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Science and Integrated Coastal Management

An Introduction

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THE PROBLEM

Today more than 60% of the world's population lives within a narrow strip of land about 100 km wide along the world's seashore and much more in the entire drainage basins of the coastal seas. Most of the megacities are located near the sea, and urbanization in the coastal zone, and thus population density, is expected to increase in the future. It appears that coastal development together with ongoing protection measures have grown out of control, and the consequent degradation or destruction of the coastal environment continues to increase. It has been estimated, for example, that within the next sixty years, erosion could destroy up to 85,000 houses (not including new development) along the 10,000 miles of U.S. ocean and Great Lake shorelines. The estimated economic cost of this property loss alone is around US$ 410 million per year (Dunn et al. 2000). The problem that we face, therefore, is how can we regain control and mitigate resource degradation to conserve environmental systems and the socioeconomic activity that depends upon them.

BACKGROUND

Three particular characteristics of coastal zones deserve attention: the extreme variability present in coastal systems, the highly diverse nature of such systems, and their valuable

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multifunctionality. The highly diverse and variable environment of the coastal zones is shaped by various processes in the land–ocean interface, such as waves and currents, sediment transport, chemical and biological modifications, and their interactions with the coastal structure. These interactions result in a dynamic equilibrium of the morphology and ecology in the coastal zones and encompass a wide range of spatial and temporal scales. Naturally fertilized by land runoff and atmospheric input, coastal oceans are the most productive realms in the marine biome, yielding high biomass in a large variety of plants and animals.

The rich diversity in "phenotypes" of coastal ocean ecosystems provides a great number of resources for human exploitation, among which food provision and permanent settlement date back to the very early phases of human development. As human societies have increasingly populated the coastal areas, exploitation of resources has become more intense and diverse. In addition to fishing, mining, trade, coastal engineering, and recreation, pressures in the coastal zone which impact coastal seas are linked to sewage and waste disposal due to urbanization, agriculture, and industrialization inland in the drainage basin and are significant. Many effects in the latter categories are in principle reversible within human lifetimes, while overfishing, mining, changes in land use (i.e., wetlands to arable land), and coastal engineering may only be remediated on a long term basis and at a very high cost. Coastal areas are therefore important economic zones supporting billions of livelihoods through flows of income derived from the utilization of the *in situ* natural capital stock and through global trading links. Simultaneously, coastal areas are sociocultural entities, with specific historical conditions and symbolic significances, as well as institutional domains with administrative boundaries that can cross national jurisdictions and which are not coincident with the scales and susceptibility of biogeochemical and physical processes.

Forecasts of economic and demographic growth and development predict dramatic increases in the habitation of coastal areas and in the use of the land–sea interface. These forecasts invariably imply considerable strain on natural resources in the coastal zone, both in the terrestrial and the adjoining marine realm. The added strain may coincide with anthropogenic and natural changes in climate and sea level. In a relatively short time, many coastal zone environments could lose their natural appearance, and their carrying capacity for human exploitation would thus diminish progressively. Intervention in this coevolutionary, jointly determined, ecological and socioeconomic system will need to be carefully undertaken and will require flexible and adaptive projects, policies, programs, and institutions. Management agencies will need to find better ways to manage the causes and consequences of the environmental change process across a range of coastal situations and the connected drainage basins. Given the generic policy goal of sustainable development, management agencies seeking to utilize coastal ecosystems sustainably should be giving a high priority to the maintenance of systems' resilience, i.e., their ability to cope with stress and shock. Such an integrated coastal strategy management, in turn, needs to be based on as good an appreciation of the systems functioning and outputs of economic and sociocultural goods and services, as is feasible.

A key objective is to retain as much coastal functional diversity as is practicable. The management strategy will require the adoption of a relatively wide perspective, in order to understand and potentially manage larger-scale (landscape) ecological processes and relevant environmental and socioeconomic driving forces more effectively. Properties of structures and processes, both natural and socioeconomic, must become subsumed with the change in both spatial and temporal scales. Climate change (from Milankovich cycles to centennial scales), and the accumulation of greenhouse gases (at anthropogenic scales) impact the nature of coastal waters, their drainage basins and the way people make their living in these changing systems. Social and economic parameters also change with the process of market globalization (< decadal scales). This has national macroeconomic consequences, which together with the actions of transnational corporations and institutions will further impinge on use of resources and services from the coastal systems (both littoral and inland).

THE SOLUTION: INTEGRATED COASTAL MANAGEMENT

Most managed ecosystems are complex and their hierarchically organized nature is poorly understood. Coastal and related drainage basin systems and processes pose a particularly complex challenge because of the spatial scales and the degree of complexity and variability in the systems that are involved. In an effort to exert some "control", i.e., reduce risk and overcome uncertainty in the coastal environment, persistent human intervention has in many ways only resulted in a state of permanent disequilibrium or undesired new states of equilibrium. Such a set of environmental conditions, driven by human reclamation and continued protection of intertidal land for economic reasons (and more recently on nature conservation grounds), is arguably more risky to humans and not less so. In the light of these difficulties, capturing the range of relevant impacts on natural and human systems under different management options is and remains a formidable challenge. An interdisciplinary scientific effort is needed to develop methodologies for better understanding and detection of ecosystem change, as well as evaluation of different ecological functions. Modeling work, monitoring of robust indicators for change, and scientific experimentation all need to be integrated more effectively.

Given the current high level of uncertainty and ignorance, the manifold socioeconomic and cultural value, as well as the pressure on coastal systems by conflicting stakeholders interests, many analysts have been advocating a much more integrated and holistic approach to coastal management (Salomons et al. 1999). This steering mechanism should be underpinned by the following interrelated sustainability principles:

- economic and ecological efficiency and the cost-benefit principle (including the "polluter pays" principle), which addresses the practical need to find long-term, cost-effective resource allocation options within the ever-present problem of resource scarcity;
- equity and fairness principle, which encompasses a number of requirements such as the need for more "civic science" in which scientists actively participate in the communication and use of science in the political process as well as more inclusionary processes to engage all relevant coastal stakeholders together with the placement of power and responsibility for planning and decision making at the lowest feasible level of governance (subsidiarity principle);
- the precautionary principle, which gives appropriate recognition to the fact that coastal science and management is and will continue to be conditioned by data and knowledge gaps as well as decision-making systems able to operate in and to adapt to the context of this uncertainty.

As a future goal, integrated coastal management (ICM) is a continuous, adaptive, day-to-day process that consists of a set of tasks, typically carried out by several or many public and private entities (Bower and Turner 1998). The tasks together produce a mix of products, services and other gains/losses of sociocultural significance from the available coastal resources. In principle, the core objective of coastal zone management is the production of a "socially desirable" mix of coastal environmental system states, products, and services. In practice, this mix is subject to intense stakeholder debate and is likely to change over time with changing demands, changing knowledge, and changing pressures.

A future, more integrated, coastal management process should include:

- integration of programs and plans for economic development, environmental quality management, and ICM;
- integration of ICM with programs for such sectors as fisheries, energy, transportation, water resources management, disposal of wastes, tourism, and natural hazards management;
- integration of responsibilities for various tasks of ICM among the levels of government — local, state/provincial, regional, national, international — and between the public and private sectors;
- integration of all elements of management, from planning and design through implementation (i.e., construction and installation), operation, maintenance, and feedback from monitoring and evaluation overtime;
- integration among disciplines, e.g., ecology, geomorphology, marine biology, economics, engineering, political science, law; and
- integration of the management resources of the agencies and entities involved.

In summary, the ICM process must aim to unite government and the community, science and management, as well as sectoral and public interests. It should *inter alia* improve the quality of life of human communities who depend on coastal resources while maintaining the biological diversity and productivity of coastal ecosystems (GESAMP 1996: Figure 1.1), and therefore the functioning of nature. Clearly, this is a formidable task, one that will only be achieved incrementally over time.

The formulation and implementation of ICM will depend on advances in transdisciplinary research and knowledge. The ultimate goal of integrated coastal zone management is to produce a set of products and services that allows the maximum net benefits for the society over as long a period of time as possible. A consensus on what constitutes a net societal benefit and the values that are implied is most likely to emerge from changes in the interests and priorities of society, as interpreted by political institutions and reflected in legislation, policy statements, principles, rules, regulations, and last but not least from advancing knowledge about ecosystem functioning and behavior. Besides regional and national economic and political activities, cross-border impacts, trade policies and international conventions also have to be considered in this context.

A prerequisite for institutional advances is a more rigorous use of current knowledge and an increase in scientific knowledge about coastal problems and their nature as well as methodologies that will help to define, analyze, and mitigate problems. For science, a novel and challenging area is emerging, where the need is clear but the appropriate approach is less clear. This Dahlem Workshop provided a platform for assembling the required expertise in environmental, cultural, social, and economic science to discuss and define a transdisciplinary approach and new scientific products in the framework of integrated coastal zone management.

GOALS AND RATIONALE FOR THE DAHLEM WORKSHOP

The overall goal of our Dahlem Workshop was to strengthen the effective use and communication of scientific knowledge in the integrated coastal management policy process. To meet this objective, it was perceived that there was a need to analyze the scientific requirements of ICM and to develop a strategy for a transdisciplinary approach to identify the problems and their nature, to find solutions, and to formulate products that could be used as guidelines for valuation, assessment, and policy making. A further step is to transfer such products by more intensified communication. "Science cannot provide the solutions, but it can help understand the consequences of different choices" (Lubchenco 1998). Thus, transfer of relevant scientific knowledge must be understandable to nonscientists involved in ICM.

The analysis of the scientific needs had to take into account the fact that present knowledge about the natural dynamics of the coastal environment and socioeconomic processes is limited, as is the knowledge about the interaction between these processes. Together with the natural dynamic equilibrium between coastal ecological systems and land–ocean processes, the balance between socioeconomic and natural processes is the new comprehensive scientific context for ICM. Thus, ICM cannot just be based on stringent scientific predictions but will have to cope with both social and scientific uncertainties. Furthermore, traditional values and perceptions existing on local to regional scales serve more often as a basis stakeholder decisions than do facts and figures. It was realized that there was an urgent need for definitions of the new role of "civic science" and identification of important scientific tasks to be conducted in ICM, accepting that a certain degree of uncertainty will always be present. A further need of equal importance is to decide whether uncertainty should be communicated to all interested parties and by what means this can be done.

The combined effects of socioeconomic and environmental changes clearly require an overall framework to investigate the interaction between environmental, social, economic, and institutional subsystems as well as to identify crucial processes and interactions. Difficulties inhibiting the formulation and implementation of an acceptable framework and its deployment are manifold: the diversity in phenotypes of coastal ecosystems and thus in their functional value, regional, and national differences in socioeconomic developmental stages, the pace of development and cultural constraints on social and environmental attitudes. Another major analytical challenge to overcome is the different temporal and spatial scales on which these subsystems react and interact, and thus the different required scales of prediction. Considerable changes in socioeconomic development can emerge within relative small spatial scales at the shoreline, for example, whereas the reaction of the marine system is influenced by changes and systems operating much larger scales. Not every coastal problem will require a fully integrated approach. However, generic strategies focused around a core of sound interdisciplinary science must be the basis for any future adaptive and inclusionary coastal management strategy.

A FRAMEWORK FOR MULTIDISCIPLINARY RESEARCH

Some analysts have questioned the entire rationale of ICM. According to Nichols (1999) ICM is actually an attempt to reorganize coastal spaces and political systems for the purpose of facilitating investment penetration by governments and/or transnational corporations. The consequence (particularly in developing countries) is the political and spatial marginalization of pre-existing resources users. To address this equity issue and others, ICM has to be more than just a process by which efficient utilization of coastal resources is promoted. Olsen et al. (1997) have strongly argued that the fundamental challenge of coastal management is one of governance (objective, process, and structures) and not of technology transfer or refined scientific knowledge alone. They recommend a learning-based approach to coastal management, which assumes that such intervention is a young endeavor inevitably beset by uncertainties, instability, and rapid rates of change. It follows that progress towards effective coastal management and sustainable forms of coastal development will only come incrementally, through analysis and experience learning over decades. A learning-based approach calls for framing coastal management initiatives as experiments and subjecting them to formal scientific testing analysis.

According to GESAMP (1996) there are five consecutive stages forming an ongoing, interactive ICM process. The process itself may go through a number of cycles before the program is sufficiently refined to produce effective results (Figure 1.1). Thus in Stage 1 of the GESAMP cycle, natural and social scientists together need to compare problem issues in the light of their different methodologies, models, and value systems (the science challenge for ICM). A consensus on a common set of pressures/problems issues needs to be established. Any gaps in scientific knowledge, their likely consequences for ICM, and the practicable possibilities for their mitigation within an acceptable time frame also need to be addressed.

The GESAMP cycle offers an excellent tool to evaluate the contribution of science as well as the most urgent needs for society that should be addressed by analysts according to their importance in the ICM policy cycle. In order to grasp the many issues, problems, and disagreements surrounding the scientific analysis, valuation, and management of coastal and related drainage basin resources, a more detailed, practical framework may be adopted. This is the organizational and auditing Drivers-Pressures-State-Impact-Response (D-P-S-I-R) approach, which although simple is flexible enough to be conceptually valid across a range of spatial scales. It also serves to highlight the dynamic characteristics of ecosystem and socioeconomic systems changes, involving multiple feedbacks with a coevolutionary process of change (Figure 1.2).

For any given coastal area (defined to encompass the relevant drainage area), there exists a spatial distribution of socioeconomic activities and related land uses: urban, industrial mining, agriculture, forestry, aquaculture, fisheries, commercial, and transportation. This spatial distribution of human activities reflects the final demand for a variety of goods and services within the defined area and from outside the area. Environmental pressure builds up via these socioeconomic driving forces and is augmented by natural systems variability, which leads to changes in environmental systems states and finally to the loss of goods and services.

Production and consumption activities result in different types and quantities of residuals as well as goods and services measured in gross national product (GNP) terms. Thus the concern might be, for example, the role and extent of changes in C, N, P, and sediment fluxes as a

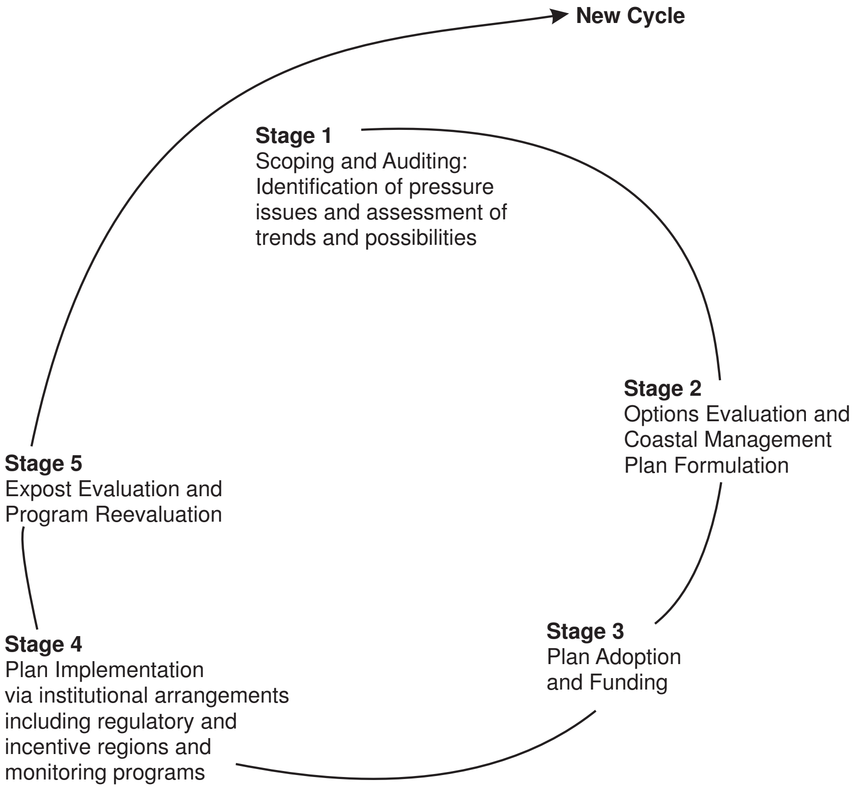

Figure 1.1 ICM program cycle (adapted from GESAMP 1996; see also Olsen, this volume).

result of land-use change and other activities. Conceptually what we have are a multiplicity of input–output (I–O) relationships, where outputs are joint products (combinations of goods and services and nonproduct outputs or residuals, which if not recycled become waste emitted/discharged into the ambient environment). I–O relationships will operate at the individual industrial process/plant level, through population settlements, agricultural cropping regimes/practices, and up to regional drainage basin scale. These residual estimates will then serve as the input to the natural science models, such as nutrient budgets. Environmental processes will transform the time and spatial pattern of the discharged/emitted residuals into a consequent short-run and long-run time and spatial ambient environmental quality patterns.

These state environmental changes impact on human and nonhuman receptors, resulting in a number of perceived social welfare changes (benefits and costs). Such welfare changes provide the stimulus for management action, which depends on the institutional structure, culture/value system, and competing demands for scarce resources and for other goods and services in the coastal zone. Within its analytical framework, an integrated (modeling) approach will need to encompass the socioeconomic, biogeochemical, and physical drivers that generate the spatially distributed economic activities and related ambient environmental quality to provide information on future environmental states.

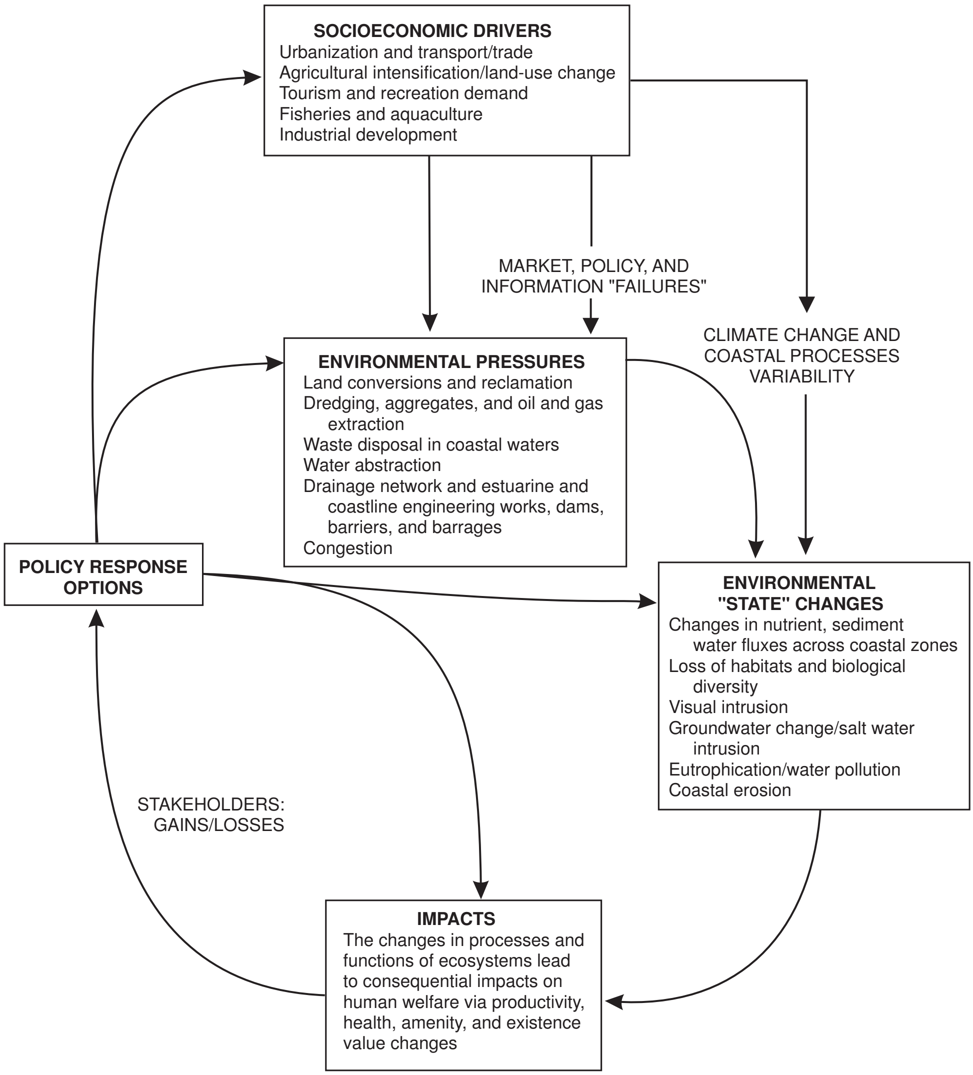

Figure 1.2 D-P-S-I-R framework: Continuous feedback process in coastal areas (Turner, Lorenzoni et al. 1998).

At the core of this interdisciplinary analytical framework is a conceptual model, based on the concept of functional diversity, which links ecosystem processes, composition, and functions with outputs of goods and services, and can ultimately be assigned monetary economic and/or other values (Figure 1.3). A management strategy based on the sustainable utilization of coastal resources principle should have at its core the objective of ecosystem integrity maintenance, i.e., the maintenance of system components, interactions among them and the

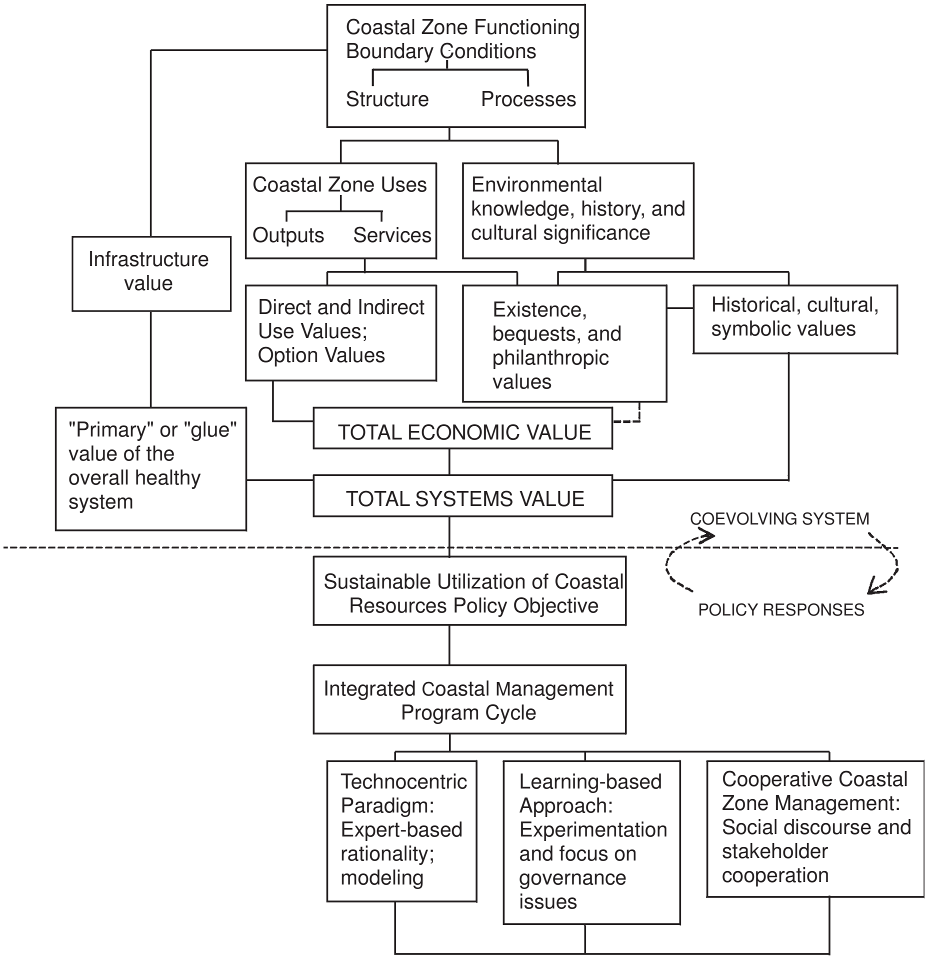

Figure 1.3. Functional and other dimensions of coastal zone values (Turner et al. 2000).

resultant dynamic behavior of the system. Functional diversity can then be defined and possible changes in functional diversity evaluated by the variety of responses to environmental change, in particular the variety of spatial and temporal scales with which organisms react to each other and to the environment. Marine and terrestrial ecosystems differ significantly in their functional responses to environmental change, and this will have practical implications for management strategies. Thus, although marine systems may be much more sensitive to changes in their environment, they may also be much more resilient (i.e., more adaptable in terms of recovery response to stress and shock). The functional diversity concept encourages analysts to take a wider perspective and examine changes in large-scale ecological processes, together with the relevant environmental and socioeconomic driving forces. The focus is then on the ability of interdependent ecological–economic systems to maintain functionality under a range of stress and shock conditions.

In Stage 2 of the GESAMP cycle (Figure 1.1), the characteristics and conditions of coastal systems that cause concern or otherwise warrant attention need to be analyzed. The scale of any habitat destruction needs to be determined together with the supporting natural processes, their linkages to habitats, and their recovery times. At this stage, the concepts of ecological integrity and functional diversity need to be operationalized. Given the overall policy objective of sustainable utilization of coastal resources, the pressure to state and stage changes to human welfare impacts in the D-P-S-I-R approach need to quantified and evaluated as comprehensively as is practical (Figure 1.3). The particularly difficult questions of the mismatch of spatial and temporal scales need to be tackled in a pragmatic but rigorous fashion, as the analysis moves from natural systems dynamics to the socioeconomic and politico-cultural realms. Keystone processes and functions, when and if they are identified, may need to be subject to a "no net loss" regulation, the cost-benefit implications of which will require examination. Multi-criteria decision support systems will be required to tackle the multiple use conflict situations that will almost inevitably arise. Futures scenario analyses based on growth rate projections and/or ecosystem management strategies can play an important role in this stage.

In Stages 3 and 4 of the cycle, the formal adoption of an ICM plan will require a reaffirmation of the cost-benefit and decision analysis work by new institutional arrangements. Monitoring of the rate and extent of change in the coastal area will be essential, as will enforcement systems (the governance challenge of ICM).

In Stage 5, natural and social scientists should evaluate the relevance, reliability, and cost-effectiveness of scientific information generated by research and monitoring and advise on the suitability of control data. These results should then be compared to a scenario without ICM (GESAMP 1996; Bower and Turner 1998).

Progress through the ICM policy cycle will also be conditioned by the degree to which "accountability" and "trust" issues are successfully tackled. No process of ICM can produce legitimate answers (and effective solutions) to the challenges posed without meaningful public participation. The public must be incorporated in a proactive, participatory, and conflict minimizing fashion. Davos (1998) believes that if ICM is crucially dependent on the voluntary cooperation of stakeholders, this raises doubts about the value of positivistic or normative ICM prescriptions in the absence of consensus. He argues that the alternative is to pursue a "cooperative coastal zone management" approach, which would rely on social discourse as its defining property. Such discourse also needs a guiding framework to facilitate the achievement of cooperative collective decisions. There is a need to establish "windows of opportunity" where policy, politics, and participants can operate together to set the sustainable resource utilization agenda and to implement it effectively (Davos 1998).

WORKING GROUP STRUCTURE AND DISCUSSION FOCI

Drawing on the GESAMP–ICM policy cycle and the D-P-S-I-R framework, background papers and discussions in the four working groups addressed the following themes/topics at this workshop:

- transboundary issues,
- shoreline development,

- integrated coastal management in developing countries,
- unifying concepts for ICM.

By addressing a variety of environmental pressures (such as land-use change in the drainage basin, habitat degradation, conflicting developments of shorelines, the role of climate change, and the persistence of resource overexploitation), the discussion groups analyzed the scientific requirements of ICM. They also sought to develop a transdisciplinary approach to identify problems, solutions, and formulate products for use in valuations, assessment, and policy meetings.

The background papers provide information about the stages of ICM in a variety of case studies. In more general terms, they discuss how to improve the use of science in the various stages of the ICM process.

In background papers and group reports, the following issues were addressed:

- methods for communicating the state of the coastal environment to the public and decision makers, including the issues of responsibility, persuasiveness, and trust (see, e.g., Boesch, de Vries, and McGlade, all this volume),
- illustration of the potential magnitude and socioeconomic consequences of anthropogenic-induced change in coastal systems (e.g., Elmgren and Larsson, Boesch, Mee, Colijn and Reise, Sarda, Pethick, Meybeck, and Deegan et al., all this volume),
- estimation of the consequences and costs of less integrated approaches compared to the possible benefits of implementing an ICM policy cycle (e.g., Crossland and Kenchington, and O'Toole et al., both this volume),
- forecasting ecosystem changes and their long-term consequences (e.g., de Vries, Meybeck, and Olsen, all this volume),
- gaining a better scientific understanding of feedbacks for the adaptive approach to management (Boesch, Olsen, Deegan et al., all this volume)
- monitoring requirements for the assessment of management results across different spatial scales and time spans.

SOME GENERAL IMPRESSIONS FROM THE DISCUSSIONS

Detailed summaries and outcomes from the four discussion groups are presented in the group reports (Jickells et al.; Schwarzer et al.; Richter et al.; Emeis et al., all this volume). Here, we present some general impressions from the workshop, which in actuality may be indicative of the ICM process itself.

As a whole, workshop participants represented a wide range of high quality expertise in the field of natural and socioeconomic sciences as well as in policy making. Initial discussions were characterized, however, by a high level of generality. This was probably due to the diversity of the different perceptions of ICM. Some participants considered ICM as an organizational endeavor, in which the core objective is to organize stakeholders and define rules for good management practices. In this sense, ICM is regarded as process management that needs to be made more inclusionary in order to deal with competing interests and power relationships. Another group of participants looked at ICM from a technocratic point of view. Here, the aim was to optimize resource exploitation with concomitant conservation of the environment. Solutions for decoupling economy from ecology appeared to be paramount from this perspective.

Such diversity in basic approach led to different opinions on how to achieve the conference objectives – improved effectiveness and communication of science in ICM. The former group put much more emphasis on the development of appropriate communication, whereas the latter focused more on improving the effectiveness of science-based solutions in ICM. This difference in foci probably reflects the existing ambiguity about the role of science in ICM, which often creates a division between coastal managers and coastal scientists. Such polarization was also reflected in the different perception of what was the limiting factor to more efficient progress in ICM: the low capacity to practice coastal governance at local, national, and regional levels or the insufficient knowledge about the functioning of the natural environment. It appeared that most participants came with a preconceived notion that the latter was the reason for slow progress. Only a few background papers defined the coastal ecosystem as comprising both the "natural environment" and the human societies living therein (Ngoile et al. and Olsen, both this volume). Nevertheless, by the end of the workshop, there was much more agreement that this definition was most appropriate and that the lack in governance capacity may be as, or more, serious for ICM than the gaps in scientific knowledge (Emeis et al., this volume).

This conclusion was further underlined by the recognition that in reality important stakeholders are often disempowered. Simple participation itself does not necessarily resolve this problem as power relationships can be complex and often informal alliances control how decisions are made (Lacerda et al.; Talaue-McManus; Ngoile et al., Richter et al., this volume).

Thus, a great deal of discussion time was devoted to attempts to reduce the difference between the various mind-sets, or at least to make a strong case that a considerable change in the more narrow way of thinking (mind-sets) was overdue. Further points of emphasis in the debate highlighted the issues of uncertainty, the experimental character of the ICM policy cycle, and the lack of incentives for scientists to join the policy cycle in all phases (see also Healey and Hennessy 1994; Emeis et al., Jickells et al.; Richter et al., and Schwarzer et al., all this volume).

The discussions about uncertainty and whether and/or how to convey it were illuminated through an assessment of different categories of uncertainty. McGlade (this volume) suggests two fundamentally different kinds of uncertainty: measurable uncertainty and ignorance. Measurable uncertainty is derived from "error bars," imprecision, and averaging over space and time, while ignorance is based on gaps in knowledge, i.e., things we do not know about or understand. Further uncertainty stems from complex model predictions (Boesch and Deegan et al., both this volume). In models, uncertainty stems from errors in measurements and understanding. Ignorance and errors may be partly reduced by the acceptance and continuous evaluation of differing opinions and by increasing appreciation of indigenous/traditional ecological knowledge (see also Berkes et al. 2000).

The ambitious but key requirement for a future, more sustainable coastal zone management is that both scientists and managers need to be involved in a continuous interactive process, such that scientists gain a better appreciation of policy formulation and implementation while managers/users better understand the functioning and variability of natural systems and the consequences of socioeconomic activities. Fisheries policies in most countries have reflected the schism between science and users. It has not been straightforward for scientists to relate their science to the various stages in the policy cycle, and for policy makers to recognize what science is needed or what scientific results have to be incorporated at which time in the policy cycle. However, if science and management proceed as largely unrelated endeavors, science and scientists may be directly involved in some stages of ICM but excluded from others. Traditionally, science has had most influence in the "issue identification/assessment" and "program preparation" stages, whereas its participation has been weak to nonexistent in later stages. No real-world examples of complete integration throughout the whole policy cycle came to light during the discussions. The cases of the management of Chesapeake Bay and the Baltic Sea come closest to this situation, but in the majority of cases, the policy cycle has not been moving beyond its early stages.

Many scientists, particularly natural scientists, are hesitant to communicate uncertainty to the public or to policy makers, as they fear that their advice will not be taken seriously. However, conference participants clearly recognized that the problem of uncertainty should not be exclusively used to ask for new science, rather that scientists should give advice based on what is known, even when this may be minimal. From the discussions it also emerged that efforts to constrain the communication of uncertainty are not justified. A striking example is the recent measures belatedly taken by governments and accepted by the public to reduce the risk of BSE, which are based on little knowledge on the pathways of infection from cattle to humans and on little quantitative information of the risks taken by consuming beef.

Most participants agreed that ICM should adopt subsidiarity and precautionary principles and should choose adaptive management as the natural way to promote ICM. In this context, scientists may be more willing to participate in all stages of the public policy cycle, as they can expect that the scientific method, testing hypothesis, will be applied more frequently. Each ICM policy cycle would appear as a part of an ongoing experiment to achieve a sustainable use of the natural resources. Choices to be taken can be underpinned with risk assessments, and predictions can be presented in "what if" scenario models (Boesch, Deegan et al., and Emeis et al., all this volume).

A largely unresolved problem which inhibits the fuller engagement of scientists in ICM is related to measurement of scientific success by different standards: peer review sets the standard within the science community. The wider practical value of science is considerably undervalued, and there is a danger that striving for scientific excellence without reference to social benefit and vice versa may lead to an ineffective use of science in ICM. The review system should be broadened and institutions should set aside funds for awards for excellent fundamental science together with its appropriate application (Richter et al., this volume).

It was acknowledged that the discussions brought new insights into the problems of using and communicating science in ICM. The background papers present the failures and successes of ICM (in many case studies) while the group reports compile sets of recommendations designed to overcome these problems. It was also recognized that a mixed group, like the one assembled for this Dahlem Workshop, is needed to focus on more specific unresolved issues in ICM, such as indicators and indices of coastal change (Olsen, this volume), as well as estimations of and use of background values to meet the requirements of the various legal directives set by national and international bodies. Furthermore, in the future it would be useful to bring together periodically (5–10 years) a mixed group of experts to focus more narrowly on a particular societally important issue (e.g., eutrophication of coastal waters, land use, shoreline destruction) to evaluate what is and is not known, as well as the implications of that state of knowledge for society. The usefulness of such an approach has been shown impressively by the activities of the International Panel for Climate Change on global warming.

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