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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON THE ISLAND OF MALTA

IDENTIFICATION AND ASSESSMENT OF POSSIBLE CLIMATIC CHANGE ON MARINE AND FRESHWATER ECOSYSTEMS

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1. Introduction

The Maltese Islands support a rich variety of natural habitats with a significant number of animal and plant species which live only on these islands (i.e. endemic species). The Malta Structure Plan (1990) refers to approximately 2000 species of plants, 50 species of fresh-water and terrestrial molluscs, over 4250 species of animals. The rich variety of living communities is due to the insular nature of the archipelago as well as to its location at the intersection of ecologically distinct regions within the Mediterranean.

The local climate is Mediterranean-type, with a mean annual rain-fall of 530mm, with 70% of this precipitation occurring during the period October-March. Summers are usually dry with maximum temperatures reaching 30 degrees celsius in July-August. The purpose of this report is to discuss possible impacts of predicted climate changes on freshwater, coastal and marine ecosystems. The major features and characteristics of such ecosystems and habitats in their present state, will be outlined first. Then we will define the possible scenarios of local and regional climatic changes by the year 2050, being predicted on the currently available data and information. The last part will identify and evaluate the possible impacts of these scenarios on the ecosystems in question.

1.1 Malta's Coastal Lowlands

The Maltese Islands have a collective shoreline of about 190 km and a surface area of 316 square kilometres, of which, 5.2% is at 7.6 m or less, above the mean sea level. Rough estimates indicate that, approximately only 1.2% of the total land surface is 1m or less above sea level. In fact, the islands' coastline is characterised by cliffs, clay slopes and boulder rocks (Figure 1). 50% of Malta's coasts and 74% of Gozo's coastline has been defined as inaccessible mainly due to physical features (Malta Structure Plan, 1990). This leads to the heavy pressures being exerted on the remaining lowlands for touristic, industrial and urban purposes.

Sandy beaches are few and constitute only 2% of the coastline. Nonetheless, these very restricted localities and the rest of the coastal lowlands support a number of habitats which are of unique ecological and scientific importance. These include: saline marsh lands, sand dunes and rocky gentle slopes. Our knowledge of such habitats is still limited though significant contributions have been made recently (e.g. Schembri et al, 1987).

Man-induced pressures on coastal lowland habitats include: urban settlement and coastal development, land-based pollution, quarrying activities. Other pressure, which are only man-induced, include shoreline erosion. Spiteri (1990) has identified a number of sandy beaches presently undergoing shore-erosion, including: Mellieha Bay, St. George's Bay, Xlendi and Marsalforn. Pretty Bay (South of Malta) has experienced dramatic expansion of its sandy beaches due to changes in local water currents induced by modifications of coastline during the development of the Malta Freeport.

1.2 Inshore marine waters

Approximately 1940 square kilometres of sublittoral (0-100m below sea level) surround the islands, with a diverse range of habitats including: step drop-offs, boulder grounds, bare sand, mud and fine sands and sea grass meadows (Malta Structure Plan, 1990).

Seasonal surface sea temperature fluctuations range from 14 degrees celsius during February-March up to 28 degrees celsius in August-September. Nearshore waters are generally oligotrophic with nutrient levels typically low. Inshore, waters exposed to urban pressures such as harbours, and semi-enclosed creeks, may occasionally show elevated nutrient levels, and moderately eutrophic conditions (Axiak et al, 1992). Tidal activities are minimal and generally overridden by other water movements. Surface sea currents generally set towards the South-East, through the local inshore currents regimes are characterised by significant variations and possibly eddy currents. Water stratification is mostly due to thermal effects and is prominent during September. Salinity, fluctuations may be quite significant inshore especially during the autumn rain storms, during which huge quantities of suspended sediments are introduced into the marine environment.

Sea-grass meadows are relatively important ecosystems, both locally as well as regionally. Posidonia oceania meadows generally occupy open sea bottoms which are not exposed to wide fluctuations in salinities and urban pressures. These form extensive prairies of high productivity and support a rich community of animals, including economically important fish and molluscs. Posidonia meadows locally extend to relatively deep waters and possibly its lower limit is one of the deepest recorded in the Mediterranean (E. Lanfranco, personal communication). This is because of our extremely clear waters and the subsequent increased light availability in the lower layers. Another sea-grass species of local importance is Cymodocea nodosa which is more tolerant to salinity fluctuations and therefore may be found inhabiting inshore waters, bays and creeks.

As for the coastal lowlands, the inshore marine communities are presently facing a number of man-induced pressures. These include land-based pollution, construction projects and shoreline development, and increased diving activities. Changes in the local and regional marine fauna and flora have also been observed due to a number of immigrant animal and plant species (Lessepsian migrants) colonizing the Mediterranean waters from the Indo-Pacific region through the Suez Canal. The immigrants are essentially warm-water species which for a number of reasons have established themselves in the Mediterranean. They include 41 fish species (Ben-Tuvia, 1985), molluscs, as well as microplankton (Lakkis, 1990). This immigration into the Mediterranean region have been mostly limited to the eastern basin though a number of species (including molluscs) have also reached the western basin. A number of such migrants have been observed in Malta including the sea-grass Halophila stipulacea and a number of fish (E. Lanfranco, personal communication). H. stipulacea inserts itself in meadows of Cymodocea and it is possible that this will bring about changes in the associated fauna communities.

1.3 Freshwater Habitats

There are no rivers on these islands and the number of permanent springs are very limited. Most freshwater habitats carry water during one part of the year and dry up during summer. Nonetheless, there are some freshwater habitats which though greatly restricted in geographical extent, manage to support a significant number of rare or endangered species as well as endemic flora and fauna. These localities include: the valleys in the Mtahleb area which support several species of freshwater snails and many rare plants; the valley system leading to Salina Bay on the NW of Malta, which includes Wied Qannotta, Wied Ghajn Rihana and Wied il-Ghasel; Bahrija Valley; Wied il-Luq at Buskett and the area known as Chadwich Lakes, being the drainage system for one of the largest freshwater catchment areas in Malta (Schembri et al, 1987). In most of these localities, rain water form temporary pools or streams which often support rich though geographically restricted freshwater communities. All of these freshwater habitats are severely threatened by competing land uses including: urban spreading, quarrying, or refuse dumping.

2. Climate Change Scenarios

The interaction and intimate association between the living components of an ecosystem and the physical environment, (including climate), is a basic concept in ecology. This interaction is two-way, i.e. climatic changes may be brought about by the living components of an ecosystem, and vice-versa. Certain living components of an ecosystem are however, less adaptable to climatic or environmental change than others, and it may be envisaged that rapid climatic changes on a time scale of a few decades, will exert impacts on ecosystems of significant proportions.

Various General Circulatory Models predict a rise in global mean temperature in the range of 1.5 to 4 degrees celsius by the 21st Century due to the 'greenhouse effect'. Such models are not yet about to predict with any reliability the magnitude of such temperature changes at the regional level. However, according to sub-grid-scale climate change scenarios recently developed by the Climate Research Unit (Guo et al, 1992), the local annual temperature change will be 0.8 to 0.9 degrees celsius per degree global change, with the largest increase being found during summer. Predictions in the relative mean sea level rise are unreliable in the absence of reliable data on local land subsidence (due to tectonic and other activities), as well as on how the predicted climatic changes will effect the water budget, and other regional parameters. Likewise, predictions in changes of precipitation rates and seasonal patterns, may be considered to be unreliable, especially when applied to the regional and local context. For the purpose of this report, two scenarios may however be considered for local climate change: a Worst-Case Malta Scenario and a Mild-Case Malta Scenario.

In the 'Worst-Case Malta Scenario' for the year 2050, we may expect an annual mean temperature rise of 3 degrees celsius with summer temperatures being elevated by 3.5 degrees celsius. Moreover, daily and seasonal temperature extremes may be more pronounced. A mean relative sea-level rise of approximately 50 cm will take place. There will be no change in the annual mean rates of rainfall, but there will be a significant change in the seasonal precipitation pattern, so that winter and spring may have lower rainfalls but autumn rainfall, and possibly the severity of the autumn rain storms, will increase.

In the 'Mild-Case Malta Scenario', the annual mean temperature will increase by 0.8 degrees celsius, with summer temperatures increasing by 1.2 degrees celsius. There will be a rise in the relative mean sea level of 24 cm. Rainfall annual rates and seasonal patterns will not be substantially changed.

3. Impacts on coastal lowlands

A rise in the mean relative sea-level of approximately 50cm, is likely to cause inundation and shoreline recession in the following localities on the Malta mainland: Ramla tat-Torri and Gharmier Bay, Mellieha Bay, Xemxija Bay (is-Simar), Salina Bay, certain lowland localities from Ghalies Point to St. George's Bay, Marsaskala Bay, St. Thomas Bay and certain localities in Marsaxlokk Bay (Figure 1). The extent of inundation in each case will be determined by the presence of coastal roads and other man-made constructions, though increased frequencies of storm surges will also threaten a number of these coastal roads. Msida Creek and Marsa Creek will be less threatened by such storm surges or waves and more easily protected by the present man-made constructions.

Inland recession of sandy beaches will be possibly only in those cases were sedimentary flux and replenishment will not be reduced by inland constructions (e.g. roads at the back of a beach) or by altered land runoff due to changes in precipitation patterns. In other cases, coastal built-up areas and constructions will prevent such inland recession of sandy beaches, leading to significant or complete losses of these areas. In spite of the very limited information available on the rates of local shoreline and beach erosions, there are indications that a number of sandy beaches are presently affected by erosion process (Spiteri, 1990).

Taking into account that sandy beaches on these islands are few, and that they all take the form of small pockets fringed by rocky coastlines (which in most cases have man-made constructions on them) it may be assumed that one major impact of the predicted climatic changes on the local coastal environment will be the increased erosion and possible loss of coastal sandy beaches. Any reduction of sediment flowing out to sea, resulting from altered precipitation patterns, and the effects of reservoirs trapping sediments (e.g. retention basins to retain stormwater as are being proposed in the Sewerage Master Plan for Malta and Gozo, COWIconsult, 1992) may accelerate this coastal erosion. Finally, our sandy beaches, threatened as they already are by a number of man-induced factors, are still likely to be negatively affected by the year 2050, even if the Mild-Case Malta Scenario of climate change is applicable.

As indicated in section 1.2, Malta's coastal area support a number of important habitats including sand dunes and saline marsh lands. At least four sites with well developed coastal sand dunes containing the full range of typical dune vegetation have been identified (Malta Structure Plan, 199). These are at ir-Ramla tat-Torri, Ghadira, Ramla tal-Mixquqa (Golden Bay) on the Malta mainland and ir-Ramla dunes in Gozo. All these localities support a number of rare, threatened or/and endemic plants and animals and as such their loss will be highly significant to the biodiversity as well scientific and cultural heritage of these islands. The same applies to a number of saline marshlands including those at Ghadira, is-Simar (Xemxija) and Salina. Such localities are important bird nesting sites and their loss will reduce the capabilities of these islands to support local bird life as well as host bird migrants.

While increased ambient temperatures may lead to increased plant productivity in such sand dune and saltmarsh vegetations, increased intrusion of seawater brought about by a rise in sea level may reduce the number of supported species which are tolerant to elevated salinities. Moreover, such habitats will be able to keep up with the general shoreline recession only if the rate of rise in sea level is slow enough (e.g. sediment inputs will have to be sufficient to replenish the habitat substrate) and only where the adjacent inland areas are free of man-made constructions such as roads, camping sites, etc....

Taking all these points in consideration, it may be assumed that climatic changes as predicted by the Worst-case Malta Scenario will negatively affect the local sand dunes and saline marsh lands, leading to a reduction in their area coverage as well as in the buffer zones which necessarily protect them from the nearby habitats including urban areas. Further detailed considerations of the likely impact of climatic changes on one of the most important of such threatened site are included in Appendix 1. The extent of negative impact of less severe climatic changes on such habitats will greatly depend on appropriate land-use management in their vicinity.

4. Impact on Near-Shore Marine Ecosystems

Life in near-shore marine environments is mostly dependent on physico-chemical parameters such as salinity, temperatures, nutrient levels, water turbidity, and bottom substrate types. Such water parameters are themselves mostly influenced by land-based activities. Moreover, the nature of these interactions is highly complex making predictions of impact of climatic changes on land-based activities (such as water run-off, sediment and nutrient inputs into the marine environment) which may in turn affect marine life, quite difficult. In our case, the limited baseline information available on near-shore marine life and on its responses to environmental fluctuations, further compounds such problems of prediction.

A rise in the mean sea level as well as in surface water temperatures, coupled with increased autumn rain storms, and a more prolonged dry season, are all bound to increase the range of fluctuations of a number of physico-chemical parameters in the near-shore marine waters, especially in semi-enclosed bays. The magnitude of such changes is however difficult to predict at present. In the Worst-Case Malta Scenario, these changes may include: wider salinity fluctuations, increased water turbidity during the autumn and winter months, elevated nutrient levels as well as more pronounced water stratification due to higher surface water temperatures. Such changes are bound to influence both primary productivity as well as the distribution of animal and plant life in near-shore coastal waters which are relatively shallow. Localities which may be thus affected, include most of the northern and north-eastern shallow coastal waters on the Malta mainland.

4.1 A case study: Marine environmental parameters in Marsamxett and Grand Harbour, and how they may be affected by climatic change

At this point, it may be useful to review data from a recent three-year field survey (1989-92) undertaken in Marsamxett and Grand Harbour as well as in a reference station, approximately 1 km off these harbours, (Axiak et al, 1992). This study showed that water stratification was well pronounced during the July-September period over all the area investigated. However, while the mean temperature difference between surface and bottom waters in Marsamxett was approximately 3 degrees celsius, that in the reference station as well as over most of the Grand Harbour was 5 degrees celsius. This pronounced water stratification in the Grand Harbour was related to the thermal emissions of the present power station in Marsa. Under these conditions, the rate of replenishment of oxygen in bottom waters is reduced to the detriment of benthic organisms. A rise in ambient temperatures due to climatic changes is bound to make such water stratification along the northern and north-eastern coastal shallow waters much more pronounced and prolonged in time.

This study also illustrates the fact that non-climatic effects (e.g. thermal emissions from a power station) may greatly influence the magnitude or even the direction of predicted changes in marine environmental parameters due to climate change at the local level. It is expected that within the next 5 years, a new power station will become operational in Marsaxlokk Bay (Delimara), which will discharge thermal emissions in the relatively shallow waters of Hofra iz-Zghira (Figure 1). A rise in ambient temperatures is bound to aggravate thermal stratification of the coastal waters at this locality as well as in the surrounding areas on the south-eastern coastline of Malta, to the detriment of the present extensive marine grass meadows.

This case study showed that while nutrient levels in the open waters (reference station) were generally low, those in the inland creeks were often quite high, leading to increased primary productivity and in some cases, to mild eutrophic conditions. While no significant algal blooms were recorded in these harbours during this study period (possible due to their transient nature), this phenomenon was recorded in the past, at least in Pieta Creek, Marsamxett (Fugde, 1977). Eutrophic conditions and possibly algal blooms may become more significant and frequent in these and other similar near-shore semi-enclosed localities (such as Marsaxlokk Bay), due to climatic changes predicted in the Worst-Case Malta Scenario.

Levels of Chlorophyll A (as an index of primary productivity) were found to be mostly determined by phosphate levels and less so by temperature. Nonetheless, no significant regression model could be developed to describe primary productivity in the area in terms of the other environmental parameters. This may be due to the complex interacting forcing functions which may affect algal productivity in inshore areas, as well as to the limited time frame over which the data was collected. It also illustrates the difficulty of predicting the nature and magnitude of impacts of climatic change on coastal primary productivity. It may be however tentatively stated that any increase in phosphate levels due to increased water run off during the autumn months may lead to enhanced productivity in this area. The present case study has also shown that one important anthropogenic activity in these ports which may lead to enhanced phosphate levels is dredging. Therefore, man-induced (non-climatic) changes may prove to be more important in determining water quality and productivity in inshore waters, than factors directly related to mild climatic changes.

As expected, salinities at the various inshore stations was found to be negatively correlated to the rate of precipitation over Marsamxett. This confirms that increased rates of precipitation during the autumn months will lead to greater salinity fluctuations in inshore waters, as well as to the introduction of greater sediment loads and turbidity, all of which may limit the range of sublittoral and benthic species which may survive in such environments.

4.2 Changes in sediment inputs and transport in inshore waters

During the autumn and winter rain storms, significantly increased turbidity at some coastal localities may be readily observed. This increased turbidity due to increased sediment inputs, may visibly extend for up to 1 to 2 km offshore. These localities include coastal areas lined with clay slopes such as Xatt l-Ahmar (Southern coastline of Gozo) and Gnejna Bay (Eastern coastline of Malta). Any increased sediment inputs into the marine environment may be expected to lead to changes in off-shore bottom profiles, as well as to altered substrate types and therefore to changes in benthic communities.

Marine grass meadows are particularly sensitive to reduced water transparency and the upper limits of the extensive present meadows at these localities may be expected to retreat to greater depths as a result of significant sediment loads in these waters due to climatic change. On the other hand, a rise in water temperatures may be expected to favour such sea-grass meadows, particularly those of Posidonia whose reproduction is known to be greatly sensitive to ambient temperatures. The net effect of climatic changes on such prairies is difficult to predict, especially since they are also highly sensitive to non-climatic anthropogenic activities such as coastal constructions and land-based pollution.

Climatic changes may also produce alterations in the coastal water currents, thereby affecting sediment transports along the shoreline. Little information is as yet available as to how climatic changes in the Mediterranean may effect the circulation patterns at the regional level. At the local level, any prediction of the effects of such climatic changes on local current speeds and direction is impossible, at our present state of knowledge.

4.4 Impact on Marine Inputs and Transport of Pollutants

Any significant alterations of such local hydrodynamics will not only affect shoreline stability, bathymetry and coastal erosion, but will also (perhaps more significantly) affect the fate of pollutants in the coastal environment. For example, the siting of the present major submarine sewage outfall at Wied Ghammieq was mostly determined by the fact that the predominant south-easterly water currents will carry the pollutants away from a number of important bathing beaches on the northern areas of the mainland. Recent studies (Axiak et al, unpublished) have already shown that the sewage plume emitted by this major sewage outfall, in some cases affect coastal waters off Marsamxett and the Grand Harbour. Any significant changes (or increased variability) in the water currents along the north-eastern coast of Malta due to climatic changes may have implications on marine contamination and transport of pollutants in these areas. The siting of any additional marine sewage outfalls (as proposed by the present Sewerage Master Plan for Malta) will have to take such factors into consideration.

It is well known that one factor leading to coastal contamination by sewage in a number of localities around Malta and Gozo, is the flooding of sewers by rain water during the autumn and winter months. Any increased occurrence of rain storms during these months will aggravate this problem though the implications on human health may be less significant since it will occur mostly outside the bathing period.

4.5 Impact on distribution of animals and plants

Temperature is known to be an important environmental factor which determines zonation of animals and plants both at the local level (e.g. on a shoreline) and at the global level (zonation due to latitude). Therefore, it may be expected that any increase in ambient temperatures (coupled with wider salinity fluctuations) will affect shoreline zonation, though the extent of this impact is difficult to determine. On a regional level, one impact of increased water temperature in the Mediterranean may be to accelerate the penetration of Lessepsian migrants from the Eastern to the Western basin, and possibly to increase the rate at which some migrants are entering the eastern Mediterranean from the Red Sea (see section 1.2). Therefore, we may expect an increased occurrence of these new species in our local habitats. This may itself affect local communities in various ways which are difficult to define and predict.

A number of studies have indicated that living communities may

often respond non-linearly to slight modifications in their environment (UNESCO, 1991). Examples of such non-linear responses include: bleaching and mass mortalities of corals in responses to elevated temperatures, and changes in planktonic communities in response to altered nutrient levels and water temperatures. One biological phenomenon which was recorded over a significant proportion of the Mediterranean, and which may be a further example of such non-linear biological responses to climatic fluctuations, is that of coastal and off-shore blooms and aggregations of the jelly fish, Pelagia noctiluca (Axiak and Civili, 1991). The impact of such jelly fish blooms proved to be significant on the epipelagic ecosystems as well as to man's activities including fishing and coastal tourism.

The more recent bloom period of Pelagia occurred during 1979-1984 and extended over most of the French coastline, Italy, the Adriatic, Malta and Greek waters. Goy (1984) had suggested that this phenomenon was related to pluri-annual climatic and hydrological cycles. The author suggested that the years prior to the bloom period are characterized by a deficit in rain fall and by anomalous high temperatures and atmospheric pressures particularly during May and June. The manner in which the predicted climatic changes by 2050, will affect such natural cycles in the epipelagic zone of the Mediterranean in general, and of the local environment in particular, need to be studied in greater detail.

5. Impact on Freshwater Ecosystems

As discussed in section 1.3, though the number of freshwater habitats on these islands is quite limited, they support a significant number of rare, endangered and endemic species. There has been an obvious reduction in such fresh water communities on these islands over the past two decades, as illustrated by a reduction in the associated flora of Bahrija, Wied Ghajn Rihana and Gnejna (E. Lanfranco, personal communication). This may be mostly due to reduced water replenishment of the aquifers probably related to increased road cover, and thereby to a decrease in the number and output of permanent and temporary springs. An increased evapo-transpiration and reduced fresh water inputs, will accelerate this reduction and degradation. Thereto, the Worst-Case Malta Scenario coupled with increased man's interference with such habitats may probably lead to their complete loss by 2050 or 2100.

Moreover, increased autumn/winter rain storms will lead to changes in the location of water courses as well as to increased disturbance of valley floors through the movement of rocks and boulders, etc... These habitats are extremely sensitive to such rain storms. For example, the vegetation at the bottom of Wied Qirda has apparently not recovered from such disturbance which occurred during a particularly heavy winter storm in 1979, and is still dominated by weed species, which are indicative of disturbed habitats (E. Lanfranco, personal communication). These considerations indicate that the local freshwater habitats and ecosystems are more sensitive to the predicted climatic changes than the marine ecosystems.

6. Conclusions

The present coastal, near-shore as well as freshwater ecosystems are threatened by a number of man-induced changes, which have been identified int he above account. Any further negative impacts on these ecosystems due to climatic changes predicted by 2050 and 2100, will have to be assessed in combination with such non-climatic hazards, otherwise this exercise of impact assessment will be irrelevant and futile.

Coastal sandy beaches, as well as sand dune and saline marsh habitats may be considered to be quite sensitive to the predicted climatic changes, due to erosion, fast shoreline recession and increased environmental fluctuations. The extent of impact on such habitats, due to less severe climatic change scenarios, will greatly depend on the present and future land-use management practices.

Impact of climatic changes on near-shore communities is likely to occur but is at present difficult to predict. Increased eutrophic conditions as well as increased water stratifications are likely to occur in certain localities, especially those which are already influenced by other non-climatic man-induced activities.

Non-linear biological responses to climatic changes have been discussed and may prove to be quite significant but equally difficult to predict, with our present state of knowledge.

Impact on the local freshwater habitats and ecosystems due to climatic changes will probably be quite severe.

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APPENDIX 1 to: Identification and Assessment of Possible Impact of Climatic Change on Marine and Freshwater Ecosystems

Impacts of Elevated Temperatures and a Sea-level Rise on the Ghadira Nature Reserve

The Ghadira Nature Reserve is located on the north-eastern coasts of Malta (Mellieha Bay) and at the largest saline marshland on these islands. It occupies approximately 6 hectares of land and is separated from the sea by a road and a narrow sandy beach which are together approximately 100m wide. Prior to 1980, this area was typically a saline marsh with water being present in a central pool for most of the year, and then drying up during the summer months. Since then, the central pool has been deepened and provided with rain water throughout the year.

This reserve is of unique scientific, educational and ecological importance. It is the first officially designated nature reserve in these islands and represents one of the few surviving habitats in the Central Mediterranean, which is utilized by a number of migratory birds as a temporary resting station on their migratory routes between Europe and Africa, while being a good wintering site for other bird species. Moreover, it supports a number of rare or threatened plant and animal species. A number of detailed studies on this nature reserve have been recently published (Centro, 1990).

During a one-year study undertaken in 1985-86, very high fluctuations in a number of physico-chemical parameters were reported, including salinity ranges from 7 up to 40 ppt, with one particular station reaching a salinity of 70ppt in September (Hili, et al, 1990). These salinity fluctuations were related both to precipitation as well as seepage of seawater through compacted beach sand and soil, which was most evident during the summer months. Oxygen levels were generally high though near-anoxic conditions (i.e. very low oxygen levels) were sometimes recorded during summer, immediately after a phytoplankton bloom. Such algal blooms were supported by elevated nutrient levels due to pollution from agricultural run off from the surrounding fields.

A rise in mean sea level of 20 to 30 cm will definitely increase the occurrence of seawater intrusions in the present marshland as well as result in more prolonged elevated salinities, in the various parts of the central pool. Borg et al, (1990) have shown that the pool has a relatively low macrofaunal species richness (i.e. a limited variety of animals) due to the wide fluctuations in salinity, temperature and oxygen levels. Prolonged elevated salinities, followed by sudden salinity drops during the autumn rain storms (which may become more pronounced, as a result of climate change), may lead to a further reduction in the range of animal and plant species which would be able to tolerate thee environmental fluctuations.

Based on the presently available data, an attempt was made to model physoplankton primary productivity as measured by chlorophyll a content in terms of the other environmental parameters, through multiple regression analysis. One regression model which could explain 45% of the variance of chlorophyll a and which was found to be statistically significant at P/0.001, indicated that primary productivity was mostly dependent on temperature, and on levels of oxygen, phosphates and nitrites. Moreover, this model indicated that with a rise of ambient temperature of 1 degree celsius, while keeping all other parameters constant, there will be a 10.5% increase in primary productivity by phytoplankton. This proves that a rise in ambient temperature throughout the whole year may lead to an increase in algal productivity (both macro and micro algal blooms) and prolonged periods of low oxygen levels. This would further reduce or eliminate the populations of aquatic animals during the summer months.

Because of the relatively small dimensions of this nature reserve, detrimental fluctuations in some environmental parameters such as salinity, may be mitigated through the controlled supply of fresh water from reservoirs. However, in the event of a more significant rise in the relative mean sea level (e.g. 40 -65 cm), then it is envisaged that there will be an equally significant shoreline recession. Given the gentle slope of the Ghadira sandy beach, this shoreline recession may be roughly calculated to reach up to 65m inland (assuming 1m shoreline recession to 1 cm rise in sea level). This recession may be either limited by the existing coastal road, or the location of the road itself may have to be changed due to its subsequent exposure to storm surges and waves. If this rise in sea level will be slow (over a couple of centuries) then there will be a gradual landward migration of this saltmarsh. However, if the sea-level rises at a rate greater than the ability of this wetland to keep pace, then it will be reduced in surface area. If any landward migration is further blocked by land development (e.g. the sprawling of the present permanent camping site on the north side of this salt marsh), then there may be a complete loss of this habitat.

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