

Assessment of Coastal Vulnerability to Climate Change

The UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies provides an elaboration of the IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. This paper presents the concepts and ideas that underpin the chapter *Coastal Zones* of the UNEP Handbook. Particular emphasis is given to the conceptual framework, which is centered around the concept of vulnerability. Further, the IPCC Common Methodology for Assessing Coastal Vulnerability to Sea-Level Rise is evaluated and compared with the Technical Guidelines. One notable difference between the 2 approaches concerns the use of scenarios. In the Common Methodology scenarios are prescribed, while the Technical Guidelines allow users maximum freedom in selecting and developing scenarios. Finally, the paper discusses 3 levels of increasingly complex assessment in coastal zones. As more experience is acquired, coastal databases improve and better analytical tools and techniques are developed, more comprehensive and integrated assessments will become feasible.

INTRODUCTION

Coastal zones are considered to be highly vulnerable to the effects of climate change, including sea-level rise (1), and since 1990 a number of major efforts have been made to develop guidelines and methodologies to assess this vulnerability. In 1992, the former Coastal Zone Management Subgroup of the Intergovernmental Panel on Climate Change (IPCC) published its latest version of a Common Methodology for Assessing the Vulnerability of Coastal Areas to Sea-Level Rise (2). More recently, the IPCC developed Technical Guidelines for Assessing Climate Change Impacts and Adaptations (3). These guidelines offer a generic framework, consisting of 7 main steps of analysis, which is designed to be applicable to any natural and socioeconomic system potentially affected by climate change.

Based on these generic IPCC Technical Guidelines, the United Nations Environment Programme (UNEP) recently published a Handbook that provides an elaboration of the guidelines for 9 important physiographic systems and socioeconomic sectors, including coastal zones (4). The Handbook is envisaged to provide practical guidance to country studies that in accordance with the Framework Convention on Climate Change aim to assess the potential consequences of climate change and identify options to respond to these effects.

After summarizing the nature of the challenge that coastal zones face given sea-level rise, this paper first presents an evaluation of the IPCC Common Methodology, and indicates the main

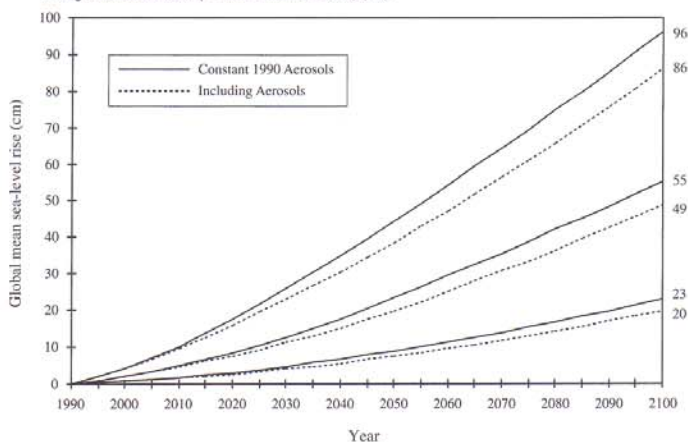
differences with the IPCC Technical Guidelines. Next, this paper presents the conceptual framework for vulnerability assessment of coastal zones to sea-level rise, as suggested by Klein and Nicholls (5). This framework has been developed based on a combination of (i) the Common Methodology and similar approaches (6, 7), including the practical experience gained with the execution and evaluation of more than 45 vulnerability assessment studies, and (ii) other methods for coastal vulnerability assessment, which have been developed in response or in addition to the Common Methodology (8, 9). This is followed by a brief introduction of 3 levels of coastal vulnerability assessment. Finally, the relevance of vulnerability assessment to integrated coastal zone management is discussed.

THE NATURE OF THE CHALLENGE

Unlike many other anticipated consequences of climate change, global sea-level rise is already taking place. Over the last 100 years, global sea level rose by $1.0\text{--}2.5\text{ mm yr}^{-1}$ (10). Present estimates of future sea-level rise induced by climate change, as presented in the IPCC Second Assessment Report and shown in Figure 1, range from 20 to 86 cm for 2100, with a best estimate of 49 cm (including the cooling effect of aerosols) (10). Moreover, model projections show that sea level will continue to rise, although at a slower rate, beyond 2100, owing to lags in climate response, even with assumed immediate stabilization atmospheric of greenhouse-gas emissions (11). Dynamic ocean effects may also be important, as they will lead to regional variability in absolute changes to sea level. However, they cannot yet be modelled and predicted with confidence (10).

When assessing impacts of sea-level rise, it is the local change (or rate of change) in relative sea level that matters, not the global or regional average. Relative, or observed, sea level is the level of the sea relative to the land. While it is affected by absolute changes in sea level, relative sea level is also influenced by ver-

Figure 1. Projected sea-level rise for the period 1990–2100, using scenario IS92a (~ Business-as-Usual) (10).



tical movements of the land, which are regionally and locally variable. These vertical movements are mostly natural phenomena, but human activities may be important as well. First, extraction of water and hydrocarbon can induce or enhance subsidence of coastal lowlands. In specific regions, this subsidence can equal or exceed the abovementioned projected global sea-level rise (12). Often-quoted examples of cities that have subsided as a result of groundwater exploitation include Venice, Italy; Bangkok, Thailand; Shanghai, China; and Tokyo, Japan. Second, removal or reduction of sediment supplies in deltas makes natural subsidence more apparent, as it inhibits compensating accretion. Third, in reclaimed coastal lowlands, oxidation of peat can lead to large declines in land level.

Irrespective of the primary causes of sea-level rise—climate change, natural or human-induced subsidence, dynamic ocean effects—natural coastal systems can be affected in a variety of ways. From a societal perspective, the 6 most important biogeophysical effects are: increasing flood-frequency probabilities; erosion; inundation; rising water tables; saltwater intrusion; and biological effects (5).

Owing to the great diversity and variation of natural coastal systems and to the local and regional differences in relative sea-level rise, the occurrence of and response to these effects will not be uniform around the globe. Therefore, vulnerability studies first need to analyze the extent to which the above effects will occur in the study area before the potential socioeconomic impacts can be assessed. The potential socioeconomic impacts of sea-level rise can be categorized as follows:

- direct loss of economic, ecological, cultural and subsistence values through loss of land, infrastructure and coastal habitats;
- increased flood risk of people, land and infrastructure and the above-mentioned values; and
- other impacts related to changes in water management, salinity and biological activity.

Table 1 lists the most important socioeconomic sectors in coastal zones, and indicates from which biogeophysical effects they are expected to suffer direct socioeconomic impacts. Indirect impacts, e.g. human-health impacts resulting from deteriorating water quality, are also likely to be important to many sectors, but these are not shown in Table 1.

Ideally, coastal vulnerability assessment would provide detailed quantitative estimates for each type of impact depicted in Table 1, as well as for all the indirect impacts. However, this would require optimal knowledge of the spatial and temporal dynamics of the 6 biogeophysical effects that trigger the impacts. In addition, it assumes that impacts of climate change can be readily distinguished from those that arise from other, natural or socioeconomic, developments. Present-day knowledge of coastal responses to multiple stresses, however, does not yet allow one to make this distinction. Especially in areas where data are limited, incorporating nonclimatic changes that interact with sea-level rise in impacting coastal zones could increase uncertainty and thereby the usefulness of assessments. Therefore, simplifying

assumptions need to be made, and the results need to be interpreted with these assumptions in mind.

THE IPCC COMMON METHODOLOGY AND THE IPCC TECHNICAL GUIDELINES

Vulnerability to impacts is a multi-dimensional concept, encompassing biogeophysical, economic, institutional and sociocultural factors. Vulnerability is usually considered to be a function of a system's ability to cope with stress and shock (13, 14). In line with this, vulnerability of coastal zones has been defined as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise" (2). Thus, vulnerability assessment includes the assessment of both anticipated impacts and available adaptation options.

Knowledge of vulnerability enables coastal scientists and policy-makers to anticipate impacts that could emerge as a result of sea-level rise. It can thus help to prioritize management efforts that need to be undertaken to minimize risks or to mitigate possible consequences. In view of the high natural and socioeconomic values that might be threatened and/or lost in coastal zones, it is therefore important to identify the types and magnitude of problems that different coastal areas may have to face, as well as identify possible solutions. In some cases, assistance may be needed to overcome these problems.

The Common Methodology was drafted to assist countries in making first-order assessments of potential coastal impacts of and adaptations to sea-level rise (2). Studies based on this methodology have served as preparatory assessments, identifying priority regions and priority sectors and providing a first screening of possible measures. The Common Methodology comprises 7 consecutive analytical steps that allow for the identification of populations and resources at risk, and the costs and feasibility of possible responses to adverse impacts.

Like Common Methodology, the Technical Guidelines consist of 7 steps. However, as is shown in Figure 2, they are not identical. In large part, this reflects the fact that the Common Methodology was developed specifically for application in coastal zones, whereas the Technical Guidelines have been designed to serve as a more generic framework for any natural or socioeconomic system. Therefore, some of the steps outlined in the Technical Guidelines do not appear in the Common Methodology. For example, the definition of the problem and the selection of the method are Steps 1 and 2 of the Technical Guidelines, while they are only implied in the Common Methodology. Testing the method is also not included as an explicit step in the Common Methodology, although the wide application of the Common Methodology and other similar approaches has allowed for extensive evaluation (15–17). Further, the assessment of autonomous adjustments is considered explicitly in the Technical Guidelines, but not in the Common Methodology. The final step of the Technical Guidelines, the evaluation of adaptation strategies, is again made up of 7 consecutive steps, which approximate Steps 5, 6 and 7 of the Common Methodology.

Table 1. Qualitative synthesis of direct socioeconomic impacts of climate change and sea-level rise on a number of sectors in coastal zones.

Sector	Biogeophysical effect					
	Flood frequency	Erosion	Inundation	Rising watertables	Saltwater intrusion	Biological effects
Water resources			✓	✓	✓	✓
Agriculture	✓		✓	✓	✓	✓
Human health	✓		✓			✓
Fisheries	✓	✓	✓		✓	✓
Tourism	✓	✓	✓			✓
Human settlements	✓	✓	✓	✓		

In conclusion, the Technical Guidelines are outlined in a similar fashion to the Common Methodology, but less steps are implied and less prior knowledge is assumed. Further, the Common Methodology is prescriptive in the choice of scenarios, but gives little detailed discussion of specific tools and techniques to conduct the actual analysis. In following the 7 steps of the Technical Guidelines, Klein and Nicholls present a range of alternative tools and techniques that can be employed in identifying coastal vulnerability, and discuss these in detail (5). Thus, users can select those tools and techniques that are most appropriate for their specific situation. Scenarios may be selected in a similar fashion, thereby allowing for sensitivity analysis.

In spite of these differences, it is important to realize that no other methodology to assess coastal vulnerability has been applied as widely and evaluated as thoroughly as the Common Methodology. It is, therefore, meaningful to learn, as far as possible, from the strengths and weaknesses that have thus been identified, as these may also be relevant to the Technical Guidelines. The Common Methodology has contributed to understanding the consequences of sea-level rise and encouraged long-term thinking about coastal zones. Nonetheless, a number of problems have been identified. These problems can be summarized as follows (16, 17):

- Many case studies that have used the Common Methodology have faced a shortage of the accurate and complete data necessary for impact and adaptation assessment. In particular, it has often been difficult to determine accurately the impact zone in many countries owing to the lack of basic data, such as the coastal topography.
- Many studies have been directed towards a single global scenario of sea-level rise (1 m by 2100), often owing to a lack of more detailed data on coastal elevations, while most studies have ignored the spatial distribution of relative sea-level rise and other coastal implications of climate change, owing largely to a lack of regional climate scenarios.
- Although the Common Methodology encourages researchers to take into account the biogeophysical response of the coastal system to sea-level rise, lack of data and models for describing the complicated nonlinear coastal processes have hindered detailed quantitative impact assessment. Many case studies have carried out a simple linear, first-order assessment by shifting the coastline landward by an amount corresponding with the sea-level rise scenario.
- As to adaptation, the Common Methodology has been less effective in assessing the wide range of technical, institutional, economic, and cultural elements present in different localities. There has been concern that the methodology stresses a protection-orientated response, rather than consideration of the full range of adaptation options.
- Market-evaluation assessment frameworks, as applied in the Common Methodology, have proved inappropriate in many subsistence economies and traditional land-tenure systems.

Unfortunately, these problems are quite fundamental for any approach to vulnerability assessment and cannot be solved overnight. Therefore, the Technical Guidelines only represent one step in an ongoing process, rather than an endpoint. In the immediate future, a more comprehensive effort should be made to develop tools and techniques that more readily meet the requirements of vulnerability assessment in an environment as dynamic

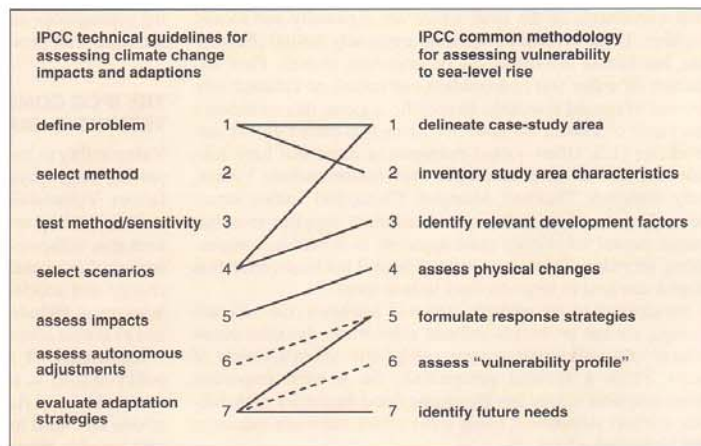


Figure 2. The IPCC Technical Guidelines (3) and the IPCC Common Methodology (2) compared.

as the coastal zone. In particular, more attention will have to be given to the effects of changing frequencies, intensities and areal occurrences of extreme weather events. At this stage, however, climate models cannot give conclusive results as to the direction and magnitude of such changes (18). Further, vulnerability assessment for sea-level rise needs to be integrated with present-day coastal zone management practices. This will allow consideration of the direct effects of human activities on the vulnerability of coastal zones, as these activities strongly influence how impacts of sea-level rise will become manifest (19).

A CONCEPTUAL FRAMEWORK FOR VULNERABILITY ASSESSMENT

As discussed below, one can distinguish between natural-system vulnerability and socioeconomic vulnerability to climate change, even though they are clearly related and interdependent. Figure 3 shows a conceptual framework for coastal vulnerability assessment that makes this distinction explicit. This framework helps to define the various concepts involved in vulnerability assessment and shows how these are related. Thus, it can be considered to be a visual glossary that aims to avoid the confusion of terms that has developed in the literature. The terminology applied in this framework is used consistently by Klein and Nicholls (5), who aim to provide guidance in identifying both types of vulnerability and consequent biogeophysical effects and socioeconomic impacts.

As shown in Figure 3, both types of vulnerability are clearly related, and proper analysis of socioeconomic vulnerability to sea-level rise requires prior understanding of how the natural system would be affected. Hence, analysis of coastal vulnerability always starts with some notion of the natural system's *susceptibility* to the biogeophysical effects of sea-level rise, and of its natural capacity to cope with these effects (*resilience* and *resistance*). Susceptibility simply reflects the coastal system's potential to be affected by sea-level rise, e.g. a subsiding delta versus an emerging fjord coast, while resilience and resistance determine the system's stability in the face of possible perturbation. As applied in ecology, resilience describes the speed with which a system returns to its original state after being perturbed, while resistance describes the ability of the system to avoid perturbation in the first place (20). Susceptibility, resilience, and resistance together determine the coastal system's *natural vulnerability* to biogeophysical effects of sea-level rise.

Resilience and resistance are functions of the natural system's

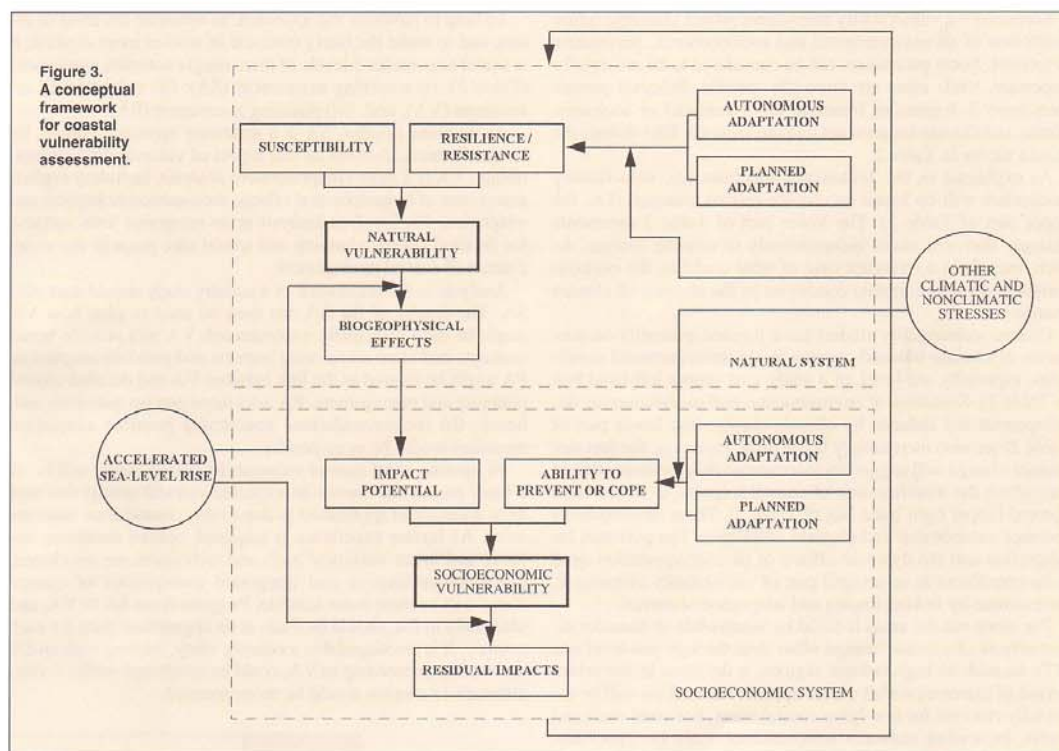


Table 2. Examples of the 4 different types of scenarios that can be used in coastal vulnerability assessment.

	Environmental changes	Socioeconomic developments
Climate-induced	Accelerated sea-level rise Changes in rainfall patterns Changes in sea-surface temperature Changes in wind and wave patterns El-Niño-related changes Sediment-budget changes	Autonomous adaptation Planned adaptation
Not climate-induced	Vertical land movement Sediment-budget changes	Population changes Land-use changes Changes in gross domestic product

capacity for *autonomous adaptation*, which represents the coastal system's natural adaptive response to sea-level rise. As opposed to susceptibility, which is largely independent of human influences, resilience and resistance are often affected by human activities. The effect of human activities need not only be negative: *planned adaptation* can serve to reduce natural vulnerability by enhancing the system's resilience and resistance and thereby adding to the effectiveness of autonomous adaptation.

The biogeophysical effects of sea-level rise are likely to give rise to a range of potential socioeconomic impacts. This *impact potential* is the socioeconomic equivalent of the natural system's susceptibility, although now it clearly is dependent on human influences. In parallel with a coastal zone's natural vulnerability, which is a function of susceptibility and resilience/resistance, *socioeconomic vulnerability* is determined by the impact potential and society's technical, institutional, economic and cultural *ability to prevent or cope* with these impacts; i.e., its capacity to adapt within the timescale of natural changes. As with the natural system's resilience and resistance, the potential for au-

tonomous adaptation and *planned adaptation* determines this ability to prevent or cope (cf. 21).

Finally, it is important to acknowledge the dynamic interaction that takes place between natural and socioeconomic systems. Instead of being considered as 2 separate systems that exist independently of each other, natural and socioeconomic systems are increasingly viewed as developing in a co-evolutionary way (22). This co-evolution is shown in Figure 3 by the feedback loop from the socioeconomic system to the natural system.

SCENARIOS FOR VULNERABILITY ASSESSMENT

The occurrence and magnitude of coastal impacts of sea-level rise will be a function of a number of future environmental and socioeconomic developments. The future is, by definition, uncertain, so plausible scenarios must be constructed to assess these potential impacts. It is important to consider uncertainty by constructing more than one scenario for each relevant parameter, thus allowing for sensitivity analysis.

Scenarios for vulnerability assessment reflect plausible future conditions of all environmental and socioeconomic parameters of interest. Some parameters can be considered to be universally important, while other are more site-specific. Relevant parameters have 2 degrees of freedom: environmental or socioeconomic, and climate-induced not climate-induced. This defines the matrix shown in Table 2.

As explained in the Technical Guidelines (3), vulnerability assessment will be based on climate-related changes, (i.e., the upper part of Table 2). The lower part of Table 2 represents changes that will occur independently of climate change. As such, they form a reference case of what could be the environmental and socioeconomic conditions in the absence of climate change.

Coastal vulnerability studies have focused primarily on scenarios of climate-induced changes in the environmental conditions, especially sea level, of a study area (upper left-hand box of Table 2). Scenarios of environmental and socioeconomic developments not induced by climate change (the lower part of Table 2) are also increasingly being used. However, the fact that climate change will trigger socioeconomic developments that in turn affect the manifestation of coastal impacts, is as yet often ignored (upper right-hand box of Table 2). These developments embrace autonomous and planned adaptation. The potential for adaptation and the dynamic effects of its implementation need to be considered as an integral part of vulnerability assessment, for example by linking impact and adaptation scenarios.

For some coastal areas it could be worthwhile to consider direct effects of climate change other than through sea-level rise (17). In mid- to high-latitude regions, a decrease in the return period of extreme rainfall events appears likely. This will be especially relevant for low-lying coastal areas. For coral reefs and atolls, increasing seawater temperatures could be important. These could adversely affect the growth potential of the coral and, thereby, its ability to keep pace with sea-level rise. Scenarios of both changing rainfall patterns and seawater temperatures may be obtained from general circulation models (GCMs).

Other climatic changes that could be relevant to coastal zones, such as changes in wind direction and intensity, remain highly uncertain. The construction of plausible scenarios using the output of GCMs is as yet impossible. However, sensitivity analysis using trend analysis (23) or arbitrary scenarios (24) could be helpful in providing insight into the possible consequences.

THREE LEVELS OF ASSESSMENT

In spite of the considerable interest around the world in assessing the vulnerability of coastal zones to climate change, many such assessments are hindered by the limited availability of data. Sometimes there has also been a mismatch between the available data, the level of effort, and the sophistication of the models utilized in vulnerability assessments. In some cases, this has led to inappropriate expectations concerning the outcomes of the assessment studies.

To help to structure the approach, to optimize the level of effort, and to make the likely outcome of studies more explicit, it is useful to consider 3 levels of increasingly complex assessment (Table 3): (i) screening assessment (SA); (ii) vulnerability assessment (VA); and, (iii) planning assessment (PA).

As its name implies, SA is a screening approach, which, by its quick nature, focuses on one aspect of vulnerability: susceptibility. VA is a more comprehensive analysis, including explicit assessment of biogeophysical effects, socioeconomic impacts and adaptation. PA involves analysis at an integrated level suitable for detailed coastal planning and would take place in the wider context of coastal management.

Analysis in the framework of a country study should start with SA. The results of the SA can then be used to plan how VA might be most effectively implemented. VA will provide broad concepts and ideas concerning impacts and possible adaptation. PA might be viewed as the link between VA and detailed coastal planning and management. PA asks more precise questions and, hence, the recommendations concerning possible adaptation measures would be more precise.

At present, most coastal vulnerability assessments will be of a basic nature and cannot be expected to yield results that will have widespread application to day-to-day coastal zone management. As further experience is acquired, coastal databases improve and better analytical tools and techniques are developed, more comprehensive and integrated assessments of coastal zones will become more feasible. Progress from SA to VA, and ultimately to PA, should be made at an appropriate pace for each country. It is envisaged that a country study, starting with an SA and rapidly proceeding to VA, could be conducted within 1 year, although 18 months would be recommended.

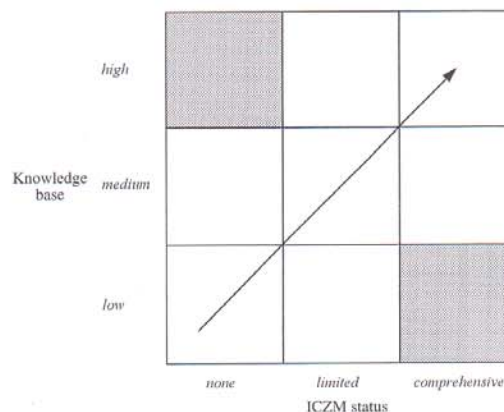


Figure 4. Knowledge base versus ICZM status, showing an evolution from a low knowledge base with no ICZM towards a high knowledge base and comprehensive ICZM.

Table 3. Three levels of assessment in coastal zones, showing the respective requirements and the factors to be considered.

Level of assessment	Requirements			Factors to Consider		
	Time	Level of detail	Prior knowledge	Socioeconomic factors	Other climatic changes	Nonclimate changes
Screening Assessment	2-3 months	Low	Low	No	No	No
Vulnerability Assessment	6-12 months	Medium	Medium	Yes	Possible	No
Planning Assessment	Continuous	High	High	Yes	Yes	Yes

FROM VULNERABILITY ASSESSMENT TOWARDS INTEGRATED COASTAL ZONE MANAGEMENT

Recognizing the multiple and growing problems in coastal zones and their multiple and interacting causes, coastal zone management is increasingly about making trade-offs aimed at resolving competing sectorial demands, rather than optimizing the output of a single resource (25). Solving such problems requires integration of management objectives, and there is an increasing interest in integrated coastal zone management (ICZM), including endorsement within Agenda 21.

It has been argued that ICZM is the most economically efficient way to manage the coastal zone (26). In terms of responding to climate change, ICZM is seen as an essential institutional mechanism that can deal with all competing pressures on the coast, including short-, medium- and long-term issues (17, 19). Climate change requires a more strategic perspective to managing long-term coastal change. In view of its global nature, it has facilitated more international and intra-national cooperation than many other classes of coastal problems.

As shown in Figure 4, vulnerability assessment can be conducted in areas with low, medium, or high knowledge bases, and with no, limited, or comprehensive ICZM in place. Vulnerabil-

ity assessment is often described as one possible trigger for ICZM (16). ICZM will, *vice versa*, increase the need for more sophisticated and detailed assessment of the implications of climate change (Table 3). Thus, an iterative evolution of vulnerability assessment within ICZM can be envisaged, progressively drawing from and also contributing to an improved knowledge base for decision making. As part of this evolution, vulnerability assessment to climate change will become embedded in wider issues, and with more focus on detailed responses, but it will remain an important element of the analysis for ICZM. Such an evolution can be seen in, for example, Egypt (the Nile delta) and Bangladesh (the Ganges-Brahmaputra delta), where initial studies raised significant concerns (27). Numerous more detailed and sophisticated studies have followed, combined with increasing emphasis on ICZM (28, 29).

The elaboration by Klein and Nicholls (5) of the IPCC Technical Guidelines (3) will not only have utility for vulnerability assessment, but also for designing ICZM strategies that address impacts of climate change. Klein and Nicholls (5) primarily address countries with low to medium knowledge and limited or no ICZM in place, yet the approach is not prescriptive. Models and approaches can and should be selected as appropriate.

References and Notes

1. Tsyban, A., Everett, J.T. and Titus, J.G. 1990. World oceans and coastal zones. In: *Climate Change: The IPCC Impacts Assessment*. McGraw-Hill, W.J., Sheldon, G.W. and Griffiths, D.C. (eds). Contribution of Working Group II to the First Assessment Report of the Intergovernmental Panel on Climate Change. Australian Government Publishing Service, Canberra, pp. 6.1-6.28.
2. IPCC CZMS. 1992. A common methodology for assessing vulnerability to sea level rise. 2nd revision. In: *Global Climate Change and the Rising Challenge of the Sea*. IPCC CZMS. Ministry of Transport, Public Works and Water Management, The Hague, The Netherlands, Appendix C.
3. Carter, T.R., Parry, M.C., Nishioka, S. and Harasawa, H. (eds). 1994. *Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Report of Working Group II of the Intergovernmental Panel on Climate Change. University College London and Centre for Global Environmental Research, London and Tsukuba.
4. Feenstra, J.F., Burton, I., Smith, J.B. and Tol, R.S.J. (eds). 1998. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. Version 2.0. United Nations Environment Programme and Institute for Environmental Studies, Vrije Universiteit, Nairobi and Amsterdam.
5. Klein, R.J.T. and Nicholls, R.J. 1998. Coastal zones. In: *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. Feenstra, J.F., Burton, I., Smith, J.B. and Tol, R.S.J. (eds). Version 2.0. United Nations Environment Programme and Institute for Environmental Studies, Vrije Universiteit, Nairobi and Amsterdam, pp. 7.1-7.35.
6. Leatherman, S.P. and Yohe, G. 1996. Coastal impact and adaptation assessment. In: *Vulnerability and Adaptation Assessments: An International Handbook*. Benioff, R., Guille, S. and Lee, J. (eds). Version 1.1. United States Country Studies Management Team, Kluwer Academic Publishers, Dordrecht, pp. 5.63-5.76, H.1-H.39.
7. Nicholls, R.J., Leatherman, S.P., Dennis, K.C. and Volonté, C.R. 1995. Impacts and responses to sea-level rise: qualitative and quantitative assessments. *J. Coast. Res. Special Issue 14*, 26-43.
8. Kay, R.C. and Hay, J.E. 1993. A decision support approach to coastal vulnerability and resilience assessment: a tool for integrated coastal zone management. In: *Vulnerability Assessment to Sea Level Rise and Coastal Zone Management*. McLean, R.F. and Mimura, N. (eds). Proceedings of the IPCC/WCC'93 Eastern Hemisphere workshop, Tsukuba, 3-6 August 1993. Department of Environment, Sport and Territories, Canberra, Australia, pp. 213-225.
9. Gornitz, V.M., Daniels, R.C., White, T.W. and Birdwell, K.R. 1994. The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. *J. Coast. Res. Special Issue 12*, 327-338.
10. Warrick, R.A., Le Provost, C., Meier, M.F., Oerlemans, J. and Woodworth, P.L. 1996. Changes in sea level. In: *Climate Change 1995: The Science of Climate Change*. Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K. (eds). Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 359-405.
11. Wigley, T.M.L. 1995. Global-mean temperature and sea level consequences of greenhouse gas stabilization. *Geophys. Res. Lett.* 22, 45-48.
12. Nicholls, R.J. 1995. Coastal megacities and climate change. *Geoforum* 37, 369-379.
13. Timmerman, P. 1981. *Vulnerability, Resilience and the Collapse of Society: A Review of Models and Possible Climate Applications*. Environmental Monograph No. 1, Institute of Environmental Studies, University of Toronto, Toronto.
14. Smith, K. 1992. *Environmental Hazards: Assessing Risk and Reducing Disaster*. Routledge Physical Environment Series, Routledge, London.
15. McLean, R.F. and Mimura, N. (eds). 1993. *Vulnerability Assessment to Sea Level Rise and Coastal Zone Management*. Proceedings of the IPCC/WCC'93 Eastern Hemisphere workshop, Tsukuba, 3-6 August 1993. Department of Environment, Sport and Territories, Canberra, Australia.
16. WCC'93. 1994. *Preparing to Meet the Coastal Challenges of the 21st Century*. Report of the World Coast Conference, Noordwijk, 1-5 November 1993. Ministry of Transport, Public Works and Water Management, The Hague, The Netherlands.
17. Bijlsma, L., Ehler, C.N., Klein, R.J.T., Kulshrestha, S.M., McLean, R.F., Mimura, N., Nicholls, R.J., Nurse, L.A., Pérez Nieto, H., Stakhiv, E.Z., Turner, R.K. and Warrick, R.A. 1996. Coastal zones and small islands. In: *Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Watson, R.T., Zinyowera, M.C. and Moss, R.H. (eds). Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 289-324.
18. Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K. (eds). 1996. *Climate Change 1995: The Science of Climate Change*. Con-
- tribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
19. Cicin-Sain, B., Dixon, R.K., Ehler, C.N., Huang, J.C.K., Johnson, B., Knecht, R., Lu, J.-M., Mersfelder, L., Mimura, N. and Ries, K.L. 1997. *International Workshop: Planning for Climate Change Through Integrated Coastal Management*. Volume I: Summary Report. Chinese Taipei, 24-28 February 1997.
20. Begon, M., Harper, J.L. and Townsend, C.R. 1996. *Ecology: Individuals, Populations and Communities*. 3rd edition. Blackwell Scientific Publications, Boston.
21. Handmer, J.W. and Dovers, S.R. 1996. A typology of resilience: rethinking institutions for sustainable development. *Int. Environ. Crisis Quart.* 9, 482-511.
22. Turner, R.K. 1996. Coastal regions. In: *Review of the Potential Effects of Climate Change in the United Kingdom*. Report of the Department of Environment, HMSO, London, pp. 211-225.
23. Zeidler, R.B., Skaja, M., Rózyński, G. and Kaczmarek, J. 1997. Wind- and sea level-induced shore evolution in Poland. In: *Proceedings of the 25th International Conference of Coastal Engineers*. American Society of Civil Engineers, New York, pp. 4364-4375.
24. Peerbolte, E.B., De Ronde, J.G., De Vries, L.P.M., Mann, M. and Baarse, G. 1991. *Impact of Sea-Level Rise on Society: A Case Study for The Netherlands*. Delft Hydraulics and Ministry of Transport, Public Works and Water Management, Delft and The Hague, The Netherlands.
25. Cicin-Sain, B. 1993. Sustainable development and integrated coastal management. *Ocean Coast. Mgmt* 21, 11-43.
26. Tol, R.S.J., Klein, R.J.T., Jansen, H.M.A. and Verbruggen, H. 1996. Some economic considerations on the importance of proactive integrated coastal zone management. *Ocean Coast. Mgmt* 32, 39-55.
27. Milliman, J.D., Broadus, J.M. and Gable, F. 1989. Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples. *Ambio* 18, 340-345.
28. Delft Hydraulics, Resource Analysis, Ministry of Transport, Public Works and Water Management, and Coastal Research Institute. 1993. *Vulnerability Assessment to Accelerated Sea Level Rise, Case Study Egypt*. Delft Hydraulics, Delft, The Netherlands.
29. Warrick, R.A. and Ahmad, Q.K. (eds). 1996. *The Implications of Climate and Sea Level Change for Bangladesh*. Kluwer Academic Publishers, Dordrecht.
30. Richard Klein was funded by the United Nations Environment Programme. Both authors wish to thank Jan F. Feenstra (Vrije Universiteit, Amsterdam) and Michael Short (United Nations Environment Programme, Nairobi) for their permission to submit this article to *Ambio*.
31. First submitted 7 April 1997. Accepted for publication after revision 21 November 1997.

Richard Klein is a senior research associate with an interdisciplinary background, working primarily on climate-related impacts and adaptations, particularly in coastal zones. He has a strong interest in combining natural and socioeconomic sciences so as to advance integrated coastal zone management. His address: Potsdam Institute for Climate Impact Research, P.O. Box 601203, 14412 Potsdam, Germany.
e-mail: richard.klein@pik-potsdam.de

Robert Nicholls is reader in coastal geomorphology and management, and has published widely on impacts of and responses to sea-level rise. His address: Middlesex University, School of Geography and Environmental Management, Queensway, Enfield EN3 4SF, United Kingdom.
e-mail: r.nicholls@mdx.ac.uk