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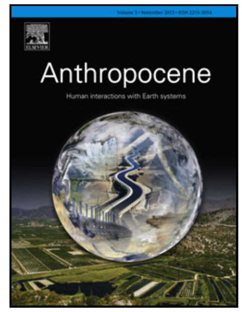

Title: Land-Ocean Interactions in the Coastal Zone: Past, Present and Future

Author: R. Ramesh Z. Chen V. Cummins J. Day C. D'Elia B. Dennison D.L. Forbes B. Glaeser M. Glaser B. Glavovic H. Kremer M. Lange J.N. Larsen M.Le Tissier A. Newton M. Pelling R. Purvaja E. Wolanski

PII: S2213-3054(16)30005-4
DOI: http://dx.doi.org/doi:10.1016/j.ancene.2016.01.005
Reference: ANCENE 102

To appear in:

Received date: 14-8-2015
Revised date: 20-1-2016
Accepted date: 22-1-2016

Please cite this article as: Ramesh, R., Chen, Z., Cummins, V., Day, J., D'Elia, C., Dennison, B., Forbes, D.L., Glaeser, B., Glaser, M., Glavovic, B., Kremer, H., Lange, M., Larsen, J.N., Tissier, M.Le, Newton, A., Pelling, M., Purvaja, R., Wolanski, E., Land-Ocean Interactions in the Coastal Zone: Past, Present and Future.Anthropocene http://dx.doi.org/10.1016/j.ancene.2016.01.005

Land-Ocean Interactions in the Coastal Zone: Past, Present & Future

Ramesh, R[1]., Chen, Z[2]., Cummins, V[3]., Day, J[4]., D'Elia, C[4] ., Dennison, B[5]., Forbes, D.L[6]., Glaeser, B[7]., Glaser, M[8]., Glavovic, B[9]., Kremer, H[10]., Lange, M[3]., Larsen, J.N[11]., Le Tissier, M[3]., Newton, A[12]., Pelling, M[13]., Purvaja, R[1]. and Wolanski, E[14].

[1] National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Anna University Campus, Chennai 600 025
[2] East China Normal University, State Key Laboratory for Estuarine and Coastal Research, People's Republic of China
[3] MaREI Centre, Beaufort Building, University College Cork, Ringaskiddy, Cork, Ireland
[4] Dept. of Oceanography and Coastal Sciences, Louisiana State University, Louisiana, US
[5] University of Maryland Center for Environmental Science, 2020 Horns Point Rd, Cambridge, MD 21613, USA
[6] Geological Survey of Canada, Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada
[7] Deutsche Gesellschaft für Humanökologie, Clayallee 271, 14169 Berlin, Germany
[8] Leibniz-Zentrum für Marine Tropenökologie (ZMT) GmbH, Fahrenheitstr. 6, 28359 Bremen, Germany
[9] School of People, Environment and Planning, Massey University, Palmerston North, 4442, New Zealand
[10] Scientific Assessment Branch, Division of Early Warning and Assessment, Nairobi, Kenya
[11] University of Akureyri, Stefansson Arctic Institute, Iceland
[12] NILU, IMPEC-Department of Environmental Impacts and Economics, 2027 KJELLER, Norway
[13] King's College London, Department of Geography, United Kingdom
[14] TropWATER and College of Marine and Environmental Science, James Cook University, Townsville, Q. 4811, Australia

[1] Except the first author, names of all authors are arranged in alphabetic order and their contribution is equal. All authors are present or past members of the LOICZ Scientific Steering Committee and/or Regional Nodes and the IPO

ABSTRACT

The Land-Ocean Interactions in the Coastal Zone (LOICZ) project was established in 1993 as a core project of the International Geosphere-Biosphere Programme (IGBP) to provide the science knowledge to answer “How will changes in land use, sea level and climate alter coastal systems, and what are the wider consequences?” In its first phase of operation (1993 – 2003) LOICZ began a fundamental investigation focused on biophysical dimensions, including seminal assessments of coastal seas as net sources or sinks of atmospheric CO_2, river discharge to the oceans, and biogeochemical modelling. In the second generation of LOICZ (2004 – 2014), increased attention was paid to the human dimensions of the coast, involving the inclusion of cross-cutting themes such as coastal governance, social-ecological systems, ecological economics and activities around capacity building and the promotion of early career scientists. This paper provides a synthesis of this work and looks forward to the future challenges for the project. With the transition to Future Earth, there is a paradigm shift emerging. The new vision is to support transformation to a sustainable and resilient future for society and nature on the coast, by facilitating innovative, integrated and solutions-oriented science. Realising this vision takes LOICZ into a third generation: to be at the forefront of co-designing, co-producing and co-implementing knowledge for coastal resilience and sustainability. LOICZ as Future Earth Coasts will continue to address ‘hotspots’ of coastal vulnerability, focusing on themes of dynamic coasts, human development and the coast, and pathways to global coastal sustainability and constraints thereof.

Keywords: LOICZ; biogeochemical models; social-ecological systems; capacity building; coastal resilience; sustainability

1. Introduction

The coasts of the world form a narrow interface zone between marine and terrestrial areas in which large and growing proportions of the human population and global economic activity are located. The low-elevation coastal zone (LECZ) encompassing 2% of the earth's land area (McGranahan et al. 2007) is home to 600 million people (10% of the total population), of whom 360 million are urban (13% of the world's total urban population) as of year 2000 (CIESIN 2009). The coastal zone sustains sensitive ecosystems providing critical habitat for many endangered species, and highly important ecosystem services in the form of coastal protection, fisheries and other living resources, rich agricultural lands, areas of high aesthetic value, and is typically held as public heritage and connects land and sea. Eight of the top ten largest cities in the world and much of the world's tourism, which are increasingly important in national economies, are situated at the coast.

Coastal regions and populations are exposed to pressures and hazards from both land and sea making the coastal zone "Arguably the most transformed and imperilled social-ecological system on earth, [which] are characterized by pervasive unsustainable practices" (Cummins et al. 2014). To address these issues, the international research consortium LOICZ (Land-Ocean Interactions in the Coastal Zone) was initiated as a core project of IGBP (the International Geosphere-Biosphere Programme) in 1993 to answer the core question "How will changes in land use, sea level and climate alter coastal systems, and what are the wider consequences?" (Crossland et al. 2005). A fundamental approach that LOICZ has taken to address this question is recognition that that the coastal zone is not a geographic boundary of interaction between the land and the sea but a global compartment of special significance for biogeochemical cycling and processes and ever increasingly for human habitation and economies. The primary objective of LOICZ was "to provide the knowledge, understanding, global vision, and predictive capacity to enable coastal communities to assess, anticipate and respond to the interaction of global change and local pressures which determine coastal change” (Kremer et al. 2005). At its core, LOICZ is a network and community of scientists from all disciplines and across 80 countries from all regions of the world who contribute their work and expertise to collectively address an overarching goal to ‘to develop the capacity to assess, model and predict (i) change in the global coastal zone under multiple forcings (including human activity), and (ii) the consequences for human welfare’ (Kremer et al. 2005). Through its activities LOICZ has served as a catalyst for methodological development, strategic research coordination, science communication, capacity building, and applications to enhance coastal sustainability at a global scale.

LOICZ has been managed through an International Project Office (IPO) supporting the strategic direction provided by a Scientific Steering Committee. The IPO was first located at the Netherlands Institute for Sea Research in Texel and financially supported by the Dutch Government. In 2006, it moved to the Institute for Coastal Research at the GKSS Research Centre (later Helmholtz Zentrum Geesthacht Centre for Materials and Coastal Research (HZG)) in Geesthacht, Germany, which supported the IPO until 2014. As of January 2015, the IPO is hosted at the MaREI Centre of University College Cork (UCC), in Ireland. The global reach of LOICZ was enhanced by a network of regional node engagement partners in East Asia, Southeast Asia, South Asia, South America and North America, with emerging regional centres in Taiwan, the Caribbean, West Africa, and the Arctic.

The history of LOICZ can be clearly demarcated into three phases, 1993 – 2003, 2004 – 2014, and from 2015 to a new third phase having transitioned to Future Earth Coasts as part of the new Future Earth programme (Fig. 1). Figure 1 shows the research foci in each phase along with the major outputs. A Web of Science search using LOICZ as the search term results in a total of 1189 publications with average citations per year of 66. In addition to peer reviewed journals outputs of LOICZ have been published in the LOICZ Research and Studies

(R&S) reports and books (http://www.loicz.org/cms02/products/publication/). These included scientific reviews of LOICZ science, guidelines, datasets and scientific planning documents and a LOICZ synthesis report (Crossland et al. 2005) and a synthesis volume on coastal nutrient fluxes (Liu et al. 2010).

1.1. First Phase: 1993-2003

In the First Phase (1993-2003), LOICZ was a core project of IGBP and primarily concerned with the complex heterogeneity of coastal systems and their biogeochemistry, with a focus on fluxes of nutrients and pollutants (Swaney and Giordani 2011; Swaney et al. 2011). There were four research foci (Fig.1), the first three of which addressed the implications of changes in external forcing or boundary conditions, the effects of global change on coral reefs, and carbon fluxes and trace gas emissions. The fourth research focus foreshadowed later developments, with attention to economic and social impacts of global change in coastal systems.

1.2. Second Phase (2004-2014)

Based on the outcomes from the first 10 years of activity, LOICZ continued as a core project under IGBP II and also became co-sponsored under IHDP (the International Human Dimensions Programme on Global Environmental Change). This was in recognition of an expanding research direction to a scientific agenda that tightly couples the social-ecological systems as they interactively influence the biogeochemistry of carbon, nutrients and sediments along the catchment–coast continuum. The new Science Plan and Implementation Strategy (Kremer et al. 2005) comprised the biogeochemical, physical and human dimensions of coastal change organized into five themes (Fig. 1).

In 2010, a mid-term evaluation of LOICZ (Turner et al. 2010) recommended a new overarching frame of *Vulnerability and Adaptation to Global Change in the Coastal Zone*, considering the interaction between natural and human factors in coastal social-ecological systems (e.g. Glaeser et al. 2009; Glaser and Glaeser 2011, 2014). This pointed to the need to integrate governance and sustainability issues along with ecological economics with natural science research (e.g. Agboola 2014; Day et al. 2014; Glaeser and Glaser 2011; Glavovic 2013a, 2013b, 2014; Hay et al. 2013; Lane et al. 2013; Mee 2012; Newton et al. 2012; Olsen et al. 2009; Patterson and Glavovic 2013; Pelling and Blackburn 2012, 2014). The mid-term evaluation also recommended the concept of LOICZ 'hotspots' (Newton et al. 2012) targeting efforts at large river-mouth systems (deltas and estuaries), coastal urbanization, islands at risk, and Arctic coasts.

1.3. Progress made over the period of IGBP support

After the first decade (1993-2003) of focus on natural science (biogeochemical) themes, which produced the classical LOICZ approach to estuarine stoichiometric budgets, the second decade of LOICZ developed an enhanced emphasis on the social sciences, namely environmental economics, sociology and the political science/governance nexus. This integration has served as a focus for collaborative research initiatives that has included more than 400 affiliated projects since 1993 providing a forum that has brought together experts and a pioneering interdisciplinary team-based approach to coastal zone science and management. This was recognized as an effective mechanism of engagement with the global science community by the mid-term review (Turner et al. 2010), which suggested developing joint research projects with active inputs from LOICZ to yield added value. The international scientific community benefits because LOICZ integrates knowledge gained at local and regional levels to build an overall global picture using a series of LOICZ research foci and assessments. In addition, LOICZ outputs are presented on the project website (www.loicz.org and www.futureearthcoasts.org), a freely accessible 'public good' contribution (Turner et al. 2010).

The evolution of LOICZ over the period 1993 to 2014 has mirrored the role of IGBP to coordinate international research on global-scale and regional-scale interactions between Earth's biological, chemical and physical processes and their interactions with human systems. Thus, LOICZ has developed its programme to reflect the international agenda of global change research. Whilst continuing with core research on biogeochemical budget models and coastal typology development, the LOICZ focus has extended to hotspots of coastal vulnerability (Newton et al. 2012; Newton and Weichselgartner, 2014; Brown et al. 2014), especially of subsiding deltas (Day et al. 2007, 2014; Overeem et al. 2009; Syvitski et al. 2009) and Arctic coasts (Forbes 2011; Larsen et al. 2014), the assessment of governance especially with respect to natural hazards and post-disaster recovery experiences (Glaser et al. 2010; Glavovic 2014; Olsen et al. 2009), a synthesis of urbanisation and coastal change processes (Sekovski et al. 2012; Pelling and Blackburn 2012, 2014), holistic assessment of social-ecological systems (Glaser and Glaeser 2014; Glaser et al. 2012; Newton et al. 2014), and adapting to a changing climate at the coast (Glavovic et al. 2015). An additional emerging theme was the issue of global constraints on achieving sustainability (Hall and Day 2009, Day et al. 2014).

1.4. Links with international research programmes

Within IGBP, LOICZ has linked with a number of other ESSP projects including AIMES, GCP, GECAFS, the new Human Health initiative, and in particular GWSP, which deals with catchment-based hydrological and freshwater resource issues. Specific contextual collaboration with IMBER through a Continental Margins Working Group, and SOLAS, to design observation and modelling strategies that link coastal systems to oceanic and atmospheric systems has taken place. As well as working with other EESP projects, LOICZ has also worked with external organizations, such as UNEP GPA and IHP/IOC of UNESCO primarily in the development of outreach and capacity building elements to the project.

2. Scientific Achievements

With over 1000 publications, books and R&S reports and a community of thousands of scientists who have in some way been involved with LOICZ over the period 1993 to 2014, it is impossible to capture all the project's achievements in a single paper. In this section we reflect on some of the key outcomes from LOICZ that have shaped the development of the project, and its contributions to our understanding of global change. This is organised from the perspectives of biogeochemical modelling carried out during LOICZ I and the LOICZ II focus to bring to centre stage the vulnerabilities of both humans and ecosystems – given the anthropogenically altered and changing state of the coast, and the mechanisms for mitigating these through defining sustainable future scenarios.

2.1. Biogeochemical Nutrient Budgeting & Typologies

The LOICZ biogeochemical model (Swaney and Giordani 2011; Swaney et al. 2011) was developed to provide a simple model for managers and planners that answers the question: 'where do the nutrients (carbon, nitrogen and phosphorus) go?' It also helps to establish whether the coastal ocean is a source or a sink of CO_2, important in the context of climate change. The model has been applied to estuaries and coastal waters worldwide (http://nest.su.se/mnode/ and Buddemeier et al. 2002; Liu et al. 2010; Swaney and Giordani 2011). More than 200 site-specific budgets form a global nutrient and carbon inventory for the coastal ocean (Fig. 2). Scientists from around the world have contributed descriptions of site budgets to a central website (see http://nest.su.se/mnode/wmap.htm; http://nest.su.se/mnode). At the end of 2002 LOICZ was able to provide a first global synthesis of nutrient fluxes and C, N and P metabolism in coastal waters, drawing on site studies from regional compilations in Mexico, Australasia, Central America, the South China Sea, South America, East Asia, Africa, the Mediterranean, the Black Sea, and polar regions, addressing questions of land-based drivers and best approximations for coastal system functions (Buddemeier et al. 2002) (Fig. 2). A significant finding was that the NEM (p-r) decreases with increasing values of the water residence time T, (Swaney et al. 2011, Xu et. al. 2013). This implies that, worldwide, rapidly flushed systems have a much smaller NEM than slowly flushed systems. These relationships and the methodology have provided the coastal scientific community with a widely used tool to quantify the biogeochemical fluxes in estuaries and coastal waters around the globe.

In its simplest mode, that of a vertically well-mixed estuary, the model divides an estuary into three compartments: namely the river, the estuary and coastal waters. It uses field data on river inflow, rainfall, salinity, and bathymetry to calculate the residence time of water in the estuary. The model is designed to be easy to use even by non-specialists as it is written in MSExcel and requires only clearly labelled input data. For more complex systems (e.g. vertically stratified systems and/or long or complex branched systems) the model can readily add additional compartments spread horizontally and/or vertically to better represent the system; the output of water and salt from one compartment is the input to the adjoining compartments (Swaney et al. 2011). The model uses field data of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) for each compartment and additional local sources of N and P such as from sewage, aquaculture and groundwater. It calculates the net budget (inflow minus outflow) of DIN and DIP in the estuary; and compares these budgets with those expected if the nutrients were conservative; from that difference and relying on classical stoichiometry, it calculates the net ecosystem metabolism

(NEM) as p-r (production minus respiration, expressed in mmol C $m^{-2}d^{-1}$) and nitrogen fixation minus denitrification (nfix-denit; in mmoles $m^{-2}yr^{-1}$). The model reveals that some estuaries have a positive value of p-r (autotrophic estuaries) and some estuaries have a negative value (heterotrophic estuaries). No clear rules of typology have been found to enable prediction upfront, in the absence of data, whether an estuary will have a positive or negative NEM. This means that field data are still needed for individual estuaries. However, provided these few field data on hydrology, bathymetry, salinity and nutrients in the three compartments are available, the nutrient budget can be calculated for any estuary.

Recently, the LOICZ biogeochemical model has been developed to include the effect of fine suspended sediment that can sequester (or release) dissolved nutrients to estimate nutrient bioavailability in estuarine and coastal waters (Xu et al. 2013, 2015). If the suspended particulate matter (SPM) was constant in the river, in the estuary and in coastal waters, there would be no problem and the LOICZ model is correct. However in most estuaries the SPM varies between the river, the estuary and the coastal waters. This has a major implication on the sequestration or release of nutrients to/from the particulate form. The LOICZ model was corrected to take account this effect and this 'muddy' LOICZ model has been applied to the Yangtze Estuary, China and demonstrated that the value of the nutrient partition coefficient in the Yangtze Estuary shows a similar dependence as that in European estuaries. High values of NEM are found, with p-r = -10.9 mmol C $m^{-2}day^{-1}$ for the non-flood season. If nutrient partitioning were neglected, this value would be -2.7 mmol C $m^{-2}day^{-1}$, which would have been wrongly interpreted as biological decay in the turbidity maximum zone and primary production in coastal waters. The rate of heterotrophy is thus three times higher than when the interaction of SPM with the nutrients is neglected (Xu et al. 2013). The LOICZ models are useful to describe the change in the flux of ΔDIP from positive to negative and the p-r from negative to positive since 1999. These changes indicate that, whereas in the past the estuary was a source of DIP and a heterotrophic system, now it has become a sink of DIP and an autotrophic system. The changing ecosystem can be explained by the upstream dam construction that decreases SPM but not organic matter and nutrient fluxes to the estuary due to increasing sewage and fertilizers (Xu et al. 2015)

The muddy LOICZ model was recently also modified to include the out-welling to the estuary of plant detritus from tidal wetlands, e.g. mangrove leaves as in the case of the Wami Estuary in Tanzania (Kiwango et al., 2015). More recently again, the muddy LOICZ model was merged with the UNESCO estuarine eco-hydrology model of Wolanski et al. (2006a and b) to extend the model predictions to plankton and fish (Wolanski and Elliott, 2015). It is being used with success in the Chilika Lagoon in India, the mangrove-fringed Wami Estuary in Tanzania, Laizhou Bay in the Bohai Sea, China and by the Government of India's National Centre for Sustainable Coastal Management for an on-going study of estuaries. The fate of nutrients and the level of eutrophication of 10 estuaries of national importance are being modelled in order to develop policies for sustainability.

2.2. Linking social and ecological systems in the coastal zone

Research in coastal areas has traditionally followed two largely disparate streams in the natural sciences and the social sciences with limited interaction (largely in the field of engineering) between the two. Over time, it has become clear that issue-focussed interdisciplinarity is needed to analyse the interrelated natural and social drivers of coastal change, including interactions and feedbacks with human systems from the inland watershed to the ocean shelf (Glaeser 2002, 2004). This focus is reflected in the development of integrated coastal management (ICM) and increased attention to disaster risk reduction, climate-change impacts and adaptation, and integrated social-ecological systems in the coastal zone. The second phase of LOICZ has echoed such developments leading to new initiatives in the field of coastal governance (e.g. Olsen et al. 2009) and the analysis of social-ecological systems at various scales and levels (e.g. Glaeser et al. 2009; Glaser and Glaeser 2014). There was also a new emphasis on pathways to effective adaptation and measures for enhancing adaptive capacity and resilience in coastal communities (e.g. Glaser et al. 2010, 2012; Glavovic et al. 2015; Hay et al. 2013; Hills et al. 2013; Lane et al. 2013) and on the application of natural science data to underpin evidence-based analysis of adaptation challenges and disaster risk reduction (e.g. Forbes et al. 2013). LOICZ outputs have provided a framework for consideration of representative social-ecological systems, including the economic drivers, costs, benefits, and resilience/adaptation challenges, to move from theoretical analysis to a more applied and integrated approach at regional and/or global scales (Glaeser and Glaser 2010). Also recognized was the importance of an explicit evaluation of the needs of policy makers, supplying science inputs that support evidence-based decision-making and adaptive management (Glaeser et al. 2009). Particular attention was paid to interdisciplinary research on risk and management of storm surges (Kremer et al. 2013).

As a precondition to effective systematic social-science engagement in research on human-nature dynamics, LOICZ social scientists have also developed a conceptual framework for managing the social-ecological dynamics of coastal ecosystems. Five quality criteria for assessment of the social dimension of ecosystem management were developed. On the basis of these criteria, seven components were integrated into a comprehensive conceptual framework for the social dimension of social-ecological management (Fig. 3) (Glaser and Glaeser 2011).

Methodology development to implement the analysis of interlinked social and ecological dynamics is relatively recent (Glaeser et al. 2009) and has been strong within LOICZ (Newton, 2012; Gari et al. 2014; Newton et al. 2014). A set of system-focused indicators for measuring and understanding sustainability-enhancing processes in tropical coastal and marine social-ecological systems was jointly developed by natural and social scientists from two LOICZ affiliated projects: Science for the Protection of Indonesian Coastal Ecosystems (SPICE) and Mangrove Dynamics and Management (MADAM) operating in North Brazil. The generic indicators for social, ecological and social-ecological system processes that were developed from the two decades of field experience in these and other projects (Glaser et al. 2012) shift the focus of social-ecological systems analysis from the analysis of system states to the processes that move social-ecological systems between alternate states – the key to transformative change. With a problem-focused definition of a specific social-ecological system, and with multi-agent modelling as the first important interface between natural and social analyses, LOICZ science has enabled the derivation of emergent social-ecological phenomena on the basis of social and natural science data. The objective, on which work continues, is to interlink social and ecological processes to develop an understanding of the underlying causes of identified system changes in coastal and marine social–ecological systems at multiple levels and across temporal, spatial, institutional and other scales.

These considerations led LOICZ to sponsor the publication of the twelve-volume *Treatise on Estuarine and Coastal Science* (Wolanski and McLusky 2011), released in early 2012 involving many former and current SSC and regional node members. Collectively, the chapters in this treatise illustrate that the effectiveness of integrated management is largely dependent on addressing the right temporal and spatial scales of issues of environmental change. It emphasises that good governance can be seriously compromised by drivers that originate at great spatial distance from the area of concern. Sustainable human-nature dynamics in coastal areas need cooperation and coordination for decision-making by stakeholders, scientists, and practitioners across traditional barriers. Such a partnership advances the capacity for communities to cope with change and reverse adverse effects on coastal zones and resources. Effective communication, partnerships, trust building, and ownership are pivotal elements in this context.

2.2.1. Linking governance and science in coastal regions

Governance is a central theme in political science, and increasingly in other social sciences. Work in South America, Asia and Africa and in various contexts around the world by Stephen Olsen and others framed ICM as a process that takes place within a governance framework wherein divergent goals, interests and understanding are negotiated in political interactions between coastal stakeholders (Olsen et al. 2009). The governance challenge is to enable key actors from government, civil society and the private sector to work together in ways that reconcile private and public, and short- and long-term, interests in pursuit of resilience and sustainability. In order to pinpoint and overcome barriers to implementing ICM, Olsen and colleagues developed the Order of Outcomes framework (Olsen et al. 2009). This recognizes that coastal governance is a long-term undertaking that requires step-wise changes in behaviour and institutional reform to overcome prevailing unsustainable path-dependencies.

Olsen and colleagues have developed conceptual frameworks and methods for assessing governance dimensions of ecosystem change. They developed a step-by-step process for assembling a baseline of trends in the condition and use of coastal resources and ecosystems and how governance choices shape the sustainability of coastal livelihoods (Olsen et al. 2009). Developing deeper understanding of the nature of coastal governance and the barriers and opportunities for advancing societal goals of resilience and sustainability lies at the heart of ongoing LOICZ coastal governance work (e.g. Glavovic 2014), including further development and application of the governance baseline framework and method. Recently, joint work between LOICZ and the Integrated Marine Biogeochemistry and Ecosystem

Research (IMBER) project has identified the continental margin as the new frontier for resource exploitation and colonization to meet the needs of coastal nations and humanity overall (Glavovic et al. 2105).

2.2.2. *Science communication and science-policy interface*

Effective science communication is the successful dissemination of knowledge to a wide range of audiences, from specialist scientists through managers and politicians to the public. LOICZ has sponsored several science communication training opportunities. These include workshops on creating conceptual syntheses portrayed in simple diagrams at the LOICZ II conference in the Netherlands in June 2005, at the Littoral 2006 conference in Poland, and at the Integrated Vulnerability Assessment of Coastal Areas workshop in the Philippines in September 2007. A full science communication training workshop was also conducted in Bangkok, Thailand, in September 2005 (Goh et al. 2012), in addition to a one-week course on science communication and integrated ecosystem assessment in Faro, Portugal, in May 2006 as part of the Erasmus Mundus Joint Master’s programme in Water and Coastal Management. LOICZ has also made significant contributions to the synthesis of science for wider audiences and in particular the application of scientific knowledge for coastal management and decision making (e.g. Le Tissier et al. 2006; Mee 2012).

Among the science communication products developed by LOICZ are the ecosystem summary diagrams produced at the Global Synthesis Workshop in Lawrence, Kansas in November, 2001. This method was used to describe the state of the Chilika Lake lagoon system on the east coast of India, facilitating dissemination of information to the scientist and lay person alike. Chilika Lake is subjected to constant pressures from both natural and human activities. Figure 4 schematically highlights causes of pressures such as overfishing, tourism, pollution and sedimentation that are easily comprehensible to coastal residents (especially fishermen) and policy makers alike, so that subsequent management action is adapted to sustain the ecosystem.

2.3. Focus on Hotspots

LOICZ hotspots are areas where rates of coastal change may exceed the capacity of natural and/or social systems to accommodate or adapt (Newton et al. 2012; Newton and Weichselgartner, 2014). Here we summarise outputs from LOICZ research into each of the 4 hotspots.

2.3.1. Arctic Coasts

Arctic coasts are undergoing rapid change on many fronts, with climate warming driving rapid reduction of sea ice, loss of land-based ice, permafrost degradation, accelerated coastal erosion and carbon delivery to the Arctic Ocean, enhanced methane release, and a host of other effects, with serious implications for Arctic coastal communities (Fig. 5). The highlight of LOICZ work on Arctic coasts was the *State of the Arctic Coast 2010* report (Forbes 2011), jointly sponsored by LOICZ, IASC (International Arctic Science Committee), the Arctic Monitoring and Assessment Programme (AMAP) of the Arctic Council, and the International Permafrost Association (IPA). The recognition of the need for such a report and the initiative to launch it arose from a joint LOICZ-IASC conference on Arctic coasts at risk in Tromsø, Norway, in 2007 (Flöser et al. 2007).

An overview of coastal stability on the circum-Arctic coast, summarizing results of the LOICZ-affiliated Arctic Coastal Dynamics Project (Lantuit, et al. 2012) fed into the *State of the Arctic Coast* report. In addition, LOICZ affiliated researchers have been editors/authors in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Larsen et al. 2014) and the 2014 Arctic Human Development Report: Regional Processes and Global

Linkages (Larsen and Fondahl 2014). These documents updated and went beyond the baseline report published in 2004 providing an assessment of the major trends in human development across the Arctic. Key findings of AR5 related to Arctic social-ecological systems included impacts of climate change on Arctic communities with narrowly based economies, and increasing impacts on Arctic residents, particularly indigenous peoples (Larsen et al. 2014). Key findings in AR5 also emphasized that the rapid rate of climate change in the Arctic may exceed the rate at which human and natural systems can successfully adapt in this region (Ibid.). Evolving efforts to address sustainability challenges in Arctic coastal communities include community-based monitoring initiatives under the Inuit Circumpolar Council, the Exchange for Local Observations and Knowledge of the Arctic (ELOKA), the LOICZ-sponsored Circumpolar Arctic Coastal Communities Observatory Network (CACCON) and Arctic Social Indicators (ASI) (Larsen et al. 2014). Arctic community and stakeholder involvement in coastal research is increasing: examples include the co-design of coastal risk assessment in the Inuvialuit Settlement Region, western Arctic Canada (Forbes et al. 2013) and new approaches to drinking water security in coastal communities of Nunatsiavut, eastern sub-Arctic Canada (Goldhar et al. 2013).

2.3.2. Islands at Risk

LOICZ-affiliated research on small islands has included leadership in the SPICE project (Science for the Protection of Indonesian Coastal Ecosystems, http://www.loicz.org/cms02/projects/documents/010049/index_0010049.html.en.html) as part of a LOICZ-affiliated coastal research collaboration (Glaeser and Glaser 2010, 2011) and a contribution to the Coral Triangle Initiative (Ferse et al. 2012).

Research on very small islands in the Spermonde Archipelago off southwestern Sulawesi identified challenges of over-population, resource depletion, social networks and hierarchies, social vulnerability, resilience, and governance facing residents of these social-ecological microcosms (Fig: 6) (Glaeser and Glaser 2010; Ferse et al. 2012), and develops policy recommendations based on the tight link between fishing livelihoods and ecosystem health in small island reef fisheries (Glaser et al. 2015). Research in the Caribbean islands under the LOICZ-affiliated project C-Change identified many similar constraints both in small islands such as Bequia (St. Vincent and the Grenadines) and in remote communities on larger islands such as Trinidad (Mycoo and Gobin 2013), (Lane, et al. 2013). Adaptive management strategies identified in the Spermonde Archipelago include an integrated co-management strategy across the region, incorporating local ecological knowledge (through local observers), and constructive integration of local power brokers (patrons), who are important stakeholders able to sway fishing decisions (Ferse et al. 2014).

A global analysis of island types, associated hazard exposure and adaption strategies highlighted the relative importance of sea-level rise (SLR), reef degradation, storm surges, storm waves, rainfall and landslides, and non-climate hazards such as tsunamis as a function of island type, size, topography, and geographic setting (Fig: 7). The figure shows four distinctive island types (raised atoll, atoll, volcanic island, continental fragment) with major (solid line) or moderate (broken line) exposure to various natural hazards and a selection of appropriate adaptation actions.

Projections of relative sea-level change were presented for 18 representative small islands in three oceans, showing that glacial meltwater fingerprinting leads to slightly enhanced SLR on tropical islands, but that the sea-level rise experienced locally (the so-called relative sea level rise), is critically dependent on each island’s crustal stability (uplift or subsidence). Because adjacent islands move differentially, vertical motion and RSL cannot be extrapolated from nearby islands, and there is a critical need for a greatly expanded network of geodetic monitoring sites or alternative strategies to measure vertical motion on individual islands as a prerequisite for realistic projections of local sea-level rise to evaluate island community vulnerability (Forbes et al. 2013).

2.3.3. River-Mouth Systems Including Deltas and Estuaries

River-mouth systems that include deltas and estuaries are extremely important ecologically and economically. These areas provide a wide variety of ecosystem goods and services such as fisheries, avian habitat, agricultural land, and storm protection (Day et al. 2013). The coastal zone is the most rapidly urbanizing area on the globe and the growing urban population is severely stressing these important systems. The biogeochemical modelling discussed earlier is now being widely applied in different coastal systems worldwide.

A number of important synthesis papers have been published by LOICZ-associated scientists (Syvitski et al. 2009, Vorosmarty et al. 2009, Giosan et al. 2014). For example, Giosan et al. (2014) showed that sediment input to most major deltas is insufficient to maintain elevation with rising sea level (Fig. 8). In addition, two recent books have been published under the LOICZ imprint in the Estuaries of the World series published by Springer (Wolanski 2013, Day et al. 2014). A recent book on integrated coastal management of the Gulf of Mexico was co-edited by a current SSC member (Day and Yáñez-Arancibia 2014). A central question of all of these studies is how global constraints affect the ability to manage coastal ecosystems in a sustainable manner. The river-coast continuum concept has been examined in a number of Research and Synthesis (R&S) Reports that have consolidated regionally organised information as Africa, South Asia, East Asia, Caribbean, Latin America (LOICZ Research and Studies Series available online from www.loicz.org).

An ongoing research project called DELTAS (http://delta.umn.edu/) is looking to answer the question: 'How do climate change, pressure on resources, and engineering/ infrastructure development make people, biodiversity, and delta ecosystems vulnerable?'

2.3.4. Coastal Urbanization

The world is urbanising, and the most rapid urbanisation is taking place on the coast. At the same time scientific knowledge on coastal systems and urbanisation processes is disarticulated. While we know a great deal about cities and the coast we know relatively little about their interactions, including the seaward and landward boundaries of coastal processes (Sekovski et al. 2012). To help resolve this, a community of practice has been built. This has been facilitated through a staged process built around key outputs. First, as part of a LOICZ International Conference in Yantai, China, a series of workshops led to the identification of key themes, case study cities and authors to shape a synthesis review of *Megacities on the Coast: Risk, Resilience and Transformation* (Pelling and Blackburn 2012).

This peer-review synthesis brought together 68 authors and was supported by IGBP, LOICZ and King's College London. The Synthesis with a prospective conclusion and executive summary is published by Routledge-Earthscan (Pelling and Blackburn, 2014) and has been a key text for the urban and coastal issue chapter in the IPCC 5th Assessment Report as well as influencing IGBP-IHDP reporting and science priorities.

Building on *Megacities and the Coast*, two discrete research projects have been funded under the Belmont Forum addressing vulnerability on the coast. Both are due to complete in May 2016. The TRUC project (http://www.bel-truc.org) - Transformation and Resilience on Urban Coasts - has a focus on coastal megacities (Kolkata, Lagos, London, New York and Tokyo). A framework (Fig. 9) has been designed to answer the research question: 'What are the constraints on policy capacity for moving coastal megacity development planning between resilience and transformation as modes of adaptation to sea-level rise and heat-stress risk?' In addition to academic outputs, the project is producing an approach for adaptation pathways that includes the integration of biophysical, flood hazard and vulnerability models with methods to solicit stakeholder assessment of organisational adaptive capacity. This unique methodology evaluates policy decisions that, while providing immediate solutions to one sector or area can increase the vulnerability of another, especially over the long term; and therefore the need for a more futuristic approach in decision-making. Results highlight the constraints on adaptation imposed by development trajectories and cultures of decision-making. For example when solutions for urban flooding are framed by competing development visions and values, as in responding to sea-level rise in Jamaica Bay, New York, options include the relocation of rental populations and the consolidation of capital through private sector led gentrification or the opening of green and blue space through state sponsored coastal retreat.

Both options have value and decisions will be informed by and help set in train wider visions of the city and its urban future. Other difficulties stem from the recognition of the need to plan for multi-hazard risk in cities where existing infrastructure and land-use are framed by single issue risk and so limit adaptation options. Common to all our cities heatwave is becoming more frequent and deadlier but continues to be managed through medical response or engineering – with risk reduction through social policy proving difficult to mobilise.

A second project, Metropole, examines the social, administrative and cultural contexts for adaptation preferences in the face of sea-level rise. The focus here is on smaller communities with 1,000 – 100,000 residents: Santos is a port city supplying Sao Paulo, Brazil; Selsy is a retirement centre on the south coast of the UK; Hollywood is a local tourist centre associated with St Petersburg, Florida. A large proportion of future urbanisation will take place in these smaller urban settlements but they are rarely a focus for study. The study combines climate-change projections and building-cost data to produce economic evaluations for a range of physical adaptation options and use this as a basis to explore the values that constrain individual and collective adaptation choices – and the gaps that emerge between adaptation preference and constrained choice. An important conclusion is the finding that small towns and cities are left out of regional adaptation planning and budget structures and are a key point of weakness in holistic coastal risk management. A clear policy outcome here would be that future planning strategies should include such small towns and cities in their framework for risk management.

2.4. Capacity Building and Cross-cutting Activities

LOICZ created two international master courses on "Water and Coastal Management" and "Ecohydrology" with EU funding from the Erasmus Mundus programme, which allowed the exchange of LOICZ graduate students, scholars and internships at the IPO. The courses are delivered by SSC members past and present to international students since 2004 and are still ongoing with financing secured until 2019. This has proved so successful that a further PhD programme "Marine and Coastal Management" was also funded. Several post-graduate students have also done internships at the LOICZ IPO. In addition a large number of early career scientists was given the opportunity to apply for funds to participate in LOICZ conferences and associated activities specifically dedicated to young scientists (Young LOICZ Forum 2011, Yantai, China). PhD students were also invited to affiliate their research projects to the network.

2.5. Key Links to Broader Earth System Science and IGBP

Earth System analysis addresses the highest possible level on the spatial scale: Planet Earth. Although the past two decades has seen significant advances in our understanding of earth system science, ensuring it successfully informs and contributes to decision-making remains elusive. New forms of transformative science are required that facilitate the participation and empowerment of ecosystem users and other influential stakeholders in reflections and decisions concerning the natural systems their livelihoods depend on. Particularly in strongly hierarchical contexts this requires the explicit establishment of two-way communications between all relevant stakeholders. LOICZ projects have been addressing this at the regional level (Glaser, et al. 2010).

The task of linking the analysis of local and regional social-ecological processes to global challenges and drivers is addressed in a 2014 special issue of the journal *Regional Environmental Change* on linking regional dynamics in coastal and marine social-ecological systems to global sustainability (Glaser and Glaeser, 2014). This publication arises from two LOICZ-supported conference sessions. In ten articles, it addresses integrating multi-level analyses, knowledge systems and governance. The question of how to link the analysis of place-specific social-ecological system features and dynamics to major global environmental change processes is far from resolved. However, scientists initially collaborating under the LOICZ Priority Topic 1 (Social-ecological Systems Analysis) show that analysis at the regional level is a promising point of departure for generating sustainability-oriented cross-scale and multi-level analyses. The approach offers the outline of a typology, grounded in regional social-ecological analysis and applied to nine coastal case studies, in which different disciplinary and other forms of knowledge can be integrated in regionally grounded analyses and action which also engages with global sustainability challenges (Glaser and Glaeser 2014).

Issue-based global analysis is also reflected in the development of earth system science, which has, over the past two decades, worked through global projects on land use, carbon, food and health issues, and on land-ocean interactions. The current restructuring of earth system science into global sustainability action research provides new opportunities for collaboration on the basis of networking between networks.

2.6. Future Challenges

There are a range of biophysical constraints that will make achieving coastal sustainability goals outlined by LOICZ and Future Earth challenging. During the 21st century, these biophysical and social constraints include energy scarcity, climate change, the loss of ecosystem services, the limitations of neoclassical economics, and human settlement patterns (e.g. Day et al. 2014, 2016, Hall and Klitgaard 2012). An important requirement and challenge for the new Future Earth Coasts project is to develop a framework within which constraints to sustainable development can be analysed and addressed in order to be considered in the preparation of sustainable development plans. There is a compelling need for new trajectories of coastal research that transcend disciplinary boundaries and the barriers between science, policy and practice in order to facilitate transformative changes necessary to transition towards safer and more resilient and sustainable pathways. LOICZ with its global network of researchers and institutions in the natural, social, and humanity sciences is working to support sustainability and adaptation to global change in the coastal zone. Its operations are feeding into the next decade of Earth system research on global sustainability that looks at the feedbacks of human interaction with nature and response options. The new LOICZ vision is to support transformation to a sustainable and resilient future for society and nature on the coast and defining what is and is not possible. This has already been initiated in LOICZ with the increasing focus on social sciences from an initial biogeochemical outlook. The development of the Future Earth research platform (www.futureearth.org) provides new opportunities for LOICZ to deliver science that is more integrated and has greater societal impact. As LOICZ transitions to Future Earth Coasts, new overarching themes have been designed to align with those of Future Earth (Cummins et al. 2014):

- Theme 1: Dynamic Coast, with the objective of improving understanding of the state of the coast, especially how nature shapes civilization (corresponds to the Dynamic Planet theme of Future Earth.
- Theme 2: Global Development and Our Coast, with a focus on improved understanding of consequences for human well-being in relation to human exploitation of ecosystem products and services - how humans harness and shape nature (corresponds to the Global Development theme of Future Earth).
- Theme 3: Transformation towards Coastal Sustainability, identifying what is and is not possible and governance pathways and processes for transformation in decision-making –how civil society can be empowered to prioritise actions towards sustainability (corresponds to the Transformations towards Sustainability

One of the strengths of LOICZ has been the extensive linkages that have been fostered with coastal practitioners. These need to be further developed and supported on a long-term basis to ensure that are applied to support the sustainable management of coasts. Whether the collaboration is actual or virtual (Turner, et al. 2010), they will have to be made resilient enough to survive with their internal resources as well as being able to mobilize external funding. Considerable consultation and capacity building across the LOICZ community will be needed with more inclusive, regionally grounded, transdisciplinary and globally networked approaches, in line with the Future Earth concept of transformative, actionable and global sustainability science. After 25 years as LOICZ the project will transition to its new title of Future Earth Coasts and develop a new initiative called ‘Our Coastal Futures’ that assesses the state of coasts around the world and provides capability building tools for communities to arrest unsustainable practices and translate scientific knowledge to inform policy by governments.

Acknowledgement

The authors acknowledge the support of Ahana Lakshmi, Senior Consultant, NCSCM, Chennai, India, in preparation of this manuscript. The help and support of the LOICZ IPO (Ellen-Barbe Goldberg and Christiane Hagemann) is greatly appreciated. Figures were prepared by Jane Hawkey of the Integration & Application Network. Scientific inputs received from Heath Kelsey, of the Integration & Application Network, University of Maryland is greatly acknowledged.

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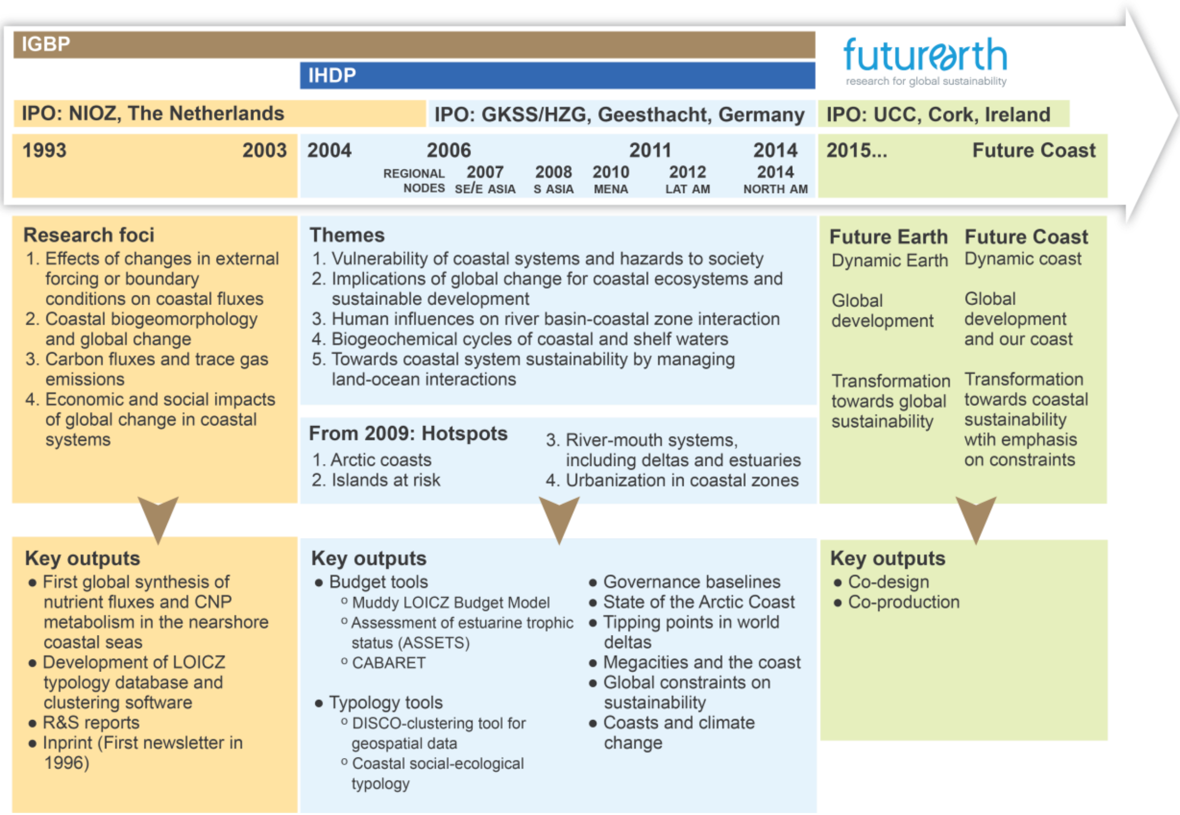

Figure 1. Timeline of activities and achievements of LOICZ (1993 to 2015).

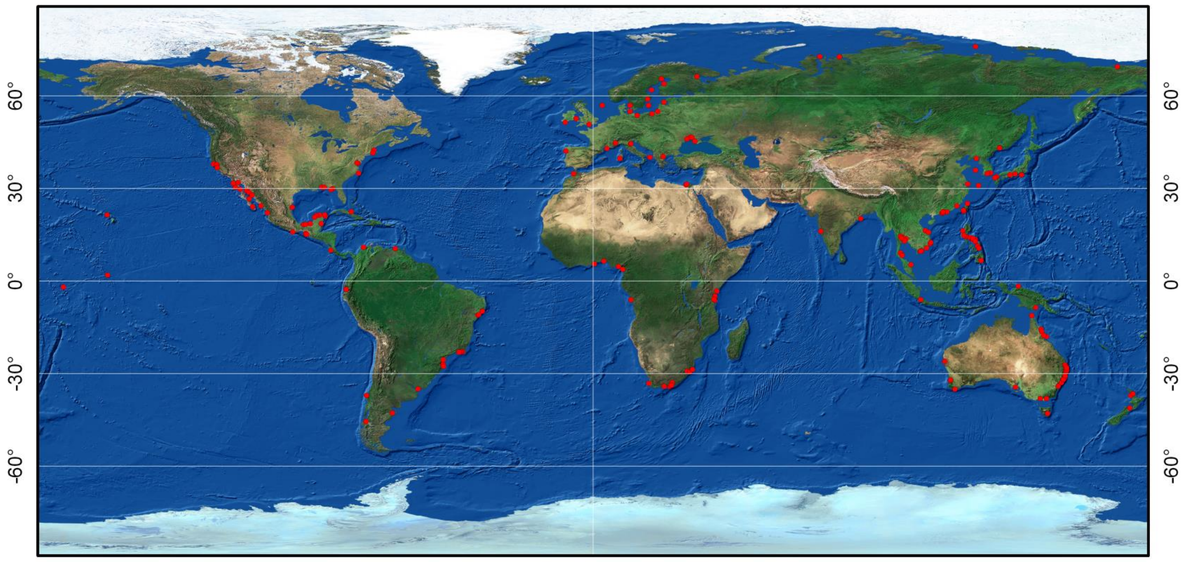

Figure 2. Map of locations of LOICZ budget sites.

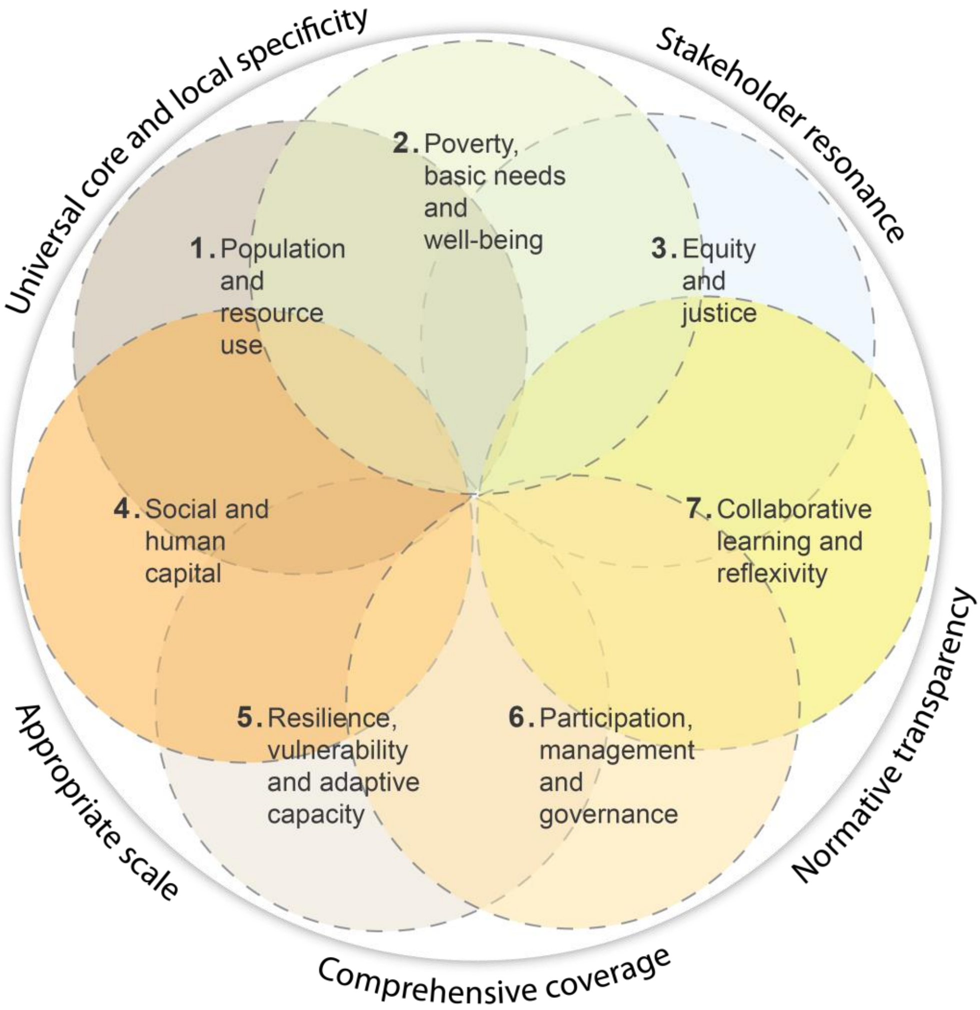

Figure 3. Social-ecological dynamics of coastal ecosystems: a conceptual framework.

Figure 4. Conceptual diagram of major activities and their impacts on Chilika Lagoon, India. The diagrams illustrate how Chilika Lake is subjected to constant pressures from both natural processes and human activities. By identifying these pressures through efforts such as an ecosystem health report card and subsequent management actions, the likelihood of Chilika Lake to sustain itself is improved. (Source: http://ian.umces.edu/pdfs/ian_report_card_425.pdf).

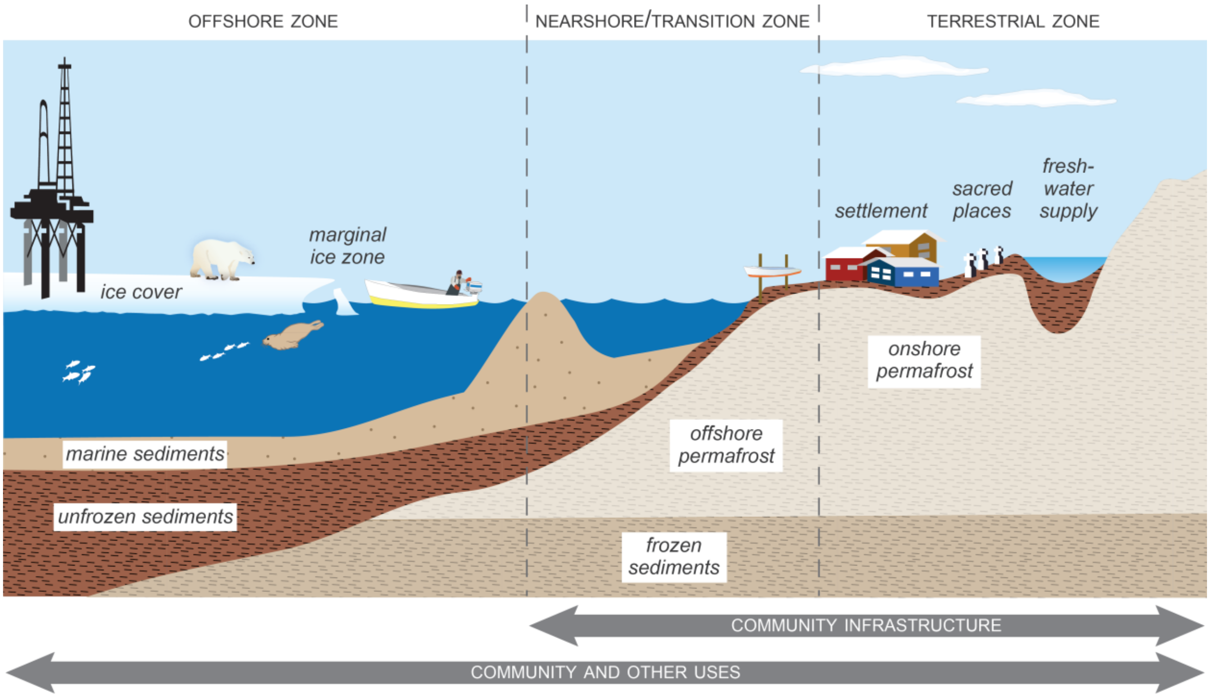

Figure 5. The human dimension in the Arctic coastal zone (reproduced from Parewick 2008).

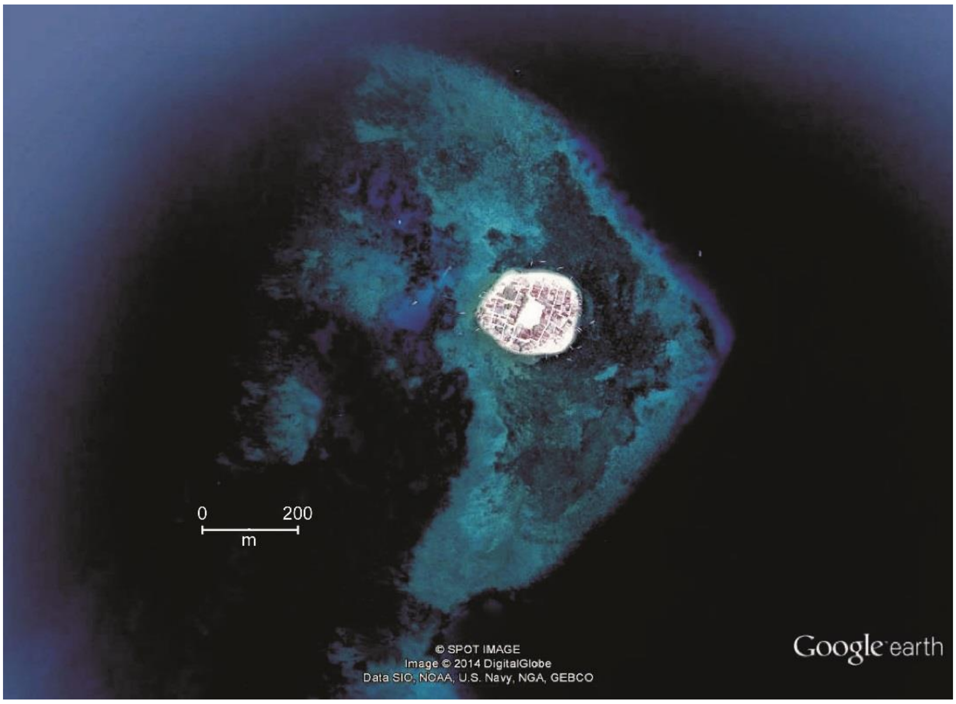

Figure 6. Dense human occupation of a miniature island (5°02'S 19°17E) in the Spermonde Archipelago, Indonesia.

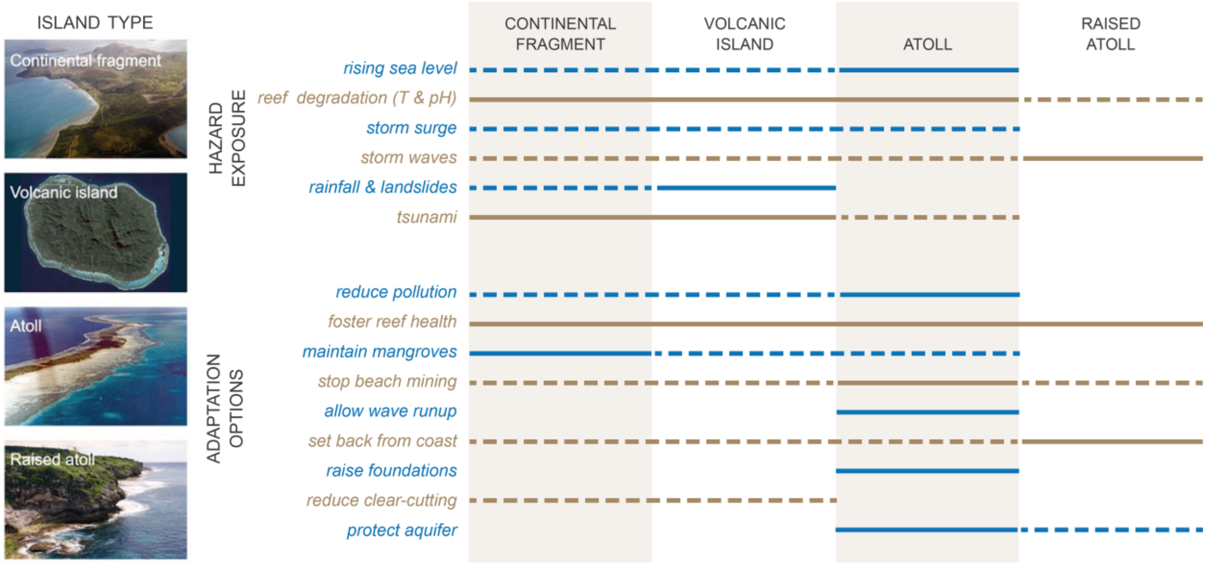

Figure 7. Template of physical island types with associated hazard exposure and adaptation options modified from (Forbes et al. 2013).

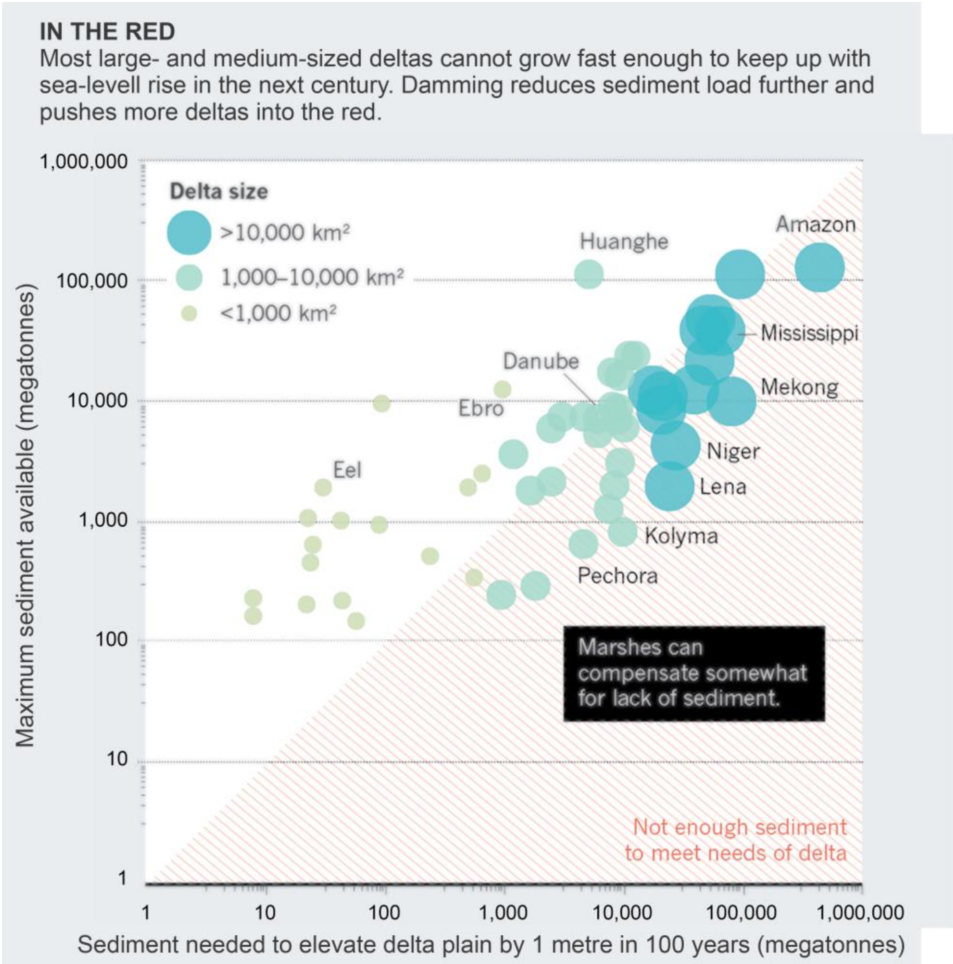

Figure 8. Sediment Input to Major Deltas and Sea Level Rise

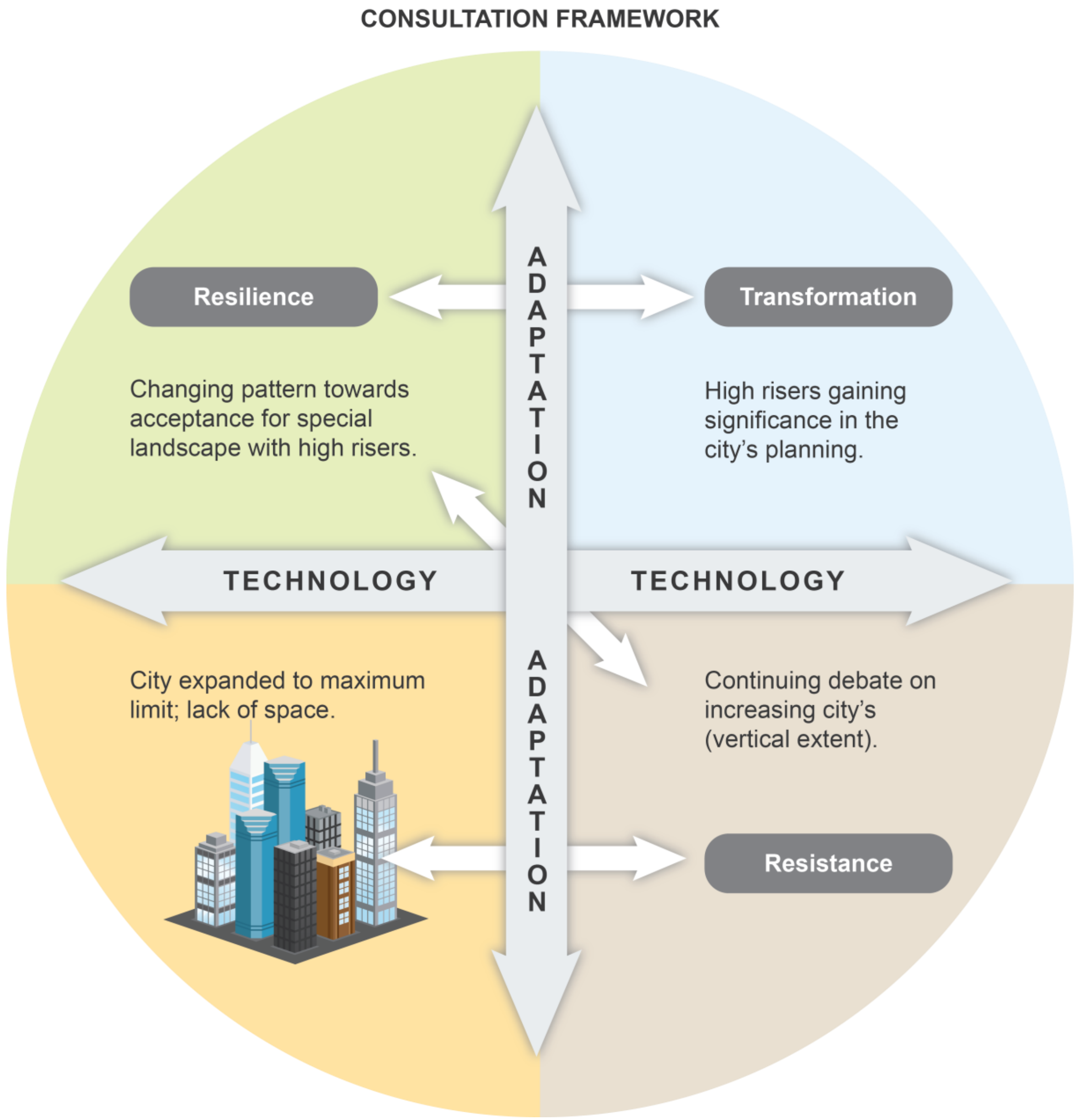

Figure 9. The TRUC Framework (Transformation and Resilience on Urban Coasts).