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Land Ocean Interactions in the Coastal Zone, LOICZ: Lessons from Banda Aceh, Atlantis, and Canute

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This special issue of Estuarine, Coastal and Shelf Science synthesizes and updates the developments in science related to Land Ocean Interactions in the Coastal Zone (LOICZ). Frequent updates about the dynamic coastal zone are useful and necessary as global change accelerates. There is an urgent need to improve the knowledge and understanding of the vulnerability of society and ecosystems to global change hazards in the coastal zone (Vermaat et al., 2005). The collection of papers in this special issue places new developments, findings, techniques and insights within the context of LOICZ science. For the convenience of the reader, the references to papers included in this special issue are printed in *italic*, whereas other references to LOICZ science are in normal print.

LOICZ is a core project of both the Global Environmental Change the International Geosphere–Biosphere Programme (IGBP) and the International Human Dimension Programme (IHDP) (Steffen et al., 2004). These two international programmes recognize the importance of the coastal zone in the anthropocene, an era of global change partly driven by human activities. LOICZ science links catchment and river-basin science to coastal science (Salomons and Turner, 2005), within the context of global change and also examines the human dimension of this change. LOICZ is the science of fluxes across boundaries: atmosphere, land, sea, sediments and the role humans play in these at the global scale (Crossland et al., 2005). Historically, scientists from disparate disciplines such as hydrology, sedimentology, biogeochemistry, economics and social sciences, have studied river basins and coasts. Although these disciplinary studies are useful to define problems, in an age of rapid global change, scientific integration is needed to solve them. This integration approach is, therefore, an important paradigm shift to find sustainable solutions to the environmental problems of the coastal zone created by past, present and future human populations (*Dennison, in this issue*).

LOICZ integrates the knowledge gained at local and regional level to build an overall, global picture using a series of LOICZ tools (www.loicz.org), including nutrient budgets, typology, conceptual diagrams and assessment frameworks (e.g. Drivers Pressures States Impacts Responses or DPSIR, see OECD, 1993; Assessment of Estuarine Trophic Status or ASSETS, see Bricker et al., 2003). LOICZ has also developed tools for issues of system sustainability and resource management that link the human dimension in the ‘‘anthropocene’’ with pressure and change. For example, coastal typology is an integrative ‘‘neutral’’ technique that bridges the gap between natural and social sciences, enabling LOICZ scientists to characterize the coast and also to analyze the pressures on the coastal zone and the resulting consequences (*Buddemeier et al., in this issue*).

The contributions in this special issue not only provide an update on LOICZ science, tools and assessment frameworks, but also illustrate some of the problems affecting the coastal zone, and provide some practical and conceptual solutions that reconcile human socio-economic activities with the coastal environment.

Human settlements on the coast are threatened by multiple risks such as tsunamis, storm surges, sea-level rise and coastal erosion. The risk and safety of the coastal inhabitants was brought sharply into focus by the tsunami of 26 December 2004 and its devastating affect on many Asian coastal communities, with Banda Aceh in Indonesia as a particularly poignant example. Whereas tsunamis are sudden and unpredictable

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events, the coastal zone is also vulnerable to more gradual processes that may have a greater, long-term impact. Changes in sea-level are linked to climate change. The importance of understanding the causes and consequences of climate change in the coastal zone has huge implications for the human dimension (IPCC, 2007).

Sea-levels have been much lower in the past −100 m are the estimates for the last ice-age, when a large volume of water was locked up as ice in the continental ice sheets. At the time of the last ice-age, Britain was attached to continental Europe and many more such land-bridges existed, facilitating the migration of species and populations (Douglas, 1995).

Scenarios of sea-level rise that take into account the thermal expansion of water as well as the melting of all the current Greenland and Antarctic ice sheets and the Artic permafrost melt may lead to an alarming sea-level rise of more than +70 m. So, one way of conceptualizing the coastal zone could be to consider the area between −100 m and +70 m from the present contour, a very different concept to that in use for the purpose of governance and management of the coastal zone. The familiar coastline of today would disappear. The changes would obliterate whole countries, such as Pacific and Indian Ocean archipelagos. Large parts of densely populated countries, such as Bangladesh and the Netherlands, would disappear, like the fabled Atlantis. Major cities such as London would be flooded as well as low-lying states, such as Florida. These scenarios are alarming but they are possible, even if not in the short term. A large percentage of the world population currently lives in the coastal zone that is far more restricted than the +70 m contour and is, therefore, vulnerable to rising sea-level. The true impact of such change is best addressed by multidisciplinary studies that combine the physical analysis of the problem using Geographical Information Services with an analysis of the ecological and socio-economic impacts of a sea-level rise (*Snoussi et al., in this issue*).

The coastal zone is geologically dynamic (Woodroffe, 2003). Volcanic and tectonic activity, rebound, tilting, erosion and deposition change the shape of the coastline constantly (Tudhope et al., 2000). However, the human dimension is also important (Syvitski et al., 2005). Human activities disrupt the delivery of land-derived materials, including sediments (Salomons, 2005). Changes in land use, deforestation, and agricultural practices such as tillage, all alter the amount of soil washed into rivers and flowing to the coastal zone (*Restrepo, in this issue*). Anthropogenic influences on the sediment load at a regional scale can impact sensitive ecosystems of the region, such as corals (Wolanski and De'ath, 2005) and seagrass beds.

The fluxes of sediment loads to the coast have also been significantly modified by humans with the construction of dams (Milliman, 1997; Yang et al., 2006). Dams retain sediment loads that would normally be transported to the sea, resulting in a deficit of sediment delivery to the coast and consequent coastal erosion. Humans also alter the natural sedimentary processes of the coastal zone in many ways (Le et al., 2007; Syvitski and Saito, 2007). Coastal defenses erected to protect specific areas of the coast trap sediments and interrupt the supply to other areas, thereby, transporting the problem along the coast instead of the sediment (Kjerfve et al., 2002). Dredging also re-suspends and relocates sediments, and dredged material may be so contaminated that is must be contained and subjected to special measures. Harbour development further degrades the coast (Wolanski, 2006).

The sediment record in estuaries is an invaluable tool for the study of global changes in the coastal zone both in the past and at present. It records rapid sea-level rise, as well as linking estuarine productivity and organic matter production to the global carbon cycle (Boski et al., 2007). Indeed, the coastal zone and shelf seas are critical areas with respect to the global carbon cycle. There is also a link between the river-basin attributes and the behavior of estuaries. Estuarine plumes may be net contributors of CO_2 to the atmosphere or, on the contrary, are sinks of CO_2 (*Salisbury et al., in this issue*).

The activities and processes in the catchment control the health and function of the coastal zone. Transitional waters, including the large family of estuaries, deltas, coastal lagoons, fjords and other such systems, play an important role in integrating terrestrial pressures and transferring some of these to coastal waters while buffering others. The geochemistry of estuaries is dominated by rapid changes in environmental master variables such as temperature, salinity, pH and sometimes Eh.

One of the main pressures in coastal zones is the increase in nutrient inputs from the land (Hong et al., 2005). At the global scale (Smith et al., 2003), nutrient inputs have increased dramatically during the 20th century. Eutrophication is now a common problem not only in lakes but also in estuaries and in the coastal zone (Rabalais and Nixon, 2002). Nutrient retention by dams can also affect nutrient ratios (Humborg et al., 1999). LOICZ nutrient budgets are a useful tool to understand how coastal systems respond to pressures of increasing nutrient inputs. The size of the catchment (Smith et al., 2005) and the physics of the receiving coastal system, such as the residence time or flushing of an estuary, largely determines the sensitivity of a coastal system to nutrient pollution. Simple LOICZ nutrient budgets can be developed and extended into nutrient-phytoplankton-zooplankton ecological models in estuaries (*Swaney et al., in this issue*).

Coastal lagoons are one of the most vulnerable coastal environments. Typically lagoons are surrounded by low-lying agricultural land, and exchanges with the sea are restricted at narrow inlets. Shallow, sheltered lagoon environments are very productive and support varied human socio-economic activities such as aquaculture, fisheries and tourism. Coastal lagoons represent 13% of the coastline, although they are unevenly distributed globally. Coastal lagoons are a common feature of many coastlines such as the Baltic, the Black Sea and the Mediterranean Sea. LOICZ biogeochemical models can be useful in these shallow, coastal lagoons (*Giordani et al., in this issue*). The models are simple to use and can be applied to a large number of systems, which allows the comparison of results in order to gain insights on the different ecosystem function of the lagoons as well as to assess net ecosystem metabolism. The biogeochemical models have been

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used in a large number of systems worldwide to give a global perspective.

A salinity gradient is established in microtidal, Mediterranean lagoons with freshwater inputs. This gradient allows salt-balance calculations. Tidally flushed Atlantic lagoons, however, have a more complex hydrography, especially when they are estuarine in wet months but anti-estuarine in dry months because of high evaporation rates. It is difficult to use the LOICZ biogeochemical model in such systems, but simple ‘‘low-tech’’ solutions can be easily applied to calculate residence times in hyper-saline lagoons using salinity as a tracer (*Mudge et al., in this issue*).

Nutrients are not the only materials delivered to the coastal zone by estuaries. Estuaries deliver other pollutants, such as metals, as well as sediments to the coastal zone. The delivery of pollutants may be highly irregular and periodic and controlled by hydrological regimes, important considerations for environmental managers who have to draw up monitoring plans. Furthermore, shallow sediments in deltaic systems are subject to resuspension, so particulate sinks may not be permanent in such shallow systems (*Radakovitch et al., in this issue*).

While rivers are the main transporters of materials from the terrestrial environment to the coastal and marine environments (Meybeck, 2003), estuaries, deltas, fjords and lagoons are not the only transition link in the catchment to coast continuum. Other links include atmospheric deposition (Pacyna and Manø, 2006), and groundwater–seawater interactions (Kontar and Ozorovich, 2006). Groundwater flows into the coastal waters maybe a significant source of nutrients to coastal zone. Conversely, seawater intrusions into groundwater may result from the over-extraction of water from aquifers, such as in many arid, Mediterranean agricultural regions, or as a result of dramatic events such as a tsunami that will also contaminate aquifers with seawater.

Remote sensing can give the large picture of coastal zone processes. Although this is a useful tool, satellite images must be calibrated by ‘‘real’’ data and sea-truthing techniques. The main constraint is that routine and frequent monitoring of the coastal zone, especially using research vessels, is often prohibitively expensive. The use of data from ‘‘ferryboxes’’ on ships of opportunity that repeatedly ply the same ferry routes can be used in conjunction with satellite images to continuously monitor the coast successfully and at a relatively low financial cost (*Petersen et al., in this issue*). This permits an assessment of coastal and shelf-sea ecosystems that combines in-situ and remotely sensed MERIS data.

In conclusion, the papers in this special issue (quoted in *italics*) and the others in the reference list demonstrate that the coastal environments are particularly vulnerable to a multitude of global changes, whether these are caused by sea-level changes, changes in sediment supply, changes in biogeochemical cycles or demographic changes. The interaction of all these simultaneous changes will cause different impacts on different types of coasts. Indeed the very concept of the coastal zone is complex. Definitions abound and reflect the multiple governance issues of the boundary between land and sea. The problems are multiplied when several nations have shared jurisdiction (Lorenz et al., 2002). Nevertheless, valuable lessons have been learned about coastal management (Olsen and Christie, 2000). Tools such as the DPSIR framework are beginning to link natural, social and economic sciences with policy responses. Ecological and environmental economics of the coastal zone are yielding exciting results. Ecosytem uses, goods and services can now be valued.

As to the future, sustainable development in the coastal zone will only be possible if ecosystem integrity and resilience is maintained. Although ecosystems are resilient, they exhibit non-linearities and regime shifts, so the onset of abrupt ecosystem collapse and the pathway to recovery are uncertain. The use of appropriate scales for management must be reconciled with governance issues and trans-boundary management. It may be futile, expensive and dangerous to try to maintain an artificially drawn coastline. It might even be necessary to use managed realignment as a better and safer choice, thereby heeding the lessons of the 10th century British King Canute who demonstrated to his subjects that even he was unable to prevent the incoming tide. Whilst it is important to seek solutions for sustainable use of coastal and marine resources (Roth et al., 2002; Burbridge et al., 2001; McDonald et al., 2001), it would be unrealistic to expect that coasts can return to a ‘‘pristine’’ state. Even as our knowledge and understanding of ecosystem function increases, we face new and emergent issues such as lifestyle chemicals, and new uses of the coastal zone and seas, for example, energy generation in offshore wind farms. These are all ongoing challenges for the LOICZ scientific community.

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