeterias), live or recorded music, sports, playgrounds, car parks, crowing roosters and barking dogs.

There are difficulties undertaking noise monitoring because environmental noise measurements can be influenced by the weather, source strength variability, ground attenuation effects, barriers and reflecting objects and time of measurement and duration. Despite these obstacles, noise measurement procedures, although complex, are followed in many jurisdictions and assist in decision-making to regulate noise.

There are many varied sources of occupational noise in industrial machinery and processes, including rotors, gears, turbulent air flow, impact processes, electrical machines, internal combustion engines, pneumatic equipment, drilling, crushing, blasting, pumps and compressors. Often, the emitted sounds are reflected from floors, ceilings and equipment. Noise is a common occupational hazard in many workplaces.

Table 13.1 Typical sound levels for various sources

Threshold of Pain	↑	140 dB	Jet engine 25 metres away
		120 dB	Jet taking off 100 metres away
Extreme		115 dB	
		110 dB	Musical band
		95 dB	Permanent hearing loss may occur
Very noisy		95 dB	
		90 dB	Pneumatic drill, 7 metres away
		90 dB	Heavy truck at 40 km/h, 7 metres away
		80 dB	Tree frogs
Noisy		75 dB	
		75 dB	Average street traffic at 40 km/h, 7 metres away
		62 dB	Business office
Moderate		55 dB	
		42 dB	Living room
Quiet		35 dB	
		31 dB	Library
		25 dB	Bedroom
Threshold of hearing		0 dB	

Source: Compiled from RTA Environmental Noise Management Manual *by Roads and Traffic Authority, New South Wales, Australia, December 2001;* Technical Guidance Note IPPC H3 Integrated Pollution Prevention and Control Draft Horizontal Guidance for Noise Part 2 – Noise Assessment and Control*, version 1. October 2001 by the Environment Agency, Bristol, England; and some local Bermuda noise readings.*

Figure 13.1 A jackhammer

Photo courtesy of Heather DeSilva

13.2 Noise Control and Legislation

13.2.1 Noise Legislation

Many countries have introduced regulations to control noise from rail, road, construction and industrial plants based on emission standards and many cities are enacting legislation to address neighbourhood community noise.

Table 13.2 lists standards set by the World Health Organisation (WHO) for noise from various activities, which if the level and duration are exceeded are considered damaging to health.

In Bermuda, there are a number of pieces of legislation which address the issue of noise. Section 7 of the Summary Offences Act, 1926 (revised 1989) places controls on the amplification of sounds according to the time of day, providing the Commissioner of Police has not issued a specific permit. Between midnight and 6 a.m., amplified sounds should not disturb or annoy any person in the vicinity. Persons should not make any noise that is likely to disturb or annoy persons dwelling in the vicinity. Between 6 a.m. and midnight, amplified sounds should not be heard more than 100 feet from the source and cause annoyance to two or more people.

The Motor Car (Construction, Equipment and Use) Regulations, 1952 (made under sections 11, 102 and 103 of the Motor Car Act, 1951) place controls on: excessive noise from defects or faulty packing of loads of motor cars or trailers; excessive noise due to a lack of care; and the unnecessary use of car horns. The Regulations require the stopping of motorcar engines when stationary to prevent noise.

The Auxiliary Bicycles (Construction, Equipment and Use) Regulations, 1955 (made under sections 30 and 51 of the Auxiliary Bicycles Act, 1954) sets a maximum standard of noise permitted in relation to any auxiliary bicycle when the engine of the auxiliary bicycle is being run at a speed which would propel the auxiliary bicycle, together with a driver, at 20 miles per hour on a level road under windless conditions, or at full throttle (whichever condition is first reached in the test). The noise standard is 93 dB at present.

The Road Traffic Act, 1947 makes it an offence to drive a vehicle on a road when the vehicle is in such a condition as to cause unnecessary noise, vibrations, smoke or smell.

The Dogs Act, 1978 makes it an offence for the noise from a dog to be an annoyance to neighbours.

The regulations (1986) under the Health and Safety at Work Act, 1982 and its accompanying code of practice (1997) cover occupational hazards to safety and health, and include risk assessment by the Health and Safety at Work Committee. This provides for powers to require operators of machinery emitting excessive noise to wear ear protectors.

Although there is no local legislation with regard to noise from aircraft, most airline jets that fly into Bermuda meet the highest engine noise environmental standards that have been imposed by the United States, Canadian and European governments. There are two aircraft noise abatement policies. One prevents aircraft from making departure turns over Ferry Reach or St. David's and the other prohibits jet powered aircraft to over-fly Bermuda below 5,000 feet.

The 1986 Bermuda National Parks Act and its accompanying 1988 Regulations have sufficient legislation in place to deal with the various forms of noise complaints or issues.

There is no legislation in place to control noise from mechanical equipment (fans, pumps and air conditioners), industrial equipment, aircraft, boat and watercraft engines, home appliances (lawn mowers, leaf blowers) or quarrying operations. This may be considered by the Department of Environmental Protection in the future.

Table 13.2 The World Health Organisation guidelines for community noise in specific environments

Specific Environment	Critical health effect(s)	L_{Aeq}* [dB(A)]	Time Base [hours]	L_{Amax}** [dB]
Outdoor living area	Serious annoyance, daytime & evening	55	16	-
	Moderate annoyance, daytime & evening	50	16	-
Dwelling, indoors	Speech intelligibility & moderate annoyance, daytime & evening	35	16	-
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	Sleeping-time	45
School, playground outdoor	Annoyance (external source)	55	During play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time	30	8	40
	Sleep disturbance, daytime & evenings	30	16	-
Industrial, commercial shopping & traffic areas, indoors & outdoors	Hearing Impairment	70	24	110
festivals and entertainment events	(patrons:<5 times/year)			
Public addresses, indoors & outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/earphones	Hearing impairment (free-field value)	85 #3	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults)	-	-	140 #1
	Hearing impairment (children)	-	-	120 #1
Outdoors in parkland and conservation areas	Disruption of tranquillity	#2		

Notes:
* L_{Aeq} *is the A-weighted equivalent continuous sound levels*
** L_{Amax} *is the A-weighted maximum noise level*
#1 *Peak sound pressure (not LAP, max) measured 100 mm from the ear*
#2 *Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be keep low*
#3 *Under headphones, adapted to free-field values*

Source: World Health Organisation (Geneva) 1999

One aspect of legislation with respect to enforcement that needs to be pursued is to grant authority to those outside the Police Service to issue a summons under the Summary of Offences Act. In the late 1990s, a plan was tabled for all affected Ministries but it presently remains dormant (Burt 2004, pers. comm.).

Political will and community support will be necessary to introduce legislation to control noise that is not presently regulated.

13.2.2 Enforcement of Legislation

It is difficult to gauge the effectives of enforcement of legislation and regulations that deal with noise. This is because noise is usually a part of a wider complaint.

The Police enforce complaints relating to the playing of loud music from car stereos and buildings, complaints about dogs barking excessively and any other matters pertaining section 7 of the Summary Offences Act (Brentano 2004, pers. comm).

The Department of Parks deals with noise complaints. Complaints about the congregation of groups include concerns about loud talking (including bad language), music from vehicles as well as noise from vehicles entering and leaving the park. There have also been complaints about noise from model powerboats and illegal motocross activity in several parks (Burt 2004, pers. comm.).

Complaints about loud music received by the Department of Parks include violation of the conditions of camping permits and concert permits. Campers sometimes play music too loud and/or too late at night. On occasion, concerts have extended beyond the hours allowed by the licence. Concert permits may be granted only for certain parks that are relatively isolated from residential areas, such as Clearwater Park. The Department of Parks, the Bermuda Land Development Company and concession operators have worked together to establish guidelines for users of this park.

Special permit applications have sections that apply to special equipment for functions i.e., bouncy castles, sound systems and public address systems. However once they are approved any follow up on site can be inconsistent due to limited resources. (Brown 2004, pers. comm.).

When an offence against the Parks Regulations is committed, enforcement is straightforward if it is immediately brought to the attention of the authorities. Problems arise when there is a time-delay in the complaint and evidence may become distorted. When the legislation is explained, most people will comply. This is also the experience of the police in attempting to deal with noise pollution by the power granted them by the Summary Offences Act. The Department of Parks has fostered a good working relationship with the Bermuda Police Service and works closely with the Department of Parks to enforce the legislation. (Burt 2004, pers. Comm.).

13.2.3 Monitoring Noise Pollution

The Department of Police collects statistics on complaints relating to noise disturbances. These relate to the playing of loud music from car stereos and buildings and complaints about dogs barking excessively and any other matters pertaining to section 7 of the Summary Offences Act.

At present the Department of Parks collects some data. There are also plans to procure a software package for management of the Department of Parks operations (including ranger, lifeguard and maintenance operations), incident reports (including noise pollution), follow ups, actions and outcomes (Brown 2004, pers. comm.).

The Occupational Health and Safety Office collects data on workplace incidents although, as with the Department of Parks, noise pollution is only one issue for which they have responsibility.

The guidelines provided by the World Health Organisation could be useful in the formulation of better policies and guidelines in the future.

13.2.4 Public Education

At present the Department of Parks has no specific public education programmes. Some park signs (such as those present in the Botanical Gardens and Arboretum) have general etiquette guidelines.

Messages about noise pollution are included with other topics through school talks and camping bulletins. General information about the 1988 Bermuda National Park Regulations is given to an individual or group by park rangers (Brown 2004, pers. comm.).

The Occupational Health and Safety Office conducts seminars on all the health and safety issues for workers on the request of employers but these sessions often comprise wide-ranging topics on the prevention of accidents on the job and noise issues may be only a part of the briefing.

The provision of more opportunities for students and the public to improve their knowledge and skill development in conflict management and mediation techniques should be considered. This would give people confidence to solve disagreements about all kinds of issues, including noise and would alleviate the need for as much intervention by government authorities.

13.3 Summary

The adverse effects of noise to human health, particularly hearing, can be cumulative with prolonged or repeated exposure. Excessive noise also has a negative impact on the amenity of an area and frightens birds and other animals.

There will be a greater need for guidelines and possible revised legislation covering noise pollution in residential areas. Informal observations indicate that noise is increasingly becoming a problem in Bermuda and needs to be addressed.

The Summary Offences Act, 1926 (Revised 1989), section 7 places controls on the amplification of sounds according to the time of day. Other legislation such as the Road Traffic Act, 1947, Motor Car Act, 1951, the National Parks Act, 1986, the Dogs Act, 1978 and the Health and Safety at Work Act, 1982, and their related statutory regulations, control activities to minimise noise pollution.

There is a need to improve enforcement of existing legislation to control noise pollution by better coordination and cooperation between the various arms of government. There are also significant gaps in the legislation and a need for improved means of collecting data concerning noise complaints and prosecutions.

There are no formal education programmes about noise pollution or existing laws for its control. Information programmes geared to school students and the public would help to raise awareness about the damage to human health (especially hearing impairment) that excessive noise causes. Education about the negative effects of noise pollution on the amenity of parks and residential areas would assist in promoting respect for quietness as well as compliance to the relevant laws. and the teaching of conflict management skills would help citizens resolve disagreements concerning a number of issues, including noise.

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4 Pest Control and Invasive Alien Species

Chapter 14

Pest Control

14

14.1 Mosquitoes

14.1.1 Introduction

Mosquitoes have caused some of the most widespread and lethal disease outbreaks in Bermuda's history and in the history of the world.

In the 1940s an outbreak of dengue fever affected several thousand Bermuda residents. Many were hospitalised and some died from the disease. The Department of Health responded with a widespread and thorough mosquito control programme as part of the 'war effort' with the British, Canadian and American garrisons all helping out. The campaign continued after the war and was eventually declared triumphant by the 1960s. The dengue fever mosquito (*Aedes aegypti*) was considered eradicated from our shores.

Unfortunately the dengue fever mosquito is back and is gradually re-establishing itself on the Island. Bermuda's population density, landscape and lifestyles have changed radically in the last 50 years and it is proving difficult to repeat the mosquito control successes of the past and to keep mosquito control on the priority list of a modern, throwaway society.

Recent, widespread outbreaks of West Nile virus in North America have served as a timely reminder that mosquitoes continue to be a serious environmental health issue.

14.1.2 Mosquito Species In Bermuda

The four most important species of mosquito in Bermuda are the following:

(a) The dengue mosquito

The dengue mosquito (*Aedes aegypti*) (see Figure 14.1) is the primary vector for the viruses that cause dengue and yellow fever. The adult is a medium-sized black mosquito recognised at close inspection by a silvery-white, lyre-shaped pattern of scales on its back that also resembles the Nike tick.

Figure 14.1 The dengue mosquito (*Aedes aegypti*) on the left and the Asian tiger mosquito (*Aedes albopictus*) on the right

Photo courtesy of the Department of Health

This mosquito lives very close to human dwellings and is an early morning and late afternoon biter. Human blood is preferred over other animals. Adult mosquitoes frequently reside inside dwellings in closets, cabinets, or cupboards when they can get access.

Eggs maybe deposited both outside and inside the home and are laid on damp surfaces within artificial containers such as buckets, barrels, plant pots or tyres. The eggs of *Aedes aegypti* can resist desiccation (or drying out) for up to one year. Eggs hatch when flooded again by water. The eggs and the adults are easily able to survive the Bermuda winter. The mosquito has been spreading since its reintroduction into Bermuda in 1998.

(b) The Asian tiger mosquito

The Asian tiger mosquito (*Aedes albopictus*) (see Figure 14.1) has breeding habits similar to *Aedes aegypti* but it appears to exhibit a much broader ecological range. This mosquito was only discovered in Bermuda for the first time in July 2000. It closely resembles its cousin the *Aedes aegypti*. Breeding in red-hot poker plants (a type of bromeliad) demonstrates that it is colonising new habitats and may prove hard to dislodge.

Although *Aedes albopictus* is of lesser importance in the transmission of dengue worldwide, studies indicate that it is more susceptible to infection than *Aedes aegypti*. *Aedes albopictus* can maintain the disease via trans-ovarian transmission. Males can horizontally transmit dengue to females during mating. *Aedes albopictus* has been found to be a competent vector for West Nile virus and may be responsible for cross species transfer (from infected birds to man).

(c) The salt marsh mosquito

The salt marsh mosquito (*Oclerotatus sollicitans*) is a mosquito vector of encephalitis and dog heartworm. This is probably the largest mosquito in Bermuda. It is black with yellow and white stripes on its body and legs. It is a most aggressive biter and is known to dive onto victims in a full frontal assault. The bites from this mosquito can leave large welts and can be quite painful. Resting females will readily attack anyone that enters their territory during the day.

Eggs are laid individually on the moist ground at the upper reaches of grassy salt marshes, especially in areas with salt meadow grass or salt grass such as at Spittal Pond and recently at White's Field inWarwick. Larvae develop in pools and puddles that are produced by exceptional high tides and/or heavy rainfalls. Since these aquatic systems tend to dry up quickly, survival to the adult stage often depends on rapid larval development. Under optimal conditions emergence of adults can occur in as little four to five days following egg hatch.

Peak abundance of adults usually occurs in the fall and spring, often in combination with high rainfall, lunar tides, and, as witnessed in November 2002, in conjunction with warm eddies of the Gulf Stream and the associated sea level rise.

(d) The common mosquito

The common mosquito (*Culex pipiens*) is the principal vector of the West Nile virus in the United States, which for the most part is a bird disease (as these mosquitoes prefer birds as a blood source over humans). Adults of the *Culex pipiens* are light brown and they lack distinctive striped markings. These are the common house mosquitoes that whine in one's ear at night.

Culex pipiens can be found in a fairly wide range of larval habitats but are generally associated with dirty water. This species not only deposits its eggs on puddles and in ditches but also in artificial containers including buckets, tyres and any refuse that hold stagnant water. This species can breed in cesspits demonstrating its ability to use even the foulest water for breeding.

Figures 14.2 (a) (b) (c) and (d) shows the spread of the *Aedes aegypti* and *Aedes albopictus* vectors. In just four years the mosquitoes at their seasonal peak (the end of August) have gone from being found in Warwick Parish and port areas to being an Island-wide phenomenon. Further spread is now likely to take place into the extreme ends of the Island.

Figure 14.2(a) Bermuda's Ovitrap Programme surveillance results from the final week in August 2000

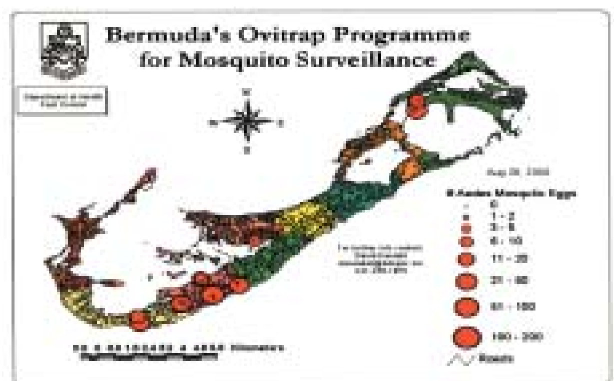
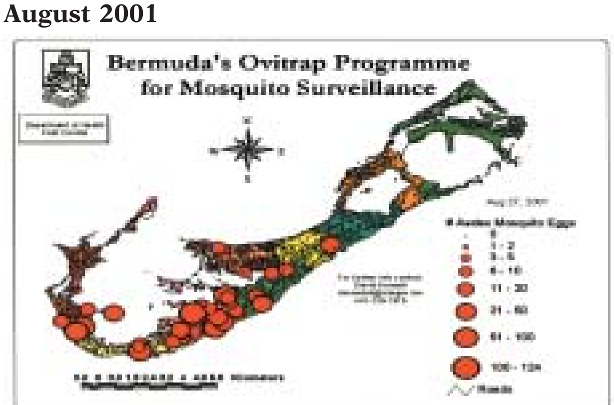


Figure 14.2(b) Bermuda's Ovitrap Programme surveillance results from the final week in August 2001



Source: Department of Health

Figure 14.2(c) Bermuda's Ovitrap Programme surveillance results from the final week in August 2002

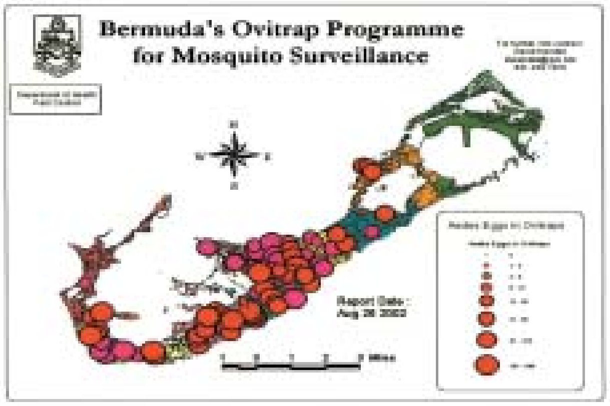
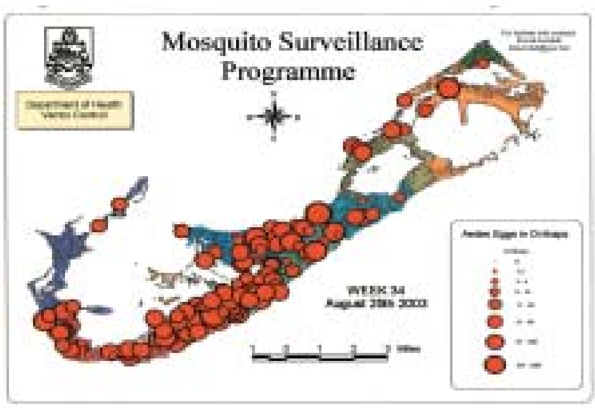


Figure 14.2(d) Bermuda's Ovitrap Programme surveillance results from the final week in August 2003



Source: Department of Health

Mosquitoes have several impacts, the first and most important of which is the risk of mosquito borne disease. Unlike the Caribbean where every generation is exposed to diseases like dengue fever, thus establishing herd immunity, in Bermuda there is no such protection. When a new disease like dengue fever is introduced to a generation of people that have never been previously exposed, mosquitoes more easily spread the virus from person to person. The result is that a dengue outbreak in Bermuda in August or September may affect residents Island-wide.

A second impact of the *Aede*s mosquitoes is that they are day-biting insects. The soft light of dawn and sunset and in shaded areas are preferred over more intensely sunlit conditions. This means that outdoor recreation coincides with peak biting times. This increases the likelihood of being bitten and detracts from the enjoyment of the outdoor environment.

Lastly, these mosquitoes are aggressive biters and in their persistence to get a blood meal they often bite repeatedly. This not only increases their success in transmitting disease but also leaves painful bites on exposed skin, typically the legs and below the knees. Insect repellents, socks and long pants are a good solution but are not welcome attire in sweltering humid weather.

4.1.3 Means of Mosquito Control

4.1.3.1 Introduction

It is interesting to reflect back on the significant, although often misguided, efforts that our forefathers invested in mosquito eradication. During the mosquito control campaign of the 1940s, 1950s and 1960s hundreds of acres of pristine Bermuda marshlands were turned into landfills and domestic refuse was buried by the ton. Mounds of rubble were removed from Black Watch Pass to fill the Pembroke Marsh. Mangroves were felled, ponds were filled in and the character of the Island changed forever.

Marshland works directed at eliminating the dengue fever mosquito had little effect towards that goal because the dengue mosquito lays its eggs in the sheltered confines of containers of water and will not breed in a marsh.

In modern mosquito control we have come to realise that there is no silver bullet and have learnt to focus instead on source reduction i.e., finding the items that hold broods of immature mosquitoes. These sources are then managed using an approach that blends persistence, thoroughness and a systematic approach.

Mosquitoes need water to complete their life cycle. Except for the adult, all life stages require an aquatic habitat (see Figure 14.3). Only by controlling stagnant or standing water can we begin to control mosquito numbers.

Effective mosquito control involves community participation, a litter free environment, frequent garbage collection, good building codes and practices (especially the storage of drinking water in cisterns that are inaccessible to mosquitoes) and the installation of screened windows and doors to reduce the potential for mosquito entry into homes.

It is now recognised that there are less ecologically destructive ways of controlling mosquitoes in marshlands. These methods include the use of mosquito predators including fish such as guppies, in conjunction with engineered drainage and maintained open water ponds and ditches, since mosquitoes prefer the stagnant water formed by clogged waterways rather than moving water.

Figure 14.3 The mosquito lifecycle – anti-clockwise egg, larva, pupa, adult

Photos courtesy of the Department of Health

4.1.3.2 'Fight the Bite' campaign

In 1998 when the dengue fever mosquito was rediscovered in Bermuda, there was no systematic check of houses for mosquito breeding being undertaken.

Figure 14.4 The 'Fight the Bite' campaign logo

Source: Department of Health

The House Index is the percentage of houses in a locality that are breeding mosquitoes. This is a yardstick by which countries are compared with one another as well as a measure of the likelihood of outbreak of mosquito-borne disease.

The launch of the 'Fight the Bite' mosquito control campaign in 2000 (see Figure 14.4) sought to generate the necessary statistics and to control the threat of dengue fever. Workers within the Department of Health that were labouring to manually dredge ditches were redeployed as Vector Inspectors.

The system of work has evolved from a proactive and thorough (albeit slow) 'end to end', 'every house checked' methodology to one that relies on mosquito surveillance systems to target our limited human resources. Without garrisons of men to perform inspections as we had in the 1940s, we have recently switched gears to a 'quick and targeted response mode'.

An extensive mosquito surveillance network in the form of 300 mosquito traps, called ovitraps or egg traps, are deployed in transects across Bermuda which are analysed weekly totaling 15,600 traps and records per year (see Figure 14.2).

Figure 14.5 shows how the computer is used to draw a buffer around the positive ovitrap so that inspection of houses in the vicinity can be targeted by proximity to the trap. The darker shaded buildings are inspected first.

Figure 14.5 Inspection priority: houses shaded by proximity to trap

Source: Department of Health

Reacting to positive mosquito traps is much more sensitive than waiting for complaints of biting from a neighbourhood. The mosquito teams follow positive ovitraps daily into a wide diversity of neighbourhoods. The mere presence of a team enhances compliance. Also by not relying only on complaint calls we avoid a blame culture that can result in hostility between neighbours.

The result is that after three years of this work people are cleaning up and are to be commended for the fact that the House Index has fallen from 15% at the outset of the campaign to approximately 5% in 2003. The Department of Health's aim is for the community to maintain the house index below the disease transmission threshold of 5%. This is a significant goal, as it will give Bermuda's inhabitants some protection against dengue fever and West Nile virus.

There has been an increased emphasis on enforcement with the mosquito control team zeroing in on and making accountable repeat offenders. More warnings and citations have also been issued when compared to previous years.

4.1.3.3 Marshland mosquito control

In November 2002 Bermuda experienced record high tides when a warm eddy from the Gulf Stream coincided with the typical high autumnal tides. Low lying areas, many of which are co-incidentally legacies of marshland reclamation projects of the past, (including school fields, golf courses, industrial land as well the nature reserves and tracts of South Shore) were underwater or swamped for several weeks.

Salt marsh mosquito eggs (*Oclerotatus sollicitans*) that had been laying dormant awaiting these perfect conditions sprang to life in an awesome display of nature's reproductive capacity. The end result was an explosive outbreak of nuisance mosquitoes across several parishes.

Unfortunately, the 'Fight the Bite' campaign had compromised the Department of Health's traditional mosquito control role in these marshlands as mentioned previously. Whilst efforts to mechanise the digging of drainage ditches have been put in place, the impacts of hurricane Fabian derailed funding for what ultimately will be an efficient and modern approach to marshland mosquito control.

4.1.3.4 Road drains

Section 30 of the Public Health Act, 1949 states that all wells or borings shall be provided with wells heads and shall be covered to adequately protect them from access by mosquitoes.

However, despite this legislation, the installation of many hundreds of wells as surface water drains have been sanctioned. Unfortunately, in most cases, these do not comply with section 30 and subsequently there is the risk that we have created perfect conditions for the entrenchment of an unwanted mosquito vector.

Therefore, government needs to ensure that great care is taken in the design and installation of drainage systems when mosquito control is a priority. In Singapore every road drain has at least one annual inspection, cleansing and then whitewashing to deter the use of the drain by mosquitoes as a breeding place. There is much merit in such a control programme.

4.1.3.5 Trash in the trees

Buckets, plant pots, tyres and barrels are the primary items found to be breeding mosquitoes on domestic premises. The unanswered question is why we are seeing the House Index decrease and yet the ovitraps are painting a picture of an ever wider spread of the dengue mosquito population.

One answer may be that until this year the inspection teams have not focused on items of rubbish thrown in the bushes. Perhaps, as residents clean up and destroy the mosquito habitats that they were once providing on their land, the insects, undeterred, move into the ubiquitous piles of refuse that are hidden by lush vegetation in almost every Bermuda neighbourhood.

The issue of the trash in the trees and bushes is not a trivial problem as participants of community cleanup initiatives have demonstrated. The Keep Bermuda Beautiful initiative and coordination of cleanup and management of volunteers is commendable but there needs to be wider support, community education and enforcement of littering laws. Cleanups are only a token effort when taken in context of the tidal wave of rubbish that is dumped into Bermuda's environment annually.

Mosquitoes breed in refuse, typically in large, discarded containers. Worryingly, breeding mosquitoes were found in discarded bottles for the first time in 2003. It is possible that the summer drought pushed these insects to seek out tiny pockets of water or it could simply be that discarded bottles lying around among the trees are a regular mosquito haven.

Until refuse and litter of this nature are removed from the landscape, and bad habits with respect to irresponsible refuse disposal are changed, we are unlikely to eradicate the *Aedes* mosquito vector from Bermuda.

14

14.2 Vermin

14.2.1 Introduction

Vermin are small animals or insects, such as rats or cockroaches that are destructive, annoying or injurious to our health.

Mankind has fought vermin for hundreds of years. Yet, vermin do not seem to be declining in the long term. Early settlers burned Bermuda's vegetation in an attempt to control rats and pesticides have been used to kill cockroaches. However, there is much concern about the consequences of pesticide use on human health and wildlife.

Rats and cockroaches are highly resilient creatures for a number of reasons:

(a) They do not rely on humans to provide food and shelter. Instead, they can nest outdoors and exploit food sources provided by plants such as nuts, seeds, fruit, and fresh or rotten vegetable matter.

(b) They often come out when humans are asleep.

(c) They breed very quickly. A male and female pair of rats can produce as many as 200 or more offspring per year. Within one year, this pair and their offspring could produce rats that exceed one thousand. One pair of cockroaches can lay enough eggs to produce thousands of offspring in less than a few weeks totalling millions in only a few months.

(d) They thrive when the conditions are right. Vermin exploit stockpiles of unprotected food and piles of debris and garbage as an opportunity to produce more offspring. They raise their offspring as close as possible to the food source, and if entry is possible into nearby buildings they may move indoors.

14.2.2 Vermin Control

Bermuda's laws recognise the need to control vermin, to prevent infestations and to protect public health. Provisions exist in the Public Health Act and there are regulations that:

(a) prescribe methods for destroying vermin;

(b) prescribe methods for rendering premises inaccessible to vermin and for the destruction of the breeding places of vermin; and

(c) prescribe general steps to be taken by owners and occupiers of premises to maintain the premises free of vermin.

The Environmental Health team enforces these laws and requires proper control of vermin in all premises that store, prepare and sell food, such as restaurants, hotels and cruise ships.

A free rodent control service is provided by the Department of Health. The Vector Control team serviced some 2,214 residential and business premises in 2003 and all farmlands were provided with a proactive service to protect important crops such as melons, pumpkins and corn. In total there were 13,408 service calls and 14,694 pounds of poison consumed. Figure 14.6 shows the monthly figures for rodent services.

Second generation anticoagulant poisons are used such as difenacoum. The first generation anticoagulant Warfarin has been replaced because resistance was reported in other countries. There are pros and cons to anticoagulant rodenticides. The rat does not realise that it is being poisoned as it ingests the bait in multiple feedings over several days and therefore there is no 'bait shyness'. Unfortunately this leaves the rodent alive a little longer, often resulting in further damage to property or crops. In terms of materials more rodenticide is needed to kill one rat and the labour cost is higher as the bait has to be replenished frequently.

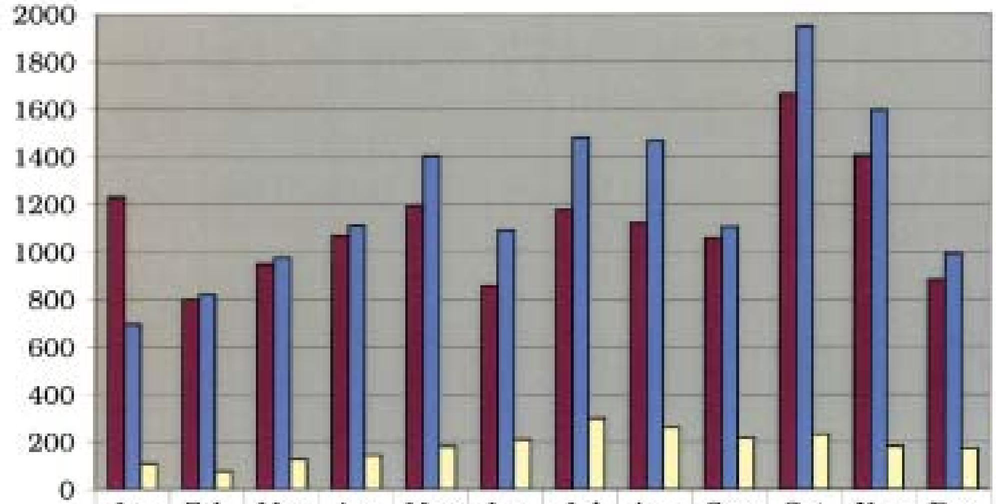
The best anticoagulant baits are dyed bright colours and have bitter flavouring agents added to deter ingestion by humans. The widely available antidote is vitamin K.

There is a move to replace acute toxins with less harmful and more environmentally friendly options.

Private pest control companies provide ant and cockroach control to the public at market rates. Alternatives to toxic pesticides such as the insect growth regulators methoprene and hydroprene are being widely deployed. Cockroaches and other insects that undergo molting (mosquitoes and fleas) will ingest or absorb these juvenile insect hormones and never mature into adults. Thus numbers are controlled as only adults can produce offspring.

Ant control used to rely mainly on Diazinon granules but this chemical is being phased out. It is likely that boric acid will take its place in the next few years.

Figure 14.6 Rodent service statistics for 2003



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Service Calls	1231	799	950	1068	1194	857	1178	1121	1058	1665	1405	882
Poison Used lbs.	697	821	975	1112	1405	1091	1482	1468	1106	1949	1597	992
Jobs In	110	77	128	145	181	211	300	261	217	232	181	171

Source: Department of Health

The pest control business is seasonal. Rodent season begins in April and continues until December, with the peak months occuring from July through to October. One factor that increases service requests (but does not indicate an increase in the number of infestations) is the fact that people spend more time outdoors in the summer months. Therefore they are more likely to encounter previously undetected rodents at this time.

Figure 14.7 A cockroach

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

14.2.3 Future Work

Detection of rodent infestations is the motivation behind the following two initiatives:

(a) Callbacks (old jobs that are reopened) will be tracked to detect hot spots; and

(b) Use of map analysis to determine clusters of accounts that would point to an underlying root cause such as improper garbage disposal, an aviary or animal feed that is accessible to rats. The question is whether there is an undetected source that needs to be addressed.

Inspectors are being encouraged and trained to be more proactive in their approach to infestations, involving a wider number of their colleagues and seeking other potential solutions to address root causes rather than relying on rodenticide alone.

Efforts are also being made to accelerate the uptake, purchase and use of tamper-proof rodenticide stations by customers.

Another initiative is needed to get the public to use lidded garbage containers or 'wheelie bins' and refrain from putting out refuse in plastic garbage bags alone.

14

14.3 Summary

Historically, mosquitoes have been responsible for causing outbreaks of some of the more widespread and lethal diseases in Bermuda and elsewhere around the world. Within Bermuda, there are four main types of mosquito, which are capable of carrying diseases such as dengue and yellow fever. These are the dengue, Asian tiger, salt marsh and common mosquitoes.

Depending on the type of breed, mosquito habitats range from within human dwellings and plants, to marshland and small pools of stagnant water. Between 2000 and 2003 a monitoring programme found that during their seasonal peak, mosquitoes have spread from within a single parish to other parts of the Island.

Between the 1940's and 1960's attempts to eradicate mosquitoes included filling in marshland and ponds and felling mangroves. This had little impact on eliminating the dengue fever mosquito as this particular species lays its eggs in sheltered water containers and does not breed within marshland. Present day mosquito control represents a more refined and less ecologically destructive approach. This concentrates on source reduction by locating and reducing items which hold broods of immature mosquitoes.

After the dengue fever mosquito was discovered in 1998, a mosquito breeding monitoring system was introduced known as the 'House Index' together with the 'Fight the Bite' campaign in 2000. A mosquito surveillance network was also established and 300 ovitraps were located across the Island. This approach allows for more selective action to be taken, where large concentrations of mosquitoes are detected and seeks to make the best use of limited human resources available for mosquito control. After three years of work, the surveillance teams have helped to significantly reduce the recorded House Index from 15% to approximately 5%.

In 2002, high tides and a warm eddy from the Gulf Stream led to an unfortunate increase in marshland mosquitoes. Insufficiently covered wells and surface drains have increased the risk of further unwanted mosquito activity. The design and installation of drainage systems therefore, needs to adhere more closely to relevant Public Health Act requirements.

Community participation is also crucial to controlling mosquitoes. By eliminating the indiscriminate dumping of refuse in woodland and open areas we can have a significant impact on reducing mosquito nuisance.

Although we have been seeking to control vermin for hundreds of years, the long term population does not seem to be declining. Rats and cockroaches are particularly prevalent forms of vermin and have several characteristics in common. They do not rely on humans for food or shelter and can survive nocturnally. They also reproduce very rapidly and thrive on stockpiles of unprotected food, piles of debris and garbage.

Current legislation set out in the Public Health Act and associated regulations recognise the need for vermin control and prescribe methods of eradication and ways of rendering premises inaccessible. A vector control team has been established by the Department of Health which provides a proactive service to help control vermin in residential and business areas and on agricultural land.

Second generation anticoagulant poisons are used against rats as a more effective source to earlier versions. This form of poison avoids 'bait shyness' but requires additional bait quantity and leaves the rodent alive for a longer period of time.

A culture of safety can be seen across the pest control industry, as acute vermin poisons are being replaced by more environmentally friendly options. For example, alternatives to toxic pesticides such as insect growth regulators are being widely deployed. This method allows for cockroaches and other insects that undergo molting to ingest juvenile hormones which prevent them from maturing into adults and producing offspring.

Future work involving the detection of vermin will include concentrating efforts on hotspots through re-visiting previous known locations and map analysis to determine clusters of vermin activity. Increased public use of tamper proof rodenticide stations is also being encouraged as well as the introduction of lidded garbage containers or 'wheelie' bins for general use to prevent access to food by rats.

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Chapter 15

Invasive Alien Species

15

15.1 The Impact of Invasive Alien Species

Over recent years, there has been growing awareness of the impact of invasive alien (non-native) species on native species and ecosystems. Whilst habitat destruction is generally considered to be the most significant cause of global biodiversity loss, in many areas invasive alien species may have as much of an impact. Certainly, amongst oceanic islands, they are generally considered to be the single largest threat to the native biodiversity (Murphy, 2002), although their effects are compounded by the combination of habitat loss and fragmentation and over-harvesting.

Hernandez *et al.*, (2002) estimated that invasive alien species are responsible for 39% of all species extinctions since 1600 and that whilst 12% of all continental animals are threatened by alien invasions, this rate increases to 31% on islands.

Evolving in the absence of large predators, mainland diseases and the need for life history traits (such as high fecundity and earlier age of first reproduction), island species readily fall victim to invasive alien species. This makes them easy prey, succumbing to the diseases they carry and failing to effectively compete for food or shelter.

Invaders in turn encounter more (or better) resources, fewer natural enemies and an often more advantageous physical environment. As a result, they can displace native species. In addition, they can also alter whole ecosystems by changing light levels and soil chemistry, increasing surface run-off and erosion and affecting nutrient cycling and pollination. They are accomplished travellers, hitchhiking rides on boats, airplanes and with travellers, as well as on produce and other imported items. Aside from their impact on native biodiversity, they often impose an enormous economic cost on agriculture, fisheries and other human activities, as well as on human health. In many jurisdictions, this amounts to billions of dollars.

There has been no real attempt as yet to measure the direct and indirect economic costs associated with invasive aliens in Bermuda. However, hurricanes Emily (1987) and Fabian (2003) both served as indicators of some of the potential costs caused simply by poorly adapted alien trees like the casuarina toppling on buildings and contributing to severe coastal erosion.

Not every alien species becomes a nuisance; many provide economic, recreational and social benefits, and are often adopted into the cultural traditions of a region. For example, prior to the arrival of exotics like oleander, hibiscus, cardinals and whistling frogs, Bermuda's landscape would have lacked the kaleidoscope of colour that nowadays entices visitors to the Island. Also without the introduction of honeybees or vegetables like the onion, Bermudians would not be able to boast of their famous honey or onions.

So where does the distinction between alien species and invasive alien species lie? An alien species is one that is non-native to Bermuda. It is an introduced alien if it did not find its way here naturally but was carried here, intentionally or unintentionally by human means. An invasive alien species is a non-native that has the ability to establish self-sustaining, expanding populations in the wild and may cause environmental and/or economic harm.

The dramatic increase in global trade and travel over the last few decades has led to rapid acceleration of alien species movements. Bermuda now imports nearly everything it needs. In 1999, an estimated 300,000 metric tonnes of goods were imported, of which the majority arrived by container ship. In the same year, there were 6,024 aircraft landings with

481,274 passengers and 1,550 cruise ship and yacht arrivals carrying 195,586 visitors. Add to this the travel undertaken by Bermudians themselves and it amounts to a significant stream of goods and people onto the Island, together with the potential for intentional and accidental, legal and illegal introductions of alien species.

Whilst the Island's marine environment has largely been unaffected by invasive alien species, Sterrer *et al.*, (2004) report that Bermuda's terrestrial biota have been drastically altered. At least 1,200 exotic species (mainly flowering plants, insects, spiders, snails, birds, reptiles and amphibians) have become naturalised, which means that of more than 1,600 resident terrestrial plant and animal species, only 27% are native. Verrill (1902) estimated that: 'perhaps 90% of all the insects have been introduced by man, since settlement'. Amongst the plants, at least 22 considered invasive are now a dominant feature of the 33% of Bermuda's land area that remains undeveloped. Of the 100 of the World's Worst Invasive Alien Species, 23 species occur in Bermuda (www.issg.org/database).

15.2 A History of Alien Invasions in Bermuda

Since the time of the first human visitors, Bermuda's shores have been assaulted by an almost continual procession of invaders as detailed by Sterrer *et al.*, (2004). This history has shown that there are three main pathways by which an invasive alien species can enter Bermuda and establish itself. They are as follows:

(a) Accidental introductions

The arrival of the common rat (*Rattus rattus*) with a cargo of grain in 1614 is perhaps the earliest reported accidental introduction. The mouse (*Mus musculus*), American cockroach (*Periplaneta americana*), weevils, flies and moths (Indian-meal moth, (*Plodia interpunctella*)) soon followed. The yellow fever mosquito (*Aedes aegypti*) seems to have become established by the end of the 18th century, causing severe epidemics between 1812 and 1864. The spiral snail (*Rumina decollata*), one of three land snails that became agricultural pests, appears to have been accidentally introduced in 1876 by Governor Lefroy, with plants from Tenerife (Verrill, 1902). It is likely that many more weeds, soil fauna, insects and snails were accidentally introduced between the 1850s and 1930s as agricultural experiments saw hundreds of introduced crop plants tested.

Perhaps the most notorious and ecologically catastrophic local example of an accidental introduction was that of the oyster-shell scale (*Insulaspis pallida*) and the juniper scale, which proved near-fatal to Bermuda's endemic cedar (*Juniperus bermudiana*) in the 1940s (see Figure 15.1). The juniper scale most likely arrived with a shipment of conifers from a California nursery on December 12 1942 whereas the oyster-shell scale came in with conifers to be planted at the new Castle Harbour Hotel sometime before 1942 (Vesey, 2002).

Figure 15.1 Dead cedars on a Bermuda hillside in the 1940s

Photo courtesy of David Wingate

Hilburn and Gordon (1989:674) recorded 228 species of beetles of which 'nearly all have been introduced accidentally by human activity', as have 53 of 59 recorded species of spiders (Sierwald, 1988). From 1966, tail-less whip spiders (*Amblypygi*) were occasionally found near the docks in Hamilton. In 1991 an apparently reproducing whip spider, (*Phrynus marginemaculatus*), was located in Tucker's Town (Sterrer *et al*., 1991). Insects continue to arrive. The citrus leaf miner (*Phyllocnistis citrella*) was first recorded in 1999, the spiraling whitefly (*Aleurodicus dispersus*) and the Asian tiger mosquito (*Aedes albopictus*) in 2000 (Jessey, pers. comm.). *Aedes aegypti*, eradicated in the early 1960s after nearly a century of effort (Bennett *et al*., 1985), has since made a comeback in 1982 (Mayers, 1983), and again in 1998. Having most likely been introduced as eggs on bromeliads, flower pots or construction equipment, both species of mosquito have since spread through Bermuda (Kendell, pers. comm.).

Despite abundant anecdotal evidence of deliberate introductions, Bermuda's near-shore marine environment has been remarkably resilient to alien species. Abbott and Jensen (1968) report that foreign marine molluscs such as *Mytilus edulis* and *Crassostrea virginica* occasionally appear in Bermuda waters, mostly on the bottoms of small wooden sailing vessels. The red boring sponge (*Cliona lampa*), which today is conspicuous on shallow subtidal hard bottoms, was not recorded prior to 1950 (Rützler, 1974). Its disjunct distribution (subtropical Florida, parts of the Bahamas and Bermuda, and the Red Sea) suggests that it is a recent arrival to Bermuda (Rützler, 2002). Meanwhile, of the 38 species of ascidians recorded, three are recent arrivals, and suspected to have been carried in by marine traffic (C. Monniot, 1972; F. Monniot, 1972).

Figure 15.2 A lionfish

Photo courtesy of Ian Murdoch

The only undisputed accidental marine introduction to Bermuda is also the most recent and farfetched. In late summer of 2000 a juvenile Pacific lionfish (*Pterois volitans*) (see Figure 15.2) was collected in a tide pool on Bermuda's south shore, the first Atlantic Ocean record of this Pacific species. Since then there have been another dozen sightings (plus several reports prior to that date, the earliest in 1984 (Clee, pers. comm.). Whitfield *et al.*, (2002) subsequently documented seemingly established, reproducing lionfish populations along the south-eastern United States, from Florida to Cape Hatteras, and suggest accidental or intentional release from aquaria as the most probable mechanism of introduction to the Atlantic. Bermuda's lionfish (of which four specimens of breeding size are currently on display at the Bermuda Aquarium, Museum and Zoo) most likely arrived as larvae or as juveniles in drifting Sargassum, underscoring the ease with which species may colonise Bermuda via the Gulf Stream.

(b) Deliberate introductions

(i) As a food resource

It was a passing visit by a Spanish vessel in the mid 1500s that saw the first deliberate introduction of an invasive alien species into Bermuda, the hog. The hog was left ashore as a future food resource for later visits and it wreaked havoc on the native flora and fauna. However, it was really with the wreck of the *Sea Venture* in 1609 that the first of many 'Noah's Arks' deliberately loaded with crop plants and domestic animals arrived.

Louis L. Mowbray in the 1920s liberated at least 13 species of Caribbean marine fishes (Smith-Vaniz *et al.*, 1999), in addition to marine iguanas from Galapagos in 1933, and a shipload of spiny lobsters from South Africa, all in the hope of complementing the commercially exploited species already present. None became established.

Feral chickens are one of the 'invasive' animals that are a very serious problem in Bermuda. Although the negative effect of feral chickens on native biodiversity needs more study, it is evident that they eat many plants and have the potential of destroying native ones. They cause economic loss by destroying ornamental plants grown by home gardeners and eating farmers' crops. They threaten human health by having the potential to transmit diseases to humans and by crowing at all hours of the night, thus disturbing sleep.

(ii) For ornamental purposes

By the time of Verrill's (1902, 1907) and Britton's (1918) pioneering surveys of Bermuda's biota, the replacement of native flora and fauna with exotics was quite advanced. The once dominant endemic cedar (*Juniperus bermudiana*) had been decimated, first by burning (in the early 1600s to rid the Island of rats) and then increasingly for its value in export and shipbuilding. By the late 1800s, large tracts of the Island were left clear-cut with opportunities for deliberate replacement or invasion by exotic plants. Seafaring and trade, an economic mainstay from the mid-1600s to the mid-1800s, would have facilitated the importation of ornamentals. Governor Lefroy 'probably introduced more species than any other individual' (Verrill, 1902:213), distributing 'throughout the islands packets of seeds from Kew, representing no less than 600 species' (Jones 1873). Earlier, French tamarisk (*Tamarix gallica*) was planted to protect coastal roads from gales, whilst the oleander (*Nerium oleander*) was introduced in 1790 for dune stabilisation.

Of the 14 land bird species now breeding in Bermuda, eight are here by human introduction (Wingate, 1959). The house sparrow (*Passer domesticus*) was brought in from Europe via the U.S.A. in 1870 and 1874 (Verrill, 1902:311). In 1905 the European starling (*Sturnus vulgaris*) was introduced to New York from where it steadily increased its range, settling in Bermuda in about 1954. The mallard (*Anas platyrhynchos*) was brought here as a domestic duck in 1960. It took readily to local ponds and has been a common, even pestiferous resident since 1962. The rock dove or pigeon (*Columba livia*) has increased steadily with urbanisation (see Figure 15.3). It is now breeding in high cliffs where it displaces the native white-tailed tropicbird (*Phaethon lepturus catesbyi*) from nesting sites.

Figure 15.3 Pigeons on a rooftop

Photo courtesy of Robin Marirea

(iii) As a biological control

In several cases the accidental introduction of pest species was followed by biological control measures, not always successfully (Bennett and Hughes, 1959). In 1875, the Surinam toad (*Bufo marinus*), a native of British Guiana, was the first of many species to be imported to control garden pests (Bennett and Hughes, 1959). It is now widespread and well suited to reproducing in Bermuda's brackish ponds. Control of the Mediterranean fruit fly (*Ceratitis capitata*), a citrus pest finally eradicated in 1962 (Woodley and Hilburn, 1994) was the reason for introducing the Jamaican anole (*Anolis grahami*) in 1905. The Eastern mosquitofish (*Gambusia holbrooki*), introduced from Washington D.C in 1928 as a largely successful biological control of mosquitoes in freshwater reservoirs, now competes with and preys on two endemic species of killifish (*Fundulus relictus* and *F. bermudae*) in the Island's few freshwater/brackish ponds (Smith-Vaniz *et al.*, 1999:84) (see Figure 15.4).

Figure 15.4 Killifish and mosquito fish

Photo courtesy of Jennifer Gray

Efforts to stem the cedar blight included insecticide spraying but this was soon abandoned in favour of biological control. Between 1946 and 1951, several million natural insect predators belonging to more than 100 species (mostly coccinellid beetles and parasitoid wasps) from all over the world, some of them reared locally, were released but the majority failed to become established (Bennett and Hughes, 1959). An entomological survey coordinated by Hilburn in the 1980s recorded nine coccinellid species (of at least 44 species released) as established (Gordon and Hilburn, 1990) (see Figure 15.5).

Biological control efforts to stem the cedar blight did not always have the intended effects. When it was realised that coccinellid beetles were heavily preyed on by previously introduced lizards, 200 specimens of the kiskadee flycatcher (*Pitangus sulphuratus*) were brought in from Trinidad in 1957 to reduce the anole population (Bennett and Hughes, 1959) (see Figure 15.6). Bennett *et al.*, (1985) conclude that 'there is nothing to indicate any appreciable decline in the lizard population or any increase in that of the coccinellids'. Meanwhile, the Kiskadee increased explosively, becoming a major threat to other birds and has been implicated in the extinction of the endemic cicada in the late 1990s.

Figure 15.5 Cedar scale insect

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

Figure 15.6 The Antiguan anole (*Anolis leachii*)

Note: This lizard is often called the Warwick lizard because it is mainly seen in Warwick Parish. It is the largest of the three introduced Anolis *lizards.*
Photo courtesy of the Bermuda Aquarium, Museum and Zoo

In the end it is difficult to assess the beneficial effect of 'one of the biggest attempts at biological control ever tried worldwide' (Vesey, 2002:46). By the 1950s, an estimated 90% of the Island's cedars had succumbed, requiring a massive effort of removing dead trees, and replacing them with imports. The Australian whistling pine (*Casuarina equisetifolia*) became the stand-in of choice, largely for its rapid growth and resistance to wind and salt. The casuarina (see Figure 15.7) dominates much of Bermuda's landscape to this day. Many other alien species were mass-planted in the 1950s, from coconuts to hibiscus, Indian laurel (*Ficus retusa*), Natal plum (*Carissa grandiflora*) and Norfolk Island pine (*Araucaria excelsa* (syn. *Araucaria heterophylla*). This set the stage for a new wave of invasive aliens of which the Brazil pepper (*Schinus terebinthifolius*) was to become the most notorious.

Figure 15.7 A casuarina tree

Photo courtesy of the Department of Planning

Between 1958 and 1972, four species of predatory snails (*Euglandina rosea, Natalina caffra, Gonaxis quadrilateralis* and *G. kibweziensis*) were introduced from Hawaii, and released in ill-advised attempts to control the agricultural pests, *Rumina decollata* and *Otala lactea*, the latter brought in as food in 1928 (Bennett and Hughes, 1959). A survey undertaken in 1988 (Bieler and Slapcinsky, 2000) records *G. quadrilateralis* as having spread beyond the release site, but *E. rosea* as 'widespread in Bermuda and [possibly] responsible for the decline of several of Bermuda's native snails, including the members of the now nearly extinct endemic genus Poecilozonites'. According to Bieler and Slapcinsky (2000), 'at least 49 species of snails and slugs are now known from Bermuda, including 11 endemic, 6 native non-endemic, 28 accidentally introduced and 4 intentionally introduced species'.

(iv) Species brought in to be held in 'captivity'

Pets, if no longer wanted any more, have occasionally been released or escaped 'back' into the wild. Two animals of most concern are feral cats and pigeons and are a threat to native biodiversity. Feral cats prey on the endemic Bermuda rock lizard or skink (*Eumeces longirostris*) and they do not discriminate between native and introduced birds, while pigeons

(*Columba livia*) compete with longtails (*Phaethon lepturus catesbyi*) for nest sites. Pigeons pose serious problems to human health in that they can transmit diseases.

Of the many escaped cage birds, three are common. The cardinal (*Cardinalis cardinalis*) was introduced from North America around 1700 and became such a farm pest in the 1800s that bounties were offered for its capture. The European gold finch (*Carduelis carduelis*) became established in 1890 (Bradlee *et al.*, 1931). All of the Island's common crows (*Corvus brachyrhynchos*) may be descended from one pair that Lady Bedford brought in from Nova Scotia and released in 1848.

More recently, the boom in trade of the red-eared slider terrapin (*Trachemys scripta elegans*) (see Figure 15.8) has resulted in hundreds of escaped and released terrapins, which now inhabit all of Bermuda's landlocked ponds. Listed as one of the top 100 invasive species worldwide any ecological damage being caused by these terrapins has nevertheless yet to be documented. The occasional release of pet guinea pigs and rabbits into Bermuda's nature reserves is causing growing alarm.

Figure 15.8 A red-eared slider terrapin

Photo courtesy of the Bermuda Aquarium, Museum and Zoo

(v) Reintroductions

There have been two documented reintroductions locally. The yellow-crowned night heron (*Nyctanassa violacea*) of which an endemic form had been breeding here in the 1600s, was reintroduced (Wingate, 1976) in a successful bid to control the common land crab (*Gecarcinus lateralis*). The large West Indian topshell (*Cittarium pica*), known as a common fossil, was reintroduced from the Bahamas in 1982, and has now re-colonised its former habitat (Wingate, 1995). Despite some concerns about the extent to which the population of common land crabs has declined with the re-introduction of the yellow-crowned night heron, neither species has been documented as being ecologically disruptive.

(c) Via vectors post-alien species introduction

In many cases, invasive alien species only become pests after a considerable time lag during which they persist in small numbers until an outbreak is triggered. In several cases, local invasiveness has resulted from synergistic interactions with fellow aliens. Bennett and Hughes (1959) observed that ants (*P. megacephala* and *L. humile*) interfered with biological control agents of scale insects (for example the ladybird beetle, (*Rhyzobius lophantae*), all of which were introduced. The giant Indian laurel tree (*Ficus retusa*), extensively planted in the 1950s as a replacement of the endemic cedar, remained sterile until its pollinator, the fig wasp (*Parapristina verticillata*) arrived accidentally in the early 1980s. This strangler fig has now become an Island-wide problem, its hemi-epiphytic seedlings sprouting from roof gutters, cracking stone walls and water tanks, and killing palms and cedar trees (see Figure 15.9). With an estimated 500 mature trees present in 1985, each producing 100,000 figs (at 150 seeds) per crop (Janzen, 1979), the potential for propagation is enormous. Dispersal of Indian laurel, as well as Brazilian pepper and asparagus fern (*Asparagus densiflorus*), is greatly enhanced by another invasive, the starling, which feeds on their fruits and on its way to roost spreads seeds over remote islets. *Asparagus densiflorus* was noted by Britton in 1914 as growing in a single garden. Its subsequent spread into most habitats including rocky shores and mangroves is most likely due to seed dispersal by birds.

15.3 Current Invasive Alien Species

As mentioned, Bermuda currently plays host to 23 of the Top 100 Worst Invasive Alien Species listed by the International Union for Conservation of Nature and Natural Resources (IUCN). Although one of these is a native (the comb jelly, *Mnemiopsis leidyi*) and several others are not locally invasive (the African tulip tree, *Spathodea campanulata*; kudzu, *Pueraria lobata*; the little fire ant, *Wasmannia auropunctata*;

and domestic species such as goat, pig, and rabbit), this still leaves 16 species that are invasive. These include the water hyacinth (*Eichhornia crassipes*), the Brazilian pepper tree (*Schinus terebinthifolius*), giant reed (*Arundo donax*), lantana (*Lantana camara*), leucaena (*Leucaena leucocephala*), wedelia (*Wedelia trilobata*); the Argentine ant (*Linepithema humile*), big-headed ant (*Pheidole megacephala*), rosy wolf snail (*Euglandina rosea*), sweet potato whitefly (*Bemisia tabaci*), the western mosquitofish (*Gambusia affinis*), giant toad (*Bufo marinus*), starling (*Sturnus vulgaris*), red-eared slider (*Trachemys scripta*), domestic cat (*Felis catus*), mouse (*Mus musculus*) and ship rat (*Rattus rattus*).

In addition, there is an even longer list of animal species widely considered locally invasive at the present time. This list is modified from Sterrer *et al.*, (2004) to reflect the views of key stakeholders participating in a workshop held in 2003 to discuss the issues of invasive alien species in Bermuda (see Table 5.1). Additionally, the cannibal snail, carpenter ant, cockroaches, lionfish, brown recluse spider and mosquito fish were also species that raised concerns.

Between 1998 and 2000, the Bermuda Biodiversity Project conducted 1,220 surveys of Bermuda's vegetation (Anderson *et al.*, 2001, DeSilva *et al.*, 2004). In total, 394 plant species were recorded of which 112 were native and 282 were non-native. Analysed separately for canopy trees and understorey plants, the survey leaves little doubt that natives are fighting a losing battle. Of Bermuda's 16 endemic plant species, 13 were recorded. However, 10 of these endemic species were either not recorded or were recorded at fewer than 30 sites. Similarly, of 148 non-endemic native plants, 99 were recorded but 124 were either absent or recorded at fewer than 30 sites. As might be expected, anthropogenic habitats (wayside, hedgerow, arable, garden and golf course) are the most heavily invaded by aliens. The few native canopy species holding out in these habitats are there largely because of deliberate planting.

Figure 15.9 An Indian laurel tree strangling a Bermuda cedar tree

Photo courtesy of the Department of Planning

Coastal habitats and peat marshes are relatively uninvaded, at least in numbers of aliens and natives retain dominance, possibly due to their adaptation for salty or acidic conditions, respectively. By contrast, upland habitats have a diverse mix of aliens in which native trees persist largely thanks to protection and planting in gardens and nature

Table 15.1 Alien animal species considered invasive to Bermuda

Taxon	Species	Common Name	Date Introduced	Introduction
Amphibia	Bufo marinus	Giant Toad	1885	Deliberate, to control garden pests
Reptilia	Anolis grahami	Jamaican Anole	1905	Deliberate, to control Mediterranean Fruit Fly
	Anolis roquet	Barbados Anole	1940s	Accidental
	Anolis leachii	Antiguan Anole	1940s	Accidental
	Trachemys scripta elegans	Red-Eared Slider Terrapin	1980s	Deliberate, as aquarium pet
Aves	Gallus sp.	Domestic Chicken	Early 1600s	Deliberate; feral at present
	Columba livia	Pigeon (Rock Dove)	1600s	Deliberate; feral
	Cardinalis cardinalis	Cardinal	Around 1700	Escaped cage bird
	Passer domesticus	House Sparrow	1870 & 1874	Deliberate, to control flies
	Corvus brachyrhynchos	American Crow	1848	Escaped cage bird
	Sturnus vulgaris	Starling	1954	Range extension from US east coast
	Pitangus sulphuratus	Great Kiskadee	1957	Deliberate, to control Jamaican Anole
Mammalia	Felis catus	Domestic Cat	1609	Deliberate; feral populations persist
	Rattus rattus	Black Rat	1614	Accidental
	Mus musculus	House Mouse	Early 1600s	Accidental
	Rattus norvegicus	Norwegian Rat	mid 1700s	Accidental
		Rabbit		Escaped/released pets
		Guinea Pig		Escaped/released pets

Source: Modified from Sterner et al., *2004* reserves. A group of 11 invasive canopy plants headed by the ubiquitous casuarina and Brazil pepper is present in nine (60%) or more of the 15 habitats and is at least visually prevalent even in exposed coastal habitats. Understorey plants, despite a wide presence of natives, are severely invaded by wedelia, fern asparagus, fennel, Japanese hawksbeard, sow thistle and cane grass. Furthermore, the frequency in the understorey of recruits of Brazil pepper, Surinam cherry, allspice, Chinese fan palm and other invasive canopy species suggests that the replacement of native forests with alien species is an ongoing process.

Several more aliens have gained dominance in only some habitats such as ponds (including water fern and water hyacinth) but at least 25 additional species, having shown vigorous growth and self-propagating abilities in anthropogenic habitats, might be considered 'invasives in waiting' (See Table 15.2). Although there is no quantitative data on the fauna of these habitats, it is expected that the habitat homogenisation brought about by the spread of so many invasive plants has affected the composition of associated biota including bacteria, fungi, and invertebrates.

Table 15.2 Alien plant species considered locally invasive

Species	Common Name	Date Introduced
Schinus terebinthifolius	Brazil Pepper (Mexican Pepper) *	1950's
Livistonia chinensis	Chinese Fan Palm **	Recorded by Britton 1918
Eugenia uniflora	Surinam Cherry **	1790 (Collett 1987)
Pittosporum tobira	Japanese Pittosporum	Recorded by Britton 1918
Pimenta dioica	Allspice**	Recorded by Britton 1918
Citharexylum spinosum	Fiddlewood**	1830 (Britton 1918)
Leucaena leucocephala	Jumbie Bean (Wild Mimosa)	Recorded by Britton 1918
Casuarina equisetifolia	Casuarina (Horsetail Tree)**	Recorded by Britton 1918
Nerium oleander	Oleander	1790
Melia azedarach	Pride of India	1790 (Collett 1987)
Ficus retusa	Indian Laurel**	After 1918
Wedelia trilobata	Wedelia **	After 1918
Asparagus densiflorus	Fern Asparagus**	1875, probably by Lefroy (Britton 1918)
Crepis japonica	Japanese Hawksbeard	Recorded by Britton 1918
Foeniculum vulgare	Fennel	Recorded by Britton 1918
Panicum dichotomiflorum	Cane Grass**	Recorded by Britton 1918
Sonchus oleraceus	Sow Thistle	Recorded by Britton 1918
Asparagus setaceus	Wedding Fern	Recorded by Britton 1918
Bidens pilosa	White Beggar's Ticks	Recorded by Britton 1918
Plantago lanceolata	English Plantain	Recorded by Britton 1918
Eichhornia crassipes	Water Hyacinth**	After 1918
Salvinia rotundifolia	Water Fern	After 1918

Notes:

(1) *After 1918 indicates that the species was not recorded by Britton (1918).*

(2) *Those species with an asterisk (**) were also widely considered as a strong threat by the stakeholders participating in the 2003 Invasive Alien Species Workshop. This groups also identified the following species as cause for concern: morning glory (*Ipomoea indica*), strawberry guava (*Psidium guajava*), Ardisia (*Ardisia accuminata*), Schefflera (*sci. name*), Murray red gum (*sci. name*), Madagascar olive (*Norhonia emerginata*), paragrass (*Panicum barbinodes*), kudzu (*sci. name*), solandra (*sci. name*), yew (*Podocarpus macrophyllus 'Maki'*), elephant ear (*Philodendron giganteum*), black medic (*Meidcayo lupulina*), Calophyllum (*sci. name*),* Clerodendron Clerodendrum *species, and Sanseviera (*sci. name*).*

Source: The Bermuda Biodiversity project survey, Sterner et al.*, 2004*

15.4 Regulatory Framework

Regulatory responsibilities for dealing with invasive alien species lie with several different government departments as detailed below. These responsibilities have evolved over time as the different departments took action in their respective policy areas to address particular threats of relevance. The activities undertaken fall into three broad categories: (1) those with legislative responsibilities, including licensing; (2) those providing technical support and advice; and (3) those undertaking protection, enforcement and control. No single department has exclusive responsibility for any of these activities.

Today, there are several legislative instruments for tackling invasive alien species.

The 1930 Agricultural Act covers the control of plant diseases and pests through the 1970 Regulations, in which a 'disease' or 'pest' refers to:

> *any form of fungi, including rusts, smuts, moulds and yeasts; any form of bacteria; any form of viruses; any form of similar of allied organisms; any living stage of land or fresh water mollusc including snails and slugs; any living stage of the small invertebrate animals belonging to the phylum Arthropoda including insects, mites, ticks, centipedes; any form of elongated invertebrates lacking appendages, known as worms, including earthworms and nematodes; any form of protozoa which may directly or indirectly affect, injure or harm plants or parts and products thereof.*

Through this regulation, the 1930 Act currently provides protection against the introduction of pest plants but does not deal with pestilent plants. Amendments to the 1930 Act are planned in order to extend this protection to include the prevention of potentially invasive plant species.

The 1930 Act also covers restrictions on animal importations, with the importation of any animal necessitating an import permit that takes consideration of:

> *the species of animal; the purpose for which the animal is to be imported; the need for such an animal or its products in Bermuda; the condition of the place which the animal is to be kept; the knowledge of the applicant as to the husbandry of the animal; the potential of the animal to become a hazard to human or animal health or the ecology of Bermuda.*

The 1975 Protection of Birds Act specifically excludes four bird species from protection. These are the common crow, starling, kiskadee and house sparrow which are all considered to be invasive aliens.

Additionally, Bermuda is committed to ratifying the Convention on Biological Diversity, which requires contracting parties to prevent the introduction of, control or eradication of those alien species which threaten ecosystems, habitats or species, as appropriate. We are also signatories to the Environment Charter for the U.K. Overseas Territories in which the Bermuda Government has committed to:

> *ensure the protection and restoration of key habitats, species and landscape features through legislation and appropriate management structures and mechanisms, including a protected areas policy, and attempt the control and eradication of invasive species.*

This commitment is further enforced through local law with the newly enacted Protected Species Act, 2003. This calls out for the development of species and habitat management plans for all listed species and implicit in this is the need for restoration efforts that will involve the removal of alien species considered to be invasive.

With this legislative backing, Bermuda's approach to dealing with invasive alien species involves a number of strategies.

(1) Prevention of New Introductions

Given the considerable constraints, not least of which are economic, in targeting and undertaking control and eradication programmes once new alien species have become established, preventing their establishment is clearly the most effective solution and must be given priority. Prevention is achieved through risk assessment and quarantine.

With the restructuring of the Bermuda Government's Ministry of the Environment in 2002, the Department of Environmental Protection has responsibility for conducting a risk assessment to determine which non-native animal species are permissible and which present too great a threat to allow their importation. It should be noted that the Department of Environmental Health is largely responsible for the prevention and control of vectors considered posing a human health hazard. Through the 1930 Agricultural Act, no animal can be imported without an import permit. The increased interest amongst the public in novel pets has placed added pressure on the Department of Environmental Protection to undertake a thorough risk assessment, in the event that a pet accidentally escapes, or is deliberately released into the wild. Health certificates must be presented for all imported animals and there is a quarantine facility for placing animals in the event of any problems.

The 1930 Agricultural Act also ensures that imported plants are inspected for the presence of pests or diseases and no plant can be imported with soil attached. The front line enforcement of these regulations lies with the Bermuda Government Customs Department. Bermuda Customs then liaises with the Department of Environmental Protection.

In 2000, the Bermuda Government Plant Protection Laboratory inspected 813 shipments of plant material containing a total of 850,000 plants (from bedding plants and bulbs to cacti, Christmas trees, fruit trees and orchids) in addition to 10,622 fruits and vegetables, 7,231 cases of citrus and 3,440 bags of seed potatoes. In 1999, the Plant Protection Laboratory made 108 interceptions of which mites, thrips, whiteflies, mealybugs, aphids, spiders and snails were the most frequent.

Interceptions of larger animals, other than undocumented domestic animals which are usually returned on the same flight, are rare (with the occasional bat hidden in a container or a smuggled snake) but suggest that a much larger number of imports continue to go undetected. It may be that the Island's relative paucity of habitats (and places to hide) has so far prevented a much larger number of intruders from becoming established.

The proposed amendments to the 1930 Agricultural Act will allow for the improved control of plant imports such that plant species considered to have a high invasive potential may be banned. This will require cooperation with international bodies to secure the most up to date information on the invasive potential of thousands of species in similar ecological conditions to that of Bermuda.

Despite this effort, it is accepted that there are improvements that could be made in current preventative measures. Firstly, there is a need for clear criteria to be developed in order to conduct comprehensive risk assessments for novel species. These should be undertaken based on the impact with regard to economic, biological, social, and animal and human health considerations. Secondly, known gaps in prevention at ports of entry need to be addressed. For example, every week shipping containers which have been stored on soil lots, arrive on Bermuda's docks without sterilisation; imported plants are transported from the airport to the Department of Environmental Protection at the Botanical Gardens before being inspected for presence of pests; cut flowers are currently not inspected; the counting and identification of hundreds of individual fish presents considerable challenges; cruise ships arrive and dock with potted plants on board; and plants and some animals, such as the dormant triops shrimp, may be purchased through the internet and mailed through the postal system undetected.

Figure 15.10 A ball python snake (*Python regius*)

Note: This python was found on a road in Pembroke having probably escaped from a residence after being illegally imported as a pet.
Photo courtesy of Robin Marirea

Within the marine environment, the 1972 Fisheries Act prohibits the importation of any fish (where 'fish' refers to 'fish of any kind found in the sea and includes turtles, crabs, crayfish, lobsters, shell-fish, shells, corals, seafans, and marine mammals of all description, whether alive or dead'), unless a licence is granted. The only exception to this is afforded to local restaurants which may import live seafood on condition that it is cooked on the facility. Concern over the dumping of ballast water and the potential introduction of invasive aliens through this means has received increasing attention internationally. The Bermuda Government's Department of Marine and Ports Services has responsibility for the emptying of ballast waters in local waters. Most freight vessels arrive in Bermuda fully laden but depart empty which means that they take on ballast water when leaving the Island, rather than releasing it here. However there is some local dumping and current policies are under review by the Bermuda Government's Ministry of the Environment.

(2) Control and Eradication

Eradication (i.e., the elimination of the entire population of an invasive species) is probably the most desirable solution to dealing with an established invasive alien species but it is typically the most difficult. Nevertheless, eradication efforts have been most successful in island environments. Bermuda bears history to a number of eradication efforts, one of the earliest being the torching of much of Bermuda in the 1600s in an effort to get rid of the plague of rats.

Eradication is typically achieved by: mechanical control (hand picking, weeding); chemical control (toxic baits, insecticides etc) hunting (larger vertebrates); and biological controls. The earlier eradication is undertaken, the more likely it is to be successful. Given that many alien species remain relatively dormant for at least some period of time before really establishing themselves, there is an opportunity for immediate action when an alien species is first identified. This has been demonstrated with such species as guinea pigs, when a prompt response to an illegal release into the wild has enabled their speedy capture. With the identification of novel alien species, if there is information that indicates that the species is invasive elsewhere, then immediate action is probably warranted. Bermuda has been fortunate that kudzu (see Figure 15.11), globally one of the most invasive plants and known to be present in one isolated hectare in Paget for over 30 years, has not yet established itself. A current initiative led by the Department of Conservation Services hopes to now eradicate this plant from Bermuda.

Another species, which might be considered suitable for eradication is the Indian laurel. Although eradication may be difficult, a programme to effectively control this species is worth pursuing.

Responsibility for early detection typically falls on the Departments of Environmental Protection, Conservation Services and Parks. However members of the public also have a critical role to play and should be encouraged to report unusual sightings. The recent reports of the Pacific lionfish in local waters have all been through public reporting. Unfortunately, it is considered likely that larval lionfish are being transported to Bermuda in the currents of the Gulf Stream from the East Coast of the United States, where they were released (perhaps accidentally) into the wild. As ongoing 'reintroductions' are probable, invasion by this species may well be beyond control. Active field surveys are necessary to make early detection effective.

Figure 15.11 Kudzu, an invasive weed

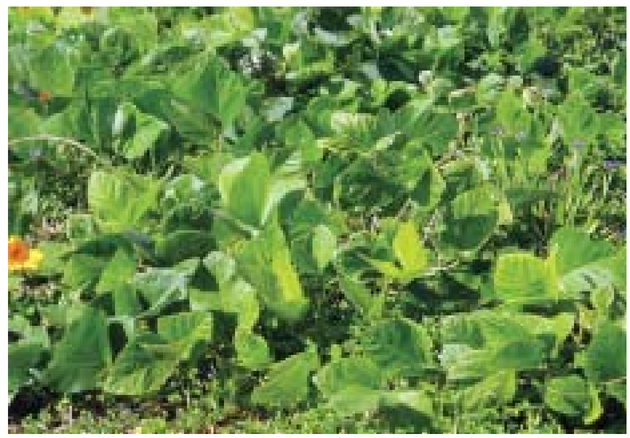

Photo courtesy of Heather DeSilva

Whilst Island-wide eradication is a lofty goal, eradication of a pest species on 'ecological islands' has been applied in Bermuda with great success. The most obvious example is Nonsuch Island, which has been restored and now represents Bermuda's pre-settlement habitats. More typically though, complete eradication is not a realistic option, and at best, an invasive alien species can be controlled. Priority is generally given to areas of ecological significance such as the Island's nature reserves and successful restoration efforts are underway in Paget Marsh and Walsingham nature reserves.

Habitat restoration is one area in which the general public can readily participate, and there have been concerted efforts (workshops, printed materials, establishment of field initiatives) to try and encourage the active participation of the public. Unfortunately, one of the issues facing many landowners keen to cull the invasives and restore the native and endemic flora is the lack of suitable replacement material. More aggressive aliens will inevitably rapidly colonise land left bare before natives can naturally establish themselves. There needs to be a

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ready supply of native plant species to replace the culled invasives which in turn demands greater resources.

Animal control is often a harder issue to tackle, largely as a result of public outcry. Efforts to control pest birds such as crows, kiskadees and pigeons have been ongoing, whilst private businesses are often hired by residents to remove rat or termite infestations. The Bermuda Feline Assistance Bureau (BFAB) has for many years undertaken a programme of trapping and neutering feral cats and there is a move to make licensing of cats obligatory, along the lines of existing dog licensing.

Given the number of invasive species already established in Bermuda, efforts to control and eradicate populations must, out of necessity, focus on prioritised areas and on species having the most significant impact where possible.

(3) Education and Public Awareness

Despite the impact of the cedar blight of the 1940s, the visual presence of known predators such as red eared slider terrapins and feral cats, and the persistence of nuisance pigeons and chickens, not all policy-makers or members of the public share the view that invasive species negatively impact biodiversity. It is essential that scientists, resource managers and conservationists clarify the issues and engage the wider community in addressing the problem.

Non-Government Organisations (NGOs) have an important role to play in raising awareness, as does the Bermuda Government's Department of Conservation Services. A number of publications have been written for the wider public highlighting the threat posed by invasive species, whilst local expositions such as the Annual Exhibition and the Eden Project and the biennial Environmental Youth Conference, have been used as platforms for further raising awareness. Pamphlets produced by the Department of Environmental Protection also highlight the dangers of illegally importing plants and animals. In addition, there is a recognised need for more extensive training of front line enforcement agencies.

15.5 Summary

Invasive alien species are non-native species that have the ability to establish self-sustaining and expanding populations in the wild. They are also likely to cause damage to natural eco-systems and economic harm. They are distinguished from other alien (non-invasive) species which are also non-native to Bermuda but are not self-sustaining and do not reproduce to the same extent as invasive aliens.

Typical alien animal species considered to be invasive to Bermuda include the feral chicken, house sparrow and red-eared slider terrapin. Common plants from the invasive alien species group include the Brazil pepper, Chinese fan palm and casuarina tree. Not every alien species creates problems and several non-invasive exotic species such as oleander, hibiscus, cardinals and whistling frogs provide colour and variety, whilst others like honey bees and onions have added economic benefits.

Table 15.3 Changes in species composition since human colonisation for the better-known taxa of terrestrial and freshwater species

Terrestrial Species	Total Endemics	Extinct Endemics	Non-endemic Natives	Introduced Naturalised	Total	% Aliens
Flowering plants	10	0	150	371	531	70
Other plants (ferns, mosses)	6	0	15	17	38	45
Mollusks	18	6	6	33	57	58
Insects	44	16	172	703	919	76
Spiders	2	0	5	34	41	83
Amphibians	0	0	0	3	3	100
Reptiles	1	0	0	4	5	80
Birds	4	3	7	9	20	45
Mammals	0	0	0	4	4	100
Total	**85**	25	**355**	**1,178**	**1,618**	73

Note: Insects: The total for introduced species excludes interceptions and isolated records
Flowering plants: The total for introduced species only includes naturalised, self-propagating species

Source Sterrer et al., *2004*

Although Bermuda's marine environment has been largely unaffected by invasive alien species, the position on land is drastically different. The adverse impact of invasive species is considered to be the single largest threat to Bermuda's native biodiversity. This is because island species have evolved largely in the absence of predators and mainland diseases. Therefore, due to the introduction of organisms that have become invasive, natives have become vulnerable to new disease exposure and displaced from habitats.

Out of the 100 of the World's Worst Invasive Alien Species, 23 of these occur in Bermuda. It has been estimated that invasive alien species are responsible for 39% of all native species extinctions since 1600. Also, whilst 12% of all continental animals are threatened by alien invasions, this rate increases to 31% on islands like Bermuda.

The dramatic increase in global trade and travel over the last few decades has led to rapid acceleration of invasive species movement. Since the arrival of the first human visitors, Bermuda has experienced a continual procession of invaders. Introductions happen both accidentally and intentionally. Accidental introductions of rodents such as rats and mice arrived through shipping. Intentional introductions have occurred as a result of imported food resources, imports for ornamental purposes and biological controls. Other reasons include species that were originally brought in as pets such as cats and pigeons which were subsequently released.

There are four main Acts which provide legislation to deal with invasive alien species, the 1972 Fisheries Act, 1930 Agricultural Act, 1975 Protection of Birds Act and the more recent 2003 Protected Species Act. Departments within the Bermuda Government's Ministry of the Environment have various responsibilities covering licensing, technical support, advice and protection, enforcement and control.

Additionally, Bermuda is committed to ratifying the Convention on Biological Diversity, which requires parties to prevent the introduction of, control or eradication of those alien species which threaten ecosystems, habitats or species. The Bermuda Government is also a signatory to the Environment Charter which commits to 'attempt the control and eradication of invasive species'.

Within the context of the above legislation the Bermuda Government is pursuing a number of initiatives to deal with invasive species including preventing the introduction of new plants and animals, controlling and eradicating existing invasives and raising public awareness.

Preventing the introduction of new invasive species is mainly achieved through risk management techniques and quarantine. In relation to these methods, no animal can be brought into Bermuda without an import permit and imported plants such as Christmas trees, fruits and vegetables are inspected for pests or disease. In addition, no plant can be imported with soil attached.

The 1972 Fisheries Act prohibits the import of live alien species with the exception of food provided to local restaurants. There is however, a need for clearer criteria to be developed for risk assessments and gaps in controlling invasive species at ports should be addressed. Future changes to legislation may ban particular high risk invasive species.

Achieving the complete eradication of invasive species is a desirable but difficult objective to achieve. However, attempts at prioritising selective eradication of pests from 'ecological islands' such as Nonsuch Island have enjoyed success.

The general public can be encouraged to participate in habitat restoration. There is also a need to provide a ready supply of native plants to replace invasives. The control of invasive animals is a difficult issue to tackle mainly due to public concern for the eradication of specific species. However, the control of animals such as feral cats through neutering has been carried out over several years.

Raising general awareness of the issues and threats posed by invasive species through environmental training and education is a further objective. A number of publications and pamphlets have been produced as well as ongoing local expositions such as the Annual Exhibition, Eden Project and Environmental Youth Conference all of which make valuable promotional contributions to this cause.

In conclusion, it is probably fair to say that as an island environment, Bermuda's vulnerability to invasive alien species, their impact on biodiversity and the economy are not widely appreciated. Therefore, there is a strong need for a more coordinated approach that draws on the support of the whole community for tackling invasive alien issues using the precautionary principle as the rationale for future policy.

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Summary and Future Monitoring

Chapter 16

Summary and Future Monitoring

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16.1 Summary of Key Issues

This State of the Environment (SoE) report has examined Bermuda's environmental assets, some of the problems and challenges the Island faces, as well as opportunities for future action.

The following is a summary of some of the key issues discussed in the report.

- Bermuda's tiny, fishhook shaped landmass and extensive coastlines contribute to its unique beauty but also contribute to its fragility;
- Bermuda's subtropical, mild climate has been described as one of its chief assets. However, with elevations not exceeding 260 feet, any significant rise in sea levels in the North Atlantic Ocean would threaten many parts of Bermuda;
- Whilst Bermuda is environmentally conscious in its collection of rainwater on roof catchments, fresh water is a limited resource which needs to be carefully managed;
- Though Bermuda's coral reefs are thought to be at 'high risk', they are generally considered to be relatively healthy;
- Bermuda is home to a number of endemic species but there is an increased threat to terrestrial habitats and species through land development;
- Bermuda is 100% dependent on the importation of fuel for transport and electricity production requirements. However, there are opportunities for the development of renewable energy sources and research has started on this;
- Bermuda's economic success has taken its toll on the environment. Increasing development pressure on the Island's limited land resources has resulted in a significant increase in the amount of land used for residential development and a concomitant decrease in the amount of open space;
- Bermuda is rich in historic buildings and fortifications and the Town of St. George is a World Heritage Site. However, there are opportunities to further protect Bermuda's heritage;
- There has been a significant loss in the amount of land used for agricultural production over the years. However, backyard gardening is growing in importance;
- Whilst the Island has a highly effective system of regulating the importation and exportation of plant material to prevent the spread of plant pests and diseases, there is little protection against the damaging effects of certain plant species on terrestrial habitats;
- Though there are effective regulations in place to protect the fishing industry and marine environment, more is needed to protect the inshore waters and coastal areas;
- Road traffic is a significant source of air pollution. The increase in the number of vehicles on Bermuda's roads and traffic congestion are also major concerns. However, there are opportunities to alleviate traffic congestion and parking problems by encouraging a modal shift from the private car. The Island's bus service is extensive and no area is more than half-a-mile from a bus route. In addition, significant improvements have been made in recent years to the Island's ferry system and infrastructure;
- Bermuda continues to be a highly sought after cruise ship destination but if Bermuda chooses to accommodate larger cruise vessels, major improvements and enhancements are required to the Island's cruise ports and shipping channels which may impact on the Island's environment;
- Most of the Island's waste disposal and recycling facilities are reaching full capacity. However, new

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facilities are being planned;

- Non-hazardous liquid waste is currently disposed of via ocean outfalls, cesspits and septic tanks/boreholes and these methods are likely to continue in the future. There are opportunities, however, to find better ways of minimising the amount of wastewater created and maximising its reuse;
- As population and housing densities increase, noise pollution is likely to become more of a concern and an issue which needs to be addressed;
- Pest control has historically been and will continue to be an issue. Whilst there are initiatives in place to deal with mosquitoes and vermin, community awareness and participation are crucial to their success; and
- Whilst Bermuda's marine environment has been largely unaffected by invasive alien species, the adverse impact of invasive alien species on land is considered to be the single largest threat to the Island's native biodiversity.

One of the key issues highlighted in this report is the need to raise the public's awareness of the issues and threats posed by certain human activities on the environment and to present opportunities and ways for people to modify their behaviour and lifestyle. It is only by doing this that we will preserve our unique and beautiful island.

Table 16.1 (a) Environmental performance indicators

ISSUE	Indicators of threats and/or of health	Management action
Climate and Air	Mean air and sea temperature statistics	Air quality monitoring programmes
	Mean precipitation and wind statistics	
	Concentrations of greenhouses gases - cardon dioxide, methane and nitrous oxide	
	Ozone layer – measured ozone depletions, CFCs consumption	
	Air quality – concentrations of nitrogen dioxide, sulphur dioxide, particulate matter (suspended and inhalable), carbon monoxide, hydrogen sulphide and lead emissions	
Fresh Water Resources	Number, type and capacity of water resources	Number of brackish and seawater treatment plants
	Average per capita consumption of water (imperial gallons per day)	Number of licensed abstractions of ground water
	Groundwater quality - nitrate and pesticide levels	Environmental health public awareness programmes
	Water quality - level of micro-organisms in tanks, number of polluted tanks	
Biodiversity and Habitats	Number of endemic, native or introduced species (terrestrial and marine)	Number of species on Protected Species Act
	Number of threatened species	Number of critical habitats protected
	Distribution of key habitats and species	Number of species restoration plans produced
	Changes in extent of critical habitats	Number of habitat restoration plans produced
Energy	Energy generation capacity (MW)	Energy saving public awareness programmes
	Industrial and commercial electricity consumption (kWh)	Renewable energy research programmes
	Residential electricity consumption (kWh)	Building design standards
	Electricity consumption per population (KWh per capita)	
	Price of electricity	
	Percentage of electricity generated by renewable energy sources	

Source: Compiled by the Department of Planning

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16.2 Future Monitoring and Next Steps

Bermuda's environment is a complex and interconnected system. In order for the health of this system to be evaluated regularly, a set of measurements must be identified. A limited number of environmental performance indicators have been selected for each topic to help highlight the main trends and point to the broad issues that need attention in monitoring the state of Bermuda's environment. The indicators selected are either a measure of threat and/or health or a measure of management action. The indicators are listed in Tables 16.1 (a), (b), (c) and (d). The list is not exhaustive and there may well be other indicators that should be added.

Some of these indicators are statistics that are

Table 16.1 (b) Environmental performance indicators

ISSUE	Indicators of threats and/or of health	Management action
Land Use and Open Space	Amount and type of land use	Amount of land protected by planning zonings as open space/national park land
	Amount of land covered by development	
	Amount of land used as open space/national park land	
	Population and Household statistics	
	Number and location of registered moorings and marinas	
Historic Sites and Buildings	Number of buildings or structures of historic and architectural importance	Number of buildings protected by legislation as listed buildings or historic monuments
	Number of areas of historic importance	Number of areas protected by planning zonings as historic areas
		Number of archaeological digs or underwater archaelogical projects undertaken
Agriculture and Plant Protection	Amount, type and productivity of agricultural use	Amount of land protected by planning zonings as agricultural land
	Number and size of fields by agricultural use	Agricultural education projects, programmes and initiatives
	Number and size of home gardens	
	Number of registered farmers	
	Number and type of plant pests and diseases intercepted	
Marine Resources	Amount and type of fish landed	Number, type and extent of marine protected areas
	Biological sampling of fish landings (size, reproductive condition)	Number and type of research programmes
	Number and extent of coral bleaching events or diseases observed	
Air and Land Transportation	Number and type of airport operations	Number of road improvement programmes
	Number and purpose of air arrivals	'Green transport' public awareness programmes
	Number and type of registered vehicles	
	Traffic counts at key junctions	
	Mode of transport to work	
	Number of residential valuation numbers	
	Number of bus passenger journeys	

Source: Compiled by the Department of Planning

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Table 16.1 (c) Environmental performance indicators

Marine Transport and the Marine Environment	Number of cruise ship visitors	Location of cruise ship berths and related facilities
	Cruise ship passenger expenditure	
	Cruise ship sewage flow and recyclable material volumes to local plants	
	Number and type of ship/yacht arrivals	
	Number, location and volume of oil spills	
	Number of ferry passenger journeys	
	Number and type of locally registered watercraft	
Waste Management and Pollution	Amount and composition of residential, commercial and industrial waste	Number and type of education programmes for waste reduction, recycling, composting and proper disposal of waste
	Amount and type of hazardous waste	Number of litter clean-up events organised annually
	Amount and type of recyclable material	Regulations regarding the provision of sewage treatment plants
	Disposal method by type and quantity of waste	Regulations regarding domestic sewage disposal
	Number of ash blocks produced	
	Amount of energy produced from waste incineration	
	Amount and type of litter collected during clean-up events	
	Amount of sewage by disposal method	
	Number, type and capacity of sewage treatment plants	
Noise Pollution	Number and type of complaints received and prosecutions made concerning noise	
	Number and type of vehicles determined to have exceeded the noise limit	

Source: Compiled by the Department of Planning

already collected on a regular basis. However, there may be other indicators for which we need to start collecting data and setting up regular monitoring programmes. It is recommended that data for these indicators be collected on an annual basis and fed into a dedicated state of the environment monitoring programme which could be co-ordinated by the Ministry of the Environment.

This first SoE report provides a useful baseline or starting point to monitor changes in our environment, and a valuable resource for those who care about Bermuda's environment and who are planning for the Island's future.

This SoE report has already provided useful background material to Bermuda's Sustainable Development Strategy and Implementation Plan. It is intended that the production of a SoE report for Bermuda will become an integrated part of the sustainable development process for Bermuda and that future reports will feed into regular reviews of the Island's Sustainable Development Strategy and Implementation Plan.

Table 16.1 (d) Environmental performance indicators

ISSUE	Indicators of threats and/or of health	Management action
Pest Control	The percentage of houses breeding mosquitoes i.e. the "House Index"	Pest control public awareness programmes
	Number of premises cautioned, warned and pending prosecution for breeding mosquiteos	
	Number of complaint calls received	
	Number and type of rodent control job requests and service calls	
Invasive Alien Species	Number, type and distribution of introduced species considered locally invasive	Regulations to protect, enforce and control the introduction of invasive species
	Number, type and distribution of species threatened by invasive alien species	Number of woodland management plans
		Number of habitat restoration programmes
GENERAL	Lack of awareness of environmental laws (%)	Number of environmental awareness surveys conducted
	Number of violations of environmental laws	Number of public environmental awareness programmes
		Number of environmental expositions and conferences held

Source: Compiled by the Department of Planning