THE CONTINUOUS CHALLENGE OF MANAGING ESTUARINE ECOSYSTEMS

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1 THE SIGNIFICANCE OF ESTUARIES IN HUMAN AFFAIRS

In the course of human history, the coastal plains and river valleys have usually been the most populated areas over the world. Proximity to water bodies has been an incentive for the location of human settlements for millennia. Presently, about 60% of the world's population lives along the estuaries and the coast (Lindeboom 2002). Located at the interface between land and the sea, estuaries are sites of significant biotic diversity and human development. Estuaries provide many goods and services including coastal protection, tourism, water purification, breeding and nursing grounds for commercial fish species, etc. The biological productivity sustaining a high level of food production in these areas has been a major attraction for human settlement, as well as the use of the rivers and estuaries as transport routes, fundamental for economic and social development.

From a human history perspective the function of estuaries as natural harbors and provider of abundant natural resources made them the location of some of the world's greatest cities. A direct consequence of human occupation of these coastal areas is that estuaries rank among the environments most impacted by human activities. In many cases the consequence of human intrusion has been disastrous. Human actions also have resulted in worldwide manipulation of the hydrological, chemical, and biological factors that regulate estuaries ecological dynamics (Strayer et al. 1999, Council 2000, Cloern 2001).

Human modification of marine environments, especially coastlines, estuaries and wetlands has gone hand in hand with social and economic development. As such, any analysis of the water resources and their conflictive management policies of these areas must be based on awareness of environmental and economical fundamentals (Allan 2005). Management efforts of marine living resources are increasingly shifting towards ecosystem-based management (Pikitch et al. 2004), and estuaries are no exception. Ecosystems are complex adaptive systems that require a flexible governance with the capacity to respond to environmental feedback (Levin 1998, Dietz et al. 2003). There is a need to deal with scientific insights, economic and social factors in making natural resource management decisions. These decisions, in turn, have ecological, economic, social and political ramifications. The inevitable result is that it becomes difficult sometimes to isolate the key elements that affect decisions about environmental impacts and the management of such resources. In addition, changing human values and social priorities also form part of the context for resource management. This facet of societal change, together with environmental stochasticity, makes management a dynamic endeavor.

2 CONFLICTING INTERESTS

The oceans cover 75% of the earth's surface, accounting for 90% of the planet's water supply. Marine ecosystems provide a wide variety of goods and services, including vital food resources for millions of people (Holmlund and Hammer 1999). Man's utilization of coastal areas sea can basically be reduced to three aspects: (1) exploitation of marine organisms for food and other purposes, (2) use of the sea as a dumping ground, and (3) land reclamation. Together with environmental functions or services provided by estuaries, such as food production, mineralization of organic wastes, and aesthetic value, there are other services and amenities that are crucial for human activity like transport function, recreational activities, tourism, etc (Figure 1). This explains why estuaries, when compared to other marine areas, have the highest mean financial value per hectare per year (Figure 1). However, the rapid degradation of estuarine systems reveals the conflicting nature of human interest in these coastal areas. Maintenance or expansion of a regional economy is a major, usually even the primary, objective. While exploiting its resources, human activities also contribute to the destruction of other resources. Sometimes this apparent paradox denotes unsustainable practices and management shortcomings. It also can be the symptom of conflicting interests between development and conservation. But a conflict of interests can also arise in the conflict between human needs. As an example, the changes in river flows due to irrigation, damming and water diversion can modify the entire food web up to the level of fisheries, with significant negative consequences (Wolanski et al. 2006). Aquaculture is also an example of an enterprise with social and economical impact, but at the same time with the potential to degrade the environment.

A large and still increasing proportion of the human population lives close to the coast; thus the loss of services such as flood control and waste detoxification can have disastrous consequences (Adger et al. 2005). Changes in marine biodiversity are directly caused by overexploitation, pollution, and habitat destruction, or indirectly through climate change and related perturbations of ocean biogeochemistry. Among several irremediable problems, regional ecosystems such as estuaries (Lotze et al. 2006), and coastal communities (Jackson et al. 2001) are rapidly losing populations, species, or entire functional groups. Human-dominated marine ecosystems are experiencing accelerating loss of populations and species, with largely unknown consequences. Marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations (Worm et al. 2006). Ultimately, since flows from natural systems are limited, a conflict between human objectives and conservation of resources is inevitable, unless the rate at which humans extract resources from the marine environment are also limited (Ludwig 1993, Ludwig et al. 1993).

3 HUMAN INFLUENCE: ESTUARINE DEGRADATION THROUGH TRANSFORMATION

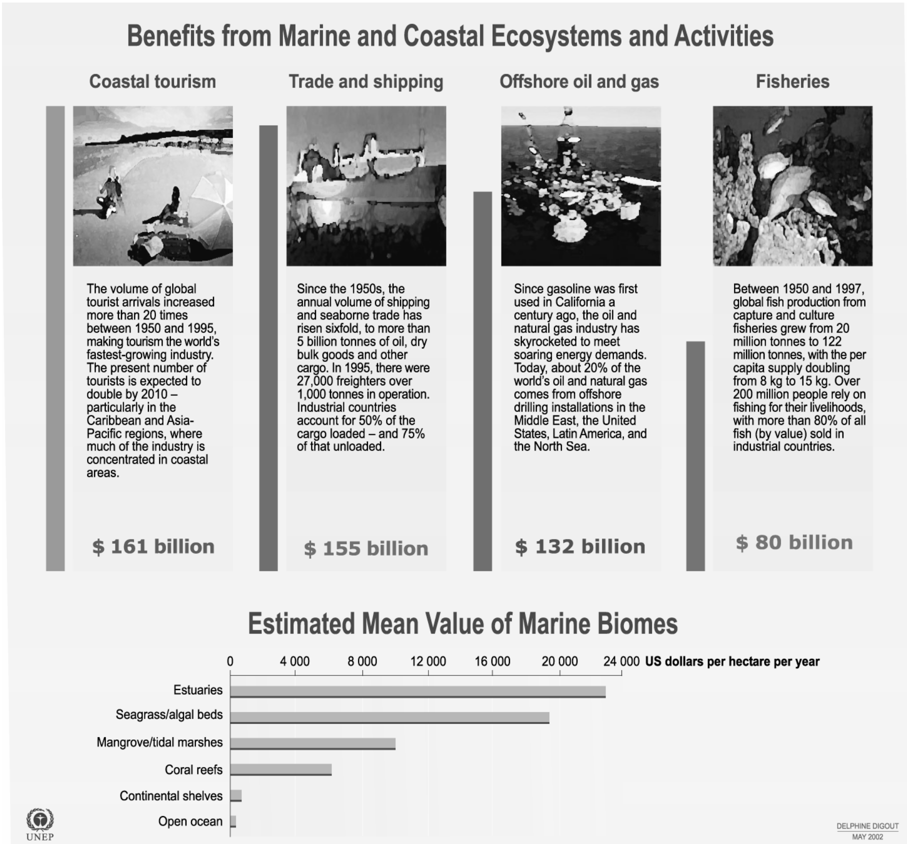
Coastal ecosystems have suffered multiple pressures, sometimes undergoing degradation in small, incremental steps that are difficult to recognize, while other in fast and huge steps. The increase of human populations in the river basins, by natural growth and internal migration, has resulted in a doubling of the population along many coasts over the last 20 years. Human activity affects ecosystem structure and functions through the disruption of the pattern and rate of matter as well as energy flow through ecosystems (Ohl et al. 2007). Transport and transformation and removal of resources driven by societal and economic pressures change the landscape and influence biodiversity, redefine the ecological state of ecosystems and the rate of delivering goods and services.

General analyses and reviews over the past two decades have identified a range of pressures that cause undesirable change in coastal ecosystems (Burke et al. 2001, Redman et al. 2004). Physical alteration, habitat degradation and destruction, pollution, water withdrawal, overexploitation, and the introduction of non-native species are the leading causes of ecosystem degradation. When compared with other marine systems, estuaries are under more intense degradation (Figure 2). Direct human impacts on estuaries have different origins, ranging from the consequences of engineering works (e.g., harbor construction, land claim, etc.) on the estuarine water residence time and change in sediment patterns, to the effects of wastewater discharges on the health of the biota. Liquid discharges and solid dumping with anthropogenic origins include an array of chemical contaminants, such as metals, organometals, petroleum hydrocarbons, organic compounds from pesticides, industrial wastes products and nutrients.

3.1 Modification and destruction of habitats

Most of the human activities related with the occupation and development of estuarine areas causes problems by habitat modification or destruction. Estuaries are dredged or filled and transformed into marinas, seaports, industrial parks, cities, and garbage dumps. Historically, most reclamation has been mainly related with flood protection and the production of agriculturally valuable land. A more recent trend is the reclamation to create land for residential housing, industry (petrochemical and oil refineries installations, etc.), and port, dock and airport facilities. Numerous estuaries have been transformed and even completely destructed through landfill to build urban or industrial infrastructures. A warning example comes from the United States where about one third of the estuaries have disappeared altogether.

Dredging and maintenance dredging of navigation channels may have several impacts on the marine environments. Estuaries are particularly sensitive areas, and any artificial deepening may result in permanent modifications in the ecological functioning of the system, even with permanent loss of environmental services. As an example, the land-building function of mangrove vegetation has very important implications in coastal management because it works as a natural barrier to protect adjacent land by enhancing sedimentation and reducing erosion by wave action, tides, and river flow. This is important for shallow estuaries that are prone to flooding, especially where the land is below sea level.



Source: Anne Platt McGinn, *The Health of Oceans*, Worldwatch paper 145, Worldwatch Institute, 1999, Washington DC (www.worldwatch.org) ; Costanza, R., et al, *The Value of the World's Ecosystem Services and Natural Capital*, Ecological Economics, 1998.

FIGURE 1: *Several activities generate significant revenues in coastal and marine areas. This graphic illustrates the economic benefits of coastal tourism, trade and shipping, offshore oil and gas, and fisheries. It also illustrates an estimation of the financial value of selected marine biomes (UNEP/GRID-Arendal 2002a).*

3.2 Port activities

Port activities are among the main driving forces in many estuaries around the world. They account for a number of known environmental pressures and have been responsible for changes in the state of the systems. There has been a continuous process of change in international transport management over the last 10 years, from a segmented modal approach towards a much more integrated transport concept tailored to better meet the pressing needs of customer industries. This, in turn, is resulting in an increasing pressure on ports to adapt their role and function to this more demanding operational environment (Juhel 2001). The interaction between the port and the city often surrounding it, in terms of transport network requirements, environmental protection, and overall safety, is a prerequisite for effective delivery of integrated logistics services. This means that the expansion of port activities, either by physical expansion or intensification of its use, or both, is always made in conjunction with the development of other supporting infrastructure. The overall consideration is that port development does not necessarily means new and better equipment; it means new and/or wider roads, larger areas for container storage and transport, traffic intensification, both in water and on land, etc.

A major problem associated with port activity in estuaries (which are shallow by nature) is the amount of dredging, both to expand the port or simply to maintain and improve navigability, as most estuarine channels require almost continuous dredging to keep them at the required depth. The disposal of thousands, if not millions of tons of sediment is a common problem which results directly from the maintenance-dredging activity. This is particularly problematic when sediments are dredged from polluted areas. Heavy metals and other pollutants that are adsorbed to the sediment and buried can still be remobilized, by a number of processes such as bioturbation, natural erosion and dredging. The disposal of dredged sediments requires an integrated management approach because they can contain potentially hazardous substances. If a system is degraded because of multiple anthropogenic pressures, as many estuaries in developing countries,as well as most estuaries in the developed world, effective management programs must be implemented to achieve sustainability. Consequently, the development of a Coastal Management Program as a management tool for port authorities should be a priority in order to prevent or minimize negative impacts of dredging activities.

3.3 Eutrophication

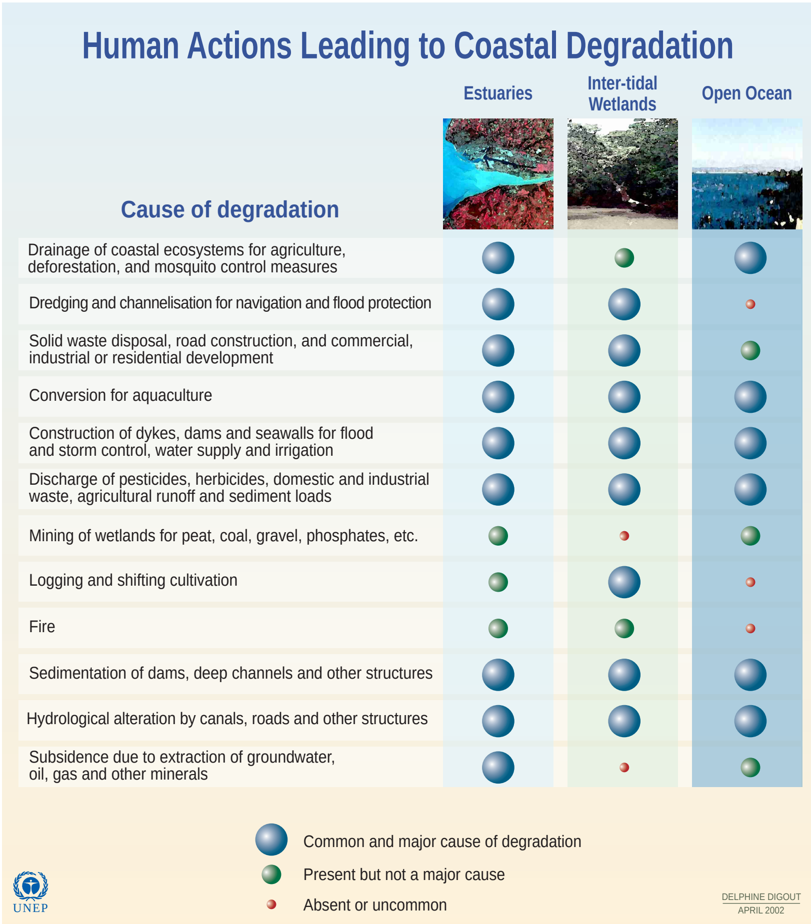
The increase in human occupation of both the estuarine and watershed is seen as the major cause of nutrient enrichment of estuarine and coastal areas. Fluxes of mineral nutrients, such as phosphate and nitrate, into the sea have world-wide more than doubled in the last decades (Meybeck 1998). The industrial and urban expansion in most developed countries has been pushing the natural state of estuarine systems to a state in which there is an artificial acceleration of nutrient-enrichment processes. Nutrient loads in many rivers have increased markedly over the last decades and this increase is thought to be at least partly responsible for the changed eutrophic status of a number of estuaries and coastal seas. This has become a significant problem in many estuaries and coastal zones, manifesting itself in symptoms such as high levels of chlorophyll a, excessive occurrence of macroalgae and epiphyte blooms, occurrence of anoxia and hypoxia, and harmful and toxic algal blooms (Bricker et al. 2003). In some ecosystems, the amount of extra nutrients is small enough that it may generate an increase of biological productivity without dramatic modification of biodiversity (Zalewski 2002). More commonly, however, the load of nutrients is so high that it degrades water quality, compromising ecological services, biodiversity, and productivity.

Estuarine ecosystems usually have a high content of allochthonous material and high concentrations of nutrients (comprising mesotrophic and eutrophic conditions), supporting high rates of phytoplankton and bacterial production. The increase of both organic material and nutrients in the system above background levels, as a result of eutrophication, poses serious threats. Physical characteristics of the estuary such as turbidity and the residence time control availability of nutrients and light in the system (Monbet 1992). To a certain extent, the residence time of an estuary determines the risk of degradation or eutrophication in the adjacent coastal areas. This depends on whether estuaries and coastal wetlands have sufficient time to deplete the nutrient reservoir, or whether nutrients make their way to the shelf without significant loss.

Cultural eutrophication reflects the enrichment of catchments areas like estuaries induced by human activities with nutrients like N and P, but not with silica. For some time now this unbalanced nutrient enrichment has been hypothesized as the cause of the shift from diatom dominance to non diatom dominance in the phytoplankton composition (Officer and Ryther 1980). Eutrophication conditions, with an increase in nitrogen and phosphorus and not in silica, forces a change in N:Si and P:Si ratios that is favorable to flagellate blooms and unfavorable to diatoms. The transition from diatom-based to non-diatom based phytoplankton communities has been associated with a degradation of the water quality (Turner and Rabalais 1994). Because Harmful Algal Blooms (HAB) occurrences are frequent near shore, local nutrient inputs are usually thought to be a causative factor. Nutrient enrichment of coastal areas may have other far-reaching consequences, such as loss or degradation of sea grass beds, fish-kills, interdiction of shellfish and other types of aquaculture and smothering of bivalves and other benthic organisms. Irrespective of the type and magnitude of the impacts, the modifications in the system induced by nutrient enrichment usually have significant economic and social costs, some of which may be readily identified (e.g. direct costs such as productivity losses), whilst others (e.g. indirect and non-use values) are more difficult to determine and tend to be ignored (Turner et al. 1999).

3.4 Oxygen depletion

Oxygen depletion is among the most serious threats that coastal systems such as estuaries can face (NRC 2000), and environmental degradation problems associated with the occurrence of low oxygen are increasing on a global scale. There is no other environmental variable of such ecological importance to coastal marine ecosystems that has changed so drastically due to human influences in recent decades (Diaz and Rosenberg 1995). Anoxia is most often associated with inputs of sewage and other organic materials. In estuaries and coastal areas near major population centers, the low dissolved oxygen levels are usually attributed to industrial and direct effluent discharges, especially from sewage treatment plants. The discharge of organic waste depletes oxygen directly as it decomposes, and the addition of nutrients can lead to oxygen depletion by stimulating primary production. There is a link between eutrophication and problematic oxygen levels because the boost in primary production promoted by nutrient enrichment leads to an increase in organic matter to be degraded by bacteria later on. The anthropogenic nutrient loading has increased the frequency and severity of hypoxia in estuaries and semi-enclosed seas (Rabalais and Turner 2001).



Source: United Nations Environment Programme (UNEP).

FIGURE 2: *Physical alteration and destruction of habitats rank among the most serious threats to coastal areas. Half of the world's wetlands, and even more of its mangrove forests, have been lost over the past century due to physical alterations, with accelerating social and economic development and poor planning being major causes. All causes of degradation are more intense in estuaries (UNEP/GRID-Arendal 2002b).*

4 HUMAN AND COASTAL SYSTEM HEALTH

Threats to human health resulting from human interaction with aquatic ecosystems involve multiple factors, which might be broadly grouped into three categories that are usually inter-linked: (1)Effects of water pollution (chemical, microbiological, radioactive, thermal) on humans and on the physiology of individual organisms; (2) The result of management of aquatic resources (e.g., wetland drainage, land reclamation, dredging, aquaculture, etc.); (3) Effects of global change affecting climate and the hydrological cycle (e.g., habitat degradation, warming, increased rainfall, storms). It is obvious that the role of humans in decreasing the quality of life in the marine environment has been enormous. The detrimental effects of pollution can directly or indirectly affect all forms of life in estuaries and this, in turn, can similarly present a hazard to human health when marine organisms are used as food or by direct contact with the water and sediments. A significant number of human activities contribute to the release of pollutants to the estuary by rivers and tributaries, run-off, groundwater and the atmosphere. Considerable amounts of these contaminants remain inside the estuary or adjacent coastal zone, particularly in poorly flushed areas.

5 MANAGING COASTAL WATER RESOURCES: A SHARED RESPONSIBILITY

In simple terms, the great challenge of this century is to find the means to develop human capital (socio-economically, culturally and equitably), while at the same time preserving and protecting natural capital. The socio-economic dimension, with its focus on human concerns, is a crucial component of the approach, taking full account of:

1. Stakeholders having input in the planning and management of the resource, ensuring especially that the interests of all quadrants of society, as well as natural interests, are fully represented;
2. The multiple uses of the resources and the range of people's needs;
3. Integrating water plans and strategies into the national planning process and environmental concerns into all government policies and priorities, as well as considering the implications of proposed and adopted actions;
4. The essential needs of the ecosystems so that they are properly protected.

Summarizing, coastal management embraces the principles of participation and transparency to attain social equality and good governance. This reaffirms that governments are the stewards of valuable assets such as their coastal waters and ecosystems, and with effective cooperative management, these common resources can contribute to sustainable economic growth.

6 THE ECONOMICAL AND ECOLOGICAL CONTEXT OF NATURAL RESOURCE MANAGEMENT

Management decisions based purely on economical considerations always compare the current market value of the natural resources against an ill-defined ecological value. However, in making decisions, relevant factors must include such things as the relative value of ecological processes, conservation priorities, and alternative land use practices. Because of the uncertainty in forecasting the economic value of alternatives, and the difficulties inherent in defining very different values in the same currency, decisions end up being taken mostly by political and social forces on short term economical considerations The concept of intergenerational equity is usually part of definitions of sustainability but this concept is intractable from a manager's perspective. Also, management decisions usually rely on dealing with the resource as it is now (e.g., available space, fish populations, etc.), instead of on the basis of their sustainability. From the perspective of developing procedures for sustainable resource use practices, there is more at stake than simply the particular interests of the resource owners or managers. A number of general principles have been suggested for the discussion of sustainability and resource use (Ludwig et al. 1993):

- Human motivations and responses should be included as part of the system to be studied and managed;
- Past examples show that resource exploitation has seldom been sustainable, and frequently scientific advice is ignored;
- Resources should be managed explicitly for uncertainty by considering a variety of different strategies, favoring actions that are informative, reversible and that are robust to uncertainty;
- Management strategies should be adaptive, considering uncertainty and surprise as an integral part of anticipated response;
- Policies and actions are required that involve not only social objectives, but that continue to improve understanding and provide for flexibility in the event of unexpected events;
- Trial-and-error must be seen as an integral part of adaptive management;
- Such an approach should be interdisciplinary and combine historical, comparative and experimental approaches to resource use.

7 ECOSYSTEM-BASED MANAGEMENT: THE SUSTAINABLE USE OF ESTUARINE RESOURCES

Sustainability is both an ecological and an economic concept. Achieving adequate sustainability practices must be a priority to maintain or restore these environments and the ecological services they provide. This, in turn, will be translated in economic benefits. Sustainable use of estuarine systems and the goods and services they support depends on: (1) efficient coupling between advances in the environmental sciences and their application for the public good, and (2) our understanding of the interdependency of ecological and socio-economic systems. Today, there are unacceptable disconnects between these processes on both counts (Bowen and Riley 2003). Ecosystem-based strategies consider the effects of human activities in the context of natural variability and change. Ecosystem-based management is emerging as a unifying approach to secure and efficient marine operations, environmental protection, resource management, land-use planning and environmental engineering (Sherman and Duda 1999, Cicin-Sain et al. 2000). This is especially significant in estuaries where the combined effects of habitat alterations, land sources of pollution, over fishing, harmful algal blooms, and invasive species are most severe (Botsford et al. 1997). Implementing a strategy of ecosystem-based management requires the capability to engage in adaptive management and a decision making process that depends on routine and rapid detection of changes in the state of the system. Although the challenges are many, the coordinated development of a multidisciplinary scientific effort may provide an important means to bridge the gap between science and management by the routine and repeated provision of scientifically credible, quantitative assessments of the status of estuarine ecosystems across the land-sea interface.

8 MEETING SOCIAL NEEDS

Estuaries and other coastal systems are experiencing unprecedented changes that make them more susceptible to natural hazards and less able to support living resources. A broad spectrum of phenomena from global warming and sea level rise to harmful algal blooms (HABs) and losses of biodiversity are exhibiting troubling trends in their magnitude or frequency. These trends are related to both natural processes and increasing human demands on coastal ecosystems to support commerce, living resources, recreation, and living space.

One of the major challenges in coastal zone management, and particularly in estuarine management, is to balance the environmental constraints with social needs. This is a rather demanding task because it starts with a fairly consensual identification of major social goals followed sometimes by a not so obvious definition of particular social needs for any specific system. Because of their nature, societal goals can only be achieved with the development of an integrated and holistic approach. They can be broadly summarized in the following list (UNESCO 2005): (1) Improve the safety and efficiency of marine operations; (2) Mitigate and more effectively control the effects of natural hazards; (3) Minimize public health risks; (4) Protect and restore healthy ecosystems in a more effective way; (5) Improve the capacity to detect and predict the effects of global climate change on coastal ecosystems; (6) More effectively restore and sustain living marine resources.

To achieve these goals, an informed management for sustainable use of estuarine services requires the capability to routinely and rapidly assess their state and health, detect changes on a broad spectrum of time and space scales, and provide timely predictions of likely future states. Relevant and informed decisions, whether they are concerned with ship routing, beach closures, fisheries management, dredging disposal, or mitigating the effects of an oil spill caused by an accident, require the provision of useful marine data and information at rates tuned to the time scales at which decisions must or should be made. This begs for an integral approach to achieve an appropriate set of priorities in the estuarine zone management that equilibrates ecological and social and economical needs. For the time being this capacity is still in an embryonic stage in most countries.

9 INTEGRATED APPROACHES TO ESTUARINE ECOSYSTEM MANAGEMENT

Estuarine areas, with their overlapping economic interests competing for the same common property resources, are where integrated approaches are most urgently needed. Integrated coastal management usually focuses on three major goals: (1) overcoming the conflicts associated with the sectoral management, (2) preserving the productivity and biological diversity of coastal systems, and (3) promoting and equitable and sustainable allocation of coastal resources (Post and Lundin 1996). The forms of integration required by coastal management have many dimensions. An example is the combination of good science with governance. Being complex systems under significant human pressures, estuaries cannot be managed in the absence of the best available information of both biophysical and social sciences. Marine sciences help characterize problems over time, distinguishing natural and human-related causes of environmental change. When combined with the results of economic and social research, these efforts contribute to innovative management solutions. Another example is the integration among sectors and disciplines. The complex overlay of processes and institutions in estuarine areas makes it impossible for a single agency or entity to meet the challenges of management alone. Success lies in forging partnership among institutions meaning, among other things, to develop an interdisciplinary dialog to achieve a holistic approach to the management of the system.

9.1 The interdisciplinary and cross-sectoral dialog

Decisions concerning water related resources management are too often taken without sufficient scientific and empirical background, addressing only short term and single goals, and ignoring the complexity of processes in aquatic ecosystems (Naiman et al. 1995). Management of socioeconomic interests and associated environmental issues requires practical assessment techniques that should be based on an interdisciplinary approach. An effective management tool should always consider the development of protection policies to reduce impacts on the environment. Developing a fully integrated, multi-disciplinary system for estuarine management has been a particularly challenging task because: (1) it requires systematic monitoring and research activities and these are usually non-existent or primitive at best, and (2) the operational capacity for detecting, assessing and predicting changes in ecosystem health, the sustainability of natural resource and public health risks, is poorly developed.

9.2 A holistic approach to the study of estuarine systems

The recent cooperation between ecologists and water managers has led to attempts to integrate an ecosystem approach into Integrated Water Resources Management (IWRM). The rationale in this approach has been to conceptualize a catchment- or basin-based holistic approach, which takes into consideration the multiple roles of water both in ecosystems and in human socio-economic systems. This involves consideration of terrestrial and aquatic ecosystems and the water links between them, requiring from water managers an understanding of the linkages between water circulation and ecosystems.

Fundamentally, this is a response to the much-criticized fragmented sector-by-sector approach to water-related resource management (aquaculture, sewage disposal, fishing, recreation, etc.). The new paradigm highlights instead the benefits that an integrated, overall approach to water management, on a catchment or basin basis, can deliver. IWRM promotes not just the cooperation across sectors, but also the coordinated management and development of land and water (both surface water and groundwater), so as to maximize the resulting social and economic benefits in an equitable manner, without compromising ecosystem sustainability. It is imperative to address the ecological and socio-economic links in the management of dynamic systems such as estuaries and coastal areas. The Driver-Pressure-State-Impact-Response (DPSIR) model (Bowen and Riley 2003) provides a framework for achieving this. This methodology will be addressed in the next chapter.

10 FINAL REMARKS

Estuarine areas have been and remain in close association with humans. This relation of human dependence on the natural characteristics of estuarine systems implies that these resources have to be managed in ways that guarantee their sustainability, but also in such a way that social and economical structures have viable development targets. Considering the scale of the multiple resource demands imposed on estuaries they, rank among the ecosystems under heaviest (and increasing) pressure. The multiple usage of the goods and services provided by estuarine systems reflects the variety of stakeholder interests and perceptions. To attain a sustainable utilization of estuarine areas and resources requires a far more complicated approach of social, economic and environmental issues, than is the case for purely marine or purely terrestrial environments. The effective use of available information in development planning and management for estuaries depends on an Integrated Water Resources Management strategy. Resource sustainability cannot be detached from the sustainability of human economies, natural communities and ecosystems. Sustainability is a moving target because ecosystems change over time and so do the economic, social and political climates in which decisions are made change. The rate of development of estuarine areas and the resulting environmental impact may largely be determined by the efforts that are devoted to the early detection of environmental problems. Hence, the successful management of estuaries and coastal waters requires a basin-wide management, which considers the river basin as the fundamental unit of territorial management (Zalewski 2002). To pursue this goal means that present practices by official institutions based on municipalities or counties as an administrative unit, or based on managing specific activities must be changed or abandoned altogether. Without these changes and a holistic approach towards the management of these systems, estuaries and coastal waters will continue to be degraded.

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