Framing the flow

Innovative Approaches to Understand, Protect and Value Ecosystem Services Across Linked Habitats

UNEP WCMC

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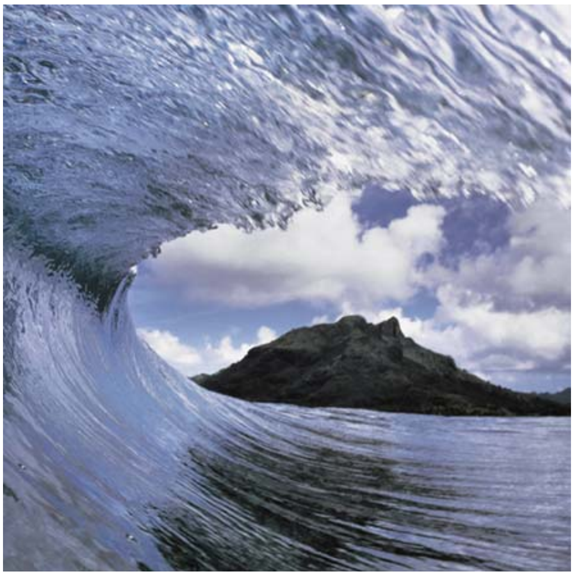

Framing the flow:

Innovative Approaches to Understand, Protect and Value Ecosystem Services Across Linked Habitats

Silvia Silvestri
Francine Kershaw

Preface

Marine, coastal and freshwater ecosystems are complex and characterised by an array of ecological functions and processes essential to the regulation and continued provision of ecosystem services of direct or indirect benefit to human welfare and society. Ecosystem services flow from their source to sink across both land- and seascapes, and call for the integrated management of connected ecosystems to optimise the flow of these services and benefits.

This publication highlights the interconnectivity and linkages between coastal ecosystems (mangroves, coral reefs, seagrasses, estuaries, and lagoons) across environmental, economic, social, and management contexts. It presents innovative approaches to better understand, protect and value ecosystems services across linked habitats, informing the trade-off of different land-use management decisions and the effects on healthy systems from drawing on ecosystem services from linked habitats.

Worrying findings are presented on the impacts of rapid natural and human induced change on the health of coastal ecosystems, the implications of these disruptions for ecosystem functioning and the delivery of ecosystem services.

At least 35% of mangroves and 29% of seagrasses have been lost in the last two decades, while coral reefs are estimated to have lost up to 19% of their original area on a global scale. A further 15% of coral reefs are seriously threatened with loss within the next 10-20 years, and 20% are under threat of loss in 20-40 years, with potentially negative impacts on fisheries and food security for vulnerable coastal populations.

Understanding the benefits of maintaining and indeed restoring the flow of ecosystem services across the complete supply chain can result in reducing risk and securing the continued supply of those services.

Finally, information on ecosystems services flows can allow planners to make the case for truly integrated management approaches, especially those bridging the divide between terrestrial watershed management, coastal zone management and marine ecosystems-based management, by stressing how an integrated approach can deliver multiple benefits to society and the environment.

This report presents further evidence of the need to develop appropriate economic and governance frameworks that best protect the essential services from natural ecosystems that human populations will need for the future.

Achim Steiner
UNEP Executive Director
United Nations Under-Secretary General

Executive Summary

This publication presents a framework for an understanding of the connectivity between tropical coastal ecosystems (including mangroves, seagrasses and coral reefs) across environmental, economic, social, and management contexts. It presents innovative approaches to better understand, protect and value ecosystem services across linked habitats, and to allow informed trade-offs between different land-use management decisions and consequent changes in different ecosystem services.

Coral reefs, mangroves, seagrasses and nearshore terrestrial ecosystems are highly interconnected by their physical and biological dependence on each other. The importance of this interdependence to ecosystem function and service provision is becoming increasingly recognised, particularly in the context of the disruptive impacts of human drivers of change.

Tropical terrestrial and coastal marine ecosystems provide a wide range of benefits and services and can be assigned substantial economic value. The 'flow' of these services can be traced over space and time, linking producing and consuming systems and human communities. Quantification of these flows is essential in order to define the ultimate beneficiaries of services, a process which can be achieved through a combination of biophysical and socio-economic analysis and modelling. One example of this approach would be the valuation of the flow of ecosystems services that can be supported by a 'with or without' scenario, using a 'what if' approach, i.e. what may happen if we stop the flow and modify the links between ecosystems?

In converting ecosystem functions (regulation, habitat, production, and information) to a quantitative value, among many aspects to be considered are: the evidence for non-linearity in ecosystem services; the spatial extent of the entire linked ecosystem responsible for service delivery; the future use of the resources; and variation in value according to the scale considered. Spatial mapping, combined with a definition of benefits and beneficiaries, can be a useful tool to support the valuation process and identify regions more likely to provide higher or lower levels of value.

Recognising the dynamic links between terrestrial, coastal and marine ecosystems, and how ecosystem services flow across these systems can help businesses improve their environmental performance, reduce risks and costs, and gain public support. Adopting the concept of flows of ecosystem services as part of business planning involves acknowledging the spatial and temporal coupling between areas where ecosystem services are generated and areas where the services are being used. It also involves understanding the mechanisms through which ecosystem services flow from source to points of usage. Each of these three components of ecosystem service – flows, source and use – are crucial for maintaining a healthy supply of critical ecosystem services, and therefore information about them is necessary to inform business decision-making.

Businesses have many additional reasons for ensuring that sources of ecosystem services are maintained over time. Maintaining access to these resources and guaranteeing their sustainable use enables businesses to operate at a desirable level of productivity, keeping costs of inputs low, avoiding scarcity, and reducing risks to the supply chain.

The awareness of the linkages between coastal ecosystems and the integration of the flow concept in management processes could lead to a more comprehensive approach which includes recognition of the need to protect the natural capital that generates services, together with the underlying ecological connections that regulate the flow of these benefits across systems. Not taking into account the interconnections between ecosystems and the flow of ecosystem services among them carries the significant risk of individual ecosystems deteriorating despite management efforts, with the consequence of loss in services and the potential to cause some ecosystems to approach their ecological tipping points. Information on flows allows planners to make the case for truly integrated management approaches, especially those bridging the divide between watershed management, coastal zone management and marine ecosystem-based management, by exhibiting how this improves the efficiency of overall management.

The transboundary nature of ecosystem service flows holds inherent challenges for the policy makers as new, holistic and cross-sectoral approaches must be developed to address the needs of complex groups of stakeholders and agencies. In these novel governance structures, the availability of simple, accessible and comprehensive information will be critical to support informed decision-making. Policy and decision makers will need to incorporate appropriate tools for resolving conflicts and trade-offs. The ability of policy makers to address the key challenge of reducing poverty worldwide is dependent on building the capacity to appropriately manage and preserve ecosystems and the services they provide. There remains a general lack of integration of knowledge of ecosystem services into development policy and the concept of ecosystem flows may help to fill this gap.

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Introduction

Most of the world 'megacities' (defined as more than 10 million inhabitants) are in coastal areas (Nicholls, *et al.*, 2007; Engelman, 2009). This is no accident as coastal ecosystems deliver a wide range of benefits to human society, including fisheries, water filtration, reduction of pollution impacts, soil formation, protection from coastal erosion, buffering of the effects of extreme weather events, recreation, tourism, support to industry, and a means of transport (Nellemann *et al.*, 2009). Owing to the provision of these services, coastal ecosystems have been attributed high economic worth through the rapidly developing field of ecosystem service valuation. Mangrove systems are worth an estimated US$4,290 annually per hectare; estuaries, lagoons and seagrasses provide benefits of around US$73,900 per year per hectare, while the annual value of a hectare of coral reefs is estimated to be US$129,000, among the most economically valuable of all ecosystems (TEEB, 2009).

These ecosystems are widely distributed, with 44% of countries containing coral reefs and around half having mangroves, both systems principally located in the tropics with Southeast Asia a major centre. Australia and Indonesia have approximately 50,000km^2 of reef each, accounting for around one third of the world's entire reef system. About one third of the world's mangroves are also found in Indonesia (UNEP, 2006). Seagrasses are estimated to cover globally about 180,000 km2 in tropical and temperate areas (Green & Short, 2003).

However, tropical coastal ecosystems are facing a wide range of threats that are disrupting connectivity and ecosystem function. Globally, at least 35% of mangroves and 30% of seagrass have been lost in the last two decades, while coral reefs are estimated to have lost about 20% of their original area (Valiela *et al.*, 2001; Waycott *et al.*, 2009). A further 15% of coral reefs are seriously threatened with loss within the next 10-20 years, with potentially negative impacts on fisheries and food security of vulnerable coastal populations (Wilkinson, 2008).

Coral reefs, mangroves, seagrasses, and nearshore terrestrial ecosystems are highly interconnected by their physical and biological interdependence, with pathways and processes that generate ecosystem services 'flowing' from one habitat to another. There is increasing recognition of the importance of the interdependence between ecosystems, and the role of these linkages in overall ecosystem function. There is need to identify and manage these linked habitats as a single ecosystem 'unit' in order to preserve the pathways of ecosystem service flow between them and to maintain the integrity of ecosystems and optimise provision of human benefits.

This publication – *Framing the flow* – seeks to promote improved management for sustainability by considering coastal ecosystem processes in terms of the generation, flow and delivery of services across linked habitats and the broader regional landscape. Viewing ecosystem services in this way has benefits and implications not only for biologists and ecological modellers, but also for the industry and business sectors, policy makers and practitioners in the field.

We provide a comprehensive overview of these perspectives, building the concept of ecosystem benefit flow, introducing recent modelling techniques designed to facilitate analysis of benefit flows, and outlining approaches to economic valuation. Advantages of integrating the ecosystem flow concept into industry and business strategies are then presented, and implications for policy makers and practitioners are discussed. Finally, key recommendations provide a platform for progressing further work in this field.

Chapter One

Conceptualising Ecosystem Benefits Across Land- and Seascapes

Ecosystem services provided by coastal habitats

Ecosystem services are defined as the direct or indirect contributions of ecosystems to human welfare (MA, 2005). One cannot speak of ecosystem services – or try to measure them – without linking them in some way to the benefits they provide to society.

The Millennium Ecosystem Assessment (MA, 2005) identified a number of common services derived from coastal ecosystems: food, biodiversity, nutrient cycling and fertility, climate regulation, disease control, flood/storm protection, and cultural amenity. These services often rely on ecological pathways connecting coastal systems – including estuaries, intertidal areas, lagoons, kelp forests, mangroves, rock and shell reefs, seagrasses, and coral reefs – with the deep ocean or mainland.

Supply of these ecosystem services relies absolutely on the ecological processes that characterise the ecosystem and its operation, and which help maintain its integrity following disturbance or stress. A recent report of the US EPA Science Advisory Board on "Valuing the Protection of Ecosystems and Services" defines ecosystem functions or processes as

> *the characteristic physical, chemical, and biological activities that influence the flows, storage, and transformation of materials and energy within and through ecosystems. These activities include processes that link organisms with their physical environment (e.g. primary productivity and the cycling of nutrients and water) and processes that link organisms with each other, indirectly influencing flows of energy, water, and nutrients (e.g. pollination, predation and parasitism). These processes in total describe the functioning of ecosystems. (EPA-SAB-09-012, May 2009)*

Increasing our understanding of these processes is essential to comprehending how ecosystem services are generated and how they transfer or 'flow' between ecosystem components and other linked ecosystems. This knowledge is essential to understanding the behaviour of any given service and is key to planning for effective management of ecosystem services.

The large scale geophysical elements of ecosystems can be as important for service delivery as the organisms present. For example, mangroves provide coastal protection from flooding but their capacity to do so during a disturbance depends both on ecosystem characteristics and on the environmental conditions surrounding the mangrove system, such as topography, slope, bathymetry, and geomorphology.

Ecosystem function and connectivity for coastal tropical habitats

Ecosystems are highly connected, linked by flow of energy and material so that processes initiated upstream may provide services in downstream systems. The conceptual model in Figure 1 provides an illustration of these relationships.

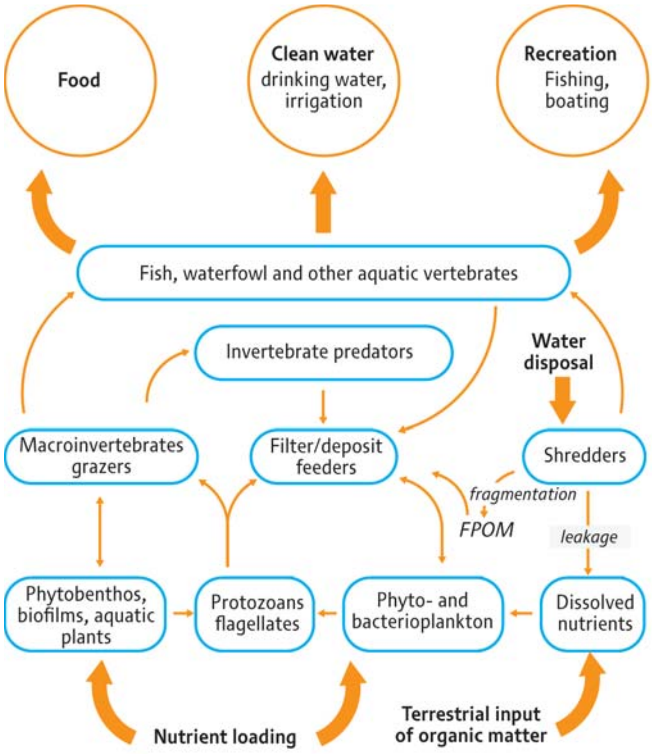
Types of service provided by coastal habitats

Provisioning services provide human populations with direct, harvestable benefits such as food, water, building materials, and pharmaceutical compounds.

Supporting services enable ecosystems to be maintained, for example, through soil formation, carbon storage and the maintenance of biodiversity. These services underpin provisioning services and so contribute indirectly to human welfare.

Regulating services control physical or biological processes within the ecosystem which enhance human welfare or quality of life, for example, climate and water regulation, the control of pests and disease (i.e. through biological control or physical barriers to their spread), and control of soil erosion and natural hazards.

Socio-cultural services are highly context-specific and provide aesthetic, religious, spiritual, recreational, traditional, or intellectual values ascribed by a community to a natural system.



Note: FPOM is fine particulate organic matter
Source: Covich, A.P., *et al.*, 2004.

Figure 1 – ***Diagram showing the complex flows of materials and energy characteristic of coastal ecosystems.*** *The capacity of systems to provide one service, e.g. clean water provision, can be impacted by excess use of another, e.g. waste disposal. Over-use of services can act as a driver of ecosystem change.*

Aquatic systems are strongly connected by the hydrological cycle. Water flows downstream from highlands to the sea, residing for a time as surface water, river flow or groundwater, before evaporating again to atmospheric water. Where ecosystems are strongly linked, defining their boundaries, and the spatial and temporal scales involved in processes that deliver ecosystem services, demands careful consideration. The smaller the system, the easier it is to measure the delivery of goods and services within it, but it may be harder to manage or predict changes in rates of flow of these services. If the goal is to maintain fisheries production in a coastal bay, it may not be sufficient to identify where the small fingerlings come from and protect their nursery habitat in adjacent marshlands or mangroves; it could be a priority to protect the quality and quantity of fresh water input from higher up in the catchment, aiming to ensure that appropriate salinity and nutrient levels are maintained. A subsequent goal might be to understand the dynamics by which these fry support populations of other fishes, perhaps also fishery target species, and other animal groups that feed and are dependent on them. Thus, a key requirement is to draw ecosystem boundaries sufficiently

large to capture the ecosystem functions and processes that produce, regulate or otherwise transform the ecosystem services of interest.

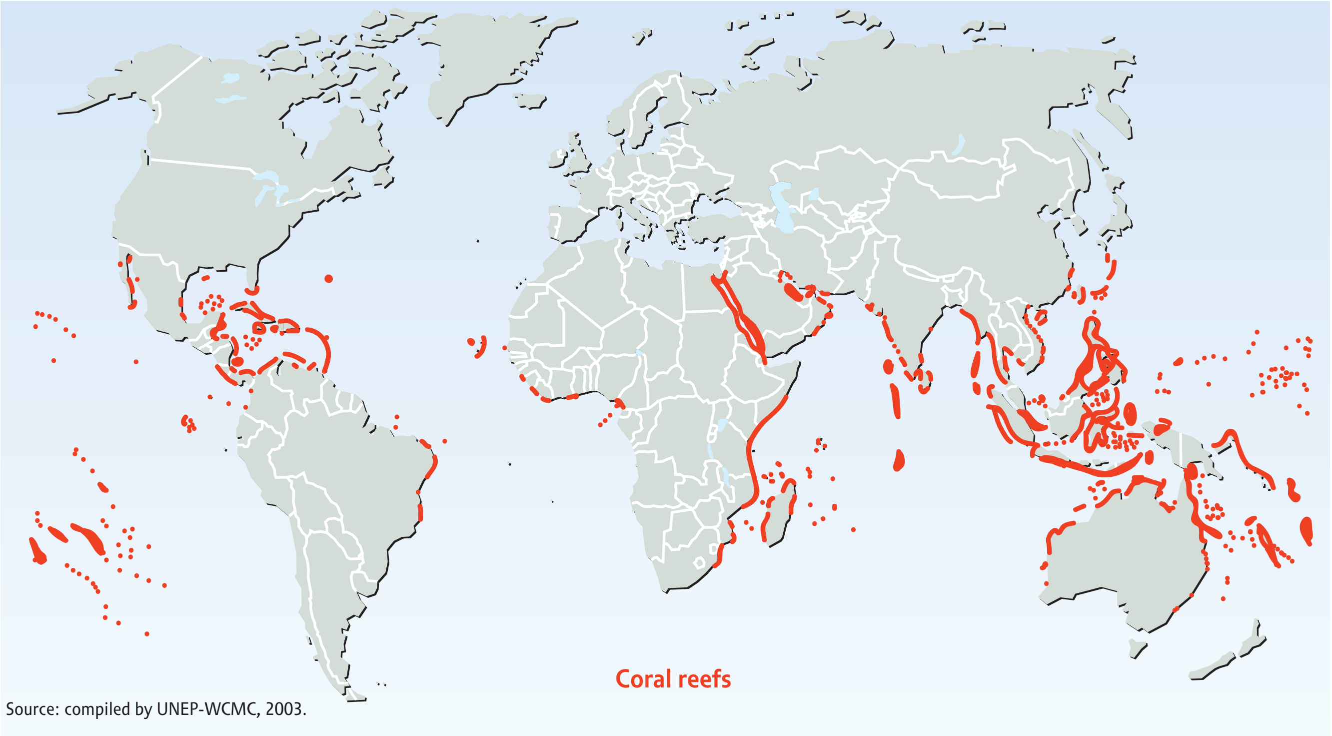
Coastal ecosystems intersect land and sea and provide both terrestrial and marine ecosystem services. This property makes them an appropriate focus for a study on the flow of ecosystem services. The high degree of connectivity in coastal ecosystems, however, creates challenges when attempting to attribute ecosystem service reduction to just one driver. Furthermore, when assessing individual consequences of change, the repercussions on ecosystem services may vary with the magnitude, periodicity and continuity of the driver.

Coral reefs, mangroves, seagrasses, and other nearshore ecosystems are highly connected by their physical and biological dependence on each other (Nagelkerken *et al.*, 2000; Nagelkerken *et al.*, 2002). With increasing recognition of this, scientists and conservation managers have started to place a greater emphasis on protecting the connectivity and flow between these ecosystems as essential to both biodiversity conservation and maintenance of ecosystem services.

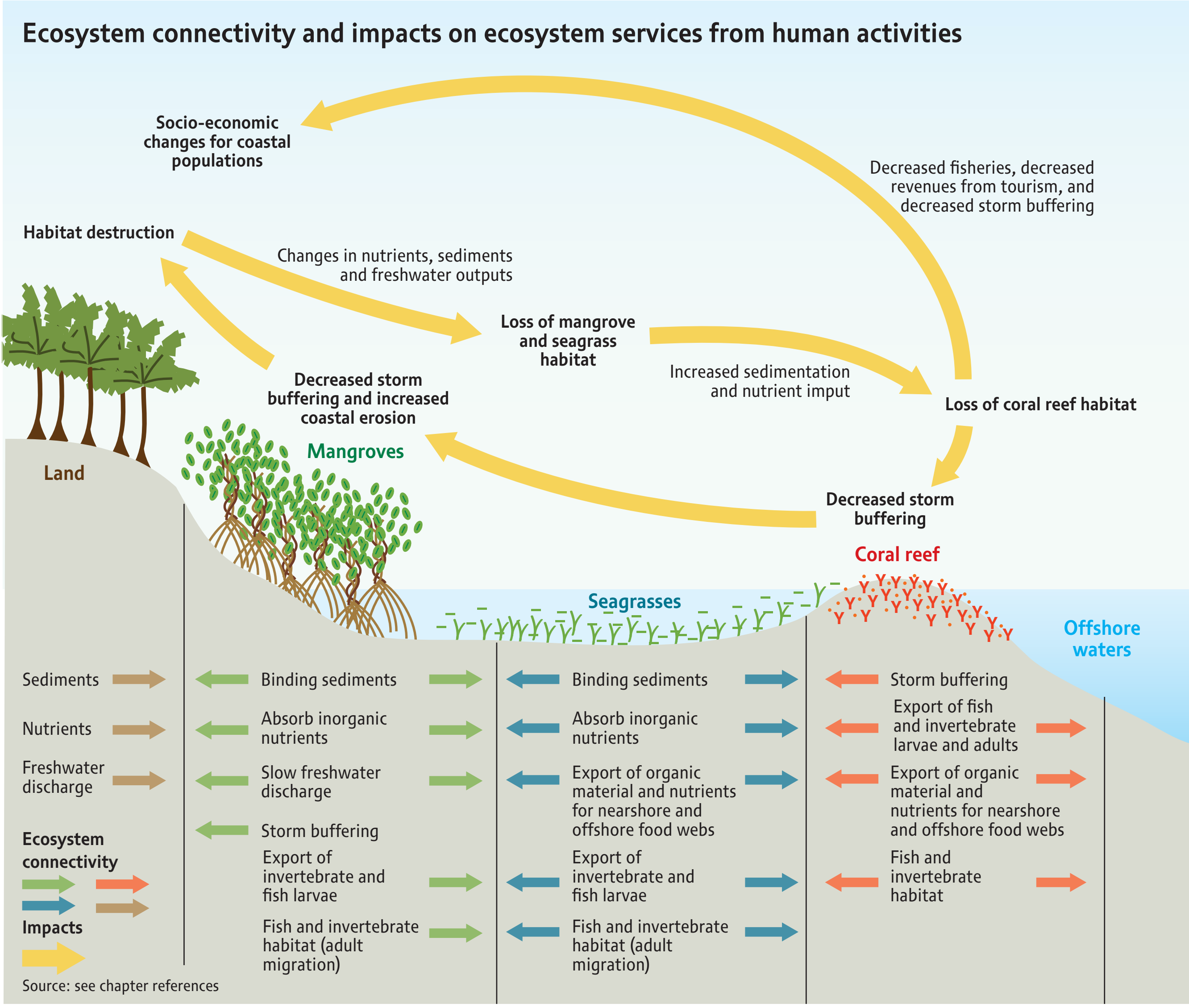
Moving from land to sea, it becomes very evident that nearshore terrestrial ecosystems play an important role in the health of tropical marine ecosystems. Deforestation or conversion of forested land can cause increased sedimentation and pollution in mangrove, seagrass and coral reef habitats (McCulloch *et al.*, 2003; Fabricius, 2005). Land use changes can also affect the flow regime of rivers, changing the quantity and timing of freshwater discharge to coastal systems (Ellison & Farnsworth, 2001). Although mangroves thrive in a saline environment, some freshwater input is needed for growth (Ellison & Farnsworth, 2001), and changes in upland hydrology, following dam construction, for example, can cause cascading effects across mangrove, seagrass and coral reef ecosystems.

Source: compiled by UNEP-WCMC, 1997.

Source: compiled by UNEP-WCMC, 2005.



Source: compiled by UNEP-WCMC, 2003.



Source: see chapter references

Figure 2 – ***Diagram showing the ecosystem connectivity between mangroves, seagrasses and coral reefs.*** *Ecological and physical connectivity between ecosystems is depicted for each ecosystem: terrestrial (brown arrows), mangroves (green arrows), seagrasses (blue arrows), and coral reefs (red arrows). Potential feedbacks across ecosystems from the impacts of different human activities on ecosystem services are also shown (yellow arrows).*

Threats to connectivity and ecosystem function

Tropical terrestrial and coastal marine ecosystems are facing an array of threats that are disrupting connectivity and ecosystem function. Threats include habitat conversion and destruction, changes in nutrient, sediment, or freshwater inputs, and reduction in fisheries production. In general, depending in part on the number and extent of freshwater catchments draining to them, coastal ecosystems suffer cumulative impacts from multiple drivers of change.

At least 35% of mangroves have been lost in the last two decades to a combination of mariculture, agriculture, urbanisation, and collection of fuel wood (Valiela *et al.*, 2001). Similarly, around 30% of total seagrass area has been lost (Waycott *et al.*, 2009) while coral reefs are estimated to have declined by up to 80% since the 1970s in the Caribbean (Gardner *et al.*, 2003) with at least 1% annual loss in the Indo-Pacific over a similar period (Bruno & Selig, 2007).

Loss of mangrove and seagrass leads to increased sediment and nutrient input to coral reefs, leading to degradation and loss of coral and potentially negative impacts on fisheries, which may in turn threaten the food security of vulnerable coastal populations. Loss of coral habitat also reduces the natural coastal defence service they provide leading to increased vulnerability. The resulting loss of infrastructure or of pristine coral habitat needed for profitable diving operations can reduce tourism revenue. Additionally, all of the major coastal tropical habitats are experiencing significant threats from climate change-related impacts and over-fishing, as well as a variety of other localised stressors (Halpern *et al.*, 2008). Case studies illustrated on figures 3 and 4 provide the opportunity to further explore examples of these key stressors.

Mangroves: Ecosystem function and connectivity

Bridging the land-sea interface, mangroves are a critical intertidal habitat in the tropics. As fresh water, nutrients and sediments flow from inland sources, mangroves bind sediment, absorb inorganic nutrients and physically slow freshwater discharge (Valiela *et al.*, 2001). They also provide critical buffering of the shoreline from erosion by storms (Barbier *et al.*, 2008), which can dramatically protect both inland infrastructure and coastal populations in low-elevation areas (Das & Vincent, 2009). Several studies have also found that mangroves can affect the presence and biomass of coral reef fish and other coastal tropical fisheries because they provide important nursery and refuge habitat for juvenile and adult fish (Nagelkerken *et al.*, 2002; Mumby *et al.*, 2004; Aburto-Oropeza *et al.*, 2008).

Seagrasses: Ecosystem function and connectivity

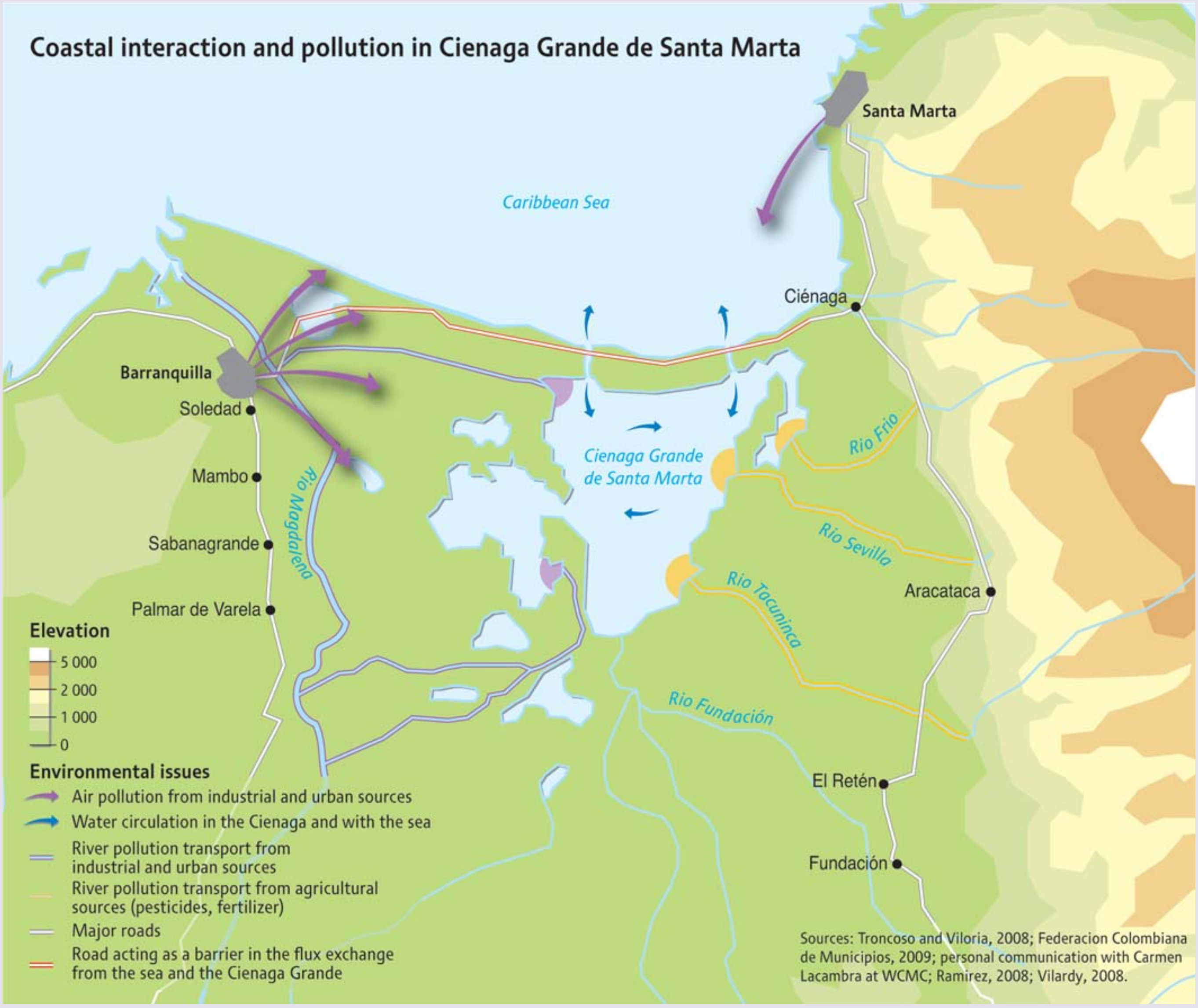
Seagrass beds are an essential ecosystem in the tropical seascape. Seagrass beds grow extensively throughout both temperate and tropical regions, primarily occupying subtidal areas, but sometimes extending into the intertidal (Williams & Heck, 2001). Like mangroves, seagrasses stabilise sediments (Orth *et al.*, 2006), sequester carbon (Duarte *et al.*, 2005), and play a key role in nutrient cycling (Williams & Heck, 2001). As one of the most productive ecosystems in the world (Waycott *et al.*, 2009), they export a substantial amount of particulate organic matter as well as plant and animal biomass, supporting or subsidising coastal and benthic food webs (Heck *et al.*, 2008). Like mangroves, seagrasses are also an important nursery and foraging habitat for several taxa including invertebrates, fish, birds, and mammals during one or more of their life stages (Williams & Heck, 2001). Many of these species, like dugongs, manatees and several species of sea turtles, are highly threatened by lack of habitat, overfishing or reduced water quality (Hughes *et al.*, 2009). In addition, seagrass extent also affects the diversity and biomass of several species of coral reef fish (Nagelkerken *et al.*, 2002; Dorenbosch *et al.*, 2005; Verweij *et al.*, 2008; Hughes *et al.*, 2009).

Coral reefs: Ecosystem function and connectivity

Coral reefs provide essential services and ecological linkages through seagrasses and mangroves back to terrestrial habitats. Coral reefs exist in a tight ecological relationship with seagrasses and mangroves, serving as the adult or foraging habitat for countless reef fish and invertebrates. Larvae from these populations are often exported back to seagrasses or mangroves for some stage of their lifetime and may migrate between all three habitats. These fisheries are both biologically and economically important. Sustainable coral reef fisheries generate US$2.4 billion per year in revenue for Southeast Asia alone (Burke *et al.*, 2002). In addition, coral reefs provide the first physical structure for shoreline protection and erosion, slowing the impact of wave action from storms. By reducing storm impacts, coral reefs may not only protect seagrass and mangroves, but also human populations and infrastructure on the coast (Kunkel *et al.*, 2006; Barbier *et al.*, 2008).

Case Study 1: Ecosystem services reduction as a consequence of coastal development:

The *Cienaga Grande de Santa Marta* (CGSM), a UNESCO Biosphere reserve and a Ramsar site in the Columbian Caribbean, has an area of 4,280km^2 and comprises a complex coastal lagoon and surrounding ecosystems, including fresh and marine waters, mangrove forests, savannahs, transition forests, grasslands, dunes and beaches, and anthropogenic agricultural landscape (Figure 3). The CGSM was previously almost entirely dominated by mangrove forests (Restrepo *et al.*, 2006), with at least 511km^2 of mangrove forest in the 1950s. Since this period, 300km^2 have been lost as a consequence of human intervention. These include: interruption of sea-land circulation by the construction of a road linking two of the most important cities in the Colombian Caribbean coast; decrease of fresh water input following an increase in river-borne sediment; deterioration of water catchments including the Magdalena river; direct domestic and sewage discharges into the system; contamination from agro-industrial discharges from banana plantations nearby and from the extensive Magdalena catchment; direct mangrove harvest; and unplanned settlement within mangrove areas. Consequences of ecosystem deterioration in CGSM have been evident for some years among local and surrounding communities.



Sources: Troncoso and Viloria, 2008; Federacion Colombiana de Municipios, 2009; personal communication with Carmen Lacambra at WCMC; Ramirez, 2008; Vilardy, 2008.

Figure 3 – ***Map showing the air and water circulation at Cienaga Grande de Santa Marta, Colombian Caribbean.*** *The lagoon, a Ramsar site and a UNESCO Biosphere reserve, supports several ecosystems and is home for more than 516 species, providing direct services to more than 350,000 people including more than 5,000 artisanal fishers. The ecological equilibrium which depends upon the circulation of water and sediments between land, sea and the several channels which drain the system has been severely interrupted.*

Vilardy (2008) has identified over 40 potential ecosystem services that the Cienaga Grande de Santa Marta could be providing to neighbouring communities and the broader Caribbean basin.

Ecosystem services directly associated with the CGSM (Ramirez, 2008):

- Influence climate and precipitation regimes
- Carbon sink
- Coastal protection
- Buffer zone
- Purification/filtration of pollutants
- Water and food provision
- Materials/products provision (salt, timber, building material)
- Recreation
- Habitat and refuge for permanent and migrant species
- Scientific value
- Pest control
- Nutrients and sediments discharge and exchange
- Habitat for 516 species of animal, including 35 migrant birds

Consequences of CGSM ecosystem deterioration (Ramirez, 2008):

- Lagoon eutrophication
- Hyper-salinisation of soils leading to soils not suitable for ecosystem restoration or subsistence agriculture
- 70% of the original mangrove forest eliminated
- Decrease of fisheries and massive fish mortality events
- Human health deterioration
- Increased poverty in the neighbouring communities
- Unplanned urban growth in towns near and within the system

Since the late 1990s the Colombian government and several environmental agencies have instigated programmes aiming towards the recovery of the CGSM, re-establishing the natural circulation of water and nutrients and restoring the CGSM ecosystem services. Mangrove forest restoration has progressed slowly but fisheries catch seemingly improved between 2001 and 2006 (Viloria & Troncoso, 2008).

Case Study 2: Ecosystem services reduction as a consequence of offshore activities

The following non-tropical case study illustrates connectivity between deep sea and shoreline ecosystems.

Sea otters and killer whales have long shared habitat around the west-central Aleutian archipelago. Recently, killer whales have begun to feed on sea otters, possibly as a result of a reduction in more usual food sources such as Steller's sea lion and harbour seal, populations of both having collapsed across the northwest Pacific, probably because of reduced availability of their prey fish (Estes *et al.*, 1998).

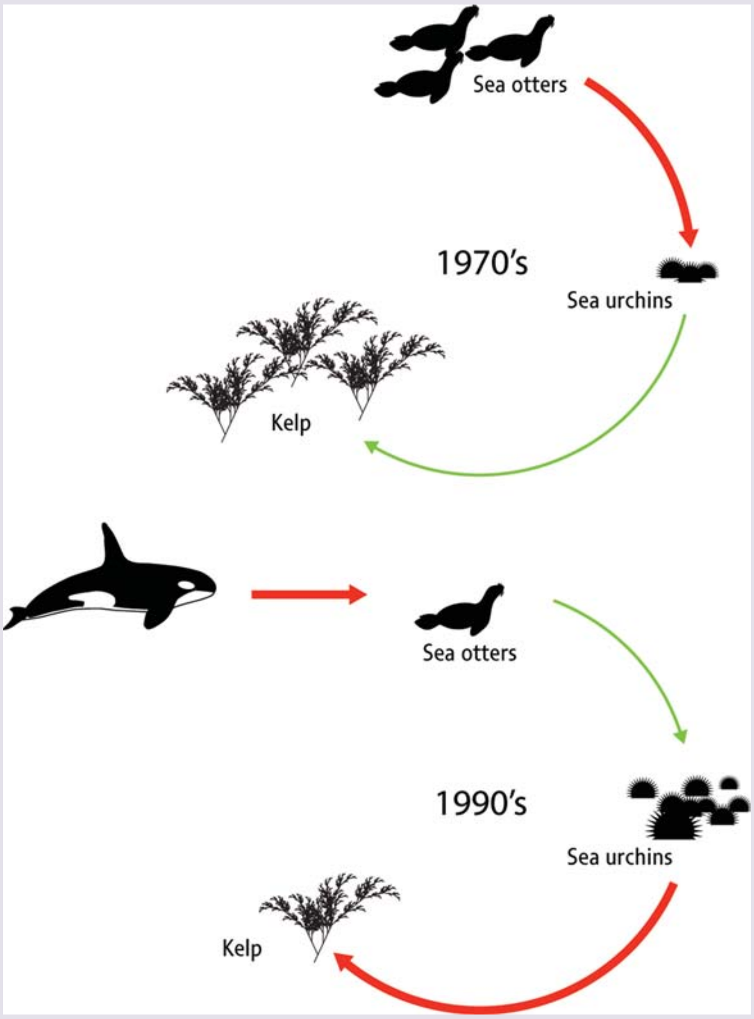


Figure 4 – ***Changes in sea otter abundance over time at several islands in the Aleutian archipelago and concurrent changes in sea urchin biomass, grazing intensity and kelp density measured from kelp forests at Adak Island.*** *Red arrows represent a strong trophic interaction, green arrows represent weak trophic interaction (Source: Estes* et al.*, 1998).*

Killer whale predation appears to have reduced sea otter populations and led to an increase in sea urchins, formerly regulated to some extent by otter predation. Sea urchins graze on kelp, but the increase in urchin populations has been accompanied by a twelvefold decrease in kelp biomass (Estes *et al.*, 1998).

Among the several ecosystem services provided by kelp forests are wave attenuation and coastal protection, hence kelp forest reduction may contribute to coastal erosion in the area (Norberg, 1999).

Here, the change in predatory pattern of the killer whale could be identified as a natural driver which has led to a change in ecosystem functioning. However, there are a range of indirect drivers which could be influencing the changes in this ecosystem, including the anthropogenic reduction of fish stocks or changes in ocean temperature.

> *Our choices at all levels – individual, community, corporate and government – affect nature. And they affect us.*
>
> – David Suzuki, Suzuki Foundation

Drivers of change

Drivers are those processes, natural or human-induced, that can alter ecosystem function and thus alter the delivery of ecosystem services. Human population growth, for example, exerts pressure on natural systems and leads to their conversion to urban, industrial or agricultural areas.

Coastal systems are naturally very dynamic, with unique diurnal and periodical changes (i.e. tides, or fresh water discharge), as well as infrequent extreme events such as hurricanes or tsunamis which can naturally drive significant change in coastal landscapes and ecosystems in a very short time.

Drivers can be largely integral to the system, such as presence of an alien species that can damage local ecological relationships, or entirely exogenous, such as climate change, and not amenable to manipulation by local factors. It is essential to understand how these exogenous drivers act on key ecological processes within the system, and so affect the flow of ecosystem services. Typically, multiple drivers act in complex synergy to produce ecosystem change, and most drivers arise ultimately from human activities. The impact on ecosystem services will vary with the magnitude, periodicity and continuity of the driver. Habitat destruction, change in land use and anthropogenic alteration of the physical, biological and chemical setting are among the most commonly reported agents affecting ecosystem services in coastal areas.

The direct consequences of some drivers and their relation to the provision/reduction of ecosystem services are listed in Table 1. The multiple arrows display the level of connectivity between the different drivers and how the provision of ecosystem services depends not only on the physical settings and enabling conditions but also on the alterations from human activities and natural disturbances.

Economic activity

Agriculture
Shipping
Unsustainable resources extraction
Aquaculture
Fishing
Tourism

Coastal development

Population growth
Coastal engineering
Political and economic incentives
Dredging
Substitution of natural ecosystems

Climate change

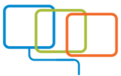
Sea level rise
Change in magnitude and frequency of natural disturbances

Alteration of natural processes

Changes in hydrological patterns
Temperature
Acidification
Terrestrial flooding
Marine originated disturbances

		Nutrient enrichment	Habitat destruction or deforestation	Pollution	Species replacement and endemic species at risk	Alteration of communities	Pressure on the resources	Elimination of connectivity	Land use change	Need for coastal defences	Change on physical settings	Ecosystem resilience reduced
Provisioning services	Food	🟤	🟤	🟤	🟤	🟤	🟤	🟤	🟤	🟤	🟤	
	Timber		🟢		🟢		🟢			🟢	🟢	
	Genetic resources	🟡🔴	🟤		🟤		🟤	🟤	🟤	🟤	🟤	
	Biochemical resources	🟡🔴	🟤		🟤				🟤	🟤	🟤	
Regulating services	Coastal protection	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴
	Water and air quality	🟢	🟢	🟢	🟢	🟢			🟢		🟢	
	Buffer from floods and storms	🟢	🟢🔴		🟢🔴	🟢	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴	🟢🔴
	Pest and disease control	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Cultural services	Recreation	⭕	🟤	🟤	🟤	🟤			🟤	🟤		
	Aesthetic and social value	⭕	🟤	🟤	🟤	🟤		🟤	🟤	🟤		🟤
Supportive services	Soil and substrata formation		🟤		🟤	🟤		🟤	🟤		🟤	
	Photo-synthesis		🟤						🟤			
	Nutrient and water cycling		🟤		🟤	🟤			🟤		🟤	

Drivers of change



Consequences on the natural environment

Provision of ecosystem services by ecosystem

🟡 Seagrasses
🟢 Mangroves
⭕ Coral reefs
🟡🔴 Seagrass and coral reefs
🟢🔴 Mangroves and coral reefs
🟤 **All the three habitats combined**

Source: personal communication with Carmen Lacambra; Workshop "Flow of Ecosystem Services between Linked Habitats: from Hilltops to the Deep Ocean", Cambridge, UK, October 6-8, 2009; Agardi & Alder, 2005.

*Table 1 – **Drivers of change in coastal areas and their consequences on the provision of ecosystem services.** The diagram shows a simplified description of drivers of change in coastal areas and their impacts on provision of ecosystem services by mangroves, coral reefs, and seagrasses. The multiple color lines display the connectivity between the different drivers and their impacts. Different widths represent different intensity of the impact. The circles of different colors indicate the link between impacts, services provided and ecosystems.*

Climate change and marine ecosystem services

Empirical observations and climate models both indicate that global climate and ocean conditions have been changing over the last 100 years and will likely change more rapidly in the future (IPCC, 2007). The oceans and atmosphere are closely related, thus climate change directly affects ocean conditions such as temperature change, acidification, low oxygen zones ('dead zones'), expansion of oxygen minimum zones, changes in ocean current patterns, and reduction in sea-ice coverage (Brewer & Peltzer, 2009). These changes affect the biology and ecology of marine organisms as well as the processes and functioning of marine ecosystems, such as primary and secondary productivity, nutrient cycling and trophic linkages, that are important to the various goods and services provided to humans.

Biological responses to these ocean changes have been observed in marine biomes (e.g. Perry *et al.*, 2005; Dulvy *et al.*, 2008; Hiddink & Hofstede, 2008; Richardson, 2008; Cheung *et al.*, 2009a). For instance, nearly two-thirds of exploited marine fishes in the North Sea shifted in mean latitude or depth, or both, over 25 years as sea temperature increased (Perry *et al.*, 2005; Dulvy *et al.*, 2008). These responses are suggested to result from changes in physiology, distribution ranges and population dynamics as ocean conditions change (Hiddink & Hofstede, 2008; Richardson, 2008; Cheung *et al.*, 2009a). Shifts in species distribution changes patterns of marine biodiversity. Based on a modelling study of the potential global shift in distribution ranges of 1,066 exploited marine fish and shellfishes, Cheung *et al.* (2009a) found that distributions of most species may shift towards the pole at an average rate of around 40km per decade. This projected distribution shift may result in a high rate of species invasion into the high-latitude regions and local extinctions across the tropics and in semi-enclosed seas (Figure 5a and 5b).

Changes in ocean conditions will also result in changes in primary productivity, population dynamics and the marine food chain, thereby reducing ocean fish productivity. Sarmiento *et al.* (2004) developed an empirical model to predict ocean primary production using outputs from global circulation models. They estimated that global primary production may increase by 0.7 – 8.1% by 2050, but with very large regional differences, such as decreases in productivity in the North Pacific, the Southern Ocean and around the Antarctic continent, and increases in the North Atlantic region. It has been observed that annual growth rates for the juveniles of eight long-lived fish species in the southwest Pacific increased in shallow waters and decreased in deep waters where ocean warming and cooling occurred, respectively (Thresher *et al.*, 2007). Using historical fisheries catch, primary production and distribution data of 1,000 exploited fish and shellfish from around the world, Cheung *et al.* (2008) developed an empirical model that showed that maximum fisheries catch potential of a species is strongly dependent on primary production and the distribution range of the species.

Combining the projected changes in distribution ranges (Cheung *et al.*, 2009a) and primary production (Sarmiento *et al.*, 2004) with the empirical model described in Cheung *et al.* (2008), Cheung *et al.* (2009b) projected future distribution of global maximum catch potential by 2055. The results suggest that climate change may cause large-scale redistribution of catch potential, with a considerable reduction in catch potential in the tropics (Figure 6).

Other changes in ocean conditions that may have direct or indirect implications for ecosystem services include:

- change in the phenology (the timing of seasonal cycles) of marine organisms (such as plankton) may lead to important consequences for the way organisms within an ecosystem interact and ultimately for the structure of marine food-webs at all trophic levels. For example, fish stocks may become more vulnerable to overfishing; and seabird populations may decline (EEA, 2008);

- warming of the global ocean may result in the symbiotic algae in corals dying or being expelled, producing coral bleaching. This is predicted to have devastating effects on coral reef-associated fish species;

- with climate change, it is highly likely that the volume of water in the sea may increase to such an extent that many of the world's corals will not be able to adapt quickly enough to the increase in depth, again with potentially serious consequences on coral reef-associated species;

- climate change is modifying the chemistry of the oceans, which can result in undesirable consequences, e.g. the rapid increase in the number of areas in the global ocean without oxygen, which are thus unable to support living creatures. It is suggested that oxygen minimum zones in the open ocean will expand under climate change;

- climate change is acidifying the ocean, which increases dissolved CO_2 and decreases ocean pH, carbonate ion concentration and calcium carbonate mineral saturation (Cooley & Doney, 2009; Secretariat of the Convention on Biological Diversity, 2009).

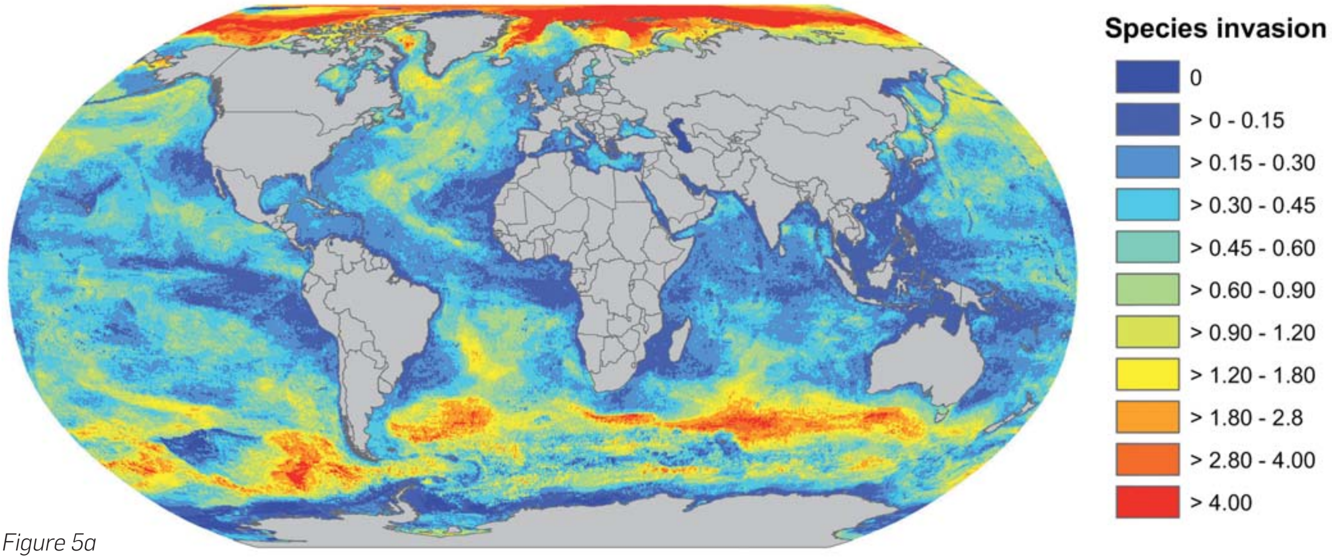


Figure 5a

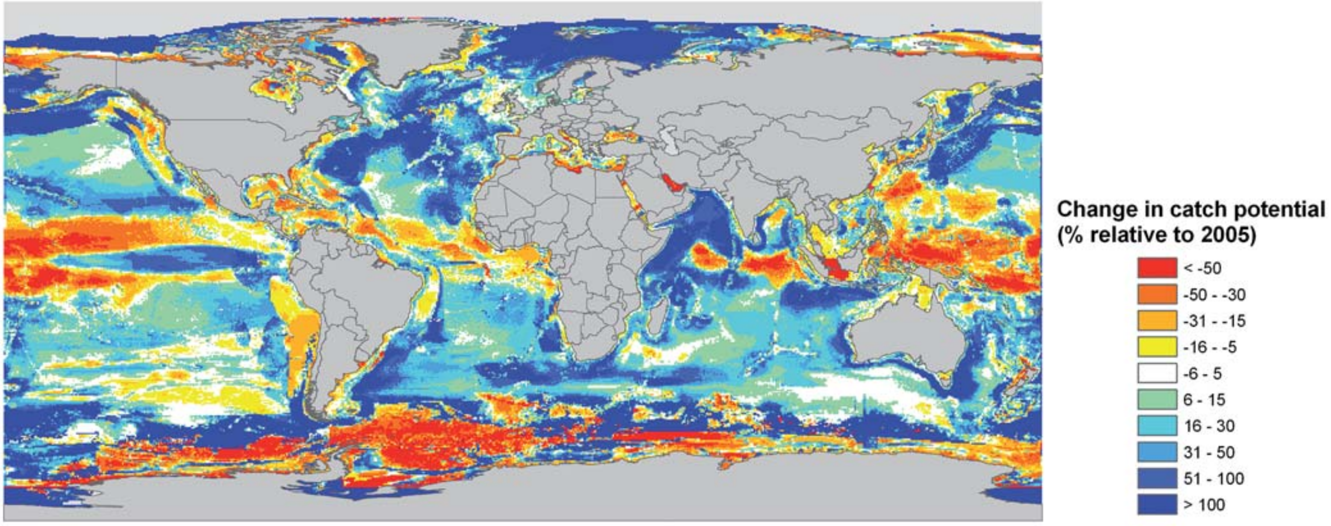


Figure 5b

Figure 5 – ***Projected rate of species invasion (a) and local extinction (b) by year 2050 relative to 2000 under the SRES A1B scenario.*** *Rate of species invasion and location extinction are the number of species occurring in a new cell or disappearing from a cell relative to their original species richness in year 2000 (redrawn from Cheung et al. 2009a).*

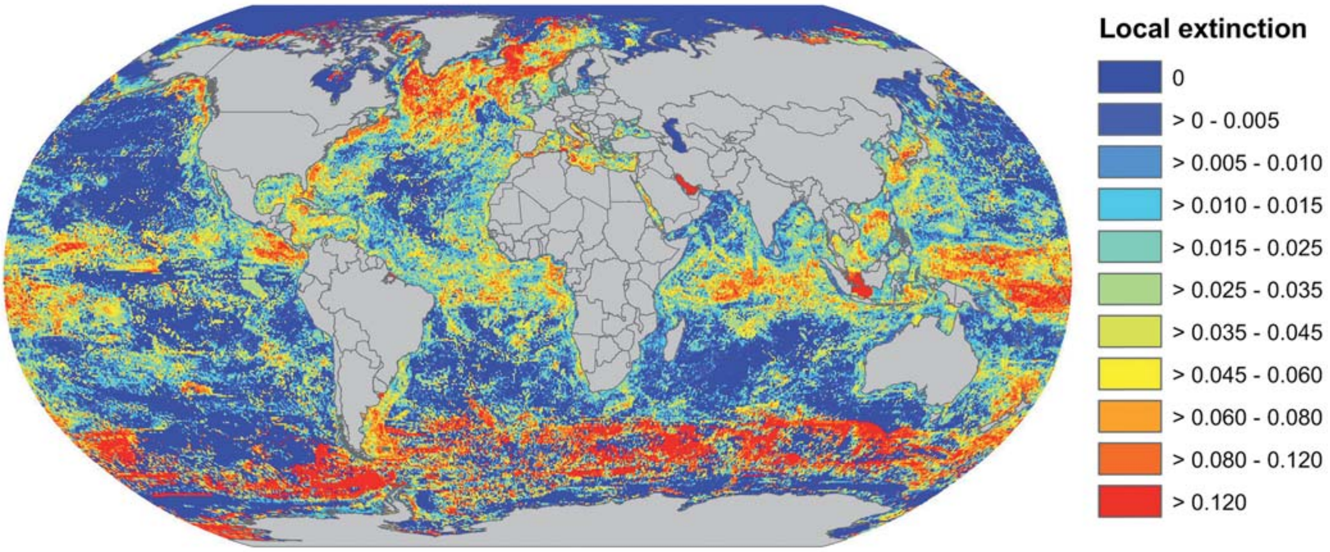


Figure 6 – ***Map of projected change in maximum catch potential under the SRES A1B scenario*** *(redrawn from Cheung et al., 2009b).*

Ecosystem resilience

In order to understand, measure or value ecosystem services it is necessary to consider the resilience of ecosystems to drivers of change and their capacity to provide services despite the pressures acting upon the system.

A highly resilient ecosystem is capable of recovering more rapidly from a disturbance than one that is less resilient. Coastal ecosystems tend to have higher resilience when several different species are performing the same role, especially if each member of a 'functional group' responds differently to disturbance so that one species may be able to take over from another. Species diversity, the biology of the organisms present (e.g. their modes of reproduction and dispersal) and habitat diversity all contribute variously to ecosystem resilience (Elmqvist *et al.*, 2003).

Although ecosystems have always been subject to exogenous disturbance, often acting as a driver of adaptation and speciation, the tipping point beyond which resilience fails is difficult to determine. As drivers of change in coastal areas intensify it becomes increasingly important to understand and assess the components of ecosystem resilience in order to maintain the delivery of ecosystem services.

Managing for sustainable ecosystem services

Improved understanding of ecosystem processes and interactions should permit the flow of ecosystem services to be tracked from source to beneficiary across land and seascapes, and so determine the boundary within which management for sustainability should operate. If the system under management does not include an area large enough to ensure that essential ecosystem processes like the recycling of nutrients, the flow of water and energy, and reproduction and recruitment of juveniles into the system are maintained, the sustainability of the system and its services are at risk. While landscape ecology pioneered the concept of understanding the physical relationships between geographic elements of a system and managing at scale, this was a precursor to the ecosystem approach to management, which recognises the feedback loops between human and ecological systems and the need to optimise these to sustain benefit flows from the system. Traditional sectoral approaches, managing to maintain a benefit stream from one part of the system while ignoring fundamental linkages to other parts of the system, will often be inadequate when the full spectrum of ecosystem services is considered.

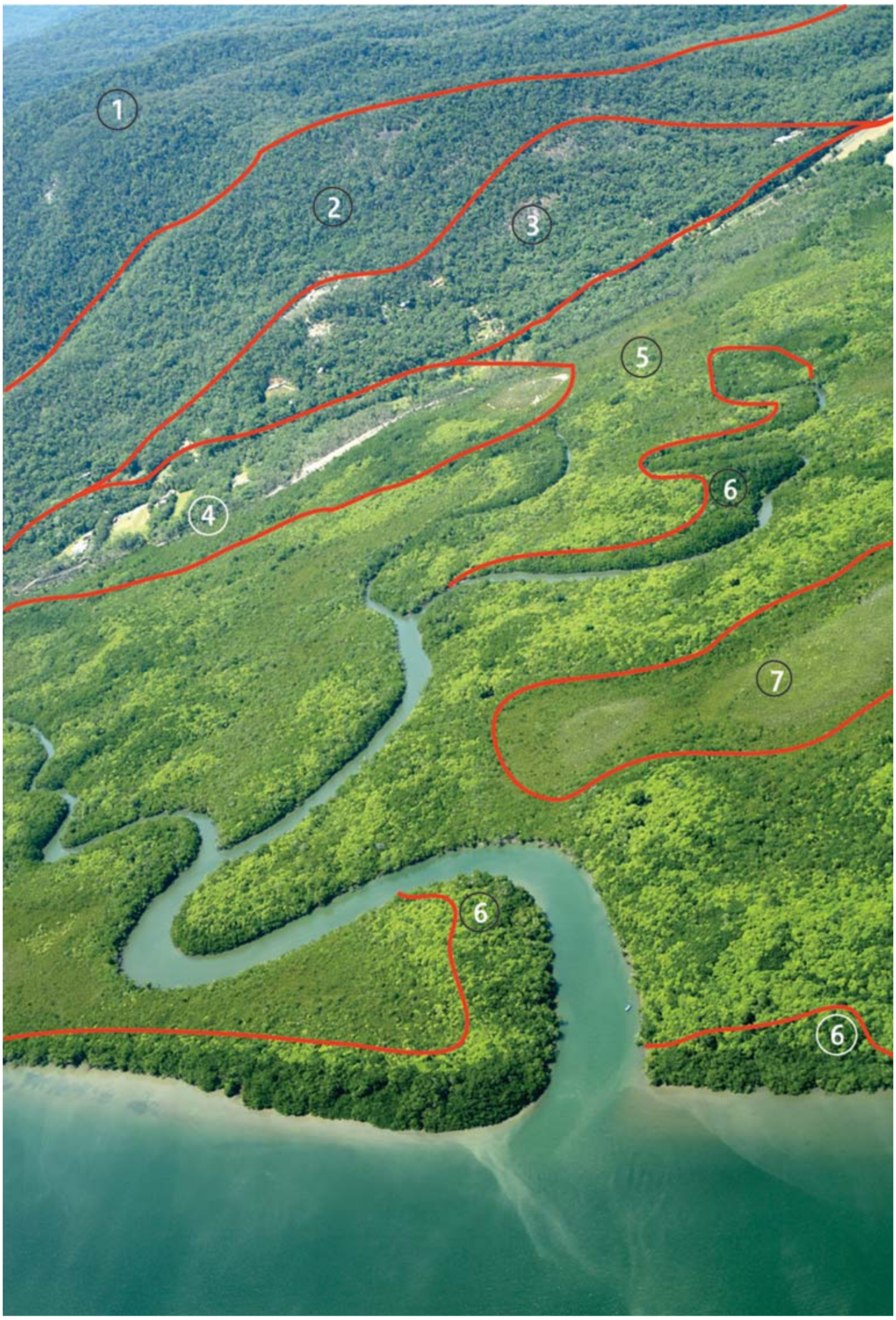
Eco-regional planning is gaining international support as an ecosystem-based approach for integrated planning and conservation of coastal and marine resources at large regional scale. This planning approach aims to identify the conservation value and production potential over large areas characterised by a shared set of ecological and biogeographic features. Understanding the linkages and common processes across the mosaic of habitats within the larger ecoregion allows managers to prioritise measures to safeguard key elements of the system and address threats from human activities strategically. In this way important ecosystem goods and services are preserved, and multiple uses compatible with these values are designed and sustained.

An example of ecoregion is the Mesoamerican Barrier Reef, which spans the length of Belize and includes portions of Mexico to the north and the coastal provinces of Guatemala and Honduras to the south. Ecoregional planning focuses on preserving the very high biological diversity in this marine hot-spot and the ecosystem services it provides.

Ecosystem-based adaptation is a closely related approach. In this paradigm, the ecosystem services produced by healthy, well-integrated, natural communities are viewed as essential to the resilience of human communities attempting to cope with climate change and other forms of global change. Protecting the integrity of ecological processes from local human stressors helps to build the natural resilience of these ecosystems and thereby to sustain their production of services well into the future. Table 2 lists some of the management measures and the adaptation benefits they yield (The World Bank, 2009).

Ecosystem-based Adaptation Creates Benefits for People	
Restoring fragmented or degraded natural areas	Secures biodiversity conservation and enhances critical ecosystem services, such as water flow or fisheries provision
Protecting groundwater recharge zones or restoration of floodplains	Secures water resources so that entire communities can cope with drought
Connecting expanses of protected forests, grasslands, reefs, or other habitats	Enables people and other species to move to better or more viable habitats as the climate changes

*Table 2 – **Table illustrating some of the management measures and the adaptation benefits they yield** (The World Bank, 2009).*



1. Protected primary forest
2. Restored secondary forest
3. Degraded secondary forest
4. Agriculture
5. Wetland
6. Coastal forest buffer
7. Former pasture

Source: personal communication with M.E. Hatziolos

Figure 7 – ***Figure showing an integrated land-and seascape in which the flow of benefits from upstream woodlands to downstream coastal areas is maintained across space and time.*** *The upper watershed is protected to capture rainwater and maintain high levels of biodiversity, which serve as refugia and sources of native plants and animals for other parts of the landscape that may have been degraded. At lower elevations, secondary forest is maintained, allowing for a balance between conservation and sustainable use, the recharging of aquifers and the continuous flow of clean water. Further down the watershed, forests degraded through logging and encroachment of agriculture threaten to interrupt ecosystem flows due to evaporation, siltation and nutrient run-off. These areas require active reforestation to maintain hydrological conditions required downstream. In the coastal plain, wetlands are maintained to buffer floodwaters, capture sediment and nutrients from waters draining into the nearshore environment, and serve as nursery grounds for fisheries. Along the exposed coast, coastal forests/mangroves are restored to prevent coastal erosion, shield backwaters from storm surge and saltwater intrusion, and strip out remaining nutrients. This allows for the flow of clean, clear, oligotrophic waters to support coral reefs offshore. The entire managed land/seascape interface is an active carbon sink, capturing and storing* CO_2 *in biomass and in detritus and sediments, where it is sequestered indefinitely.*

These strategies suggest a new landscape paradigm which actively manages key elements of the ecosystem, balancing production with conservation, and harvesting with restoration. Figure 7 depicts an integrated land- and seascape in which the flow of benefits from upstream woodlands to downstream coastal areas is maintained across space and time.

Best management of tropical coastal seascapes must address the connectivity of the constituent ecosystems, including the adjacent terrestrial ecosystems, demanding coordination between institutions and integrated catchment-coastal management, allowing for the protection of local ecosystem process as well as monitoring and control of drivers outside the immediate target management system.

Key future research must include a better understanding of how these linkages between ecosystem functions and processes affect the delivery of ecosystem services. In addition, we need to develop better estimates of the trade-off entailed by different kinds of development, such as tourism, housing or agriculture, and the resultant loss of ecosystem services from previously healthy ecosystems. Increasing agricultural production to bring food security to inland populations may reduce food security for coastal populations because of increased sediment and nutrient load and consequent decreased fisheries production. New economic and governance frameworks must be developed, taking account of connectivity across ecosystems to best protect essential services and minimise the potential for conflict.

A sound scientific understanding of the hydrological system – including how it functions and how it is affected by human influence – is important. Unraveling the web of ecological interactions and processes that regulate the ecosystem service within the target system and understanding the nature of linkages (economic, social and ecological) between this and adjacent systems across the land-sea interface is essential to understanding key drivers, putting a value on preserving production functions and sustaining the quality of the ecosystem services of interest.

Possible constraints include failure to account for the effects of externalities such as climate change, which may be outside the scope of local management entirely. Current valuation methods are inadequate to quantify many of the regulating and supporting services, or the production functions which cannot be attributed a market value although they may be fundamental to provision of ecosystem goods and services. Hence they are treated as free goods by society and discounted in tradeoffs in the planning and development of the ecosystem, or heavily degraded through pollution and conversion. Thus wetlands, particularly marshlands and mangroves, were treated as wastelands and converted at rapid rates over the last 100 years for coastal development and aquaculture. The repercussions of this misguided development are now being felt in the loss of vital natural coastal defense services, resulting in severe flooding and saltwater intrusion as sea levels rise and hurricane activity intensifies with climate change.

Chapter Two

Capturing and Quantifying the Flow of Ecosystem Services

‘Quantifiability’ of environmental services

Quantifying environmental services involves quantifying both the processes that provide the material to be consumed, the flow of that material, and the points in space and time at which the flow is consumed or supports humanity in some way and is thus recognised as a service.

In discussions on environmental services one should distinguish between those services that are provided by the environment (environmental services *per se*) and those that are a function of the ecosystem (ecosystem services). In some cases services are provided by environments irrespective of the ecosystem, for example, mountain zones often have high rainfall because of orographic precipitation (i.e. rising, cooling air is able to hold less water vapour) which is independent of the ecosystem on the mountains in question. The same ranges might also provide specific ecosystem services, such as the contribution to water resources made by tropical montane cloud forests (by ‘fog stripping’ – the interception and capture of moisture by foliage). This ecosystem service is a function of the cloud forest ecosystem and is significantly reduced when cloud forest is converted to pasture, whereas simple elevation-related rainfall is unaffected.

Ecosystem processes providing benefits in one zone may have undesirable effects in another. For example, forest planted upstream of drylands will increase water withdrawal by evapotranspiration and potentially reduce downstream water availability in those drylands.

Some services are more readily quantifiable than others. Provisioning services that provide material goods (food, fibre and water) and recreational value (a major part of cultural services) are the best understood and valued, whereas regulating services (maintenance of air, soil, water, and ecosystem stability) are relatively poorly understood and inadequately valued. Non-use cultural values are perhaps the most important and least understood (Spurgeon, 2006). Most progress has been made to date in:

- quantifying the services that lead to agricultural and fisheries production;
- the provision of high quality drinking, irrigation or industrial water;
- the sequestration and storage of carbon and regulating functions such as coastal protection;
- on the valuation side, more progress has been made in the valuation of services like recreation and aesthetic values compared with the regulating services.

Representing flows of environmental services between suppliers and consumers

Quantifying productivity and flows of water and carbon has a long history in hydrological modelling and in modelling terrestrial and oceanic ecosystem productivity. Quantifying these *as services* is a more recent trend and requires an understanding of their flow and consumption. Flows of services can occur over space at variable scales, between producing and consuming ecosystems (e.g. environmental flows of water which maintain freshwater habitats) or from nature to humanity and then between human communities (a process often mediated by markets and trading systems).

Quantifying such flows requires combined biophysical and socio-economic analysis and modelling, performed at a variety of spatial scales that incorporate the complexity of production, flow, consumption, and trading relationships in order to record the ultimate beneficiaries of services. These beneficiaries may be on different continents to the sites where the services were produced, as, for example, in the case of agricultural commodities and hydro-power generation. Quantifying environmental services flows also requires an understanding of the value to individuals, markets and societies of the services provided and the cost of not having access to them.

Spatial aspects of the supply side of ecosystem services have been relatively well explored. A number of recent studies have used Geographic Information Systems (GIS) analysis to measure the ecological factors contributing to the provision of services (Naidoo & Ricketts, 2006; Beier *et al.*, 2008; Nelson *et al.*, 2009). These studies explore how the provision of ecosystem services varies across the landscape. However, far fewer studies have explicitly identified the demand side, or human beneficiaries (Hein *et al.*, 2006) or mapped these beneficiaries (Beier *et al.*, 2008). Yet the need for such mapping is increasingly recognised (Naidoo *et al.*, 2008). Supply and demand mapping are complex, since ecosystem services provision and use often occur across different spatial and temporal scales (Hein *et al.*, 2006) and some services can be ‘consumed’ without loss and thus still available for further consumption. The ‘spatial mismatch’ or flow problem in ecosystem services – cases where regions of service provision and use differ – is well recognised (Ruhl *et al.*, 2007; Tallis *et al.*, 2008; Tallis & Polasky, 2009). The ecosystem services research community has so far concentrated on static mapping of ecosystem service provision, and failed to quantify the

cross-scale flow of ecosystem services to different groups of human beneficiaries. Existing attempts at spatial flow categorisation (Costanza *et al.*, 2008) break ecosystem services into coarse categories based on how their benefits flow across landscapes to beneficiaries, but in order to adequately to address this spatial flow problem, methods are needed to quantitatively assess spatio-temporal flow of clearly identified services to clearly identified beneficiaries.

There is much research to be done to better connect the largely biophysical process knowledge available with new knowledge on human consumption of environmental services and ecosystem services and their flows through markets and societies. Ultimately, the entire economic system is fundamentally based on environmental services and ecosystem services, yet these are typically regarded as external to the production-consumption process. So long as they remain externalities, markets will continue to undervalue environmental services and ecosystem services and use them unsustainably, it is therefore essential to better understand the nature and flow pattern of these services in order to develop policies able to share their benefits more equitably and more sustainably.

Conventional approaches to quantifying the generation and flows of environmental services

(a) Marine services

A variety of approaches have been used to quantify services delivered by marine ecosystems. Valuation exercises using benefits-transfer approaches have applied estimates of ecosystem service values for specific marine habitats to extrapolate the global value of ecosystem services (e.g. Costanza *et al.*, 1997). Although simple, and important for raising awareness of the importance of invariably undervalued, non-market ecosystem services, this approach can be misleading (Plummer, 2009) and is not adequate to address the flow between areas of provisioning and use. More sophisticated 'production function' approaches have been used to ask how changes in natural system functions lead to changes in the flows and value of ecosystem services, but these have largely focused on a subset of habitats (Barbier, 2003; Barbier, *et al.*, 2008) or single services (Batie & Wilson, 1978; Bell, 1989; Soderqvist *et al.*, 2005). The most well-studied service is the provisioning of food from fisheries; food web and ecosystem models have been used to understand how human activities affect complex interactions among species and habitats and how these can in turn influence catch of target species (e.g. Pauly *et al.*, 2000; Christensen & Walters, 2004; Fulton *et al.*, 2004a, b). With the exception of food from commercial fisheries and aquaculture, conventional approaches to quantifying flows of marine services have focused on the modelling and measurement of biophysical processes. While these ecosystem features are essential to mapping flows across landscapes and between habitats, they only account for the supply of the service; without incorporating demand they cannot quantify the service *per se* (Tallis & Polasky, 2009).

(b) Terrestrial water and carbon-based services

Before water quantity, quality and regulation came to be considered as environmental services, hydrologists spoke of water resources and of flood regulation and mitigation. Hydrological assessment based on climate and river-flow monitoring networks, coupled with empirical or physically-based models, were and are used to assess water resources and flood dynamics. A range of models exist for this purpose at scales from global (WATERGAP 2, http://www.usf.uni-kassel.de/watclim/pdf/watergap_model.pdf) to local (SWAT, http://swatmodel.tamu.edu/). Many of these models can, with some modification, be applied to study of the flow of hydrological ecosystem services. A number of projects have used SWAT (e.g. http://www.valuingthearc.org) and the CGIAR Challenge Programme on Water and Food (http://gisweb.ciat.cgiar.org/wcp/pes_workshop_nairobi.htm). The difficulties in applying these existing approaches to service valuation are that:

- (i) they were often not designed for application in the types of environment where ecosystem services are most important (for example, tropical mountains);
- (ii) they are highly data demanding and these data are often not available for less developed countries;
- (iii) they focus on the hydrological processes rather than the role of environments and ecosystems;
- (iv) they often do not incorporate a valuation function so their outputs are in hydrological rather than economic units.

However, a new breed of hydrological models is focused much more on understanding ecosystem services. These include the InVEST hydrology module (http://invest.ecoinformatics.org), FIESTA (http://www.ambiotek.com/fiesta), the AGUAANDES policy support system (http://www.policysupport.org/links/aguaandes) and Co$ting Nature (see below).

Assessments of flow of environmental services associated with carbon have focused on the measurement or simulation of terrestrial carbon balances, including the evaluation of sources and sinks, rather than the valuation of carbon services *per se*. Most carbon models focus on carbon cycle modelling and simulate carbon sequestration and the growth of terrestrial carbon stocks. InVEST 1.0 has a carbon storage and sequestration module which gives the user the option to account for the value of carbon stored or sequestered in the biomass and soils of ecosystems, either via market prices or social values. No other ES-focused dynamic simulation tool currently contains any carbon component, though Co$ting Nature (see below) presents a global valuation of carbon storage and sequestration.

New approaches to quantifying the generation and flows of environmental services

Here we review some of the cutting-edge approaches to quantifying the generation, consumption and flows of environmental services.

(a) InVEST

The Natural Capital Project, a partnership of Stanford University, The Nature Conservancy and World Wildlife Fund, has embarked on a two-year program to develop a suite of spatially explicit, process based models for mapping and valuing services provided by coastal and ocean ecosystems (Ruckelshaus & Guerry, 2009). The marine InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) approach, derived from terrestrial InVEST, addresses many of the limitations of previous methodologies. Models consist of a biophysical step, where supply of the service is quantified, a use step where demand for the service is quantified, and an economic step for valuation in monetary terms. Sufficiently general to be transferable, marine InVEST assesses a suite of ecosystem services and can be used with diverse habitats, policy issues, stakeholders, data limitations, and scales.

Managers and policy makers often lack the tools to integrate across sectors and issues, and to elucidate potential trade-offs among ecosystem services. Models for a variety of marine ecosystem services are currently in development within the marine InVEST tool, including: food from commercial fisheries and aquaculture; protection from coastal erosion and inundation by marine habitats; wave energy generation; and recreation (e.g. whale watching, recreational fishing and scuba diving). By mapping and valuing a suite of services, the marine InVEST approach can elucidate the relationships between services and help to identify management options that minimise trade-offs.

In order to inform decision making effectively, marine InVEST is built to be relevant to the needs and questions confronting managers and policy makers. The models map and value ecosystem services under current and future management, and climate-change scenarios. Marine InVEST is best employed within a stakeholder-engagement process that identifies alternative management scenarios, such as a change in the number of aquaculture farms or wave energy conversion facilities, the siting of marine protected areas, harvest regulations, and

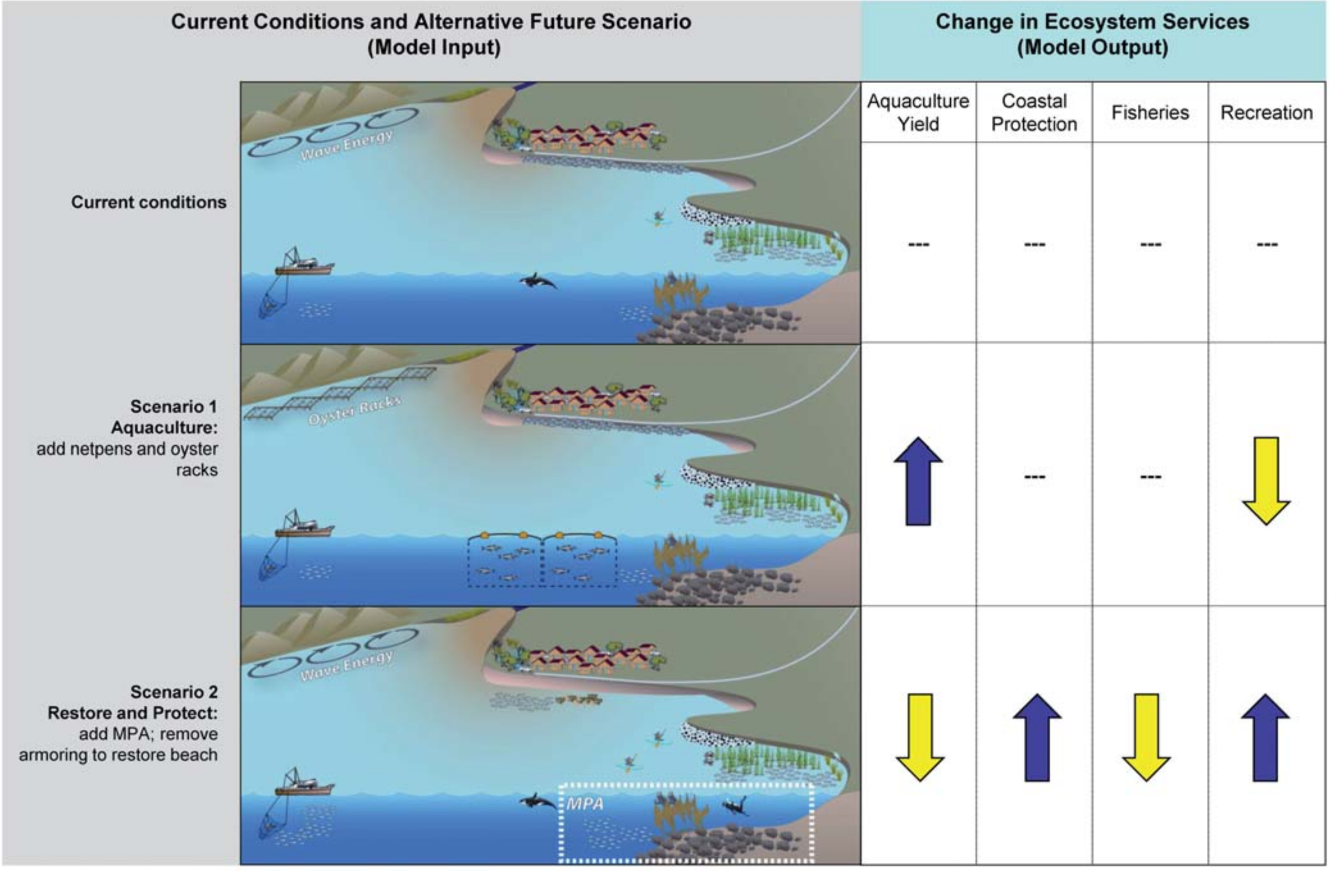


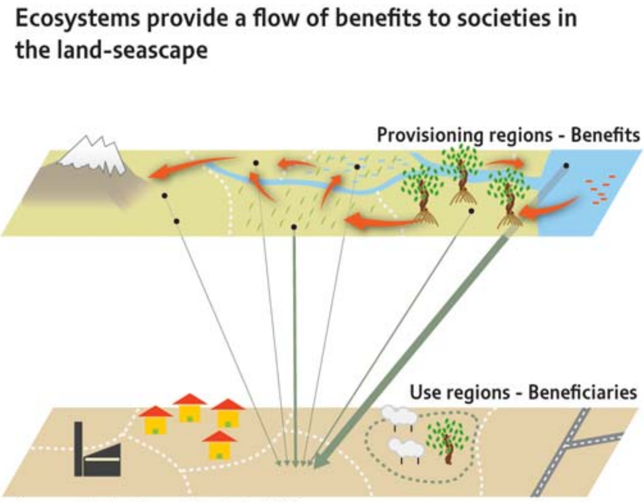
Figure 8 – ***A hypothetical illustration of Marine InVEST model inputs and outputs. Inputs include spatially explicit information about current conditions and potential future uses of the marine and coastal environment.*** *Outputs include modeled changes in a wide range of ecosystem services based on changes in inputs to production functions. Qualitative outputs are shown here for simplicity; quantitative outputs (in biophysical and economic terms) will be output by the models. Question marks indicate uncertainty in directional change. Spiral symbols at the base of dunes represent wave action at feeder bluffs resulting in beach nourishment. The ecosystem service of coastal protection is predicted to increase in Scenario 2 because removal of shoreline armoring in conjunction with natural beach nourishment and restoration of biogenic habitat increases this ecosystem service that was previously provided by an anthropogenic hard structure.*

habitat restoration scenarios (see Figure 8). Marine InVEST models how alternative management scenarios, coupled with climate change, are likely to influence ecosystem structure and function, and then how such changes might affect the flows of marine ecosystem services.

Marine InVEST is based on production functions that define how the biophysical processes characteristic of an ecosystem lead to flows of ecosystem services (i.e. adding demand for and valuation of those processes). Much previous research has been focused on the ability of habitats such as mangroves, wetlands and corals, to attenuate storm surge and wave action. However, this focus on the supply side of coastal protection services does not account for the use of this service. For example, are there people and structures that would be affected by coastal erosion or flooding? The marine InVEST models for coastal protection address this problem by providing biophysical outputs (such as reduction in wave height per area of marsh), ecosystem service outputs (such as reduction in the area of property eroded or inundated per unit area of marsh) and outputs in economic (such as the avoided damage to property or structures per area of marsh) and other valuation terms (such as avoided displacement of people). The models are spatially explicit in order to account for landscape heterogeneity (Tallis & Polasky, 2009), such as variation in the area and density of biogenic habitat, or hydrodynamic conditions that could influence the delivery of the service (Moller, 2006; Koch *et al.*, 2009), and the location, type and intensity of use. Like the terrestrial InVEST tool, all marine InVEST models produce output in the form of maps and data tables (Nelson *et al.*, 2009).

(b) Quantifying ecosystem service flows in ARIES

ARIES (ARtificial Intelligence for Ecosystem Services) is a new web-based tool for ecosystem services assessment, planning and valuation, developed by the University of Vermont, Conservation International, Earth Economics, and UNEP-WCMC (Villa *et al.*, 2009).



Source: Adapted from Villa *et al.*, 2009

Figure 9 – ***Diagram illustrating the approach used by ARIES in order to quantifying ecosystem service flows of matter, energy, or information from a provisioning region to spatially identified recipients.*** *Each modelled provisioning region produces a homogeneous quantity of a benefit supplier. Estimation of the flow to use regions often requires a transport- or agent-based model, so to assess flood regulation as an ecosystem service, a hydrologic model can be used to estimate runoff based on the initial location of runoff or snowmelt. Arrows in the provision regions indicate spatial flows. Connections between provisioning and use regions show the relative dependence on benefits to a beneficiary of different parts of the landscape. In the above example, beneficiaries are most strongly dependent on services provided by inshore marine systems.*

By creating *ad-hoc*, probabilistic models of both provision and use of ecosystem services in a region of interest, and mapping the actual physical flows of those benefits to their beneficiaries, ARIES helps discover, understand and quantify environmental assets, and what factors influence their value according to explicit needs and priorities.

Analysis of multiple ecosystem services can enable system users to overlay services, identifying areas that provide multiple 'stacked' or 'co-benefit' services, to compare tradeoffs between services, and consider the policy options that affect their provision.

The primary objective of the tool is the valuation of the flow of ecosystem services between linked habitats. The outputs of ARIES have numerous practical and novel uses for conservation and economic development planning. Notably, they can show which regions are critical to maintaining the supply and flows of particular benefits for specific beneficiary groups. By prioritising conservation and restoration activities around provision and consumption of particular services, benefit flows may be maintained or increased. Similarly, focusing development or extractive resource use outside these regions can prevent decline of benefit flows. Scenario analysis completed in ARIES can highlight areas that need to be preserved in order to maintain the interconnections between ecosystems, aiming to ensure their full functionality. By identifying parties that benefit from or degrade benefit flows, these maps can also support implementation of Payments for Ecosystem Services (PES) programs (with beneficiaries or polluters paying according to use). Finally, specific maps for an ecosystem or beneficiary group of interest can also be generated. Such maps can show either (a) the parts of the landscape from which a specific beneficiary's benefits are derived, or (b) the beneficiary groups receiving benefits from a specific ecosystem region of interest.

Marine and coastal ecosystems provide many goods and services of value to humans, but the behaviour of these systems is complex and can change rapidly. Linkages and tradeoffs between services require integrated planning and management in order for service levels to be preserved. Ecosystem services for probable consideration in ARIES include flood protection of critical coastal habitat, sedimentation, and the provision of nursery habitats for valuable fish populations.

The ARIES technology (Villa *et al.*, 2009) couples probabilistic models of ecosystem service provision, use, and sink with SPAN models to quantitatively assess ecosystem service flows (Figure 9).

Johnson *et al*. (in review) introduce a novel Service Path Attribution Network (SPAN) algorithm that models the flow of matter, energy or information from a provisioning region to spatially identified recipients, while determining the sink dynamics that occur along the flow path. SPANs are ideal for modelling ecosystem services, because spatial flows for each service can be based on uniquely defined flow characteristics between regions of provision and use. The benefit received may accrue from receipt of a quantity at the beneficiary's location (as in the receipt of ecosystem goods, aesthetic views, or proximity to open space), or from the absorption of a negative quantity en route to the beneficiary (as in the mitigation of flood waters, uptake of nutrients, or deposition of sediment). The ARIES technology (Villa *et al.*, 2009) couples probabilistic models of ecosystem service provision, use and sinks with SPAN models to quantitatively assess ecosystem service flows. In order to use SPANs, it is necessary to quantify the initial location of benefit carriers and the spatial location of their beneficiaries.

(c) Co$ting Nature

Co$ting Nature (costing nature) is a collaboration between King's College London and UNEP-WCMC and comprises the Co$ting Nature global analysis and the Co$ting Nature PSS (Policy Support System).

The global analysis uses a web-based series of interactive maps that, for particular systems (e.g. protected areas, cloud forests, forests in general, or ecoregions), defines their contribution on a site by site basis to the global reservoir of a particular service and its realisable value (based on flows to consumers of that service). The services so far defined are water (quantity and quality) and carbon. This analysis aids visualisation and understanding of both the magnitude and geographical distribution of services at a global level and some estimates of their economic value.

For a chosen site, the Co$ting Nature PSS allows the quantification of service provision but also fosters an understanding of the impact of scenarios for changes in land use, climate and service consumption on service supply and distribution downstream in the flow network. It is designed to help test policies for land use and other interventions by simulating their impact on the distribution of service provision. It has a core of biophysical models and is intended to support those working to understand flows of ecosystem service (without necessarily valuing those flows in economic terms). It has both a scientific and a policy support interface that operates the same models but provide different levels of output detail. Services examined to date include water purification and carbon sequestration.

(i) Water: dilution and purification services – protected areas and natural ecosystems can be assumed to provide higher quality water than agricultural, industrial and urban areas that are subject to human influence (pollution, pesticide, herbicide, and fertiliser application). Thus, mapping the global protected areas system and their relation to rivers can yield an indication of where protected areas provide a service and how many people benefit from it. Moreover, since people will pay for cleaner water (or else have to pay for water treatment to achieve the same), the economic value of this water can be established if the downstream consuming populations are known (Figure 10).

Figure 10 – ***Realisable water value of protected areas (millions of US$/park/yr).*** *Note that realisable water value is the direct value of water for human use – there are intrinsic values of water that are not accounted for here – for example, environmental flows that sustain other ecosystem functions. Australia excluded. See* http://www.policysupport.org/costingnature *for the global analysis.*

(ii) Carbon: storage and sequestration. By taking existing maps of global carbon storage (Gibbs *et al.*, 2007) and combining them with new maps for global carbon sequestration based on 10-year time series of decadal satellite data, we can calculate the carbon storage and carbon sequestration by ecosystem, protected area (Figure 11) or ecoregion, and thereby understand where human emissions are being offset by nature and estimate the economic value of these offsets.

Elements of the Co$ting Nature policy support system focused on water in the Andes are accessible at http://www.policysupport.org/costingnature/pss. The model currently allows the simulation of complex hydrological processes and their outcomes at 1km or 1ha scale using a GIS database and models defining the hydrological provisioning services, their downstream flow networks and their consumption at dams, cities and by agriculture. The intention is to incorporate agricultural production and carbon sequestration services to this system in the near future.

Conclusions: Providing the data to internalise nature's role in the economic system

Modelling environmental service provision across multiple services is in its infancy. All of the tools discussed are at early stages of development and release. At this stage it is important that a number of approaches continue to coexist and practitioners communicate and learn from each other. No one approach is the best approach under all circumstances.

In these early approaches the different services are often modelled concurrently but not well connected in process terms, making it difficult to analyse, for example, the impact of terrestrial services on the marine services, or the trade-offs between carbon and water services of forests. All of the available tools have significant data requirements and, whilst they are generally designed to

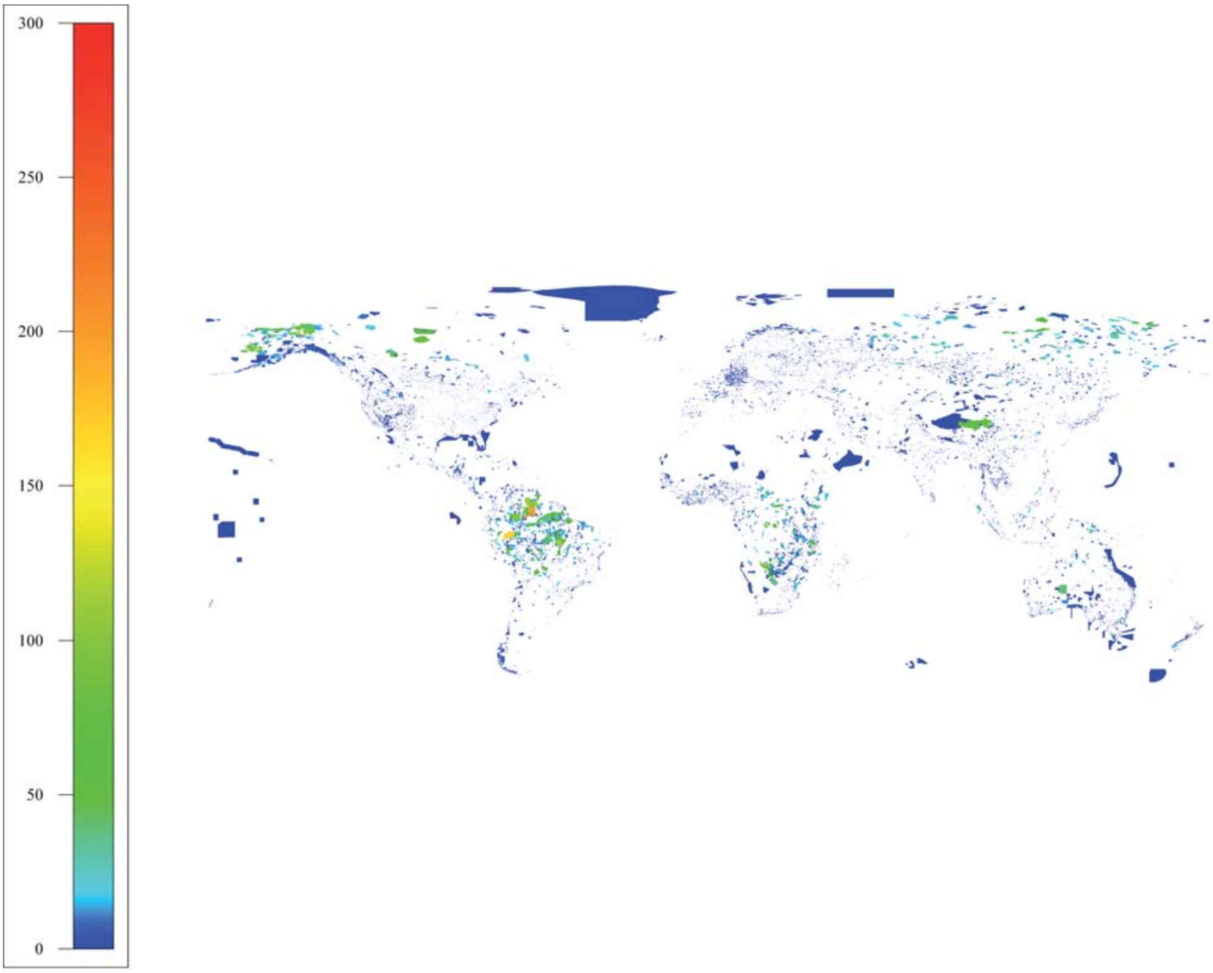


Figure 11 – ***Carbon sequestration of the global protected areas system (millions of tonnes C per yr).*** *Areas of low sequestration are generally ice covered, marine, desert or at high latitudes.*

be parsimonious and make use of readily available data, there can still be significant barriers to their effective use in a particular environment.

As with all modelling efforts, the level of uncertainty associated with outputs is variable and significant, and this can impede effective communication with decision-makers. ARIES is perhaps best developed in this regard since its use of Bayesian techniques allows quantification of some elements of uncertainty. Of course, a model is no more than a hypothesis of how the systems work in reality, and output quality is limited by the quality of input data. The challenge in understanding and managing ecosystem service flows will be to provide a suite of tools that:

(i) communicate with each other rather than compete;

(ii) use the best available data;

(iii) are driven by end users and can be applied with the levels of capacity that exist in the decision making contexts for environmental service assessment;

(iv) act as a common information platform, accessible to all and around which negotiation for more sustainable use of environmental services can be facilitated.

Chapter Three

Valuing Ecosystem Services of Coastal Habitats

What is economic valuation?

Economics is a science of trade-offs. Economic valuation facilitates the translation of ecosystem services into comparable human values and offers a way to compare the diverse benefits and costs associated with ecosystems by attempting to measure them in terms of a common denominator. The ability to compare very unlike things with a common metric is an activity we undertake implicitly every day: shall we go out to dinner or give money to charity? Shall we invest in health care or in foreign wars? Through the use of markets and market-like arrangements, economic valuation facilitates the comparison of valuable stocks and flows of ecosystem services. Economic valuation of ecosystem services, much like benefit-cost analysis, does not lead directly to policy decisions, as it provides only a partial view of the context within which decisions must be made. Frequently, however, economic valuation of ecosystem services provides the only non-zero estimate of the value of biodiversity against which goods and services whose total value is well reflected by the marketplace can be reasonably compared.

Why undertake economic valuation?

Economic valuation of ecosystem services can help us to understand the interconnections among people and ecosystems across space and over time. Economic valuation can raise awareness of the environment, improve resource allocation decisions for scarce and valuable resources, particularly when the market fails to do so, and provide the means to trace the distributional implications of decisions to stakeholders.

More specifically, economic valuation can raise awareness by revealing the willingness to pay of individuals and society for environmental services, estimating human welfare losses due to environmental degradation and the true costs and benefits of environmental protection. Economic valuation can improve land use decisions, inform pricing for natural resource-based experiences, identify avenues for fiscal reform, and facilitate the transfer of financial resources from those who benefit from ecosystem services to those who manage them.

What are the general categories of economic value?

Pagiola *et al.* (2004) summarise the common motivations and approaches to ecosystem service valuation (Figure 12). The main framework used is a Total Economic Value (TEV) approach, based on five different types of economic value organised in two general categories. The two general categories of economic value are use, or active value, and nonuse, or passive value. Use value is further divided into consumptive use and non-consumptive use value, while nonuse value is divided into existence and bequest value. Lastly, option value has been considered a nonuse value, but is now increasingly categorised as a use value.

Use value implies that individuals derive direct benefit from being in the presence or vicinity of the natural resource. Consumptive use value is when the resource is, through its use, consumed or used up such that other people or economic activities do not have an opportunity to enjoy the resource. Non-consumptive use value implies that users do not consume, or use up, the resource in the process of enjoying it. As such, non-consumptive uses of resources do not preempt current or future non-consumptive uses or future consumptive uses of the resource. Indirect use values are derived from ecosystem services that provide benefits outside the ecosystem itself (i.e. the storm-protection function of mangrove forests).

Nonuse value implies that people derive benefit from the natural environment without having direct contact with it; the value is independent of use of the resource, but dependent on its quality and/or quantity. Existence value is manifest when individuals experience benefits from aspects of the natural environment that they do not reasonably expect to experience personally. Bequest value is the value that individuals derive from providing desirable features of the natural environment to future generations. Option value has to do with choosing not to use a resource today, while retaining the option to use it in the future. As a result, it can be considered a nonuse value in the current period with an option for (consumptive or non-consumptive) use value in the future.

What are the common economic valuation methods?

Economists employ a number of techniques to estimate social and individual values for natural resources. These techniques include direct and indirect market-based methods and non-market valuation methods. Direct market price analysis is an appropriate technique to assess the use value of natural resources. It is best used when the good or service in question is commonly traded in the

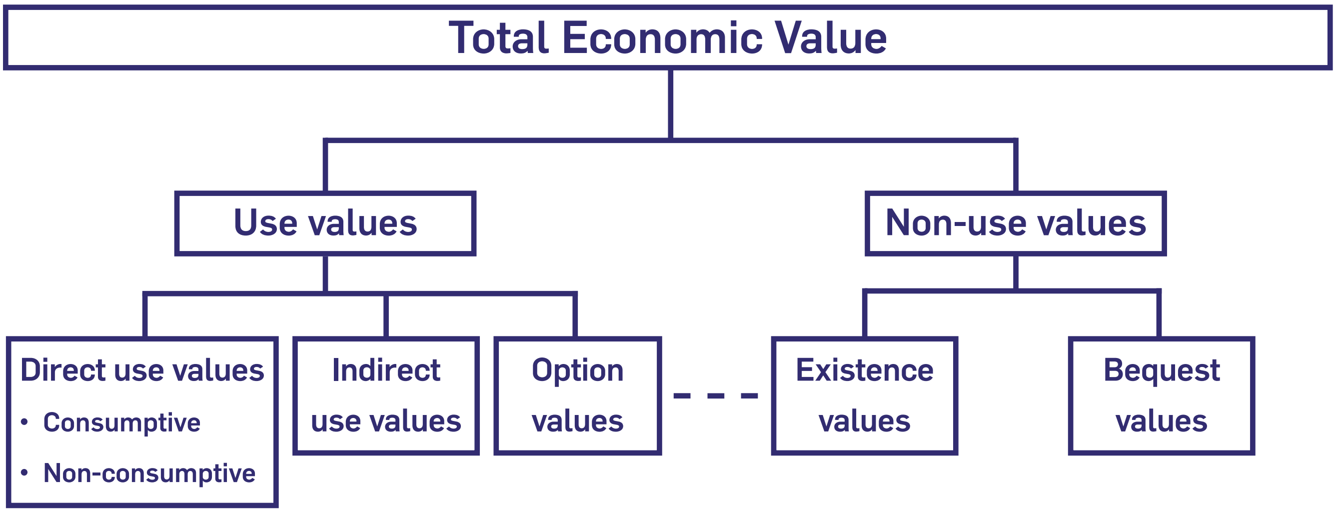


Figure 12 – ***Category of the total economic value (TEV).*** *Source: modified from Beaumont & Tinch, 2003.*

> *Not everything that can be counted counts, and not everything that counts can be counted*
>
> – Albert Einstein

open market and can be considered the total value of the good, and if there are no important external effects in its production or consumption. That is, the price is generated through purchase behavior and price equals value.

Indirect market price analysis also allows the analyst to value use values, but typically the value in question is embedded in the market price of another good or a closely related good traded in the market. It can be that markets are malformed due to the features of the goods and services themselves or due to the institutions evolved for their management.

The two most common indirect market valuation techniques are the travel cost method (TCM) and the hedonic price method (HPM). The TCM is a commonly employed analytical tool to facilitate understanding of the demand for tourism services. The HPM is a commonly employed analytical tool used to understand the housing market, but it has applications to all products with multiple separable and valuable features.

For many issues concerning stewardship of natural environment there are few market signals of any kind to provide guidance as to its relative social value. This is particularly the case with expressions of nonuse value. However, without attempting to derive a usable economic value, it is tempting for policy makers to ignore the social worth of the environment or to assume that it is essentially zero. Nothing could be further from the truth, as most often these non-market valuation techniques are criticised for the uncertainty over the value estimated and for attempting to place a value on the priceless, the infinitely valued. In the market-based methods, people reveal their preferences for environmental goods and services through their purchase decisions. With non-market techniques, such as contingent valuation (CV) and contingent behavior (CB), consumers are enticed, through choices in a survey, to state their preferences via a hypothetical, or contingent, market or 'choice experiment'.

Another methodology employed is benefit transfer that uses results obtained in one context in a different context and is applied when suitable comparison studies are available.

What are the general considerations and challenges when conducting an economic valuation?

Economic valuation works best when:

- the preferences of all those who are affected by the valuation decision are taken under full consideration;
- important changes in ecosystem services across alternatives are fully accounted for;
- those who are asked to express their preferences are able to understand the alternatives and express their preferences;
- policy alternatives are available to align incentives such that those who are affected by changes in the flows of ecosystem services can communicate with those who are charged with their stewardship.

All four of these criteria raise a variety of important challenges, prominent among which is locating accurate and reliable data for nonmarket values on a par with that which the market provides for marketed products.

In many cases, rich or important natural resources are found where poor people live. When markets and market-like mechanisms are used to derive social values, poor people have less ability to reflect their values in absolute terms, having fewer 'votes' in a market-based resource allocation system. This typically contributes to problems with concentrated costs among a few and diffuses benefits among many and inequitable decision-making.

Finally, equating use and nonuse values is more difficult than it might appear. Most studies focus on the direct use values of marketed products, for which data can be obtained more easily. Nonmarket ecosystem services are rarely or unreliably valued, due to poor data on biophysical relationships. Most analyses are site-specific and focus on a single good or service at one point in time, and assume fixed prices. The extent that multiple ecosystem service values derived from a single site should be added together ('stackability') is a matter of significant debate. Non-use values are difficult to define, tricky to estimate and even harder to capture, due to free-riding, lack of accepted transfer mechanisms and variation in people's ability to understand what is being valued. As a result, actually valuing biodiversity (e.g. via species richness or genetic diversity) presents a formidable challenge.

Approaches to valuation: toward a third generation economics based approach

The approach based on Total Economic Value (TEV), previously described, can be regarded as a first generation of economics based approaches. Examples applied to coral reefs are cited by Cesar (2002) and Ahmed *et al.*, (2004), highlighting that the benefits and values from this ecosystem come not only from direct uses, such as tourism and fisheries, but also from indirect uses (Spurgeon, 2006).

In a more integrated 'second generation' approach, the economic valuation attempts to focus on other aspects (Spurgeon, 2006):

- economic impact (to assess the contribution to local, regional and national economies);
- financial aspects (to determine the sustainability of enterprises and organisations);
- socio-economic analysis;
- other indicators (e.g biodiversity).

Approach	*Why do we do it?*	*How do we do it?*
Determining the total value of the current flow of benefits from an ecosystem	To understand the contribution that ecosystems make to society	Identify all mutually compatible services provided; measure the quantity of each service provided; multiply by the value of each service
Determining the net benefits of an intervention that alters ecosystem conditions	To assess whether the intervention is economically worthwhile	Measure how the quantity of each service would change as a result of the intervention, as compared to their quantity without the intervention; multiply by the marginal value of each service
Examining how the costs and benefits of an ecosystem (or an intervention) are distributed	To identify winners and losers, for ethical and practical reasons	Identify relevant stakeholder groups; determine which specific services they use and the value of those services to that group (or changes in values resulting from an intervention)
Identifying potential financing sources for conservation	To help make ecosystem conservation financially self-sustaining	Identify groups that receive large benefit flows, from which funds could be extracted using various mechanisms

Table 3 – ***Approaches to valuation of ecosystem services.*** *Source: Pagiola* et al.*, 2004.*

A 'third-generation' economic based approach has been proposed by Spurgeon (2006) with the intention of:

- incorporating modern business management principles and approaches to enhance ecosystem benefits to society, reduce management costs and help reach conservation objectives. These potentially could include marketing (market segmentation, targeting and positioning), financial and management accounting (business plans, budget/profit and loss), operation management (e.g. performance objectives), organisational behavior (group dynamics), and strategy (e.g. scenario planning);
- gaining a better understanding of what values mean and how to estimate most of them. This can allow to carry out more accurate and complete valuations and help improve decision-making that affects tropical coastal ecosystems;
- involving appropriate use of innovation, technology and collaboration;
- accounting more for spirituality, quality of life and inter-generational equity.

Economic values of services in coastal ecosystems

A substantial positive economic value can be attached to many of the marketed and non-marketed services provided by coastal ecosystems (Agardy *et al.*, 2005). These values are a combination of use and nonuse values. However, there are also other types of ecosystem service values that these coastal ecosystems provide. Many people derive great pleasure in the fact that the colorful coral reefs exist in the sea (existence value); perhaps they would like the ecosystems to stay intact for the enjoyment and benefit of their children (bequest value). All of these values combine to form the final ecosystem service value of an ecosystem.

Coral reefs provide a wide range of services to around more than half a million people (Agardy and Alder, 2005). The benefits from these ecosystem services are significant, estimated to be around US$172 billion annually (Martínez *et al.*, 2007). The values change regionally, according principally to who benefits directly and the type and size of the coral reef system. The estimated annual benefit from coral reefs is about US$129,200/ha. Much of the economic values of coral reefs are generated from nature-based and dive tourism, with the net benefits estimated at nearly US$79,099/ha. Mangroves are estimated to be worth on average US$4,290/ha, while estuaries, lagoons and seagrasses are estimated to provide benefits to an average value of US$73,900/ha (TEEB, 2009).

Coastal systems generate a variety of seafood products such as fish, mussels, crustaceans, sea cucumbers, and seaweeds. Many commercially important marine species, like salmon, shad, grouper, snapper, bluefish, striped bass, and invertebrates (such as shrimp, lobster, crabs, oysters, clams, mussels), use coastal nursery habitats. Capture fisheries in coastal waters alone account for US$34 billion in yields annually (MA, 2005).

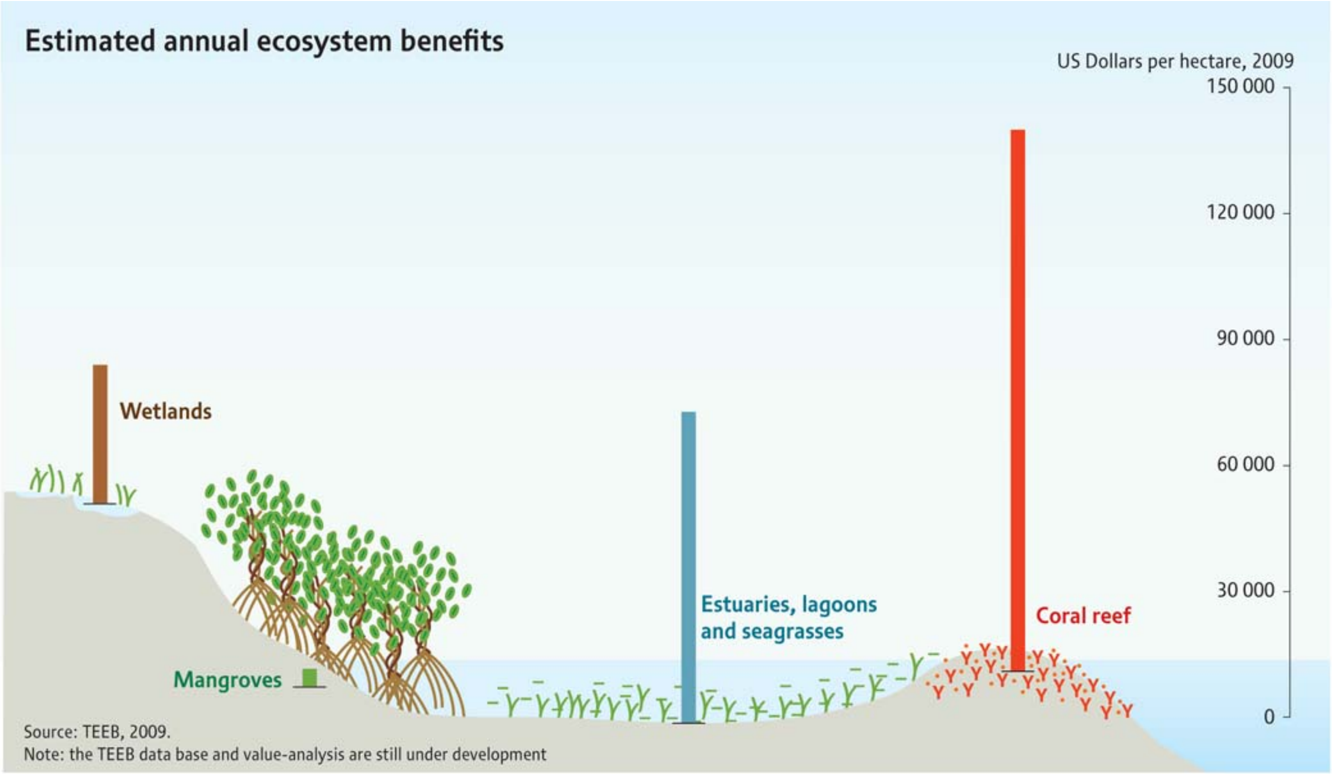


Figure 13 – ***Estimated annual ecosystem benefits for coastal ecosystems.***

Mangroves are permanent or temporary habitats for many aquatic animals, and provide hatching sites and nursery grounds for many marine fishes. The annual market value of seafood from mangroves is estimated at US$750-16,750 per hectare (MA, 2005).

Valuing ecosystem services provision, use and flow

Combining information on the biophysical mechanisms of ecosystem services provision together with the economic implication of the use of ecosystem services could allow better management and governance (MA, 2005).

The quantitative understanding of ecosystem service provision and use has not sufficiently evolved to allow the productive use of spatial mapping, economic valuation and related tools to inform accurate decision and policy making (Boyd & Banzhaf, 2007; Wallace, 2007; Turner & Fisher, 2008).

A comprehensive approach has to take into account the complex, multi-scale dynamics of ecosystem services provision, use and flow in order to inform decisions and allow for scenario analysis in a quantitative and spatially explicit fashion.

The estimation of stability and time required to return to equilibrium after disturbance are in most cases based on linear methods (CIESM, 2008), but ecological-economic systems typically react in a non-linear manner. This is problematic for analysis. In non-linear systems, small perturbations can become magnified and lead to qualitatively unexpected behaviours at macroscopic levels. Monetary analysis may be misleading if we do not know how close a system is to a threshold, or tipping point (TEEB, 2009), but we are still far from having developed a system to anticipate shifts with any precision (Biggs *et al.*, 2009).

There are many site-specific studies of marine ecosystem services, looking at issues of subsistence fishing, shoreline protection, tourism, and recreation. It remains difficult to combine the values of different sectors, and there are issues around adding up the different ecosystem service values ('stackability') at a single site or type of site. However, in order to give policy makers some information so that they can begin to include the values of ecosystem services into their decision making, this strategy of creating aggregated bodies of information from multiple sites is being attempted by a range of researchers, across a range of ecosystem types.

The MA classification of ecosystem services communicates the importance of nature in satisfying different domains of human well-being, but, as has recently been highlighted, this classification does not lend itself well to economic decision-making (Boyd & Banzhaf, 2007; Wallace, 2007). The main issue is that benefits and human beneficiaries are not explicitly linked. The flow of benefits is the only quantity that relates supply and demand and therefore is a natural candidate for a quantitative statement of value. Ecosystem valuation, environmental accounting (Boyd & Banzhaf, 2007), development choices and supporting payments for ecosystem services programs may be better supported by improving the definition of these benefits and beneficiaries.

Spatial mapping, combined with a definition of benefits and beneficiaries, can be a useful tool to support the valuation process and identify regions more likely to provide higher or lower levels of value (Boyd & Wainger, 2003). The ecosystem services flow information can be used to build a transfer function to translate previously assessed economic values for specific benefits into estimated valuation portfolios when that is required by the users (Villa *et al.*, 2009). This approach has been supported by international organisations and agencies in order to overcome the lack of value estimates at target sites, particularly in developing countries, due to time and budget constraints that limit original study (Desvouges *et al.*, 1998; Shrestha and Loomis, 2001).

The primary goal is to provide policy makers with a measured quantitative value, more easily weighed against competing concerns, in order to enable better decision making in natural resource management. Among the multitude of factors to be addressed are: the evidence of the non-linearity in ecosystem services; the large dimension of the ecosystems delivering services; the future use of the resources; the fact that the value varies according to scale; the opportunity to create a hierarchy of options; the principle of equity among beneficiaries; the fact that the values can change quickly; the difficulty of evaluating some ecosystem services (temporal and seasonal factors); the need to adapt analytic and presentational tools to the specific needs of policy makers; and the scope for developing 'with or without' scenarios.

Chapter Four

Application for Industry and Business

Impact and dependence on Ecosystem Service Flow for Industry

Businesses have many reasons for ensuring that sources of ecosystem services are maintained over time. Most importantly, businesses are often major beneficiaries of ecosystem services, in that they depend on natural assets such as water (e.g. bottled water industry or aquaculture), pollinators (e.g. food industry), soil erosion control (e.g. hydroelectric plants), or scenic beauty (e.g. tourism industry). Maintaining access to these resources and guaranteeing their sustainable use enables businesses to operate at a desirable level of productivity, keeping costs of inputs low, avoiding operating in scarcity conditions and reducing risks to the supply chain.

Terrestrial, coastal and marine ecosystems are connected by hydrology, geomorphology and movement of species, nutrients and minerals. They provide an array of interlinked services that are necessary for a wide range of industry operations but may be directly impacted by them. Because such services do not occur in isolation, ecosystem impacts can be far reaching, and lead to tradeoffs among services. The challenge for industry is to determine where their supply chain relies on ecosystem services and where and how their operations may impact ecosystems and the flow of services. Ultimately industry will benefit from taking an integrated approach to the management of ecosystem services by incorporating these services into environmental management systems.

Changes being made to ecosystems are resulting in an increased likelihood of potentially serious and abrupt changes in physical and biological systems, such as disease, decreased fresh water availability, spread of low oxygen ('dead') zones in water bodies, and fishery collapse. Capabilities for predicting such abrupt changes are improving, but for most ecosystems and their services, science cannot yet forecast thresholds beyond which nonlinear changes will be encountered (MA, 2005; TEEB, 2009).

The value of these interconnected ecosystem services is generally not reflected in markets (TEEB, 2009), but their degradation is likely to impact industry through increased risk, higher operational costs (where the supply chain depends on services or where impact must be mitigated), stricter regulations, and lost opportunities.

Although Environmental Impact Assessments (EIAs) are becoming increasingly aware of the potentially negative impacts of land management spreading between ecosystems, not enough importance is attached to the environmental opportunities that can arise from interconnected systems exchanging energy, matter and information in ways that directly benefit human well-being. For example, nutrient-rich sediments that accumulate in rivers play an important role in supporting downstream wetland communities.

Historically, there has been a limited conceptual framework for business to view ecosystem services holistically as they flow across and between ecosystems, from mountain tops to the ocean. Benefits of maintaining the flow of ecosystem services derive not only from reducing risk and securing supply of those services, but also in restoring the flow of services between and among ecosystems.

How the concept of the flow can enhance business competitiveness and strategy

Recognising the dynamic links between terrestrial, coastal and marine ecosystems, and how ecosystem services flow across these systems could help businesses improve their environmental performance, reduce risks and costs, and gain larger public support. Adopting the concept of ecosystem service flow as part of business planning involves acknowledging the spatial and temporal coupling between areas where services are generated and those where they are being used. It also involves understanding the mechanisms through which ecosystem services flow from points of source to points of usage. Sound information on the three components of ecosystem service – flows, source and use – is necessary to inform business decision-making and enable ecosystem health to be maintained.

Businesses might also be interested in maintaining ecosystem services that do not directly impact business operations but are important to local communities and specific beneficiaries. In this case, adopting the concept of ecosystem service flows entails that businesses evaluate the potential impacts of their activities over the entire array of beneficiaries that depend on a given ecosystem service, whether in the immediate vicinity or further along the terrestrial-marine gradient. This practice of managing direct and indirect impacts would have the advantage of reducing conflict with interest groups, increasing community support and extending 'social license' to operate.

In this context, effective risk management requires maintaining critical pathways of ecosystem services across the terrestrial-marine gradient, and understanding how these pathways can change as a response to interventions on the landscape. Acknowledging the spatial flows of ecosystem services across the landscape also provides businesses with the opportunity to identify mitigation options and ways to positively influence existing pathways to reach more beneficiaries, and perhaps marginalised communities.

Ultimately, environmental performance that is based on maintaining the sources of ecosystem services, recognising the existence of multiple beneficiaries and accepting the need to protect critical ecosystem service pathways can result in lower costs of operation, regulatory compliance and conflict.

How the concept of the flow can support environmental performance expectations

Businesses are increasingly being asked by informed consumers to improve their environmental and social performance by reducing emissions, increasing efficiency in resources use and maintaining fair relationships with workers and local communities. Public concern for sustainability is a stronger driver of technological innovation and sustainability agendas than governmental regulation. In many cases, businesses adopt sustainability measures on a voluntary basis, exceeding regulatory environmental performance standards. Within the context of a dynamic and integrated view of ecosystem services along the terrestrial-marine gradient, businesses have the opportunity to demonstrate improved performance by maintaining ecosystem service sources, negotiating with ecosystem services beneficiaries and ensuring that critical flow paths of ecosystem services are not interrupted.

How can ecosystem flows be incorporated by industry-led initiatives

It is important that businesses are able to understand their dependence and impact on ecosystem services in a holistic way, in the context of the broader landscape. To ensure this is covered in a consistent manner, the assessment of ecosystem services should be an integral part of Environmental Impact Assessments. Considerations should not only be for a specific site but also help industry understand how services are interconnected to predict upstream and downstream consequences. This will ultimately support an assessment of dependency, which from the perspective of industry will ensure the sustainability of supply of those services that the industry depends upon.

Adaptive management – an opportunity

Risk is inherent to any decision about extracting resources, building infrastructure, and adhering to a fluctuating market economy in a globalised world. Businesses face uncertainty regarding the amplitude of impacts in space and time. The flow of services from terrestrial, to coastal, and to marine ecosystems can serve as a useful framework for managing risk and uncertainty. Businesses can identify and rate key actions and operations that have higher or lower probability to impact ecosystem service sources, ecosystem service beneficiaries and flow paths. Environmental decisions that are typically affected by high levels of uncertainty are, for example, those related to establishing sustainable harvest levels (e.g. with fisheries) and to containing hazards to human health and to supplies of water and food. In particular, high uncertainty surrounds the existence and identification of ecological thresholds beyond which ecosystems are not able to provide a continuous flow of goods and services.

In conditions of high uncertainty, decision making can be enhanced by adopting an adaptive management approach. Adaptive management involves flexibly adjusting decisions to the changing environmental and social contexts, especially in face of the complex interactions between terrestrial, coastal and marine systems. While businesses have well established directives on how to manage risk through environmental impact assessment protocols, adopting an adaptive management framework could result in a more comprehensive assessment of impacts on the use of ecosystem services from points of origin to areas where beneficiaries are located.

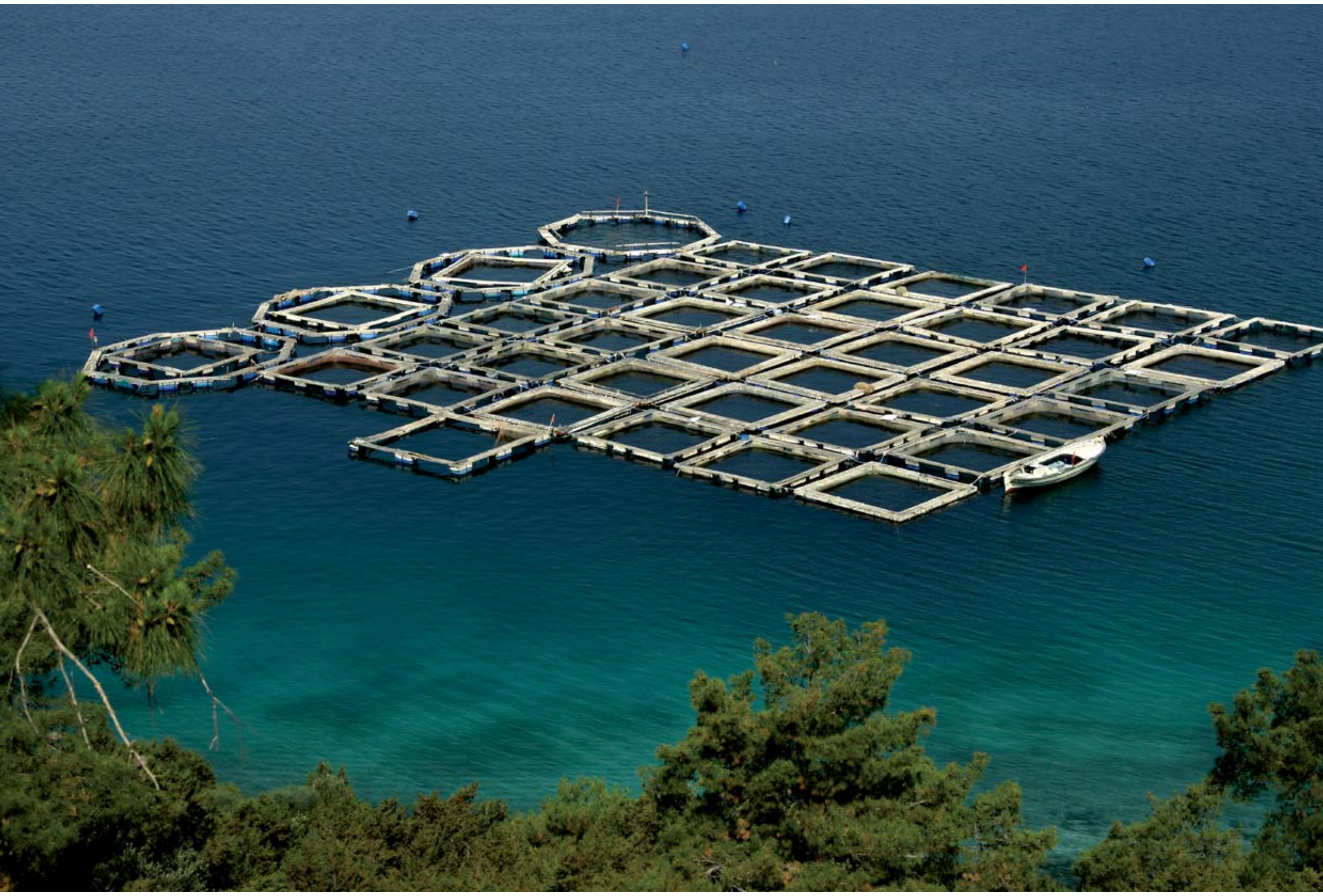
Securing private sector action – SWOT analysis

There are clear advantages to be had for the private sector in incorporating ecosystem flows into business strategies. There are many potential ways in which this concept can be integrated, though there remain a number of challenges to securing private sector action. Figure 14 illustrates a SWOT analysis for integrating ecosystem flow concept into EIAs, risk assessments and any mitigation processes.

There is a series of challenges to be overcome in order for the ecosystem flow concept to be integrated into risk assessment and mitigation processes. Nonetheless, innovation and technology can potentially minimise potential damage to ecosystems and mitigate impacts that may already be occurring, and this creates significant new business opportunities. Growing awareness of the value of ecosystem flows and the interconnections between ecosystems and their services is likely to bring significant competitive advantages for those industries at the forefront.

Strengths	*Weaknesses*
• Use of ecosystem services tools • Development of policies and frameworks to incorporate flow issues in the company's activities • Improved risk assessment • Improved community relations	• Lack of reliable and accessible data on the distribution of ecosystem services • Limited understanding of how impacts propagate across interconnected systems and of how to assess environmental costs over multiple affected ecosystems and dimensions (e.g., environmental, social cultural, etc.)
Opportunities	***Threats***
• Decrease regulatory uncertainty • Develop an Adaptive management that can allow modification of the strategic plan • Integrate Environmental Impact Assessment and Ecosystem Services Assessment • Develop Early Screening Tools • Apply tools to facilitate the transition from policy to performance • Use tools and dataset developed in context of cross-sectoral partnerships	• Uncertainty on prediction of ecosystem changes

Figure 14 – ***A SWOT analysis for integrating ecosystem flow concept into EIAs, risk assessments and any mitigation processes.***



Chapter Five

Implications for Policy Makers and Practitioners

How information on flows can improve marine and coastal management

Understanding ecosystems and their interconnected elements, as well as the linkages between ecosystems, is key to improving environmental management in general, and marine policies in particular. Conversely, ignoring the interconnections between ecosystems and the flow of ecosystem processes and services carries the risk of ecosystems deteriorating despite management effort, with consequent loss in services. Information on flows can allow planners to make the case for truly integrated management approaches, where linking watershed management, coastal zone management, and marine ecosystem-based management, can potentially so much improve management efficiency overall. Such information also allows decision makers opportunities to better evaluate trade-offs and make informed choices, and can enhance leadership potential among a range of people.

Across all scales of governance, information on flows provides impetus for improved, more holistic management. Such knowledge can help spur international agreements (both regional and global) as well as transboundary co-operation (bilateral and others). At national scales, knowledge about flows will enhance nascent Marine Spatial Planning and Comprehensive Ocean Zoning initiatives, as well as sustainable-use programs such as certification, environmental taxation and subsidy policies (for an example, see Box 1 on Great Barrier Reef Marine Park Rezoning).

At more local scales, information on flows can help build capacity for effective coastal and marine management, by generation and sharing of information as well as institutional networking. Information on flows should be made available to agencies in the developing world, which may not have the capacity and resources to derive such information independently.

Better engaging the private sector in conservation and environmental policy is necessary. Information on flows could promote creation of new sources of conservation and management funds through Payments for Ecosystem Services (PES), providing opportunities for private sector investment to complement public sector management. At the same time, the prospect of being able to develop market mechanisms to support conservation and supplement government-based management can be used to stimulate policy reform that enables market development.

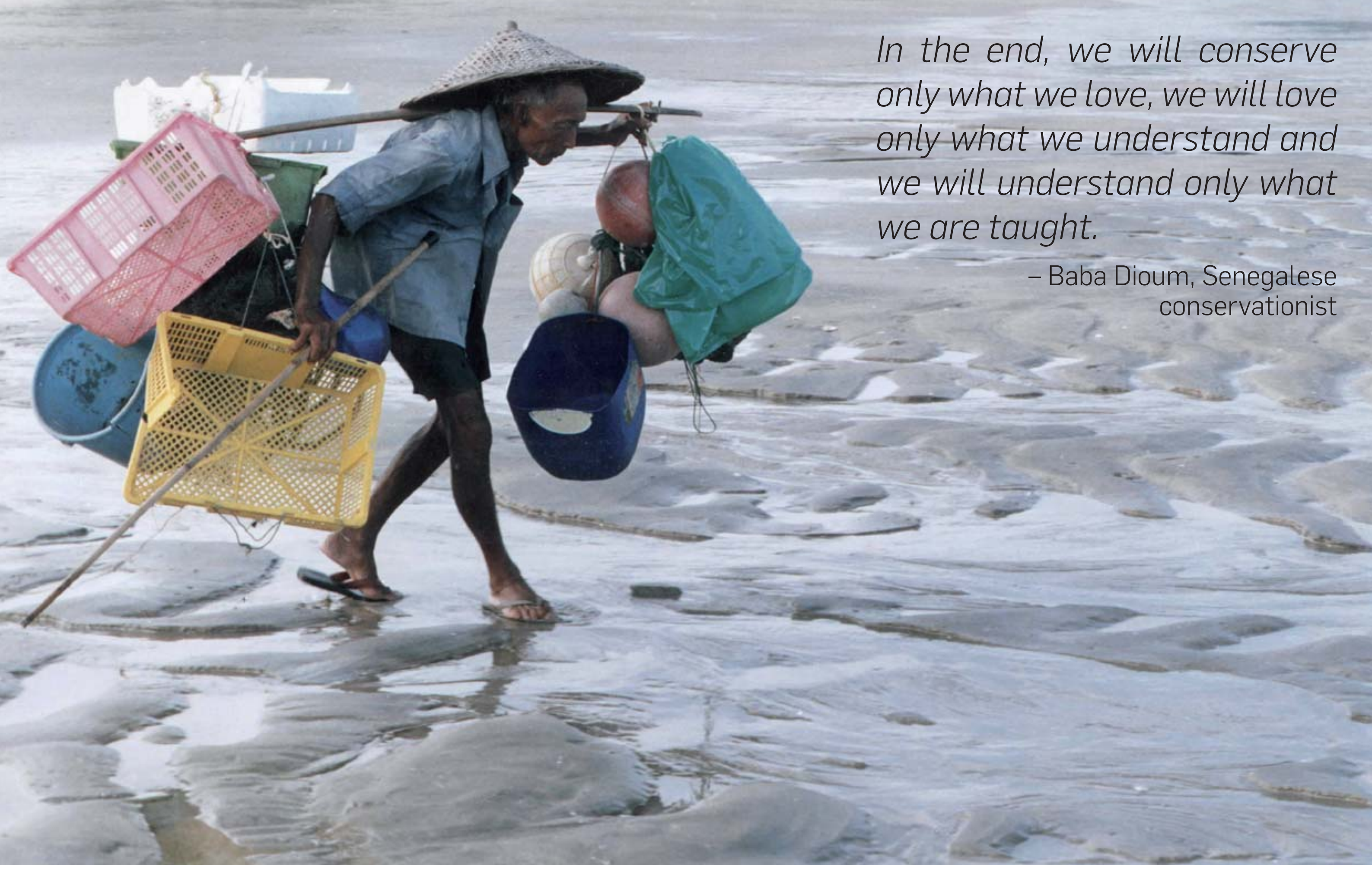
Information on flows can raise general public awareness about the interconnectedness of ecosystems and the intrinsic and immutable relationship between ecosystems and human well-being, highlighting the critical link between ecosystem health and human health. The publication of the Millennium Ecosystem Assessment (MA, 2005) provides an example of how access to appropriate information can significantly raise the profile of ecosystem services and their critical role in sustainable development processes (see below).

Examples of how this awareness can be incorporated into practical policy and legislative measures are beginning to gain ground (see Box 2).

Box 1: Using information on flows to design rezoning of the Great Barrier Reef Marine Park

The Great Barrier Reef Marine Park (GBRMP) is a vast multiple-use area spanning some 350,000km^2 of ocean adjacent to the Queensland coast of Australia. Management of the GBR Marine Park presents the same sorts of challenges that management of any complex suite of marine and coastal habitats provides, including how the management authority can use scientific information not only to regulate activities in the protected area, but also to influence activities in adjacent areas of land and freshwater that also affect the condition of the park's highly valued reef ecosystems.

Between 1999 and 2004, the Great Barrier Reef Marine Park Authority (GBRMPA) undertook a complex planning and consultative program to develop a new zoning plan for the GBR Marine Park. The primary aim of the program was to better protect the range of biodiversity in the Great Barrier Reef, by increasing the 'no-take' area and including representative examples of all different habitat types. A further aim was to minimise the impacts on the existing users of the marine park. A comprehensive program of rezoning, strongly based on the best available biological, physical, social, economic, and cultural sciences was achieved in 2004, after extensive public consultation. Information on connectivity between different portions of the vast reef system, such as source areas for larval recruits and eventual settlement (sink) areas, as well as connections between freshwater, estuarine and the marine areas of the reef complex helped guide decision-making. The final rezoning plan meets the aims of ensuring protection of all bioregions in no-take zones while minimising the impact on reef users.



In the end, we will conserve only what we love, we will love only what we understand and we will understand only what we are taught.

– Baba Dioum, Senegalese conservationist

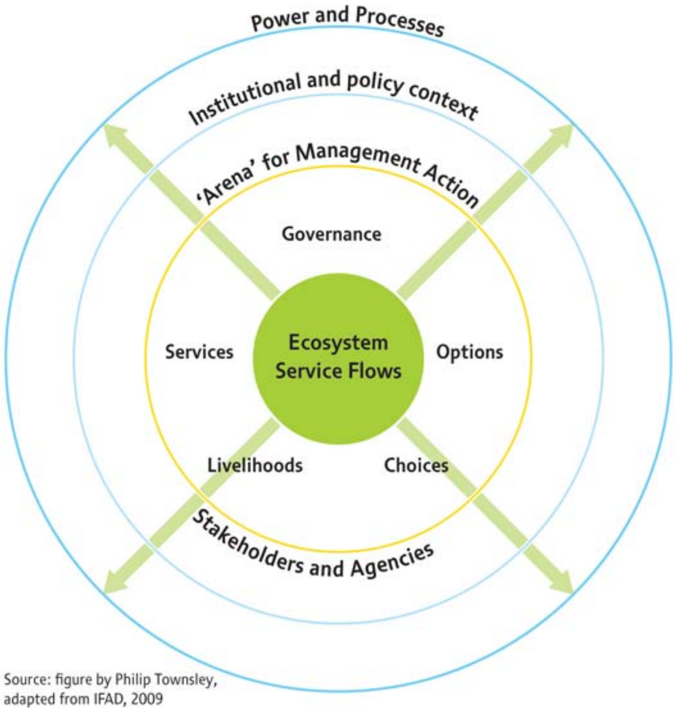
Box 2: Recognising ecosystem service flows in policy

An increasing number of initiatives world-wide are highlighting the importance of the linkages between ecosystems and promoting their incorporation into policy on the management of the environment.

UNEP's Hilltops 2 Oceans (H_2O) Partnership was launched at the WSSD in 2002 to highlight how water flows and river systems constitute highways of "…both life and death, prosperity and poverty…", providing essential water supplies but also transporting pollution, sediments and pathogens over large distances from the hilltops to the oceans.

The US-supported Whitewater to Bluewater Initiative, also launched at the WSSD, has also been working to strengthen national and regional institutional capacity to implement cross-sectoral management of watersheds and marine ecosystems. Particular emphasis has been given to promoting better governance arrangements and cooperation mechanisms and engaging with the private sector to improve water, land and coastal management through the application of a 'Ridge-to-Reef' approach.

At the national level, South Africa's Water Law of 1998 provides an example of the incorporation of similar approaches into national policy. The law explicitly recognises the linkages between upstream water use and the health of downstream ecosystems such as estuaries and promotes efforts to improve agricultural practices in catchments and ensure minimum flow requirements for healthy freshwater and estuarine systems. In the UK, the 2009 Marine and Coastal Access Act is a new marine planning system designed to bring together the conservation, social and economic needs of England's coastal and marine areas. Similarly the European Union (EU) has worked for the last 3 years to develop a common approach ('roadmap') to maritime spatial planning (not a direct competence of the EU but of the 27 Member States). The roadmap (http://ec/europa/eu/maritimeaffairs/spatial_planning_en.html) is based on 10 principles to guide Member States development of their own maritime spatial plans and, in particular, a shared approach to be applied in the Exclusive Economic Zones. A common EU maritime spatial planning approach would be key to successful implementation of the new EU marine environmental law. The 2008 Marine Strategy Framework Directive (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0056:EN:NOT) facilitates maintaining or improving the integrity of marine ecosystem functions and services by asking Member States to develop marine strategies to achieve 'good environmental status' of European marine waters by 2020. In this way, the Marine Strategy Framework Directive constitutes the vital environmental component of the 2007 EU's Integrated Maritime Policy, designed to achieve the full economic potential of oceans and seas in harmony with the marine environment.



Source: figure by Philip Townsley, adapted from IFAD, 2009

Figure 15 – ***Diagram illustrating how ecosystem service flows are nested in a series of layers of interaction, from the stakeholders and agencies directly concerned, to the area of power and processes through the institutional and policy context.*** *The arrows emphasise the need to understand how those services are transformed by different stakeholders into livelihood outcomes, services, income, etc., what are the various agencies, service providers and governance arrangements that play a role in managing or affecting those ecosystem services, the institutional and policy context in which they operate, and the power relations that influence this context.*

Challenges for policy processes in dealing with ecosystem service flows

Even within single ecosystems, the policy processes involved in dealing with complex interactions that do not necessarily correspond to institutional, administrative and sectoral boundaries are challenging. Dealing with flows of ecosystem services is even more demanding. Institutions and policy makers, who are often used to addressing single sectors or spheres of concern, will have to deal with an even more complex set of interactions between different geographical areas, administrative and political groups, and possibly even cultures and nations. This will mean developing new and more holistic, cross-sectoral approaches to policy formulation.

Linking policy decisions to policy outcomes – what happens on the ground

Often the ways in which statements of policy will be translated into action on the ground are not clearly defined. This leaves too much room for the familiar situation where the 'right' policies are in place but no impacts are perceived because of failures in implementation. Of course, this does not apply solely to policies dealing with the management of ecosystem flows, but the more complex the reality being addressed through policy, the more important it becomes for linkages between policy decisions, implementation and impacts to be carefully thought through. This involves understanding all the levels involved in policy development and the different spheres through which policy results can be achieved. The accompanying figure (Figure 15 tries to show this in relation to management of ecosystem service flows.

It must be understood that policy decisions about ecosystem service flows will have impacts not only on ecosystems, but above all on people. They are likely to affect people's access to services (including ecosystem services), the governance context in which they live, the ways in which they create and sustain livelihoods for themselves and their families, and on the options open to them and the choices they can make about the future.

Dealing with complex sets of stakeholders and agencies

The variety of stakeholders involved in policy relating to

ecosystem flows is potentially high. But understanding these arenas for management action, and the roles, interests, relative influence, and responsibilities of the different stakeholders and agencies involved, is critical. This requires a proper appreciation of how to carry out in-depth stakeholder and institutional analysis, moving beyond simply identifying who these stakeholders are, to understanding what their roles might be in the management process.

This needs to be complemented by a more flexible and creative approach to working with these sets of stakeholders and agencies. Those promoting the management of ecosystem flows need to move beyond the ‘multi-stakeholder workshop’ to develop mechanisms for creating sustained engagement in the management process by different sets of interested parties. Particularly in less-developed countries, and where poor and marginalised groups may be affected by new management initiatives, attention is required to developing sustainable means of engaging these groups in decision-making. This means enhancing their capacity to make their voices heard, and ensuring that they have access to information about ecosystem management and the capacity to use that information to make informed choices about how to adapt to new management measures.

Informing and influencing institutions and policy makers

In spite of the complexity of the institutional and policy context, it is important to be systematic in the process of informing and influencing elements within that context. At the policy and institutional level, different individuals and interest groups will be involved, all with specific concerns in relation to the process, as well as different levels of influence on potential outcomes. Understanding these thoroughly will be integral to identifying key leverage points where information and advocacy can be targeted for maximum effect.

Having appropriate information about ecosystem service flows is critical to the informing and influencing process. The primary results of research on ecosystem service

flows is likely to be complex, with multiple sets of variables, and often be bewildering for non-specialists, including policy makers. A key challenge therefore is to ensure effective communication, and there will typically be a need to distill the outputs of analysis into simple, accessible and comprehensible messages that can actually inform policy makers and be used by them in their decision making.

Dealing with trade-offs and resolving conflicts

Almost any form of ecosystem management can generate winners and losers and, consequently, give rise to conflict. Failures in promoting better ecosystem management are consistently linked to failure to predict and address these conflicts rather than to purely technical issues. Providing stakeholders with transparent and convincing mechanisms for analysing the trade-offs involved and in addressing the conflicts which arise is therefore crucial. Policy and decision makers need to have the appropriate tools incorporated in their management approaches (Brown *et al.*, 2001).

Understanding power, process and the 'rules of the game'

Formally recognised policy development is embedded in a context of power and processes which will always strongly condition both the process itself and the policy outcomes that it generates. This context is dynamic, complex and particularly difficult to understand as it is made up of (often unwritten) 'rules of the game' – historical precedent, cultural norms and surrounding social and economic structures. However, those promoting new forms of management ignore these aspects at their peril, as it is often this context that will dictate what actually happens, as opposed to what is supposed to happen (Lobo, 2008).

There is no universal protocol available, but developing appropriate tools for policy makers to address this context of power and processes would greatly enhance chances of uptake of new policy approaches to ecosystem services management. In particular, it could help to determine what is possible and what is not possible and what strategies for promoting new management processes are most appropriate in any given setting.

Ways forward: using information to influence policy

The important challenges that remain in integrating an appreciation of the importance of ecosystem flows into policy processes are clear. The Millennium Ecosystem Assessment (MA, 2005) discussed in Box 3, has illustrated how appropriate information can play a key role in raising the profile of ecosystem services. In particular, it has increased policy makers' understanding of how the key challenge of addressing poverty worldwide is intimately linked with our capacity to better manage, and preserve, ecosystems and the services they provide.

However, there is still an overwhelming lack of integration of knowledge on ecosystem services and poverty. Rarely is information on ecosystem services and poverty generated, analysed, stored or used jointly by relevant institutions in developing countries. Secondly, knowledge is not shared between and within countries, and there are widespread difficulties with lack of access to existing information. As yet, there is little precise guidance available to show exactly how ecosystem services can contribute towards poverty alleviation; this is not, for example, a topic usually addressed in country-specific Poverty Reduction Strategy Papers (PRSPs). There are some, limited, suggestions of how Payment for Ecosystem Services (PES), Protected Areas or Community-Based Natural Resource Management (CBNRM) may provide benefits, but no systematic or comprehensive analysis exists to adequately guide policy.

Providing this sort of guidance remains a key challenge for the future.

Box 3: Information and policy – the case of the Millennium Ecosystem Assessment

The publication of the Millennium Ecosystem Assessment (MA) in 2005 provided a landmark example of how information can be used to raise the profile of ecosystem services and influence policy agendas worldwide. In particular, the MA framework provided a useful starting point for conceptualising holistically the linkages between ecosystems, the services they provide and human well-being. Particularly important was the establishment of direct links between key areas of concern for policy makers, such as poverty alleviation and the maintenance of ecosystem health and service flows. The MA highlighted how findings from around the world suggest that the trends and changes influencing ecosystem services are having profound impacts on the poor, leading to further pressure on resources.

The MA delivered a stark message: our management of the world's ecosystems is already causing significant harm to some people, especially the poor, and unless addressed will substantially diminish the long-term benefits we all obtain from ecosystems. One of the major gaps identified by the MA concerns the lack of integration of concerns about ecosystem services and poverty, and the fact that "very few macro-economic responses to poverty reduction have considered the sound management of ecosystem services as a mechanism to meet the basic needs of the poor. Importantly, it also highlighted how failure to incorporate considerations of ecosystem management in the strategies being pursued to achieve many of the eight Millennium Development Goals will undermine the sustainability of progress that is made toward the goals and targets associated with poverty, hunger, disease, child mortality and access to water" (Chopra *et al.*, 2005).

Since the publication of the MA a number of important scientific studies have emerged which have advanced knowledge in this field and illustrated the complexities involved in incorporating ecosystem service flows into policy and decision making. Recent research has shown how measures to conserve biodiversity will not necessarily correspond to measures to maximise ecosystem services. The relationships between different sets of priorities such as conservation, service provision and optimal use are rarely simple and the importance of seeking trade-offs and synergies is becoming increasingly apparent (Srinivasan *et al.*, 2008; Turner & Fisher, 2008).

As the initial findings of the MA have been built on, research gaps identified by the MA have started to be filled, but at the same time new gaps are opening as the field of science directed towards understanding ecosystem services and human well-being expands. For example, a recent paper highlighted the need to identify appropriate institutions and incentives to guide investments in ecosystem services, noting three key areas that in particular require further work: ecosystem production functions and service mapping; the design of appropriate finance, policy and governance systems; and how these solutions can be implemented in diverse biophysical and social settings (Barbier *et al.*, 2008; Naidoo *et al.*, 2008; Kareiva *et al.*, 2007).

Key Recommendations

This publication presents a framework for conceptualising the connectivity between coastal ecosystems across environmental, economic, social, and management contexts. It presents innovative approaches to better understand, protect and value ecosystem services from linked habitats, and elucidate the trade-offs implied by different management decisions and potential loss of ecosystem services.

Key recommendations of this publication are summarised below.

- In converting ecosystem functions (regulation, habitat, production, and information) to a quantitative value, the following ecological and sociological aspects need to be considered:

  Ecological:

    - Non-linearity and overlap in ecosystem services;
    - The large extent of the entire, linked ecosystem truly responsible for service delivery;
    - The difficulty of evaluating some ecosystem services, because of temporal and seasonal factors, for example.

  Socio-ecomical:

    - Recognition that the value assigned to the natural resources is more an indicator for decision-makers than the 'true' value of the ecosystem;
    - The fact that value changes rapidly and that this may condition different decisions during the time;
    - The opportunity to create a hierarchy of options;
    - The principle of equity among beneficiaries;
    - The provision of desirable features of the natural environment to future generations.

- The use of spatial planning tools and modelling processes should be encouraged to support valuation process and the identification of regions more likely to provide higher or lower levels of value.
- In order to improve environmental performance, reduce risk, and increase public support, it is suggested that the ecosystem flow concept be embedded in business strategies in the following ways:
    - Incorporating knowledge on the spatial flows of ecosystem services across landscapes in order to increase opportunities to identify mitigation options and ways to positively influence existing pathways to reach more beneficiaries or specific groups of marginalised beneficiaries;
    - Evaluating potential business impacts over the entire array of beneficiaries that depend on a given ecosystem, whether in the immediate vicinity or further along the marine-terrestrial gradient;
    - Carrying out effective risk management through the maintenance of critical pathways of ecosystem services and understanding how these pathways can change as a response to interventions on the landscape;
    - Use the concept of ecosystem service flows as a framework for managing risk and uncertainty. Businesses can identify and rate key actions and operations that have higher or lower probability to impact ecosystem service sources, beneficiaries, and flow paths;
    - The use of early screening tools;
    - The adoption of datasets developed in the context of cross-sectoral partnerships;
    - The development of adaptive management strategies in order to be able to flexibly react to the complex interactions between terrestrial, coastal and marine systems, and to potentially result in a more comprehensive assessment of impacts and use of ecosystem services from points of origin to areas where beneficiaries are located;
    - Ecosystem service assessment should be integrated into the Environmental Impact Assessment framework in order consistently to elucidate the industrial dependence and impact on ecosystem services. Attention must be given not only to a specific site but also to potential upstream and downstream consequences,

aiming to generate a comprehensive picture of dependency and so facilitate sustainability.

- Enhancing the understanding of ecosystem elements and linkages between ecosystems among policy-makers and practitioners should be prioritised in order to improve marine environmental management. Information on flows should be used in environmental planning to develop effective and truly integrated management approaches, especially those bridging the divide between watershed management, coastal zone management and marine ecosystem-based management.

- More comprehensive management approaches should be developed through awareness of the linkages between coastal ecosystems and maintenance of ecosystem service flows, increasing the recognition by managers of the need to protect the natural capital that generates these services, together with the underlying ecological connections that regulate benefit flow across systems.

- Explore ways of communicating simple, accessible and comprehensible information on natural resource valuation to policy-makers and managers in order to ensure informed decision-making is taking place in new and transboundary governance structures.

- Tools for resolving conflicts and trade-offs should be embedded into analysis and development of management of linked habitats and ecosystem flows.

Glossary

Adaptation
Adjustment in natural or human systems to a new or changing environment. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Biodiversity
The full range of natural variety and variability within and among living organisms, and the ecological and environmental complexes in which they live. It includes genetic diversity within species, the diversity of species in ecosystems and the diversity of habitats and ecosystems.

Biome
The largest unit of ecological classification that is convenient to recognize below the entire globe. Terrestrial biomes are typically based on dominant vegetation structure (e.g. forest and grassland). Ecosystems within a biome function in a broadly similar way, although they may have very different species composition. For example, all forests share certain properties regarding nutrient cycling, disturbance, and biomass that are different from the properties of grasslands. Marine biomes are typically based on biogeochemical properties.

Carbon capture and storage
A process consisting of the separation of CO2 from industrial and energy-related sources, transport to a storage location and longterm isolation from the atmosphere (IPCC, 2007).

Carbon sequestration
The process of increasing the carbon content of a reservoir other than the atmosphere (Chopra *et al.*, 2005).

Coastal systems
Systems containing terrestrial areas dominated by ocean influences of tides and marine aerosols, plus nearshore marine areas. The inland extent of coastal ecosystems is the line where land-based influences dominate, up to a maximum of 100 kilometres from the coastline or 100m elevation (whichever is closer to the sea), and the outward extent is the 50m-depth contour. See also *System*.

Connectivity
Allowing for the conservation or maintenance of continuous or connected habitats, so as to preserve movements and exchanges associated with the habitat.

Driver
Those processes, either human induced or naturally present, which alter an ecosystem's natural function and therefore may alter the delivery of ecosystem services.

Ecological linkage
A series (both contiguous and non-contiguous) of patches which, by virtue of their proximity to each other, act as stepping stones of habitat which facilitate the maintenance of ecological processes and the movement of organisms within, and across, a landscape (Molloy *et al.*, 2007).

Eco-regional planning
A planning approach which aims to identify the conservation value and production potential over large areas bound by a shared set of ecological and biogeographic characteristics.

Ecosystem
A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (UNEP, 2006).

Ecosystem function
See *Ecosystem process.*

Ecosystem integrity
Supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organisation comparable to that of a natural habitat of the region (Jorgensen & Miller, 2000).

Ecosystem management
An approach to maintaining or restoring the composition, structure, function, and delivery of services of natural and modified ecosystems for the goal of achieving sustainability. It is based on an adaptive, collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic and institutional perspectives applied within a geographic framework, and defined primarily by natural ecological boundaries.

Ecosystem process
An intrinsic ecosystem characteristic whereby an ecosystem maintains its integrity. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem resilience
The ability of an ecosystem to respond and/or recover from a disturbance and return to its equilibrium state, i.e. a resilient ecosystem is one that is likely to recover more rapidly than a less resilient one.

Ecosystem services
The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth. The concept 'ecosystem goods and services' is synonymous with ecosystem services.

Ecosystem services flow
See *Flow of services.*

Ecosystem services pathway
See *Ecological linkages* .

Ecosystem-based adaptation
An approach which focuses on the protection of ecological processes from human stressors with the aim of building or improving the natural resilience of the ecosystem in order to sustain the production of services into the future.

Environmental services
See *Ecosystem services.*

Driver
Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

Driver, direct
A driver that unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy (compare *Driver, indirect*).

Driver, indirect
A driver that operates by altering the level or rate of change of one or more direct drivers (compare *Driver, direct*).

Eutrophication
The increase in additions of nutrients to freshwater or marine systems, which leads to increases in plant growth and often to undesirable changes in ecosystem structure and function.

Flow of services
The movement of ecosystem services between the areas that provide them and those that benefit from these services.

Habitat
The environment on which a given species or ecological community depends for its survival. The environment can be physical (e.g. rocky reefs or marine caves) or created by living organisms (e.g. seagrass meadows or deep coral banks).

Landscape
An area of land that contains a mosaic of ecosystems, including human dominated ecosystems. The term cultural landscape is often used when referring to landscapes containing significant human populations or in which there has been significant human influence on the land.

Marine Spatial Planning
A public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process (UNESCO).

Mitigation
An anthropogenic intervention to reduce negative or unsustainable uses of ecosystems or to enhance sustainable practices (UNEP, 2006).

Ocean Zoning
Ocean zoning is a planning tool that allows a strategic allocation of uses based on a determination of an area's suitability for those uses, and reduction of user conflicts by separating incompatible activities.

Payment for Ecosystem Services
It is a voluntary arrangement in which one or more agents ('providers') of an ecosystem service will receive agreed compensation from one or more beneficiaries ('buyers') of ecosystem services, on the condition of sustaining the provision of the ecosystem services.

Primary Productivity
The amount of production of living organic material through photosynthesis by plants, including algae, measured over a period of time.

Seascape
Large, multiple-use marine areas, defined scientifically and strategically, in which government authorities, private organizations, and other stakeholders cooperate to conserve the diversity and abundance of marine life and to promote human well-being.

Sink
Features or land-scape configurations that have the ability of depleting the benefits as they flow from sources to

beneficiaries. They can be natural elements (e.g. levees and visual blight) or human elements (users themselves).

Sustainable use (of an ecosystem)

Human use of an ecosystem so that it may yield a continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations (UNEP, 2006).

System

In the Millennium Ecosystem Assessment, reporting units that are ecosystem-based but at a level of aggregation far higher than that usually applied to ecosystems. Thus the system includes many component ecosystems, some of which may not strongly interact with each other, that may be spatially separate, or that may be of a different type to the ecosystems that constitute the majority, or matrix, of the system overall. The system includes the social and economic systems that have an impact on and are affected by the ecosystems included within it. Systems thus defined are not mutually exclusive, and are permitted to overlap spatially or conceptually (UNEP, 2006).

Threshold

See *Tipping point.*

Tipping point

The point at which a relatively small change in external conditions causes a rapid change in an ecosystem. When a tipping point has been passed, the ecosystem may no longer be able to return to its state. The trespassing of the tipping point often leads to rapid change of ecosystem health.

Trade-off

Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems.

Transboundary

A function, service or process which crosses ecosystem and/or political boundaries/delineations.

Trophic linkage

A descriptor of the energy transfer relationship between organisms in a related food chain or web.

Acronyms

ARIES	Artificial Intelligence for Ecosystem Services
CB	Contingent behaviour
CBNRM	Community Based Natural Resource Management
CGIAR	Consultative Group on International Agricultural Research
CV	Contingent valuation
EIA	Environmental Impact Assessment
EPA-SAB	Environmental Protected Areas – Science Advisory Board
EEZ	Exclusive Economic Zone
FIESTA	Fog Interception for the Enhancement of Streamflow in Tropical Areas
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
HPM	Hedonic price method
IMM	Integrated Marine Management
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IUCN	International Union for Conservation of Nature
MA	Millenium Ecosystem Assessment
PES	Payment for Ecosystem Services
NOAA	National Oceanic and Atmospheric Administration
PRSP	Poverty Reduction Strategy Papers
PSS	Policy Support System
SPAN	Service Path Attribution Network
SWAT	Soil and Water Assessment Tool
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCM	Travel cost method
TEV	Total economic value
UNEP-GPA	United Nations Environment Programme Global Programme of Action
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
UNESCO	United Nations Education, Scientific and Cultural Organisation
US EPA	Unites States Environmental Protection Agency
WaterGAP	Water – Global Assessment and Prognosis
WSSD	Word Summit on Sustainable Development

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References

Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., & Sala, E. (2008). Mangroves in the Gulf of California increase fishery yields. *Proceedings of the National Academy of Sciences of the United States of America*, 105:10456-10459.

Agardy, T. & Alder, J. (2005). Coastal systems in *Ecosystems and human well-being: Volume 1: current state and trends: analytical approaches for assessing Ecosystems and human well-being*. Island Press, Washington, DC. pp.513-549.

Agardy, T., Alder, J., Dayton, P., Curran, S., Kitchingman, A., Wilson, M.A., Catenazzi, A., Restrepo, J., Birkeland, C., Blaber, S., Saifullah, S., Branch, G., Boersma, D., Nixon, S., Dugan, P., & Vörösmarty, C. (2005). Coastal Systems and Coastal Communities in *Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Current State and Trends. Findings of the Condition and Trends Working Group*. Island Press.

Ahmed M., Chong, C.K. & Cesar, H. (2004). *Economic Valuation and Policy Priorities for Sustainable Management of Coral Reefs*. Penang, Malaysia: World Fish Center.

Barbier, E.B., Koch, E.W., Silliman, B.R., Hacker, S.D., Wolanski, E., Primavera, J., Granek, E.F., Polasky, S., Aswani, S., Cramer, L.A., Stoms, D.M., Kennedy, C.J., Bael, D., Kappel, C.V., Perillo, G.M.E. & Reed, D.J. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. *Science*, 319:321-323.

Barbier, E.B. (2003). Habitat-fishery linkages & mangrove loss in Thailand. *Contemporary Economic Policy*, 21:59-77.

Batie, S. & Wilson, J. (1978). Economic values attributable to Virginia's coastal wetlands as inputs in oyster production. *Southern Journal of Agricultural Economics,* 10:111-118.

Beaumont, N.J. & Tinch, R. (2003). Goods and services related to the marine benthic environment. *CSERGE Working Paper ECM* 03-14.

Beier, P., Majka, D.R. & Newell, S.L. (2009). Uncertainty analysis of least-cost modeling for designing wildlife linkages. *Ecological Applications*, 19(8):2067-2077. doi: 10.1890/08-1898.1

Bell, F.W. (1989). *Application of Wetland Valuation Theory to Florida Fisheries*. Florida Sea Grant Program, SGR-95.

Biggs, R., Carpenter, S.R. & Brock, W.A. (2009). Turning back from the brink: detecting an impending regime shift in time to advert it. *Proceedings of the National academy of Sciences*, 106:826-831.

Boyd, J. & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63:616-626.

Boyd, J. & Wainger, L. (2003). *Measuring ecosystem service benefits: The use of landscape analysis to evaluate environmental trades and compensation*. Washington, DC, Resources for the Future.

Brewer, P.G. & Peltzer, E.T. (2009). Limits to marine life. *Science*, 324(5925):347-348.

Brown, K., Tompkins, E. & Adger, W.N. (2001). *Trade-off Analysis for Participatory Coastal Zone Decision-Making*. Overseas Development Group, University of East Anglia, Norwich.

Bruno, J.F. & Selig, E.R. (2007). Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. *PLoS One*, 2:e711.

Burke, L., Selig, E.R. & Spalding, M. (2002). *Reefs at Risk in Southeast Asia*. World Resources Institute, Washington, DC.

Cesar, H.J.S., ed. (2002). Collected Essays on the Economics of Coral Reefs. *Coral Reef Degradation in the Indian Ocean (CORDIO)*, Kalmr, Sweden: Kalmar University.

Cheung, W.W.L., Close, C., Lam, V., Watson, R., & Pauly, D. (2008). Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series,* 365:187-197.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., & Pauly, D. (2009a). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries*, 10:135-151.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D., & Pauly, D. (2009b). Large-scale redistribution of maximum fisheries catch potential under climate change. *Global Biology Change*.

Christensen, V. & Walters, C.J. (2004). Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling,* 172:109-139.

Chopra, K., Leemans, R., Kumar, P., & Simons, H. (2005). *Ecosystems and Human Well-being: Policy Responses, Volume 3*. Island Press, Washington DC.

CIESM (2008). Economic valuation of natural coastal and marine ecosystems. N. 37 in Briand, F., ed., *CIESM Workshop Monographs*, 112pp., Monaco.

Cooley, S.R. & Doney, S.C. (2009). Anticipating ocean acidification's economic consequences for commercial fisheries. *Environ. Res. Lett,* 4:024007, 8pp.

Costanza, R., d'Arge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature,* 387:253-260.

Costanza, R., Pérez-Maqueo, O., Martínez, M.L., Sutton, P., Anderson, S.J., & Mulder, K. (2008). The Value of Coastal Wetlands for Hurricane Protection. *AMBIO: A Journal of the Human Environment,* 37(4):241-248.

Das, S. & Vincent, J.R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. *Proceedings of the National Academy of Sciences of the United States of America*, 106:7357-7360.

Desvouges, W., Johson, F. & Banzhaf, H. (1998). *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method*. Edward Elgar, 244pp.

Dorenbosch, M., Grol, M.G.G., Christianen, M.J.A., Nagelkerken, I., & van der Velde, G. (2005). Indo-Pacific seagrass beds and mangroves contribute to fish density coral and diversity on adjacent reefs. *Marine Ecology-Progress Series*, 302:63-76.

Duarte, C.M., Middelburg, J.J. & Caraco, N. (2005). Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences*, 2:1-8.

Dulvy, N.K., Rogers, S.I., Jennings, S., Stelzenmüller, V., Dye, S.R., & Skjoldal, H.R. (2008). Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *Journal of Applied Ecology* 45:1029-1039.

EEA (2008). *Impacts of Europe's Changing Climate – 2008 Indicator-based Assessment*. EEA Report No 4/2008.

Ellison, A.M. & Farnsworth, E.J. (2001). Mangrove communities in Bertness, M.D., Gaines, S.D. & Hay, M.E., eds., *Marine community ecology*, pp.423-442. Sinauer Associates, Sunderland, MA.

Elmqvist, T., Folker, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B., & Norberg, J. (2003). Response diversity, ecosystem change, and Resilience. *Frontiers in Ecology and the Environment,* 1:488–494.

Engelman, R. (2009). State of world population 2009 – Facing a changing world: women, population and climate. United Nations Population Fund (UNFPA), report 2009, 96pp.

EPA-SAB (2009). *Valuing the protection of ecological systems and services. A report of the EPA Science Advisory Board*. Washington, DC. 138pp.

Estes, J.A., Tinker, M.T., Williams, T.M., & Doak, D.F. (1998). Killer Whale Predation on Sea Otters Linking Oceanic and Nearshore Ecosystems. *Science,* 282:473-475.

Fabricius, K.E. (2005). Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin*, 50:125-146.

Fulton, E.A., Parslow, J.S., Smith, A.D.M., & Johnson, C.R. (2004a). Biogeochemical marine ecosystem models II: the effect of physiological detail on model performance. *Ecological Modelling,* 173:371-406.

Fulton, E.A., Smith, A.D.M. & Punt, A.E. (2004b). *Ecological indicators of the ecosystem effects of fishing: Final Report*. Report No. R99/1546, Australian Fisheries Management Authority, Canberra.

Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A., & Watkinson, A.R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, 301, 958-960.

Gibbs, H.K., Brown, S., O'Niles, J., & Foley, J.A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environ. Res. Lett.,* 2:045023 (13pp) doi: 10.1088/1748-9326/2/4/045023.

Green, E.P. & Short, F.T. (2003). *World Atlas of Seagrasses*. Prepared by the UNEP World Conservation Monitoring Centre. University of California Press, Berkeley, CA.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*, 319:948-952.

Heck, K.L., Carruthers, T.J.B., Duarte, C.M., Hughes, A.R., Kendrick, G., Orth, R.J., & Williams, S.W. (2008). Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems*, 11:1198-1210.

Hein, L., Koppen, K., de Groot, R.S., & van Ierland, E. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics,* 1 May 2006, 57(2):209-228

Hein, L. & van Ierland, E. (2006). Efficient and sustainable management of complex forest ecosystems. *Ecological Modelling* 190(3-4):351-366.

Hiddink, J.G & Hofstede, R.T. (2008). Climate induced increases in species richness of marine fishes. *Global Change Biology,* 14:453-460. Throughout.

Hughes, A.R., Williams, S.L., Duarte, C.M., Heck, K.L., & Waycott, M. (2009). Associations of concern: declining seagrasses and threatened dependent species. *Frontiers in Ecology and the Environment*, 7:242-246.

IFAD (2009). *Guidance notes for institutional analysis in rural development programmes*. IFAD, Rome.

IPCC (2007). Summary for Policymakers in Solomon, S., Qin, D., Manning, M., Marquis, M., Avery, K., Tignor, M.M.B., Miller, H.L. Jr, & Chen, Z., eds., *Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the IPCC*, pp. 1-18. Cambridge University Press, Cambridge.

Johnson, G.W., Bagstad, K.J., Snapp, R., & Villa, F. In review. Service Path Attribution Networks (SPANs): Spatially quantifying the flow of ecosystem services from landscapes to people. Submitted to: *Springer-Verlag Notes in Computer Science*.

Jorgensen, S.E. & Müller, F., eds. 2000. *Handbook of Ecosystem Theories and Management*. Boca Raton, London, New York, Washington DC, Lewis Publishers: 600pp.

Kareiva, P., Watts, S., McDonald, R., & Boucher, T. (2007). Domesticated Nature: Shaping Landscapes and Ecosystems for Human Welfare. *Science,* (319) 5833:1866-1869.

Koch, E.W., Barbier, E.B., Silliman, B.R., Reed, D.J., Perillo, G.M.E., Hacker, S.D., Granek, E.F., Primavera, J.H., Muthiga, N., Polasky, S., Halpern, B.S., Kennedy, C.J., Kappel, C.V., & Wolanski, E. (2009). Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment,* 7:29-37.

Kunkel, C.M., Hallberg, R.W. & Oppenheimer, M. (2006). Coral reefs reduce tsunami impact in model simulations. *Geophysical Research Letters*, 33.

Lobo, C. (2008). *Institutional and organizational analysis for pro-poor change: a sourcebook*. International Fund for Agricultural Development (IFAD), Rome.

MA (2005). *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC.

Martínez, M.L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., & Landgrave, R. (2007). The coasts of our world: Ecological, economic and social importance. *Ecological Economics,* 1 August 2007, 63(2-3):254-272

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J., & Barnes, D. (2003). Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature*, 421:727-730.

Moller, I. (2006). Quantifying saltmarsh vegetation and its effect on wave height dissipation: Results from a UK East coast saltmarsh. *Estuarine Coastal and Shelf Science,* 69:337-351.

Molloy, S., O'Connor, T., Wood, J., & Wallrodt, S. (2007). *Addendum for the South West Biodiversity Project Area*, Western Australian Local Government Association, West Perth

Mumby, P.J., Edwards, A.J., Arias-Gonzalez, J.E., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczynska, M.I., Harborne, A.R., Pescod, C.L., Renken, H., Wabnitz, C.C.C., & Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature,* 427:533-536.

Nagelkerken, I., Roberts, C.M., van der Velde, G., Dorenbosch, M., van Riel, M.C., de la Morinere, E.C., & Nienhuis, P.H. (2002). How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology-Progress Series,* 244:299-305.

Nagelkerken, I., van der Velde, G., Gorissen, M.W., Meijer, G.J., van't Hof, T., & den Hartog, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuarine Coastal and Shelf Science,* 51:31-44.

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R., & Ricketts, T.H. (2008). Global Mapping of Ecosystem Services and Conservation Priorities. *PNAS,* 105(28):9495-9500.

Naidoo, R. & Ricketts, T.H. (2006) Mapping the Economic Costs and Benefits of Conservation. *PLoS Biol* 4(11):e360. doi:10.1371/journal.pbio.0040360

Nellemann, C., Corcoran, E., Duarte, C.M., Valdes, L. DeYoung, C., Fonseca, L., & Grimsditch, G. (2009). *Blue Carbon. A Rapid Response Assessment*. United Nations Environment Programme, GRID-Arendal, www.grida.no.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K., Daily, G., Goldstein, J., Kareiva, P., Lonsdorf, E., Naidoo, R., Ricketts, T., & Shaw, R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7:4-11.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O. Hay, J.E., McLean, R.F., Ragoonaden, S., & Woodroffe, C.D. (2007). Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., & Hanson, C.E., eds., Cambridge University Press, Cambridge, UK, 315-356.

Norberg, J. (1999). Linking Nature's services to ecosystems: some general ecological concepts. *Ecological Economics,* 29:183–202.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., & Williams, S.L. (2006). A global crisis for seagrass ecosystems. *Bioscience*, 56:987-996.

Pagiola, S., van Ritter, K. & Bishop, J. (2004). *How much is an ecosystem worth: Assessing the economic value of conservation*. The International Bank for Reconstruction and Development/World Bank. Washington, DC.

Pauly, D., Christensen, V. & Walters, C. (2000). Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science,* 57:697-706.

Perry, A.L., Low, P.J., Ellis, J.R., & Reynolds, J.D. (2005). Climate change and distribution shifts in marine fishes. *Science,* 308:1912-1915.

Plummer, M.L. (2009). Assessing benefit transfer for the valuation of ecosystem services. *Frontiers in Ecology and the Environment*, 7:38-45.

Ramirez, A.R. (2008). *Programa Cienaga Grande de Santa Marta, una Propuesta Institucional de Recuperacion*. Seminario – Taller Internacional de Expertos, 28 y 29 de enero de 2008.

Restrepo, J.D., Zapata, P., Díaz, J., Garzón-Ferreira, J., & García, C. (2006). Fluvial fluxes into the Caribbean Sea and their impact on coastal ecosystems: The Magdalena River, Colombia. *Global and Planetary Change,* 50(1-2):33-49.

Richardson, A.J. (2008). In hot water: zooplankton and climate change. *ICES Journal of Marine Science*, 65(3):279-295.

Ruckelshaus, M.H. & Guerry, A. (2009). Valuing marine ecosystems? *Marine Scientist,* 26:26-29.

Ruhl, J.B., Kraft, S.E. & Lant, C.L. (2007). *The Law and Policy of Ecosystem Services*. Island Press, Washington, DC. 345pp.

Sarmiento, J.L., Slater, R., Barber, R., Bopp, L., Doney, S.C., Hirst, A.C., Kleypas, J., Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., & Stouffer, R. (2004). Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles*, 18:GB3003, doi:10.1029/2003GB002134.

Secretariat of the Convention on Biological Diversity (2009). *Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity*. Technical Series No. 46, Montreal, 61pp.

Shrestha, R. & Loomis, J. (2001). Testing a meta-analysis model for benefit transfer in international outdoor recreation. *Ecological Economics*, 39:67-83.

Soderqvist, T., Eggert, H., Olsson, B., & Soutukorva, A. (2005). Economic valuation for sustainable development in the Swedish coastal zone. *Ambio,* 34:169-175.

Spurgeon, J. (2006). Time for a third-generation economic-based approach to coral management in Côté, L.M. & Reynolds, J.D., eds., *Coral Reef Conservation*, pp.362-390. London, Cambridge University Press.

Srinivasan, U.T., Carey, S.P., Hallstein, E., Higgins, P.A.T., Kerr, A.C., Koteen, L.E., Smith, A.B., Watson, R., Harte, J., & Norgaard, R.B. (2008). The debt of nations and the distribution of ecological impacts from human activities. *PNAS*, 105(5):1768-1773.

Tallis, H., Kareiva, P., Marvier, M., & Chang, A. (2008). An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences*,105(28):9457-9464.

Tallis, H. & Polasky, S. (2009). Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *The Year in Ecology and Conservation Biology, 2009: Annual Review of the New York Academy of Sciences*, 1162:265-283.

TEEB (2009). *The Economics of Ecosystems and Biodiversity for National and International Policy Makers, TEEB climate Issues Update.* September, 2009

The World Bank (2009). *Convenient Solutions to an Inconvenient Truth: Ecosystem-based Approaches to Climate Change*. June 2009 Environment Department, 91pp.

Thresher, E.R., Koslow, J.A., Morison, A.K., & Smith, D.C. (2007). Depth-mediated reversal of the effects of climate change on long-term growth rates of exploited marine fish. *PNAS,* 104:7461-7465.

Turner, R.K & Fisher, B. (2008). Environmental Economics: To the rich man the spoils. *Nature,* 451(7182):1067-1068.

UNEP (2006). *Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment*. UNEP. 76pp.

Valiela, I., Bowen, J.L. & York, J.K. (2001). Mangrove Forests: One of the World's Threatened Major Tropical Environments. *BioScience*, 51:807-815.

Verweij, M.C., Nagelkerken, I., Hans, I., Ruseler, S.M., & Mason, P.R.D. (2008). Seagrass nurseries contribute to coral reef fish populations. *Limnology and Oceanography,* 53:1540-1547.

Vilardy, S. (2008). Aproximación a los Servicios de los Ecosistemas en la Ciénaga Grande de Santa Marta y su relación con el bienestar humano. *Análisis y Retos de la Gestión en el Sistema Socio-Ecológico Cienaga Grande de Santa Marta*. Seminario – Taller Internacional de Expertos, 28 y 29 de enero de 2008.

Villa, F., Ceroni, M., Bagstad, K.J., Johnson, G., & Krivov, S. (2009). *ARIES (Artificial Intelligence for Ecosystem Services): A new tool for ecosystem services assessment, planning, and valuation*. 11th Annual BIOECON Conference on Economic Instruments to Enhance the Conservation and Sustainable Use of Biodiversity, Conference Proceedings. Venice, Italy, September 2009.

Viloria, E. & Troncoso, J. (2008). *Estado Actual de la Calidad de Agua, Vegetación y Actividades Pesqueras en la Cienaga Grande de Santa Marta Seminario* – Taller Internacional de Expertos 28 y 29 de enero de 2008.

Wallace, K.J. (2007). Classification of ecosystem services: Problems and solutions. *Biological Conservation,* 139:235-246.

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., & Williams, S.L. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, 106:12377-12381.

Wilkinson, C. (2008). *Status of coral reefs of the world: 2008.* Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, 296pp.

Williams, S.L. & Heck, K.L. (2001). Seagrass community ecology in Bertness, M.D., Gaines, S.D. & Hay, M.E., eds., *Marine community ecology*, pp.317-337. Sinauer Associates, Sunderland, MA.

Other Relevant Reading

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S., & Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science,* 309(5373):1036-1039.

Adger, W.N., Kelly, P.M. & Ninh, N.H., eds. (2001). *Living with environmental change: social vulnerability, adaptation and resilience in Vietnam.* London, UK, Routledge.

Agardy, T. & Alder, J. (2005). Chapter 19: Coastal Systems in *Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Current State and Trends.* Washington DC, Island Press, pp.513- 549.

Allison, E.H. & Ellis, F. (2001). The livelihoods approach and management of small-scale fisheries. *Marine Policy,* 25:377-388.

Allison, E.H., Adger, W.N., Badjeck, M.-C., Brown, K., Conway, D., Dulvy, N.K., Halls, A., Perry, A., & Reynolds, J.D. (2005). *Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty.* London, Fisheries Managament Science Programme MRAG/DFID, Project no. R4778J. Final Technical Report.

Alongi, D.M. (2008). Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science,* 76:11-13.

Badola, R. & Husein, S.A. (2005). Valuing ecosystem functions: an empirical study on the storm protection functions of Bhitarkanika mangrove ecosystem, India. *Environmental Conservation,* 32(1):85-92.

Bonan, G.B. (2008). Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. *Science,* 320:1444-1449.

Brooks, N., Adger, W.N. & Kelly, M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change,* 15:151-163.

Brown, K. (2006). Adaptive Institutions for Coral Reef Conservation in Côté, L. & Reynolds, J., eds., *Coral Reef Conservation*. Cambridge, Cambridge University Press, pp.455-477.

Brunner, E.J., Jones, P.J.S., Friel, S., & Bartley, M. (2008) Fish, human health and marine ecosystem health: policies in collision. *International Journal of Epidemiology,* 1-8.

Butler, C., Chambers, R., Chopra, K., Dasgupta, P., Duraiappah, A.K., Kumar, P., McMichael, T.A.J., & Wen-Yuan, N. (2003). Chapter 3: Ecosystems and Human Well-Being in Sarukhan, J. and Whyte, A. (eds.), *Ecosystems and Human Well-being: A Framework for Assessment*, Island Press, Washington DC, pp.71-84.

Carpenter, K.E. & Springer, V.G. (2004). *The center of marine shore fish biodiversity: the Philippine Islands*. Multiple datasets show global maxima of marine biodiversity in the Indo–Malay–Philippines archipelago (IMPA). Analysis of distribution data for 2,983 species reveals a pattern of richness on a finer scale and identifies a peak of marine biodiversity in the central Philippine Island.

Cassels, S., Curran, S.R. & Kramer, R. (2005). Do Migrants Degrade Coastal Environments? Migration, Natural Resource Extraction and Poverty in North Sulawesi, Indonesia. *Human Ecology,* 33(3):329-363.

Cheung, W.W.L., Lam, V.W.Y. & Pauly, D. (2008). Dynamic bioclimate envelope model to predict climate-induced changes in distribution of marine fishes and invertebrates in Cheung, W.L., Lam, V.W.Y. & Pauly, D., eds., *Modelling Present and Climate-shifted Distributions of Marine Fishes and Invertebrates*. Fisheries Centre Research Reports 16(3), University of British Columbia, Vancouver.

Conservation International (2008). *Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation*. Center for Applied Biodiversity Science, Conservation International, Arlington, VA

Costanza, R., Andrade, F., Autunes, P., van den Belt, M., Boerma, D., Boesch, D.F., Catarino, F., Hanna, S., Limburg, K., Low, B., Molitor, M., Pereira, J.G., Rayner, S., Santos, R., Wilson, J., & Young, M. (1998). Principles for Sustainable Governance of the Oceans. *Science,* 281:198-199.

Covich, A.P., Ewel, K.C., Hall, R.O., Giller, P.S., Goedkoop, W., & Merritt, D.M. (2004). Ecosystem services provided by freshwater benthos in Wall, D.H., ed., *Sustaining biodiversity and ecosystem services in soils and sediments*, *SCOPE*, 64:45-72. Washington, DC: Island Press.

Daily, G.C. & Matson, P.A. (2008). Ecosystem Services: From theory to implementation. *PNAS* 105(28):9455-9456.

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.K., Rasmussen, M.S., Hansen, L.B., Quarto, A., & Suryadiputra, N. (2005). The Asian Tsunami: A Protective Role for Coastal Vegetation. *Science,* 310: 643.

Donner, S.D. & Potere, D. (2007). The Inequity of the Global Threat to Coral Reefs. *BioScience,* 57:314-315.

FAO (2007). *The State of World Fisheries and Aquaculture – 2006*. FAO, Rome.

Eltahir, E.A.B. & Bras, R.L. (1994). Precipitation Recycling in the Amazon Basin, *Quarterly Journal of the Royal Meteorological Society*, 120:861-880.

Goklany, I.M. (2001). *The Precautionary Principle: A Critical*

Appraisal of Environmental Risk Assessment. Cato Institute, Washington, DC, 119pp. Available from www.cato.org.

Guzman, H. (2003). Caribbean coral reefs of Panama: present status and future strategies in Cortes, J., ed., *Latin American Coral Reefs*, pp. 241-274. Elsevier, The Netherlands.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., & Hatziolos, M.E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, 318:1737-1742.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., & Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology and Evolution*, 20(7):380-386.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., & Warner, R.R. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems*.* *Science,* 293(5530):629-637.

Lacambra, C., Spencer, T. & Moeller, I. (2008). Tropical Coastal Ecosystems as Coastal Defences in *The Role of Environmental Management in Disaster Risk Reduction and Climate Change Adaptation*, ProAct Network.

Lange, G.M. & Jiddawi, N. (2009). Economic value of marine ecosystem services in Zanzibar: Implications for marine conservation and sustainable development. *Oceans and Coastal Management,* 52(10):521-532.

Latief, H. & Hadi, S. (2008). The Role of Forests and Trees in Protecting Coastal Areas Against Tsunamis. Regional technical workshop "*Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees?*" Khao Lak, Thailand, 28-31 August 2006.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., & Jackson, J.B.C. (2006). Depletion, degradation and recovery potential of estuaries and coastal seas. *Science,* 312(5781):1806-1809.

Mazda, Y., Magi, M., Kogo, M., & Hong, P.N. (1997). Mangroves as a coastal protection from waves in the Tong King Delta, Vietnam. *Mangroves and Salt Marshes,* 1:127-135.

Mazda, Y. Wolanski, E. & Ridd, P.V. (2007). *The Role of Physical Processes in Mangrove Environments: Manual for the preservation and utilization of mangrove ecosystems*. TERRAPUB. Japan.

Moberg, F. & Rönnbäck, P. (2003). Ecosystem services of the tropical seascape: Interactions, substitutions and restoration. *Ocean and Coastal Management,* 46:27–46.

Moeller, I. & Spencer, T. (2002). Wave dissipation over macro-tidal saltmarshes: Effects of marsh edge typology and vegetation change. *Journal of Coastal Research,* 36: 506-521.

Newton, K., Cote, I., Pilling, G., Jennings, S., & Dulvey, N. (2007). Current and Future Sustainability of Island Coral Reef Fisheries. *Current Biology,* 17(7):655-658.

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution,* 10(10):430.

Pearce, D. & Moran, D. (1994). T*he Economic Value of Biodiversity*. Earthscan Publications Limited, London, UK.

Peterson, M.S. (2003). A Conceptual View of Environmental-Habitat-Production Linkages in Tidal River Estuaries. *Reviews in Fisheries Science,* 11:291-313.

Rranganathan, J., Irwin, F. & Repinski, C.P. (2009). *Banking on nature's Assets: How Multilateral Development Banks Can Strengthen Development by Using Ecosystem Services*. World Resources Institute.

Scheffer, M., Carpenter, S.R., Foley, J., Folke, C., & Walker, B.H. (2001). Catastrophic shifts in ecosystems. *Nature,* 413:591–96.

Townsley, P., Onibon, A. & Messer, N. (2009). *Guidance notes for institutional analysis in rural development programmes.* International Fund for Agricultural Development (IFAD), Rome.

Turner, R.K., Paavola, J., Cooper, P., Forber, S., Jessamy, V., & Georgiou, S. (2003). Valuing nature: lessons learned and future research directions. *Ecological Economics,*46: 493-510.

UNEP (2008). *The question of environmental refugees in the South Pacific region*. United Nations.

Whittingham, E., Campbell, J. & Townsley, P. (2003). *Poverty and Reefs*. IMM-DFID-IOC/UNESCO. 260pp.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., & Watson, R. (2006). Impacts of Biodiversity loss on ocean ecosystem services. *Science,* 314(5800):787-790.

Zeitlin Hale, L., Meliane, I., Davidson, S., Sandwith, T., Beck, M., Hoekstra, J., Spalding, M., Murawski, S., Cyr, N., Osgood, K., Hatziolos, M., Van Eijk, P., Davidson, N., Eichbaum, W., Dreus, C., Obura, D., Tamelander, J., Herr, D., McClennen, C., & Marshall, P. (2009). Ecosystem-based Adaptation in Coastal and Marine Ecosystems. *Renewable Resources Journal*, 25-2009(4). Washington, DC.

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