Coastal Zones: Ecosystems under Pressure

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Abstract
The inherent natural systems of the coastal zone and examples of changes in their state, at least at local levels, are recognised in the scientific arena and across much of the wider community. The entire spectrum of coastal habitats - coral reefs, mangroves and tropical wetlands, seagrass systems, rocky shores and estuaries, salt marshes and sand dune communities, coastal forests and woodlands, estuarine and deeper shelf communities – are subject to pressures from humans and natural changes. Our awareness and scientific understanding of the dynamics in coastal ecosystems (the scales of variability and forcing) has increased over the last decades. Observations and measurements of elements of human forcing leading to change and loss of ecosystems have been increasingly documented. However, we are still grappling with ways to express, model and understanding the synergies of multiply forcings, their scales of interaction, and indicators and metrics for measurement of change and resilience in and across ecosystems. Here, we attempt to address these issues and summarise the developments from research efforts over the last decade, especially on drivers and pressures of change, and provide recommendations for focussing future research.

1. Introduction
The world’s coastal zone is under extraordinary and increasing pressure from human use and habitation and from changes in global climate. The resources and amenities of the coastal zone are crucial to the societal and economic needs of the global population. While it represents less than 20% of the land surface, the coastal zone presently is:
  a major food source (most croplands and much agriculture, most of the global fisheries),
a focus of transport and industrial development,
a source of minerals and geological products including oil and gas,
a location for most tourism, and
an important repository of biodiversity and ecosystems that support the function of the Earth’s systems.

New commercial and socio-economic benefits and opportunities continue to be developed from use of coastal resources, products and amenities and the issues of environmental management and sustainability challenge planners, managers and policy makers (Cicin-Sain and Knecht 1998, WRI 2000).

Since the 1992 Earth Summit in Rio de Janeiro, there have been numerous advances in both our understanding and approach to the coastal zone and the issues of its dynamics and changes, not the least being a general accord about what constitutes the domain. Over the last decade, a multiplicity of projects and programs addressing the coastal zone have been put in place, particularly at local and national levels. Regional and global programs have been developed; some are being implemented and some are in evolution. Political, institutional and management initiatives (considered elsewhere in this Conference) encapsulate three major conceptual advances embraced by coastal science, viz., a) that humans are an integral component of the ecology and function of ecosystems (von Bodungen and Turner 2001); b) that the water continuum of river basin catchments into the coastal ocean is a fundamental unit for coastal assessment and management (Salomons et al. 1999, Kremer and Kohn 2000); and c) that an ecosystems approach is required for coastal zone management (Wulff et al. 2001). New tools and techniques have been developed with applications to the coastal zone; for scientific inquiry, concept building through to monitoring and assessment (e.g. Sala et al. 2000). These range across functional scales from molecular level assay to space-platform observations and
measurements. While capacity building initiatives and extended global communications have increased public awareness of the issues, thus furthering broader understanding, the resolution of problems in the coastal zone remains as an enormous challenge if we are to meet the often stated goals of sustainable resource use and maintenance of Earth system function. For example, a recent evaluation of the impacts of marine pollution from land-based sources found that marine environmental degradation has continued and in many places has even intensified (GESAMP 2001). The Intergovernmental Panel on Climate Change in 2001, while revising earlier assessment values, noted and projected increased global temperatures and allied CO₂ concentrations which will dramatically influence the coastal zone differentially across regions. Global assessment of the environment (OECD 2001), of world resources (WRI 2000), of oceans and coastal seas (IOC in press), and of global change (IGBP 2001) describe a tapestry of pressures, impacts and predictions. These paint a picture of trends towards further degradation in the coastal zone (e.g., overfishing, greenhouse gas emissions) despite some local and regional successes in coastal management that are arresting processes such as pollution, eutrophication, and urban wastes impacts on water quality (e.g., the Rhine River and Baltic Sea).

Here, we provide a contextual framework for the coastal zone, with comment on its benefits and values before attempting to provide an overview of the natural and human pressures and threats that affect the changing and dynamic coastal zone. A brief comment on current assessments of the status of marine coastal ecosystems is made and key challenges for research are noted.

2. The Coastal Zone
The coastal zone encompasses river basins and catchments, estuaries and coastal seas and extends to the continental shelf – the domain surrounding the land-sea interface extending to the landward and seaward limits of marine and terrestrial influences (Figure 1). There is no single definition for the coastal zone. However, there is general adoption of the OECD Environment Directorate’s approach that suggests the definition of the coastal zone needs to vary according to the type of problem being addressed and the objectives of management (see, for example, Commonwealth of Australia 1993).

A common rule-of-thumb is to include the landward area to 100km from the coast (WRI 2000). In LOICZ, while setting spatial dimensions to address key issues of land-ocean interaction, the coastal zone is nominally considered to extend from 200m elevation to 200m depth (Pernetta and Milliman 1995).

![Figure 1. The LOICZ global coastal zone.](image-url)
This region is viewed as encapsulating the material fluxes and processes of transformation, storage and interaction of coastal materials, including human dimensions. In the LOICZ typology approach to integrating processes and interactions in the global coastal zone, the coastal domain is described by 49,000 pixels of half-degree resolution, generally extending 70-90 km inland and to the continental shelf edge (www.kgs.ukans.edu/Hexacoral).

**Table 1. Characteristics of the global coastal zone**

<table>
<thead>
<tr>
<th>The coastal zone:</th>
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<tbody>
<tr>
<td>- comprises &lt;20% of the Earth’s surface</td>
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<tr>
<td>- contains &gt;50% of the human population</td>
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<tr>
<td>- is the location of 70% of cities with &gt;1.6 million inhabitants</td>
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<tr>
<td>- yields 90% of the global fisheries</td>
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<tr>
<td>- produces about 25% of global biological productivity</td>
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<tr>
<td>- is the major sink for sediments</td>
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<tr>
<td>- is a major site of nutrient-sediment biogeochemical processes</td>
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<tr>
<td>- is a heterogeneous domain, dynamic in space and time</td>
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<td>- has high gradients, high variability, high diversity</td>
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The coastal zone is a relatively small but dynamic area of the Earth’s surface. It is the location for more than 50% of the human population, providing wide societal benefits, containing an extensive tapestry of natural ecosystems and habitats and functions as a significant and complex region for biogeochemical transformation (Table 1). Its heterogeneity in physical, chemical, biological and human dimensions is a challenge to measure, model and manage. Biogeochemically it can be considered as a region of dominant horizontal gradients, exchanges and fluxes, but the vertical interactions with atmosphere, soil and groundwater sustain vital processes. Temporal dimensions and variability are crucial to coastal zone dynamics and natural function. It is not in a steady state, but changes across time in response to forcings – from daily (e.g., tides and precipitation-river flow), seasonal (e.g., climatic patterns), annual (e.g., fisheries yield), and decadal (e.g., ENSO) to glacial-interglacial scales (e.g., sea level was about 100m lower 8000 year ago in many parts of the world and in Scandinavia considerably higher than present).

A multiplicity of human uses and benefits are derived from the coastal zone (Table 2). Resources, products and amenities are as heterogeneously dispersed at local and regional scales as the natural settings and processes, and subject to changing patterns of availability, quality, limitations and pressures. The human dimension is crucial in modifying, directly and indirectly, the entire fabric of the coastal zone through exploitation of living and non-living resources. Urbanisation and land uses are resulting in degraded water and soils quality, pollution and contamination, eutrophication, overfishing, alienation of wetlands, habitat destruction and species extinction. Indeed, current research by LOICZ on C-N-P nutrient processes in estuaries suggests that sites of intense human pressures may be leading to homogeneity in biogeochemical function, especially where high loads of nutrient are discharged, and that there may be few, if any, sub-regional scale examples of un-impacted coastal environments.
Table 2. Resources, products and amenities in the coastal zone

<table>
<thead>
<tr>
<th>Resource – natural materials</th>
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<tbody>
<tr>
<td>Water – surface, ground</td>
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<tr>
<td>Forests and timber</td>
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<td>Arable land</td>
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<tr>
<td>Food</td>
</tr>
<tr>
<td>Geological ores and deposits</td>
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<td>Ecosystems and biodiversity</td>
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<th>Products – natural and human derived commodities</th>
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<tbody>
<tr>
<td>Food</td>
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<tr>
<td>Fisheries</td>
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<tr>
<td>Habitation</td>
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<tr>
<td>Industrial goods and processes</td>
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<tr>
<td>Oil, gas and minerals</td>
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<th>Amenities – natural and human-derived services</th>
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<tr>
<td>Transport and infrastructure</td>
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<td>Tourism</td>
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<td>Recreation and culture</td>
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<tr>
<td>Biodiversity</td>
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<tr>
<td>Ecosystem services</td>
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3. Values and Benefits of the Coastal Zone

The resources, products and amenities of the coastal zone are crucial to the societal and economic needs of the global population. Equally, the natural functions of wetlands, forests, agricultural regions, and estuarine and coastal marine ecosystems are playing a vital role in Earth function – for example, as system “kidneys” for nutrient transformations and exchange, as variable time-scale sinks and reservoirs for materials storage. These benefits from the coastal zone are obvious both to society and nature, and are usually the seat of multiple-user conflicts at local and sometimes regional scales, resolution of which is usually addressed through integrated coastal management approaches (e.g., Burbridge 1999, Kremer and Kohn 2000).

Valuing the human resource use and natural environmental services of the coastal zone has been a basis of increasing scientific effort over the last decade. It has proven difficult and has frequently led to contentious outcomes often because of differences between the models, metrics and methods (especially of dealing with time scales) of the more traditional economic and social science disciplines and those of the evolving approach of ecological economics (Jickells et al. 2001). Obviously, monetary units are the more commonly used measures of both approaches but there is well-founded debate on both the rigour of each approach (and levels of uncertainty) and the ability of monetary terms to capture and measure human perceptions and ecosystem functions.

Despite this uncertainty, it is clear that the global coastal zone has a high value. For example, from an assessment of global ecosystem goods and services by Costanza et al. (1997) a value of US$24 trillion per year can be ascribed to the coastal zone compared with global GDP of US$18 trillion. Irrespective of any debate on detail, it can be agreed that such services are of high value. Recent attempts to gain a measure of the various sectors of the global economy show similarly high values for the coastal zone. Global tourism was estimated at US$3.5 trillion per year (WTTC 1999) most of which takes place in the coastal zone. Fisheries exports are about US$52 billion per year (FAO 1999). Allied with the latter value is an estimate that around 1
billion people depend on fish as a source of protein (Laureti 1999 cited in WRI 2000), an estimate not captured in the fisheries export monetary figure.

The research approach to valuation and measurement of benefit from human and ecosystem activities in the coastal zone is a field of challenge and one that is attracting much current effort (Turner et al. 1998, Voinov et al. 1999, Gren et al. 2000, Aquirre-Munoz et al. 2001). Other than temporal elements and metrics for expression, modelling approaches and scaling mismatches between model elements are being tackled in particular (e.g., Talaue-McManus et al. 2001). It seems likely that future assessments from these approaches will not only ascribe even greater gross value to the coastal zone, but new tools should contribute significantly to enhancing future assessments of trade-offs and options for integrated coastal management decisions.

4. Pressures and Changes
The last decade of research and environmental management approaches has seen a marked improvement in our knowledge about how global environmental change and human activities influence the coastal zone – its ecology, function, products and benefits. We know there is degradation of natural and artificial ecosystems and their benefits and resources. We know there are societal opportunities for wiser use and the need for greater preparedness for changes. However, we are limited in our ability to scientifically and objectively measure, assess and predict the natural and human dimensions of these changes and the effects of different pressures. Differentiating human-induced changes from naturally forced changes remains a challenge. These problems derive from the complexity of endogenous natural functions and biogeochemical interactions, the inherent complexity of the human dimension, and the synergies, feedbacks and disjuncts in scaling between natural and socio-economic interactions in the heterogeneous landscape of the coastal zone. However, targetted research and new tools for measurement and concept development are delivering exciting and often surprising outcomes (e.g., IGBP 2001). While the intellectual challenges in this work are high for the science, management and policy arenas, an equally important challenge is to find ways to effectively communicate and apply the knowledge.

The impact and influence of human populations in the coastal zone is recognised but poorly documented. Indeed, estimates of population in the coastal zone are diverse and range from 37% to 80% and the variability is dependent not only on the spatial units used for the estimate (Robert Bowen pers. comm.). Burke et al. (2000) cite census estimates of 2.075 x 10^9 (in 1990) and 2.213 x 10^9 (in 1995, representing 39% of global population) people living within 100km of the coastline. LOICZ estimates from Landscan data include 2.7 x 10^9 (in 1998, or 52% of global population) people within the coastal typology delimited global database (i.e., within less than 100km from the coastline). Importantly, the population density in the coastal zone is far from being uniformly distributed (for example, ranging from near-zero in polar regions to around 90% in Australia, most island states and some European nations) and elevated densities coincide with urban conurbations and “altered” landscapes (Burke et al. 2001).

Historically humankind has been closely associated with the coast reflecting the evolution of trade and commerce and resource access. However, there is a trend for coastal migration from rural to urban environments in many countries, and most (14) of the world’s megacities are coastal. Patterns of tourism and global trade exacerbate these densities; for example, the Mediterranean coastal zone population swells from 130 million to 230 million for most of summer (Han Lindeboom, pers. comm). The challenges for management and planning are obvious, and the pressures imposed by people are geographically highly variable in nature and intensity and often connected. It is now considered that “human activities are influencing or even dominating many aspects of the Earth’s environment and functioning” leading to the suggestion we are now in “another geological epoch, the Anthropocene era” (IGBP 2001).
Figure 2. Schema of DPSIR framework (adapted from Turner 1998).

Table 3. Systems and their key pressures. (from GESAMP 2001)

<table>
<thead>
<tr>
<th>System</th>
<th>Key Pressures</th>
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<tbody>
<tr>
<td>Coral reefs</td>
<td>eutrophication, sediments, overfishing, destructive fishing, reef mining, aquarium and curio trade, diseases</td>
</tr>
<tr>
<td>Wetlands</td>
<td>reclamation and development</td>
</tr>
<tr>
<td>Seagrass beds</td>
<td>siltation, coastal development, eutrophication, physical disturbance</td>
</tr>
<tr>
<td>Coastal lagoons</td>
<td>reclamation, pollution</td>
</tr>
<tr>
<td>Mangroves</td>
<td>excessive exploitation, reclamation, development, aquaculture</td>
</tr>
<tr>
<td>Shorelines</td>
<td>development, habitat modification, erosion</td>
</tr>
<tr>
<td>Watersheds</td>
<td>deforestation, soil erosion, pollution, habitat loss</td>
</tr>
<tr>
<td>Estuaries</td>
<td>reduced water flow, siltation, pollution,</td>
</tr>
<tr>
<td>Small islands</td>
<td>sea level changes, waste management</td>
</tr>
<tr>
<td>Continental shelves</td>
<td>pollution, fishing, dredging, navigation</td>
</tr>
<tr>
<td>Semi-enclosed seas</td>
<td>pollution, coastal development, fishing</td>
</tr>
</tbody>
</table>
We use the DPSIR framework (Figure 2, Turner 1998, Turner and Salomons 1999) to organise commentary on the dominant pressures and effects on the global coastal zone (Table 3). The drivers and pressures on coastal systems are dominantly the result of human behaviour and are amenable to management and policy decisions (“Response”) – a major subject of the Rio meeting in 1992. It is becoming increasingly apparent that the forcing by natural drivers and pressures is being modified in degree and intensity by human activities.

4.1 Drivers and Pressures

The natural dynamics of the planet provide stressors and result in changes to all regions of the globe. Human activities exacerbate many of these changes. Recent assessments by IGBP-IHDP-WRCP-DIVERSITAS concluded: “…we know that the Earth System has moved well outside the range of natural variability exhibited over the last half million years at least. The nature of changes now occurring simultaneously in the global environment, their magnitudes and rates, are unprecedented in human history, and probably in the history of the planet. The Earth is now operating in a no-analogue state.” (IGBP 2001). These changes and forcings act as pressures and drivers on state and function within the coastal zone and elsewhere.

Natural forcings

Global systems and climate patterns. Large-scale phenomena influence climate, including the global “ocean conveyor belt” or thermohaline circulation pattern (Broeker 1994), and regionally ENSO (El Nino-Southern Oscillation) in the Pacific and the North Atlantic Ocean Oscillation. Evidence is accumulating of historical shifts in pattern and intensity of these phenomena that can influence biotic distribution and diversity and impact on coastal processes (IPCC 1996). The “ocean conveyor” influences heat fluxes and greenhouse gases in the atmosphere and it may change on various time scales affecting climate and thus parameters such as temperature and precipitation patterns, trade-wind intensity and wave climates. ENSO is driven from the Pacific but teleconnects to at least North America where elevated sea level, increased erosion and changes in the rainfall patterns have been observed. It affects global distribution and concentrations of CO$_2$ and there are indications of increased intensity and frequency in ENSO events over paleo time-scales. The potential for further changes in forcing on many natural and human-related pressures in the coastal zone is obvious. For example, recent major global events of bleaching in shallow coral reefs is ascribed to high sea surface temperatures (Wilkinson 2000), a forcing parameter linked to these large-scale phenomena.

Sea level. Sea level in the coastal zone continues as a major issue of concern particularly in deltas and low-lying areas, and in small island states. The dominant driver of sea level change is sea and air temperature. IPCC estimates that global average surface temperature has increased by 0.6°C in the 20th Century and is projected to increase by about 2.5°C (1.5 to 4.5°C modelled range) over the next 100 years (Zillman 2001). Further, IPCC has estimated sea level to have risen at rates of 1.0-2.5 mm per year over the last century, and modelling scenarios project a further increase of 10-88cm over the next 100 years. Other IPCC projections indicate with high confidence that natural systems will respond dynamically, that the responses will vary locally and with climate, that wetlands may survive where vertical accretion rates are sufficiently nourished by sediments, and that engineering infrastructure in the coastal zone may be a barrier to the landward dynamics of ecosystems. Potential impacts could include shoreline erosion, severe storm-surge and flooding, saline intrusions into estuaries and aquifers and altered tide ranges. The resilience of coastal ecosystems is a vital element and a current project is examining vulnerability and risk through a global network applying a common methodology (see SURVAS, [www.survas.mdx.ac.uk](http://www.survas.mdx.ac.uk)) Already many coastal regions are experiencing significant increases in relative sea level as a result of subsidence – resulting from isostatic and tectonic adjustments or human activities; a new program of research is seeking to evaluate these and related changes to improve modelling and understanding (Goodwin et al. 2000).

CO$_2$. Changes in CO$_2$ concentration and other greenhouse gases in the atmosphere have implications for the coastal zone directly and indirectly from effects on temperature elevation.
and climate. Over the last 150 years atmospheric CO₂ has increased 30% to around 285ppm – to just within the maximum levels experienced over the last 400,000 years, as inferred from ice core records (IGBP 2001). However, current projections suggest that this could double over the next 100 years, placing us outside the envelope of previous experience; the IPCC considers that human activities continue to influence this increase (Zillman 2001). Impacts on terrestrial crops and agriculture, the biological processes of the ocean (the major sink for global atmospheric CO₂), influence on climate, temperature regimes and marine coastal systems are hot issues of research and debate. Changing patterns of productivity in marine waters are forecast through sink-source-interactions between elements within the carbon cycle, and a decrease of up to 30% has been projected for calcification rates in coral reefs in response to a doubling in CO₂ concentration (Kleypas et al. 1999).

Human forcings

Land-based resource uses

Agriculture. Croplands and managed pastures are associated with much of the coastal zone and major river basins that discharge into the coastal seas, supporting local and global societies and economies. However there are environmental costs. While the conversion of forests and grasslands to managed agriculture is increasing less rapidly (Wood et al. 2000), there is increased intensification of cropland and agricultural production through application of fertilisers, pesticides and herbicides, and irrigation. Use of fertilisers continues to grow from levels of about 150 x 10⁶ tonnes per year in 1990 to projected use in excess of 200 x 10⁶ tonnes per year (Bumb and Baanante 1996, cited in WRI 2000). A recent assessment by UNEP considers the global nitrogen overload to be one of four major emerging environmental issues (Munn et al. 2000) as does GESAMP (2001) for effects on eutrophication, human health and general water quality of fresh and marine coastal waters and within allied ecosystems. In immediate coastal lands, alienation of wetlands (mangroves, saltmashes, dune systems) continues as sugarcane, rice and mariculture facilities are expanded. Freshwater used for irrigation accounts for significant changes in flows affecting inter alia coastal sedimentation processes and delta maintenance. For example, in the Yellow River and Nile River flows have been reduced by more than 90% with concomitant coastal erosion and changes in trophic systems of the coastal receiving waters.

Forestry/deforestation. Forests yield valuable timber and non-wood products (food, cash crops, industrial raw materials) for human society. Estimates for trends in deforestation are difficult due to patchy statistics and measurements (Matthews et al. 2000). However, it is known that significant tracts of forest continue to be lost in river basins in many parts of the world, diminishing watershed protection and increasing erosion that influences river transport, water quality and impacting on coastal ecosystems through increased sedimentation rates, and elevated nutrient inputs (Scialabba 1998). Major reforestation projects are in-train in different parts of the world, especially in developed countries, as a move to increase carbon sequestration from atmospheric CO₂ as well as for improved management of land and riparian zones.

Damming & irrigation. Globally, more than 41,000 large dams (>15m high) are in operation impounding 14% of runoff: a 7-fold increase in dams over 50 years and the numbers are increasing (WRI 2000). These provide hydroelectric power, industrial and other human needs including flood mitigation (Goudi 1994). Small reservoirs and dams in local catchments number in the millions. Smith et al. (2001) consider that globally impoundments may account for sequestration of almost 2 gigatonnes C per year – equivalent to the “missing carbon” in current models. The effects of damming and irrigation on water transport are obvious and manifested in multiple examples of coastal erosion through all regions of the world in response to reduction of sediment flows (Milliman 1997). Such effects impact coastal ecosystems, increase saline intrusions, diminish coastal groundwater discharge and reduce biodiversity. More subtle pressures through changes in water quality are coming to light through recent research, notably the effects of damming on reducing silicate loads to coastal waters (Conley et al. 1993) with a resultant shift in phytoplanktonic communities from dominantly diatoms to
flagellates (e.g., Black Sea, Humborg et al. 2000). This has ramifications for coastal biogeochemical cycles including sequestration of carbon and elevation of eutrophication, as well as trophic structures in estuaries and coastal seas (e.g., the Bay of Bengal and areas of major river plumes such as the Amazon) dependent on land-derived nutrient inputs (Ittekkot et al. 2000).

**Urbanisation and industrial development**

Industrialisation, urbanisation and wastes. The development of the coastal zone to meet urban and industrial needs is mirrored by the global distribution of population. Both intensity and areal extent of these developments is increasing concomitantly with population. The resultant pressures and effects on the natural resources and ecosystems continue to be recognised and in some cases measured through monitoring and other scientific assessments allied with integrated coastal zone management initiatives (e.g., Jickells 1998). Nutrient and contaminant wastes, atmospheric loads, sewage and other urban and industrial materials including oils and detergents have been identified as continuing global issues by GESAMP (2001). The report notes some advances in control of contaminant and point-source discharge and diminished pressures in response to environmental management and technological fixes. Technological and legislative advances for controlling substance emissions is increasingly associated with locations in the developed world and some localities in the developing world. Habitat destruction through increasing footprints of urbanisation remains a major issue. Megacities are attracting attention to try and understand their footprints of influence and to establish special needs for management approaches. For example, Paris has significant impacts measurable 75km downstream in the River Seine and water quality remains affected 200km downstream (Meybeck 1998). Even upstream the “Paris effect” is visible since water demand and flood protection needs of the city have resulted in extended river management and reservoir constructions affecting flow patterns. The advance of “the global economy” is raising management issues about local industrial performance and environmental impacts by multinational companies operating across different locations of the world and within opportunities for different environmental standards.

Reclamation & shoreline development. The extent of conversion of natural habitats – wetlands, estuarine and coastal habitats – by land reclamation and engineering structures (sea walls, revetments, groynes, breakwaters) generally reflects population pressures and attempts to protect coastal infrastructure from storms and other high-energy events (Arthurton 1998, Burke et al. 2001). Road causeways and ribbon developments for tourism facilities and industries adjacent to marine transportation often alienate habitats serving as natural fisheries nurseries. Hard structural engineering options including flood mitigation barrages and dykes (e.g., the Ijsselmeer, The Netherlands) have effects on water quality, habitats and sediment processes. Their impact on the processes of sediment transport on the coast can result in increased local and displaced erosion, and require mitigation by costly and continuous sand nourishment schemes. This frequently leads to intensified dredging from near-shore and riverine systems. The application of hard engineering structures to coastline defence diminishes subsequent options for coastal management (e.g. Pethick 2001). While coastal protection interventions through coastal armouring are continuing around the world, there is some shift in thought among planners and coastal managers towards ensuring that natural mitigation services are captured in shoreline planning. In Cuba, recent tourist developments are constrained behind a coastline setback zone of several hundreds of meters. In the highly-engineered Netherlands, new policy strategies encompass “building with nature” instead of “working against nature” (de Vries 2001) where coastal flats and sand dunes systems are now being protected and maintained in order to act as natural buffers.

**Transportation.**

Marine transportation is the life-blood of global commerce with 95% of world trade moved by shipping. Port and infrastructure developments frequently require dredging, with associated mobilisation and distribution of sequestered nutrients and contaminants, modification of estuaries and coastal shoreline from engineering structures and provide additional point sources
for alien discharges including oil. The translation of products and minerals from global one location to another has management and impact ramifications for landfill, pollution and contaminants. In recent years the issue of the food-chain toxic, tributyl tin, used in anti-fouling paints seems to have been mostly resolved by conventions and local management. A major issue is the transport and introductions of non-indigenous species which can have devastating effects on receiving systems, affect local fisheries and aquaculture economies, and public health. Ballast water is a key element in species transfer, particularly of pathogens, spores and cysts that can result in harmful algal blooms and human diseases. Practices and treatment of ballast water is a major issue for the International Maritime Organisation, the International Council for the Exploration of the Seas as well as ports authorities, and measures are being taken to minimise ballast water transfers of living propagules. Air transportation is a major component of transient population shifts closely allied with tourism and commerce affecting coastal zones.

**Mining and shoreline modification**
Sand mining for minerals, oil and gas extraction and dredging of sediments have a multitude of environmental consequences ranging from dispersal and resuspension of sediments, bathymetric changes, altered groundwater flows, loss of habitats and fisheries and impact on shoreline stability by alteration of natural sedimentation-erosion processes. Dredge materials account for 80 to 90 % by volume of materials dumped into the ocean and several hundred million cubic meters of coastal sediments are dredged annually worldwide (Robert Bowen, pers. comm.). This remains an on-going issue. The coastal zone is a major focus for oil and gas extraction with inherent potential for ecosystem impacts; in recent years the application of new techniques and spill management and contingency plans have seen a relative decline in oil spills (Burke et al. 2001). However, there are mounting concerns about land subsidence and erosion, and allied impacts on coastal ecosystems, from subterranean removal of oil and gas (and also groundwater). For example, along the West African coast, the natural barrier island-lagoon structure is subject to subsidence and erosion (among other pressures) at a rate of about 25-30m per year with potential for greater impact on human habitation and ecosystems (Awosika 1999).

**Tourism**
Tourism is of benefit and value to economies of most countries generating US$3.5 trillion and about 200 million jobs, and has grown enormously over the last decade (WTTC 1999). In many countries, especially small island states, it is the major sector of the economy. The coastal zone is a major focus for global tourism and economic and societal benefits are invariably offset by impacts on the environment. Coastal development and population expansions, often seasonal, are legacies and tourist activities frequently place direct pressures and impacts on the coastal system. These pressures depend on the type and style of tourism (Pearce 1997). The pressures from tourism encompass the array of factors associated with urban developments and act to expand the location of elevated population densities into new localities in the world. Concepts of sustainable tourism (Moscardo 1997) have been introduced to the industry by the World Tourism Organisation and related bodies to enhance environmental management and awareness. Demands for eco-tourism and a quality environment are apparently increasing and there are good examples of well-managed tourism facilities and activities such as in the Great Barrier Reef where partnerships between the industry and the environmental management agencies ensure quality of visitor experience and sustained ecosystems (Crossland and Kenchington 2001). However, societal support and infrastructural developments to underpin tourist populations continue to have negative pressures on coastal systems globally and the relative balance between benefits and negative feedback on the environment requires further determination (WRI 2000).

**Fisheries**
Global fisheries have high socio-economic significance, providing more than 6 % of the protein consumed by humans, being especially important in developing country economies and food supplies. (see WRI 2000). An estimated 90% of the marine fish catch which has decreased from
almost 100 to about 90 million tonnes annually comes from the coastal zone (freshwater fisheries are important regionally) with about 30% currently derived from aquaculture. While global wild-stock catches are declining, pressures are not; fleet capacity is estimated as being 30-40% greater than need (Grainger and Garcia 1996). Overfishing remains a major problem for most regions of the world and the fishing down of trophic levels (Pauly et al. 1998) is a major concern for ecosystem function as well as for socio-economic performance. Direct effects of trawling and by-catch issues in coastal systems are well-documented and show major impacts on ecological structure and influence biogeochemical cycles (e.g., see Sainsbury et al. 1997, Kaiser and Groot 2000). Poison and explosive fisheries are endemic in many coral reef regions causing reef destruction and trophic alterations. Commercial and recreational fisheries in coral reefs and associated systems may be leading to symptoms of eutrophication by removal of herbivores (see Szmant 2001). The expansion of aquaculture through the last decade, particularly in Southeast Asia and China, has major ramifications for coastal zone management from the allied pressures imposed on an array of ecosystems, including restriction of water flows in estuaries, benthic system changes, physical and chemical changes in sediments, oxygen depletion, and eutrophication.

4.2 State (and Impacts)
The status of coastal ecosystems is the subject of many efforts and publications, from local to regional to global in scales. This is addressed by national state of the environment reporting, academic and applied management studies, and by global assessment from programs run by inter-governmental and non-governmental organisations. The recent report on World Resources 2000-2001 (WRI 2000) provides a scorecard that paints a less than desirable picture of the state of the global coastal zone. The program of coral reef assessment reports that human activities continue to threaten their stability and existence, with 11% of global reefs lost, and 16% not fully functional (Wilkinson 2000). Mangrove loss is reported as being in excess of 50% (Kelleher et al. 1995) and while there is evidence of re-afforestation by planting and from changes in natural sedimentation processes, the net trend is downwards (Burke et al. 2001). Direct loss of other wetlands and seagrasses near the coastal interface have been documented at regional and local scales but a comprehensive global assessment has yet to be achieved. In all cases, the changes in the coastal zone result from a fabric of local and regional differences in drivers and pressures across different regions and across various scales.

4.3 Responses
Responses by environmental management and policy to changing pressures and status of the coastal zone are manifold, some successful and others less successful (e.g., GESAMP 1996, Cicin-Sain and Knecht 1998, Clark 2001, von Bodungen and Turner 2001), and are discussed elsewhere in this Conference. In some cases, initiatives were already developed or in place prior to UNCED 1992, in others efforts have been developed in response to the Rio Conference and other societal pressures. However, the wheels grind slowly in governments and in major international agencies, particularly to fit consultative and funding cycles, and thus the advent of a number of programs to address key issues is now just becoming apparent. The increase in local and sometimes wider participatory management approaches based on local communities is a noteworthy advance during the last decade, as environmental awareness and knowledge in many coastal communities and national populaces has improved.

There are major efforts in global scientific assessment of the coastal zone to determine the drivers, pressures, state and impact on the systems in order to provide a basis on which to build management approaches and policy actions. Some of these have resulted from the accords of UNCED in 1992. The IGBP program is completing its first 10-year stage of assessing global change with several core projects addressing issues related to the coastal zone (IGBP 2001). The Intergovernmental Oceanographic Commission of UNESCO in 1995-6 moved to embrace the “brown waters” of the coastal seas and has initiated a number of actions including the GOOS (Global Ocean Observing System, with its accompanying Coastal-GOOS program). The Global Coral Reef Monitoring Network has been established. The UNEP Regional Seas
program, FAO programs and GESAMP continue with vital initiatives. Through the GEF (Global Environmental Facility within the framework of UNEP), large programmes are launched to monitor Large Marine Ecosystems (LME) and to strengthen the development of governance in the management process in these LMEs. A global water programme, GIWA (Global International Waters Assessment), is being led by UNEP (United Nation Environmental Programme) with financial participation of various other international organisations to assess the environmental conditions and problems of international waters. The Millenium Ecosystem Assessment, started in 2001, and aims to provide a global environmental assessment to underpin various Conventions (Biological Diversity, Combat of Desertification, Wetlands) and to provide information for policy and other decision-makers. Regional policy directives relate to and underpin coastal zone management and assessment. For example, the EC Water Framework Directive announced by the European Union in November 2000 as well as the European Commission’s communication to the Parliament on a proposal for a coherent strategy for coastal zone management, and HELCOM and OSPAR for the Baltic and North Atlantic Seas.

5. Challenges
There is mounting concern about the sustainability of human use of the coastal zone and the patterns of degradation in whole ecosystems and habitats, and on resources and amenities. We have developed a firm understanding that human dimensions and natural systems interact and are intimately bound together in the various pressure and resultant state of the coastal domain. Also, it is apparent that existing tools and concepts for measurement and analyses are inadequate to meet the needs for understanding human-nature interactions. We are aware that there is a wide heterogeneity in the expression of pressures, changes and state of coastal systems, and that limited comprehensive data and information is available at all scales of measurement (availability and accessibility are two prongs of this problem). In particular, societal demands on the scientific community for information and knowledge as part of a joint resolution process are increasing despite the relatively poor history of communication between science and users (Biesecker 1996, Kremer and Pirrone 2000). Here, participatory approaches in program design, implementation and assessment can prove fruitful (Crossland 2000). Frequently asked questions deal with sustainability issues (e.g., How to identify wise use options?), planning and management approaches (e.g., How to measure and predict impacts and changes?) and policy-related developments (e.g., What are the risks and vulnerability to change?).

Considering the multiplicity of processes, changes and forcings (natural and human-driven) across the dynamic and heterogeneous global coastal zone, we make the following recommendations as priorities for future research effort:

1. Integrated and multidisciplinary team approaches. While often stated, there is an imperative for real collaboration between natural, social and economic disciplines. Global examples exist and the knowledge benefits from such team interactions are clear. New approaches are needed to assist team actions, such as the DPSIR framework, and “wiring diagrams” used in IGBP for the development of cross-cutting projects.

2. Targetted research. Thematic and programmatic research approaches should be applied to coastal zone research rather than the traditional, piecemeal approach of task-based, disciplinary effort. Questions of different scalings in time and space need urgent consideration along with new tools for assessment and measurement across scales and within socio-economic research. A focus should be placed on understanding whole ecosystem function and forcing, vulnerability and risk, changing pressures, feedbacks and integration of forcings. Improved models (conceptual, numeric, deterministic, probabilistic) for top-down and bottom-up approaches are required. Efforts on socio-economic research needs to be enhanced.

3. Synthesis and integration of information. New scientific enterprise is always welcome but better use needs to be made of existing data, information and knowledge; research
funding bodies need to shift policies in this regard. New tools, approaches and efforts should be exerted for the synthesis of scientific data into information and knowledge - and outcomes need to be made accessible to users and the community. Along with further concerted effort to engage with users, science programs should include a clear strategy for communication and delivery of information.

4. **Regionality.** Thematic projects, synthesis and integration should be directed to assessment at regional scales to more fully understand the tapestry of the coastal zone and to resolve response and management options that address the vital transboundary and teleconnections elements. The application of common methodologies will increase regional integration of information and options.

5. **Non-linearity of processes (feedbacks and thresholds).** The non-linear relationships of forcing and function are apparent in the coastal zone and there is a requirement for developing new concepts, tools and approaches to encompass this in modelling and predictions, scenario building and vulnerability-risk assessments.

6. **Monitoring and indicators of functions and changes.** Proxies for process and change and indicators of system function and response are required to better understand and measure change and the effectiveness of management and policy applications.

7. **Improved databases and access.**

Underpinning such research enterprise is the need for continuing and enhanced capacity building in both science and management training and awareness.

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**References**


