Changes to processes in estuaries and coastal waters due to intense multiple pressures – an introduction and synthesis

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Abstract

From the 2013 ECSA conference 'Estuaries and Coastal Areas in Times of Intense Change' a theme emerged that has ended up being the focus of this Special Issue of Estuarine Coastal and Shelf Science, namely 'Changes to processes in estuaries and coastal waters due to intense multiple pressures'. Many parts of the world are continuing to experience unprecedented rates of economic growth, and those responsible for managing coastal and estuarine areas must respond accordingly. At the same time, global climate change and sea level rise are also continuing, placing new or more intense pressures on coastal areas that must be dealt with in ways that are as far as possible managed as a result of good scientific understanding. There are other pressures too, which depend on the system concerned. This article provides an overview of the papers contained within the Special Issue and provides a discussion of how these fit within the main theme of intense multiple stressors, considering how a balance can be achieved between the needs of various different stakeholders and interest groups, and the sustainability of the system concerned. We categorise the papers in four main groupings: (1) stressors related to sea level rise; (2) stressors related to changes in fresh water inputs; (3) stressors related to anthropogenic pollution; and (4) the use of indicators as a means of assessing the effects of stressors, and reflect on the fact that despite the diversity of different challenges and geographical regions involved many of the approaches and discussions contained within the Special Issue have strong similarities, leading to a set of overarching principles that should be considered when making recommendations on management strategies.

Introduction

Much has been made of the rapidly changing nature of the factors affecting the world's coasts and estuaries. Of central importance to scientists, managers and policy makers is the response of these natural systems to the ongoing changes. The theme of this Special Issue of Estuarine Coastal and Shelf Science is 'Changes to processes in estuaries and coastal waters due to intense multiple pressures'. Most scientists and engineers working in coastal and estuarine fields have an appreciation that there are a number of factors that must be understood before it is possible to formulate a strategy for managing a coastal or estuarine area given the diversity of external stressors that may affect the area concerned. Systems tend to be faced with threats caused by the combination of a number of factors (Jennerjahn and Mitchell, 2013), therefore there is a need for multidisciplinary approaches to manage a given area, as well as an ongoing discussion between scientists, engineers, and managers on the approach required. One of the more common themes of the papers published as part of this SI, for example, has to do with sea level rise (SLR) and its effects on salinity and water levels in the coastal and estuarine zone. This can represent a multiple stressor on its own due to the many ways in which increased sea levels force organisms and humans to adapt rapidly to a changing environment. About half of the 20 papers contained in this Special Issue contain some reference to the effects of SLR. It is also worth mentioning the geographical spread of the case studies and situations described, representing a total of 11 countries/regions in all (Table 1).

The 53rd conference of the Estuarine and Coastal Sciences Association (ECSA) took place at the Hilton Hongqiao hotel in Shanghai from 13-17 October 2013, and the idea behind this special issue began to take shape based on some of the work and themes presented and discussed at this meeting. The theme of the conference was 'Estuaries and Coastal Areas in Times of Intense Change', and in excess of 400 delegates attended and took part in the multidisciplinary scientific sessions. Despite the breadth and diversity of the topics discussed in the sessions, there were some remarkable similarities between the problems investigated by researchers in different countries. We decided to group the papers into four key categories, in order to help readers by bringing the articles together under common themes, as follows. Theme 1 concerns the stressors primarily associated with sea level rise. Theme 2 concerns stressors associated with changes to fresh water flow, while theme 3 concerns stressors primarily associated with changing anthropogenic inputs. Finally, theme 4 is related to the use of indicators as a means of understanding the effects of multiple stressors on an ecosystem. We readily accept that there is much overlap between the four themes, but that this is hardly surprising given the overarching thrust of the SI concerning the effects of multiple stressors. Changes in, or the effects of, one stressor may well have an impact related to the effects of one or more of the other stressors or a combination of them.

With this introduction and synthesis we therefore seek primarily to pull together the different strands highlighted by the authors of the articles in the SI by categorising and then contextualising these works within other current themes in the field. Secondarily we seek to highlight the common areas where the authors have highlighted key areas of concern for further work or discussion and make some comments on the need for further work and collaboration that may help to inform current scientific and management decision makers. The remainder of the article is structured as follows: after discussing each of the four themes in turn, we end with a brief final discussion, which seeks to highlight areas of continued uncertainty in the field that would benefit from further research.

Theme 1 – stressors associated with sea level rise

With the range of sea level rise predictions in the latest IPCC report, it is perhaps unsurprising that so much attention should be focused on the effects of this phenomenon. Huang et al (2015) address the specific implications on oyster growth at a site in the Gulf of Mexico, USA. It is interesting to note here that the results of their 3-dimensional model reveal effects in terms of the multiple stressors that form the theme of this special issue. As well as the obvious point that rising sea levels lead to increased salinity in coastal areas and estuaries, so they also alter patterns of circulation and stratification within the area of interest, affecting in this case the distribution of oysters and informing management approaches.

A similar story is told by Yang et al (2015) where the additional stressor of human development is also mentioned. Here, also in the USA but this time on the West Coast, the authors refer to managing the point of saline intrusion by regulating the fresh water input, which in a developed system may well represent a commonly used approach in estuaries and coastal areas where the competing pressures of sea level rise and fresh water abstraction are keenly felt. In both these articles, the point is well made that a sophisticated, carefully calibrated numerical model is clearly key to understanding the impact of the management strategy required for a given set of outcomes in a given system.

It is perhaps unsurprising that so much attention should be paid to the above systems given their relatively low tidal ranges; in these cases the effects of relatively modest rises in mean sea level are clearly of great interest to residents and scientists alike. In Suursaar et al. (2015), however, the focus is on the effects of increased storminess in coastal areas, rather than rising sea levels per se. In this case the effects of the multiple stressors are different. Increased storminess is, it seems, more likely to ‘grab the headlines’ and lead to loud calls for emergency funding measures to provide engineering solutions quickly. The authors offer no conclusive solution to the problem of predicting patterns of storminess, although in their case study they do point to the importance of considering large, accurate datasets and relating these to general global trends such as the North Atlantic Oscillation.

The last two papers in this category are both centred on Chinese cases, where the effects of multiple stressors are well known in terms of the interaction between environmental and anthropogenic factors. Both studies in fact refer to the same estuary (Changjiang/Yangtze), though in different respects. Cui et al (2015) focus their attention on the particular threat of multiple stressors to coastal wetlands; their notion of vulnerability assessment using a set of indicators is useful and has been applied to other systems in a variety of ways (e.g., Jiang et al., 2015; Kunte et al., 2014). What emerges from studies of this kind is the urgent need for a coordinated management approach to the problem of sea level rise to head off the threat of disappearance of sensitive coastal areas.

An interesting complimentary view is applied by Li et al (2015a) who consider the influence of multiple stressors including sea level rise on fresh water supply to the megacity of Shanghai. Their scenario-building approach is very helpful; we see the implications of long-term predicted change for this important system. The ‘sinking’ of the delta in this case is clearly a worry in terms of the balance of processes in the medium term. The authors have been able to illustrate the concerns using their method at various time scales.

Theme 2 – stressors associated with changes to fresh water flow

In the second theme we bring together those studies predominantly related to changes in fresh water flow, and the multiple stressors related to these. Low-salinity plumes associated with river-dominated estuaries affect local and regional biogeochemical cycles and ecosystem services. Ge et al. (2015) present a modelling study of the low-salinity plume and its detachment off the Changjiang Estuary using the Finite-Volume Community Ocean Model (FVCOM). By conducting model experiments, the authors were able to diagnose the potential causes of the plume detachment. They suggest that the non-uniform distribution and variability of the wind play a key role in driving the plume detachment. This new hypothesis is different from the strong asymmetric tidal mixing mechanism raised in previous studies (e.g., Moon et al., 2010; Rong and Li, 2012), which will be of interest to the research community and could inspire further studies on this topic.

Changing fresh water flow into the coastal zone is fast becoming a stressor in its own right, firstly because of the changes in the flow itself and secondly because of its dissolved and particulate load, which are becoming altered in terms of amount and composition. Man-made alterations in hydrology and land use, both alone and in combination with global scale changes in atmospheric moisture transport and precipitation change the fluxes into estuaries and coastal waters. Land use change and river channelisation may increase fluxes into the coastal zone, while river damming and water extraction may reduce fluxes. Therefore, it is becoming more and more important to understand temporal patterns of fresh water flow and its dissolved and particulate loads, i.e., periods of high and low flow. Hitchcock and Mitrovic (2015) investigated this for two estuaries in Australia and studied the influence of 'flood flows', normal 'fresh flows' and 'base flows' in carbon, nitrogen, phosphorus, bacteria and chlorophyll-*a* dynamics. They found discharge to be the overall control, meaning that a small number of short-term events, i.e., the 'flood flow', is responsible for the major part of the annual inflow into estuaries and coastal waters. However, they also found the interplay between carbon, nutrients and bacteria to be more complex and varying between the different flow categories, indicating the need for further studies designed in a way to capture the full spectrum of flow conditions over a hydrological year.

The last two papers in this theme focus on the effects that freshwater discharge exerts on biota through a multifactorial control of many physiochemical variables (e.g., nutrient concentration, salinity and temperature, among others). Although estuarine species and communities are generally tolerant to changes in environmental variables (Elliott and Whitfield, 2011), abrupt and marked changes in freshwater input may strongly affect community organization and functioning, as also demonstrated elsewhere in this Special Issue.

Specifically, the paper by Sin and Jeong (2015) provides an example of the effects of an episodic and dramatic freshwater discharge on phytoplankton taxonomic structure and size in the Youngsan River Estuary (South Korea). During the summer monsoon when the reservoir water level peaks, eutrophic fresh water is discharged into the upper reach of the river, causing short-term variations in phytoplankton species composition, diversity and biomass and a shift in size structure from a nano-size-dominated to a micro-sized-dominated community due to the presence of micro-sized freshwater phytoplankton transported from the reservoir. Based on the trophic role of phytoplankton and its bottom-up control on upper trophic levels, this paper provides insights into the potential impact of prolonged freshwater discharge on food web structure and fisheries through changes in the quality and supply of basal food sources (i.e., phytoplankton) for consumers. In addition, in the Youngsan River estuary, freshwater discharge was responsible for the presence as well as dominance of red-tide forming species such as the harmful dinoflagellate *Heterocapsa* sp., which dominated the phytoplankton community, outcompeting other species. These results contribute to the current debate on the relationship between nutrient supply, selection and dominance of harmful algae. A clear and univocal relationship is far from being ascertained, while the role of nutrients seems site-specific and strongly constrained by the hydrodynamics in driving bloom occurrence (e.g., Davidson et al., 2012; 2014).

Another example of the interdependency of marine coastal ecosystems on boundary and adjacent environments is provided by Li et al. (2015b). Indeed, a clear influence from upwelling and terrestrial runoff (i.e., river discharge and aquaculture effluent) on coral communities in Hainan Island (China) was detected. By reducing temperature and increasing nutrient supply and turbidity, terrestrial input and seasonal upwelling resulted in macroalgal overgrowth, which outcompeted coral communities both directly due to space competition, but also indirectly by reducing coral recruitment. Temperature- and nutrient-driven bottom-up controls, along with top-down controls due to overfishing, seem to promote macroalgae and reduce coral recovery, causing a shift from a coral-dominant phase to a macroalgae-dominant one, with implications for ecosystem processes (e.g., resistance and resilience, secondary production) and services provided by coral reefs (e.g., recreational activities, support to fisheries, shoreline protection).

Theme 3 – stressors associated primarily with changing anthropogenic inputs

Theme 3 is related to those studies focused on changes to anthropogenic inputs. Metals, organic pollutants and radionuclides are studied in several estuarine and coastal regions. Iron and manganese ore mining is an important human activity in the catchments of the rivers Mandovi and Zuari in the Indian state of Goa and leaves its imprint in estuarine suspended matter and sediments. Their mineralogy and isotope geochemistry at the same time reveals the effects of natural processes like weathering and seasonal variations (monsoon vs. pre-monsoon) on the one hand as well as of the anthropogenic inputs on the other. High strontium isotope ratios and portions of kaolinite at the river end stations indicate intense chemical weathering of laterites, typical of the humid tropics. High contents of iron and rare earth elements and high Sm/Nd ratios along almost the entire length of the estuaries indicates high inputs of iron ores (Purnachandra Rao et al., 2015). Ores brought from mines are stored on the shores and are washed into the estuaries either directly from there or from barges transporting them downstream to the port, in particular during the monsoon season (June – September) with its heavy rainfalls.

The Terminos Lagoon in the southeastern Gulf of Mexico is an estuarine tropical lagoon of primary concern, because it is fairly large, it is ecologically and economically important because of its biological diversity and its richness in fish and other marine resources, and it is subject to several natural and anthropogenic stressors. By analysing surface sediments for texture, carbonate and trace metals Magallanes-Ordóñez et al. (2015) investigated the possible adverse effects of oil released from the nearby Campeche Bank, where about 75 % of Mexican oil production occurs. They found an enrichment of elements only for Ni and Ca, the former indicating a more terrestrial influence in the western part of the lagoon, while the enrichment of the latter indicates a more biogenic influence in the eastern lagoon. The enrichment of Ni could originate from the oil exploitation area and/or effluents from the nearby cities or from an initially enriched source rock. Trace element contamination of Terminos Lagoon from the oil exploration area appears to be negligible. Other natural stressors like summer storms and the effect of the *nortes* season with its heavy rainfall appear to be important controls of sediment composition and distribution.

Botello et al. (2014) report metal and polycyclic aromatic hydrocarbon (PAH) concentration in water and sediments from the NW Gulf of Mexico, with the aim of evaluating possible inputs from the massive oil spill caused by the sinking of the Deepwater Horizon Platform (DWH) in the deep waters off Louisiana, USA in April 2010. PAHs were below detection limits in surface waters. PAHs in sediments were largely pyrolytic in origin and had a low probability of harmful effects to benthic organisms as assessed by the sediment quality guidelines (Long et al., 1995). Similarly, relatively lower metal concentrations in sediments were ascribed to a primary lithogenic source. However, the authors pointed out that the present study does not provide sufficient proof to exclude potential long-term adverse environmental effects from the DWH oil spill in Mexico territorial waters, and ongoing investigations are required.

Harbours are places where industrial and domestic effluents dominate the spectrum of anthropogenic inputs. Dong et al. (2015) report the pollution of Kaohsiung Harbor, Taiwan's largest port, with butyltins. In the past two decades the tributyltins (TBT) present in antifouling paints of ship hulls have received a great deal of attention. TBT concentrations above EAC (environmental assessment criteria) levels of the OSPAR's (Oslo and Paris Commission) coordinated environmental monitoring programme (CEMP; OSPAR, 2009) were found in all sediments of Kaohsiung Harbor. Although being lower than in many other international ports and coasts TBTs reached levels likely to have a negative influence on reproduction of gastropods. Dong et al. (2015) also found monobutyltins (MT) and dibutyltins (DT), which are degradation products of TBTs but are also original compounds of heat-resistant stabilizers in the manufacturing of PVC. Because of their maxima found near river mouths they likely reflect the input of Kaohsiung City, not only Taiwan's largest port, but also its largest industrial city, rather than TBT degradation. Interestingly, they found lower TBT concentrations in harbour sediments than in a previous study (sampling in 2009 vs. 2006; Chen et al., 2010) and ascribe this to an overall ban of TBT painting in Taiwan in 2008 and the frequent dredging of harbour sediments allowing for faster degradation of TBTs.

The release of greenhouse gases is one of the most prominent anthropogenic contributions to global change. Methane is one of these gases. It is not as abundant as carbon dioxide, but its warming potential is many times higher. Reshmi et al. (2015) investigated the methanogenic activity in anaerobic sediments of the estuarine Ashtamudi Lake in the southern Indian state of Kerala, which is under the influence of the densely-populated catchment of the Kallada River. They find the highest methanogenic activity during the SW monsoon in August when rainfall is very high, washing dissolved and particulate matter from the intensively used hinterland into the estuary. There it leads to high organic matter accumulation, which provides the substrate for aerobic and anaerobic mineralization. Despite being unable to disentangle the individual contributions of anthropogenic stressors, Reshmi et al. (2015) can demonstrate that inputs from chemical industries, coconut husk retting from coir industry, contaminations from fishing and its processing industries as well as urban sewage discharges obviously contribute to the high organic matter accumulation. In such a way seasonal variations of naturally high river inputs can aggravate the detrimental effects of anthropogenically increased organic matter inputs.

Disentangling the multitude of stressors and assessing their individual contributions to an overall effect on receiving coastal water bodies is a considerable challenge. Assessing the cumulative effect on water quality and ecology therefore might seem an easier task, but this is not always the case. Water quality models are an established instrument for assessing the environmental status of coastal waters, but they require a detailed understanding of the system considered, as Li et al. (2015c) point out in their attempt to establish such a model for Jiaozhou Bay in China. It is a semi-enclosed bay that receives domestic and industrial effluents from Qingdao and other cities in the surrounding areas, which lead to eutrophication of the bay. The extremely weak hydrodynamics of the bay hampered Li et al.'s (2015c) attempt to assess the carrying capacity of the bay for nitrogen and phosphorus. They ended up with satisfactory simulations of nutrient distribution, but with unsatisfactory quantitative assessments, for now. This, in turn, is also required for a proper local- to regional-scale management of water quality.

Theme 4 – the use of indicators to measure the effect of stresses

In recent decades, many indicators have been adopted to assess anthropogenic impacts on marine coastal ecosystems. Most assessments have included a set of physico-chemical and biological indicators as also used by worldwide legislative initiatives (e.g., the Water Framework Directive in Europe, The United Nations Convention on Law of the Sea; the Oceans Act in USA, Australia or Canada). While abiotic information represents the essential background knowledge, there is a general consensus that bioindicators provide fundamental support for environmental quality assessment. A plethora of approaches, parameters and indices concerning different levels of the biological and ecological hierarchy from the molecular to the macro-ecological are currently used for assessing impacts and for monitoring purposes. However, the current direction of travel is towards a “holistic functional approach” that “takes the ecosystem and separates it into a set of process-related objectives and then recombines these to give a holistic approach” (Borja et al., 2010) in agreement with legislative directives (e.g., European Marine Strategy Framework Directive, MSFD, 2008/56/EC). The use of consistent and coherent approaches across different regions is a fundamental point, and for this reason any additional knowledge may further support implementation of legislative initiatives (e.g., MSFW) is important. Accordingly, this Special Issue includes papers that contribute to a wide debate on the use of indicators for the development and testing of methods for assessing anthropic impacts and stresses, encompassing abiotic and biotic indicators of different biological organisational levels.

Assessing the effect of stresses on coastal water bodies is easy in some cases, but almost impossible in others. For example, measuring the input of groundwater and its constituents and hence assessing its effects on coastal waters as a technique is still in its infancy. In particular, global estimates appear to be little more than educated guesses. In the context of this challenge radioactive isotopes have proven good indicators of submarine groundwater discharge. In order to understand the geochemical behavior of radium (Ra) isotopes, which are a frequently used tracer, Su et al. (2015) investigated water and sediments in the Chinese Changjiang River and its estuary. They found variations in the activities and ratios of Ra isotopes related to hydrology alterations in the river caused by the Three Gorges Dam as well as to changes in physicochemical properties in the brackish estuary, where desorption from the particulate to the dissolved phase plays an important role. Baseline studies like this are essential for the use of any element as indicator or proxy.

Working at the molecular level, De Souza et al. (2015) reconstructed the genetic population structure and demography of the mussel *Mytella charruana*. This is a species that is widespread in Central and South America and invasive in North America, with a high level of dispersion, and hence high gene flow, and low levels of population genetic structure. Due to its high dispersal, climate-driven variables (e.g., temperature, salinity, currents) may limit gene flow. A geographical distribution of the two matrilinear haplogroups (haplogroup A is predominant on the northern coast and B on the northeastern and eastern coasts) of *M. charruana* was evident, probably because of hydrodynamism and/or local selective forces. However, a distinct population was found among those from the northern coast, most likely as a consequence of a founder effect and also due to isolation by distance. The role of environmental factors in selecting distinct lineages of mussels is discussed, with the implications for how global change may affect genetic structuring of several species.

Marsden and Baharuddin (2015) provide an example of the physiological responses, in terms of mortality/survival and growth, of the gastropod *Amphibola crenata* to a combination of stressors (i.e., increased nutrients and chemical contaminants) along a contamination gradient. The use of mortality as a response parameter is very common and consistent in the literature, and also in this study mortality showed a very clear spatial pattern, being higher in locations close to a sewage outfall. Growth has been used less extensively, and shows rather contrasting results in the literature, with gastropods either increasing or decreasing growth with nutrient increase. This is because higher food availability (i.e., primary producers) *per se* is not enough to promote growth in grazers, as changes in food quality and/or the contextual deterioration of abiotic variables (e.g., oxygen levels) may also have an effect. This was also found in the study by Marsden and Baharuddin (2015), one interesting result of which was that gastropod growth decreased with increasing chlorophyll-*a* values in sediments, with the indirect effects of oxygen depletion and/or nutrient enrichment (i.e., ammonia, nitrate) suspected to be involved in this process. Consequently, both growth and survival may be useful tools for monitoring estuarine conditions.

When moving towards higher organisational levels (i.e., ecosystems), the use of indicators of stress becomes particularly challenging due to the extreme complexity of their processes and functions. Most of the available indices of ecosystem quality focus only on a particular species or ecosystem component. There is a need for a systemic integrated index able to include and reflect the inherent complexity of ecosystems. Montefalcone et al. (2015) evaluated the ecosystem effects at a functional level of the phase shift occurring in the Mediterranean *Posidonia oceanica*, investigating both ecosystem structure indicators (i.e., biological habitat provisioning, species richness and biomass) and ecosystem functioning ones (i.e., exergy and specific exergy). As expected, the regression of *Posidonia oceanica* and its replacement, firstly by the less complex seagrass *Cymodocea nodosa* and then by *Caulerpa* macroalgal species (both native and alien), resulted in a decrease in all indicators investigated, including exergy and hence ecosystem functioning. Exergy is a proxy for the ability of a system to accumulate complex biomass and to function effectively (Jørgensen, 1981; Silow and Mokry, 2010), and thus for ecosystem functioning, higher values being typical of ecosystems with higher efficiency, quality and functioning. Hence its use may synthesise and/or complement existing approaches to evaluating ecosystem quality. However, despite the integrated and systemic nature of this index, as also recognised by Montefalcone et al. (2015), its calculation is laborious and requires a very large data set. Consequently, while effective from a theoretical point of view and intriguing from a scientific one, it probably does not hold enough promise to be widely adopted and applied.

An interesting approach for assessing anthropogenic pressures is based on the use of isotopic markers ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$). The use of this technique has increased almost exponentially in recent decades (Layman et al., 2012) because of its versatility for exploring a number of ecological (e.g., food web structure and dynamics, trophic niche width, partitioning and overlapping, trophic level) and applied issues (e.g., pollutant transfer routes in marine food webs, effects of eutrophication, invasive species, climate change on trophic relationships and structure). This versatility is reviewed by Mancinelli and Vizzini (2015) who highlight that, in spite of the increased number of isotopic studies and the acknowledgement of the significance of the “food web approach” to reconcile the structure and function of biodiversity (Thompson et al., 2012), there is still a need to implement effective indicators and monitoring tools to meet the requirements of legislative initiatives and support management actions. With this purpose, current knowledge gaps are shown and future directions for implementing holistic impact indicators are proposed, along with a new methodological-theoretical framework for the assessment of multiple anthropogenic pressures and their effects on marine coastal ecosystems. In this context, classic indicators (i.e., trophic level) and recently implemented isotopic metrics (see Layman et al., 2012) are identified as potentially useful food-web indicators at different ecological scales for the assessment of the cumulative effects of multiple pressures. So far, however, the application of these indicators in marine ecosystems is still in its infancy; there is a need for studies to scrutinise the ecological implications of these indicators for monitoring purposes and their effectiveness as monitoring and management tools.

Discussion and future research directions

We now turn our attention to the issue of what can be gleaned from these articles in terms of the areas of greatest interest to current research. The notion of multiple stressors and how to deal with them is not a new idea (Thrush et al, 2008) but it is clear that it is only by using a multidisciplinary approach that we can begin to understand how changes in one parameter influence the stresses experienced in terms of another. What may be needed is more in the line of a risk assessment (Monbaliu et al, 2014) in order to allow scientists and managers to consider the severity of the stressors and the effects of any mitigation measures on the severity of the hazard in question. Perhaps too more recognition should be given the effects of multiple *physical* stressors (e.g., Ding et al., 2013) given that, for example it is often a combination of high tides and strong winds that tends to cause the most obvious damage. What therefore is the most appropriate response given the diversity of approaches to understanding and managing the problems described in this special issue? We suggest the following three guiding principles:

1. There is a need to collect more data over a range of temporal and spatial scales relating to the interaction between anthropogenic intervention and sensitive coastal ecosystems, and to use the results to drive models to show the effects in the more extremely sensitive cases.
2. There should be more dialogue between scientists and managers on management interventions and controls in cases where multiple stressors have a moderate-to-severe effect on lives or livelihoods.
3. There should be an agreed and effective international framework for the management of coastal and estuarine systems and related decision making processes based on sound scientific understanding.

The results from all the studies describe useful steps forward in terms of our scientific understanding and our techniques to model and manage the coastal and estuarine environment. Our obligation is now to extend the reach of our understanding by focusing on areas under greatest threat from the multiple stressors.

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Table 1 Summary of articles in the Special Issue

Author	Country/region	Category	Major stressors
Huang et al.	USA	1	SLR and fisheries
Yang et al.	USA	1	Estuary physical response to SLR
Suursaar et al.	Baltic	1	Coastal storminess
Cui et al.	China	1	SLR and coastal wetlands
Li et al. (a)	China	1	SLR and water resources
Ge et al.	China	2	Fresh water plumes
Hitchcock and Mitrovic	Australia	2	Fresh water and water quality in estuary
Sin and Jeong	South Korea	2	Fresh water and water quality in estuary
Li et al. (b)	China	2	Fresh water and impact on coral reef
Purnachadra Rao et al.	India	3	Anthropogenic effects on sediments
Li et al. (c)	China	3	Nutrients in enclosed polluted bay
Dong et al.	Taiwan	3	Polluted sediments in harbour
Magallanes-Ordóñez et al.	Mexico	3	Anthropogenic sediment pollution in enclosed harbour
Reshmi et al.	India	3	Seasonal and anthropogenic effects in estuary
Botello et al.	Mexico	3	Pollutants related to oil spill
Marsden and Baharuddin	New Zealand	4	Nutrients in estuary
Montefalcone et al.	Italy	4	Seagrass and loss of functioning
De Souza et al.	Brazil	4	Stresses in coastal organisms
Mancinelli and Vizzini	Italy	4	Ecosystem pressures using isotopes
Su et al.	China	4	isotopes in estuary to trace properties of concern