Unbounded boundaries and shifting baselines: estuaries and coastal seas in a rapidly changing world

Little, S.[1*], Spencer, K. L.[2], Schuttelaars, H. M.[3], Millward, G. E.[4] and Elliott, M.[5]

[1] Nottingham Trent University, School of Animal, Rural and Environmental Sciences, Brackenhurst, Southwell, Nottinghamshire NG25 0QF.

[2] Queen Mary University of London, School of Geography, Mile End Road, London E1 4NS.

[3] Delft Institute of Applied Mathematics, Delft University of Technology, Mekelweg 4, 2628 CD Delft, The Netherlands

[4] Plymouth University, Faculty of Science and Environment, Marine Building, Drake Circus, Plymouth, Devon, PL4 8AA

[5] Institute of Estuarine and Coastal Studies, University of Hull, Hull, HU6 7RX, UK.

*Corresponding author: sally.little@ntu.ac.uk, +44(0)115 848 5278.

Abstract

This Special Issue of Estuarine, Coastal and Shelf Science presents contributions from ECSA 55; an international symposium organised by the Estuarine and Coastal Sciences Association (ECSA) and Elsevier on the broad theme of estuaries and coastal seas in times of intense change. The objectives of the SI are to synthesise, hypothesise and illustrate the impacts of global change on estuaries and coastal seas through learning lessons from the past, discussing the current and forecasting for the future. It is highlighted here that establishing impacts and assigning cause to the many pressures of global change is and will continue to be a formidable challenge in estuaries and coastal seas, due in part to: (1) their complexity and unbounded nature; (2) difficulties distinguishing between human-induced changes and natural variations and; (3) multiple pressures and effects. The contributing authors have explored a number of these issues over a range of disciplines. The complexity and connectivity of estuaries and coastal seas have been investigated through studies of physicochemical and ecological components, whilst the human imprint on the environment has been identified through a series of predictive, contemporary, historical and palaeo approaches. The impact of human activities has been shown to occur over a range of spatial and temporal scales, requiring the development of integrated management approaches. These 30 articles provide an important contribution to our understanding and assessment of the impacts of global change. The authors highlight methods for essential management/mitigation of the consequences of global change and provide a set of directions, ideas and observations for future work. These include the need to consider: (1) the cumulative, synergistic and antagonistic effects of multiple pressures; (2) the importance of unbounded boundaries and connectivity across the aquatic continuum; (3) the value of combining cross-disciplinary palaeo, contemporary and future modelling studies and; (4) the importance of shifting baselines on ecosystem functioning and the future provision of ecosystem services.

Keywords: estuaries, coasts, coastal seas, global change, environmental change, climate change, Anthropocene

1. Introduction

Since the beginning of the 20th Century, human population growth and activities have exerted significant pressures on natural systems, which has led to anthropogenic-driven environmental change on a global scale (Meybeck and Vörösmarty, 2005, Waters *et al.*, 2016, Rockstrom *et al.*, 2009). These pressures include: (1) modification of the atmosphere and the climate through increasing greenhouse gas (GHG) emissions; (2) degradation and destruction of habitats (e.g. urban and agricultural expansion and seabed modification); (3) over-exploitation of resources (e.g. hunting, fishing and harvesting); (4) modification of the hydrological cycle (e.g. river-diversion, dam construction and freshwater abstraction); (5) introduction of invasive species; and (6) release of contaminants into the environment (from fossil fuel combustion, fertiliser applications, intensive agriculture, changing sediment yields and aquaculture) (Parmesan *et al.*, 2013, Rockstrom *et al.*, 2009). These pressures do not occur in isolation, they are linked and interact, leading to cumulative, synergistic and antagonistic effects on natural systems over a range of spatial and temporal scales (Steffen *et al.*, 2007, Lotze *et al.*, 2006, Scavia *et al.*, 2002, Brown *et al.*, 2013).

Global change is occurring rapidly (Waters *et al.*, 2016, Rockstrom *et al.*, 2009). In the last 50 years, world population has grown rapidly (from 2.5 billion in 1950 to 7.6 billion in 2017; United Nations, 2017) and the world's ecosystems have changed more extensively than in any other period in human history (Pimm *et al.*, 1995, Ceballos *et al.*, 2017). The Earth is currently experiencing a period of mass global species extinction (the sixth great extinction event; Ceballos *et al.*, 2017), and atmospheric concentrations of GHG's have substantially increased (e.g. atmospheric CO_2 concentration has risen from 310 to 407 ppm since 1950; Scripps Institution of Oceanography, 2017) resulting in a rapid global warming (IPCC, 2013). Since 2010, new global record temperatures have been set in 2014, 2015 and 2016 (Hughes *et al.*, 2017a). This rapid rate of change and the resultant impact on ecosystems has increasingly become an issue of global concern and has led to the proposal of a new geo-stratigraphic Epoch, where humans have become a global factor affecting ecosystems; the Anthropocene (Waters *et al.*, 2016, Steffen *et al.*, 2011).

All ecosystems are affected by human pressures; however, estuaries and coastal seas carry a disproportionate human load (Birch *et al.*, 2015, Neumann *et al.*, 2015). Globally, more than 600 million people live in low-lying coastal regions (between 0-10 m above sea level; McGranahan *et al.*, 2007), with more than 150 million people living within 1 m of high tide (Lichter *et al.*, 2010). Many of these are concentrated in urban agglomerations, where population density continues to increase (between 1950 and 2000 the percentage of the world's population living in urban areas grew from 30 to 50%; Neumann *et al.*, 2015, Steffen *et al.*, 2007, McGranahan *et al.*, 2007). In 2009 67% of the world's megacities (cities with more than 10 million inhabitants) were located on the coast, with an additional 80% having a coastal influence (von Glasow *et al.*, 2013). Urbanisation and increased anthropogenic activity both on the coast and within catchments (e.g. aquaculture, fisheries, agriculture and land-use change) have resulted in habitat loss and modification and the release of contaminants, sediments and nutrients into estuarine and coastal systems (Meybeck and Vörösmarty, 2005, Sinha *et al.*, 2017). These pressures look set to increase, as by 2025, the population in coastal zone megacities is projected to reach 301.7 million people (von Glasow *et al.*, 2013).

In addition to this rapid anthropisation of the coastal zone, global climate change, and its associated effects, pose further threat to coastal seas and estuarine ecosystems (IPCC, 2014). Whilst the specific impacts of climate change will vary geographically (based on regional contexts and the physical and geological setting; Perillo and Piccolo, 2011), coastal and estuarine systems around the world are becoming increasingly vulnerable to global sea level rise, increased temperatures, ocean acidification, changes in wind patterns and storminess and changes in the availability of water and nutrients from precipitation and runoff from land (Day *et al.*, 2011; IPCC, 2014). Likely consequences of these changes include habitat loss through coastal erosion, coastal squeeze and marine transgression (Gutierrez *et al.*, 2011, Jackson and McIlvenny, 2011), enhanced risk of coastal eutrophication, harmful algal blooms and hypoxia (Sinha *et al.*, 2017), reductions in water clarity (Capuzzo *et al.*, 2015), landward incursion of saltwater into estuaries (Little *et al.*, 2016) (and coastal groundwater aquifers; Ferguson and Gleeson, 2012) and corresponding movement of the turbidity maxima (Jalon-Rojas *et al.*, 2015). The resulting impacts of these changes on ecology and biogeochemical cycling have consequences for the structure and functioning of estuaries and coastal seas (Hughes *et al.*, 2017b, Elliott *et al.*, 2015, Richardson *et al.*, 2012).

Whilst we do not yet fully understand to what extent global change will affect estuarine and coastal processes (Richardson *et al.*, 2012), it is clear that these systems face unprecedented pressures, which will affect human societies through the loss of the ecosystem services they provide (e.g.

provisioning services such as food, fuel and fibre; regulating services such as nutrient cycling, atmospheric and climate regulation, waste processing, disease regulation and flood hazard regulation; and cultural services such as tourism, education, recreation, amenity and aesthetical values; MEA, 2005, Barbier *et al*., 2011). Coastal systems (including estuaries, continental shelf area, sea grass, coral reefs, mangroves and wetlands) are clearly valuable resources (total economic value estimated at ~US$ 575,011 per ha per year at 2007 price levels; de Groot *et al*., 2012), which face competing and often conflicting socio-economic and environmental demands. They are also complex systems, connected and naturally variable, governed by interacting geomorphological, hydrological and ecological processes acting at a range of temporal and spatial scales (Elliott and Whitfield, 2011, Whitfield and Elliott, 2011). The need to balance these socio-economic and environmental demands in a complex environment, whilst confronting the consequences of global change requires innovative multi-sectoral management approaches based on excellent and fit-for purpose multi-disciplinary science (Elliott and Whitfield, 2011).

With this objective in mind, the Estuarine and Coastal Sciences Association (ECSA) and the publisher Elsevier organised the 55th ECSA international symposium in London, UK on the 6th of September 2015. This multi-disciplinary symposium brought together 363 researchers and professionals from 223 institutions and 36 countries to discuss and address issues of outstanding scientific importance in the science and management of estuaries and coastal seas. The goal of the symposium was to synthesise knowledge from a variety of disciplines to stimulate future multi-disciplinary research and aid global environmental management of these systems in the face of multiple pressures (as outlined above). This Special Issue consists of 30 individual papers which are discussed in relation to main focus of the symposia; learning lessons from the past, discussing the current and forecasting for the future, addressing the impacts of global environmental change on estuaries and coastal seas across the globe.

2. Overview of the problem

The theme of the meeting and this Special Issue (SI) is based on a consensus that estuaries and coastal seas are changing, threatened and in a state of global decline due to multiple drivers resulting in interacting pressures which act over a number of spatial and temporal scales. These include the effects of global climate change (e.g. global sea level rise, increasing temperatures and ocean acidification; IPCC, 2014) and other human activities (e.g. invasive species, over-extraction of resources, habitat loss and alteration, introduction of organics, nutrients, pollutants and contaminants, marine litter and changes to water flow; Syvitski *et al.*, 2005, Lotze *et al*., 2006). These pressures have been linked to the depletion of > 90% of formally important estuarine and coastal species (i.e. large vertebrates and habitat-providing species; Lotze *et al*., 2005), the loss of > 65% of coastal vegetated ecosystems (Lotze *et al.*, 2006, Polidoro *et al.*, 2010), water quality degradation (nutrient input into the oceans has trebled since 1970; Smith *et al.*, 2003) and accelerated species invasions (Ruiz *et al.*, 1997).

Estuaries are particularly vulnerable to these pressures as they are 'open' ecosystems with ill-defined and changing unbounded boundaries (Elliott *et al.*, 2015). Estuaries are both connected to and part of a dynamic aquatic continuum, linking the terrestrial environment (through streams, rivers and run-off) with the continental shelf and open ocean (Elliott *et al.*, 2015). Energy, organisms and matter flow within, through and between these unbounded systems (Hyndes *et al.*, 2014), so pressures acting on a range of spatial (e.g. local, regional and global) and temporal (i.e. days, months and decades) scales converge and impact on estuaries (i.e. endogenic pressures emanating from within the system and exogenic pressures emanating from outside the system) (Raimonet and Cloern, 2017, Elliott, 2011). As a result, estuarine baselines are shifting. Marine transgression and saline incursion from global sea level rise are increasing the extent of marine influence inland (Little *et al.*, 2016). Habitat loss and reclamation (e.g. managed realignment) are altering the morphology of the coastline, through changes to sediment erosion and deposition processes (Cazenave and Cozannet, 2014). Increased suspended sediments in the water column (through increased coastal erosion, decreased estuarine sediment sinks and changing weather patterns) are reducing water clarity in coastal seas, changing energy fluxes through the marine food web (Capuzzo *et al.*, 2015). Increased temperatures and species introductions are resulting in species redistribution, turnover and range shifts, with consequences for functional biodiversity (Johnson *et al.*, 2011, Lotze *et al.*, 2006, Walther *et al.*, 2009, Graham *et al.*, 2014). Increasing chemical, organic and microbial pollution of coastal waters and sediments are leading to changing timings and extents of algal blooms and hypoxic zones (Sheahan *et al.*, 2013).

These unbounded boundaries and shifting baselines have resulted and continue to result in changes to ecosystem structure and functioning and our ability to monitor, assess and manage these systems in order to ensure continued provision of ecosystem services in to the future. In addition, these changes will impact upon the ability to comply with environmental legislation (e.g. the use of baselines/reference/threshold values to assess Good Environmental and Ecological Status (as per the Marine Strategy Framework Directive and Water Framework Directive respectively; Elliott *et al.*, 2015).

One of the most prominent and challenging issues facing researchers and professionals in the field is that in order to predict, manage and mitigate the impact of global change in a complex unbounded environment, we need to understand: (1) the natural variability and interacting processes occurring within and between these systems; and (2) how the system responds to endogenic managed and exogenic unmanaged pressures and their interacting effects. With a solid understanding of the structure and functioning and natural variability of these systems (both before and during human influence), we can then (3) forecast for different future scenarios with greater confidence. In such complex systems, this requires a holistic approach which reaches across traditional disciplinary divides (e.g. physical, chemical and ecological; palaeo, contemporary and theoretical). We can then (4) propose appropriate adaptive management approaches based on a strong scientific foundation in collaboration with policy makers and stakeholders.

2.1 Learning lessons from the past

Humans have altered and manipulated estuarine and coastal systems for thousands of years (Weckström *et al.*, 2017, Canuel *et al.*, 2017, Long *et al.*, 1998, Taffs *et al.*, 2008) making it difficult to isolate anthropogenic from environmental influences and identify reference (or ‘baseline’) conditions for contemporary and future modelling studies (Lotze *et al.*, 2006, Bentley *et al.*, 2017). Studies that apply a long-term perspective are key here, as they can indicate trajectories of change both before and during human occupation that more traditional contemporary studies cannot (e.g. preceding the instrumental record). This is valuable in determining the degree of anthropogenic influence in estuarine and coastal areas (i.e. fluctuation from this baseline), understanding natural variability of the system and for contextualising present-day trends and ecosystem functioning in the longer-term, all of which are essential for successful coastal management and restoration (Bennion and Battarbee, 2007, Santschi *et al.*, 2001, Bentley *et al.*, 2017). In this SI, a number of authors applied palaeoecological or historical approaches to evaluate human imprint and gain a pre-industrial perspective on estuarine status.

Using sedimentological and diatom evidence, Andrén *et al*. (2016) reconstructed the history of eutrophication and quantified total nitrogen (TN) concentrations for the Gårdsfjärden estuary in the central Bothinia Sea. The imprint of anthropogenic activity was recorded from 1920, when discharges of industrial point source pollution resulted in hypoxic bottom waters. Good ecological status was recorded prior to this point and TN reference conditions for the estuary were successfully determined.

Álvarez-Vázquez *et al*. (2016) and Bojórquez-Sánchez *et al*. (2017) investigated trace element enrichment in estuarine and lagoon sediments in order to evaluate the impact of human activities over time. Álvarez-Vázquez *et al*. (2016) investigated the lithogenic imprint of trace metals in the Galician Rias (NW of the Iberian Peninsula) during the Anthropocene. Slight human impact was observed from the mid-20th century linked to river damming, bridge/road constructions and changes in catchment land use. The pre-industrial record showed lithogenic differences in the drainage basin, highlighting the importance of using local background references in contamination studies. Bojórquez-Sánchez *et al*. (2017) investigated trace element enrichment in the Salada coastal lagoon in Veracruz (Mexico), which receives cooling water discharge from the Languna Verde Nuclear Power Plant. Sediments (dated from 1900-2013) were enriched in silver (Ag), arsenic (As) and chromium (Cr) which corresponded to the geology of the coastal zone and local mining activity. The profiles of the element fluxes reflected the construction (1970s) and operation of the power plant; however, no evidence of pollution was detected.

Donnici *et al*. (2017) employed a palaeo-approach to investigate the sedimentation rate and lateral migration of tidal channels in the Lagoon of Venice (Northern Italy) over the Holocene (past 5,000 years). Buried tidal channels were identified and mapped and compared with historical and current maps, revealing human intervention on some of the tidal channels (i.e. simplified morphology) and a general reduction in the number of channels over time. The importance of understanding the natural morphological evolution of these environments before implementing artificial interventions was highlighted. Liu *et al*. (2016) employed historical bathymetric data to investigate the morphological evolution of Jinshan Trough in Hangzhou Bay (China) from 1960-2011. Whilst complex and driven by multiple factors, Liu *et al*. (2016) postulated that human activities (i.e. coastal reclamation) and climate (i.e. storm surges) were likely two of the main influencing factors on morphological change, through changes to erosion and deposition processes.

2.2 Discussing the current

2.2.1. Unbounded boundaries and the importance of scale

The connectivity of estuaries to marine and freshwater sources is widely accepted as being integral to the structure and functioning of estuarine and coastal ecosystems (Elliott and Whitfield, 2011, Gillanders *et al.*, 2011). Despite this, we do not fully understand the importance of this connectivity on ecosystem health and resilience (Raimonet and Cloern, 2017, Hyndes *et al.*, 2014). In this SI, Wolanski (2016) and Qian *et al*. (2016) explored the importance of these unbounded boundaries and scale for coastal flora and fauna and the development of hypoxic zones.

Wolanski (2016) investigated the importance of unbounded boundaries for self-recruitment and connectivity for a range of estuarine and coastal fauna and flora from a number of case study areas. By integrating physical oceanographic observations and modelling with studies of species behaviour, tracking and population dynamics, Wolanski determined that the spatial scales for self-recruitment and connectivity vary between species from a few metres to 10, 000 km and temporal scales vary from one to three generations. Wollanski (2016) identified that these unbounded boundaries, together with the hydrology and ecological dynamics of particular species, was key in creating the "functional connectivity between parts of the aquatic continuum from the river catchment to the open seas".

Qian *et al*. (2016) also noted the importance of scale and connectivity in understanding the impact of non-local drivers of summer hypoxia in the East China Sea off the Changjiang (Yangtze River) Estuary; one of the largest coastal oxygen-depleted areas in the world. Qian *et al*. (2016) identified that the formation and maintenance of the hypoxic conditions in the East China Sea were related to the initial dissolved oxygen (DO) level of the source water masses, the biogeochemical alterations of the water mass mixture during travel and the evolution of DO on the pathway to the hypoxic zone. The source water masses mixed ~1300 km upstream and travelled ~60 days to reach the of the hypoxic zone. Qian *et al*. (2016) argued that far field drivers should be taken into account in order to better predict the future scenarios of coastal hypoxias in the context of global warming.

2.2.2. Biology and ecology

Human activities are resulting in widespread and unprecedented biodiversity loss and turnover (β-diversity scale) in many biological components (Ceballos *et al.*, 2017, Pandolfi and Lovelock, 2014). Such changes have potential implications for the provision of ecosystem services, based on the role of biodiversity in ecosystem functioning (Naeem *et al.*, 2012). This role is subject to much debate (i.e. the Biodiversity Ecosystem Function (BEF) debate; Strong *et al*., 2015), however over the last decade, functional diversity (measured by the value and range of the functional traits of an organism present in a community) has increasingly been used over (or in addition to) traditional structural assessments of biodiversity (i.e. species taxonomic diversity, abundance and biomass) to assess and manage the impact of human pressures on estuarine and coastal systems (Dolbeth *et al.*, 2016, Covich *et al.*, 2004). This is because these trait-based approaches can provide information on multiple aspects of ecosystem function and as such detect anthropogenic stress (Dolbeth *et al.*, 2016), which is often not visible using a structural approach (i.e. the Estuarine Quality Paradox; Elliott and Quintino, 2007).

Helenius *et al*. (2016) applied a functional trait-based approach to investigate the drivers of littoral zooplankton community distribution and spatial heterogeneity in a shallow coastal area of the northern Baltic Sea (southwest Finland). Salinity and to a lesser extent turbidity and temperature were found to be the main predictors of the spatial patterns and functional diversity of the zooplankton community. Therefore, this study provides important baseline information, essential to assessing the impacts of eutrophication and temperature rise on plankton communities in brackish coastal areas with narrow salinity gradients.

Silva-Júnior *et al*. (2016) employed a traits-based approach (food acquisition and locomotion) to quantify the functional diversity of fish in four tropical estuaries in northeast Brazil, subject to different levels of human impact (e.g. mangrove deforestation, shrimp farming, fishing etc.) and environmental conditions. Silva-Júnior *et al*. (2016) determined the functional typology of fish assemblages per estuary by combining fish abundance and functional dissimilarities data into a multivariate analysis. The species contribution in functional typology could therefore be assessed and the diversity assessment of estuarine fishes improved, and may be an important tool in estuaries faced with perturbations. Differences between estuaries were identified based on the functional typology and attributed to marine influenced hydrological features, similar levels of species abundances and morphological traits.

Mancinelli *et al*. (2017) investigated the trophic role and feeding flexibility of the invasive Atlantic blue crab (*Callinectes sapidus*) in the Mediterranean Sea. The authors observed that *C. sapidus* had a high trophic flexibility expressed at both an inter- and intra- population scale and postulated that this trophic generalism is likely linked to their invasion and establishment success. *Callinectes sapidus* is one of 106 alien marine crustacean species recorded in the Mediterranean Sea, many of which have become established (Galil, 2011). These invasive crustaceans have had profound ecological impacts through changes to the community composition and biodiversity loss of native marine species (Galil, 2011).

Habitat restoration on estuaries and coasts is a key approach to restoring habitats detrimentally impacted and/or lost through human activities (Elliott *et al.*, 2007). Replicating the structure and function of natural habitats in the restored sites has, however, proven difficult (Mossman *et al.*, 2012, Elliott *et al.*, 2007). Barnuevo *et al*. (2017) reviewed the practice of large-scale monospecific mangrove plantations in the Philippines in order to assess whether restoration measures were able to reproduce the structure and functioning of natural mangrove forests. Barnuevo *et al*. (2017) found that even after 60 years of establishment, the structural development and complexity of the planted forests were lower than the reference natural forests, but inter-site differences were observed. Secondary succession was inhibited in a densely planted monospecific plantation (reflected by a low regeneration potential), whereas recruitment and colonisation of non-planted species were promoted in a secondary site. The authors identified the importance of reviewing current reforestation practices in order to focus on restoring the characteristics and functioning of natural mangroves, rather than solely focussing on the socio-economic benefits (e.g. fuelwood, timber and coastal protection). The importance of this was highlighted by Abdullah and Lee (2016), who observed that the complex dynamic habitats and the spatial heterogeneity of natural mangrove environments played an important role in the spatio-temporal structure of meiofaunal assemblages in eastern Australia. Meiofauna significantly contribute to ecosystem functioning in soft-sediment ecosystems (Nascimento *et al.*, 2012) and were recorded in highest densities in sediments where food proxies were in high availability and habitat structure provided the best conditions.

2.2.3. Pollution and contamination

Increased inputs of sediment, pollutants and contaminants (e.g. organic matter, inorganic nutrients, metals and organic chemicals) are major threats to the health of global estuaries and coasts (Dachs and Méjanelle, 2010). The causes are wide-ranging, but most often linked to urbanisation of the coastal zone and development of catchments for urban, industrial and intensive agricultural uses (Sutherland *et al.*, 2016, Sharley *et al.*, 2016). Coastal and estuarine waters receive contaminants, both via the catchment (e.g. riverine inputs; Sharley *et al*., 2016) and local anthropogenic activities via point and diffuse sources (Jeffries *et al.*, 2016, Eggleton and Thomas, 2004). Many of these contaminants accumulate in estuarine sediment (through binding with particulate matter and settling) and become part of the water-sediment system (Koukina *et al.*, 2016). At high concentrations, these contaminants can have toxic or enriching effects on biota and interfere with important ecosystem functions (e.g. fluxes of energy or material through productivity, decomposition and nutrient cycling). In this SI, a number of contributors investigated the sources and distribution of metals in estuarine and marine sediments.

Koukina *et al*. (2016) demonstrated that both natural (e.g. turbidites) and human pressures (e.g. urban and industrial activities) influence the abundance and speciation of potential contaminants (and therefore change their bioavailability) in the Cai River estuary and Nha Trang Bay in the South China Sea, Vietnam. Marmolejo-Rodríguez *et al*. (2016) investigated geochemical associations and anthropogenic influences of major and trace elements in the Central Pacific Mexican Shelf (CPMS); an area influenced by natural (e.g. storms and hurricanes) and anthropogenic pressures (industrial coastal areas, farming, fishing and agriculture). An anthropogenic influence was detected for mercury (Hg) and silver (Au) in the CPMS near the heavily industrialised harbour of Lazaro Cardenas, which has implications for biota through their high toxicity in marine waters.

Zaborska *et al*. (2016) investigated the distribution of heavy metals and ^{137}Cs in the central part of the Polish maritime zone, to assess the potential impact of contaminant re-suspension during construction and functioning of a proposed wind farm development. Within the 9000 km^2 study area of the Polish economic zone, the deepest regions (e.g. Slupsk Furrow and Bornholm Basin) were found to contain the largest contamination by heavy metals. Deeper areas have been recorded as being a sink for heavy metals and radionuclides, as they are characterised by fine-grained sediments, which heavy metals attach to. The shallow (20-40m) sandy sediments of the Southern Baltic were characterised by the lowest concentration of heavy metals (often below natural environmental background) and are therefore appropriate for offshore wind energy construction.

Fialkowski and Rainbow (2016) used the amphipod crustacean *Talitrus saltator* to investigate the spatial distributions of trace metal bioavailabilities in Baltic Sea coastal waters. Variations in the geographical distributions of metal bioavailabilities were observed, with western regions of the Baltic experiencing higher bioavailabilities than the eastern region. The regions influenced by the Oder and Vistula rivers had noticeable differences in metal bioavailabilities.

A number of contributors investigated the sources and impact of organic matter and contaminant discharge on benthic sediment biogeochemical processes. Wang *et al*. (2016) observed that in the northern Taiwan Strait, settling particulate organic matter (POM) was primarily from marine sources and the re-suspension of bottom sediment by currents. Sutherland *et al*. (2016) compared the impact of urban storm drain organic matter and contaminant discharge on benthic sediment biogeochemical processes in high and low flow systems (i.e. a highly flushed channel and poorly flushed embayment respectively). Increased oxygen consumption from benthic metabolism was evident closest to poorly flushed discharge points, related to the high retention and accumulation of organic matter and contaminants in the sediment. Sutherland *et al*. (2016) stated that monitoring benthic oxygen fluxes in this way could be a sensitive measure of ecological change in sediments following large inputs of storm water contaminants (i.e. following high precipitation events).

Global climate change impacts including increasing temperatures and changing precipitation patterns and storminess may play a significant role in organic matter degradation in estuarine sediments. Vincent *et al*. (2017) found that higher heterotrophic microbial activity appeared to be favoured by higher temperatures in the Ashtamudi estuary in Kerala, India. In addition, the contribution of organic matter and nutrient deposition to estuarine sediment via urban run-off during the monsoon season, resulted in a two-fold and five-fold increase in methanogenesis and denitrification respectively, increasing the production of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4). Canu and Rosati (2016) modelled the long-term (100 yrs) dynamics of the mercury cycle in the Marano-Grado Lagoon (a Mediterranean mercury hotspot), and showed that a sea level rise (of 0.315 m) and temperature rise (+2.5°C) may increase sediment methylmercury (MeHg) by up to 87% and 95% of current levels. Mercury bioaccumulation in biota was projected to increase accordingly.

2.2.4 Sediment dynamics

Human activities (e.g. port developments, dredging, management of intertidal areas, deforestation and freshwater abstraction) and climate change (e.g. global sea level rise, drought, changes to wind and precipitation patterns and storminess) can modify processes controlling sediment erosion, transport and deposition; increasing suspended sediment loads in estuaries and coastal seas (Capuzzo *et al.*, 2015, de Jonge *et al.*, 2014, Syvitski *et al.*, 2005). In this SI, a number of contributors investigated the physical processes that govern the transport and behaviour of fine sediments in estuaries.

Jalón-Rojas *et al*. (2017) employed a combined spectral analyses approach to investigate the relative contribution of environmental forcing frequencies on turbidity variability in the Gironde and Loire estuaries in west France. The main environmental factors affecting turbidity were related to river flow, including hydrological regime and discharge variability, tidal range, tidal cycles and turbulence. The relative influences of these forcings on turbidity depended on estuarine region (lower or upper estuary) and the time scale (multi-annual or seasonal). Mitchell *et al*. (2016) investigated the impact of different freshwater flow conditions on estuarine turbidity in the tidal reaches of the Kaipara River, New Zealand. A clear turbidity maximum was observed under low-flow conditions, where fine sediment was transported landwards and trapped in the upper part of the tidal reach. This turbidity maximum was flushed downstream under high flows. Sediment suspension was controlled by both local resuspension of material and by advection of previously suspended material by the main flow. Braga *et al*. (2016) employed Landsat 8 satellite images to investigate spatial and temporal variations of suspended matter patterns and distribution in the Po River prodelta (Italy) from 2013-2015. River discharge, wind and wave fields, coastal currents and circulation at local and basin scale explained most of the variability in surface turbidity in the prodelta. Smaller (sub-mesoscale) structures (i.e. plumes and sand bars) were observed in the near shore environment and were linked to the interaction between hydro-meteorological factors, coastal currents and prodelta morphology.

Boudet *et al*. (2016) and Slinger (2016) modelled sediment transport patterns in the mouth of the Rhone delta and intermittently open-closed estuaries respectively. Using the Delft3D numerical model, Boudet *et al*. (2016) identified that total sediment transport at the Rhone delta outlet was only influenced by the river flow, whereas at the mouth-bar, total sediment transfer depended on an equilibrium between the influence of storms and floods and on the succession of these events. Slinger (2016) developed a model to simulate the opening and closure of the mouths of small, wave-dominated estuaries characteristic of the coasts of South Africa, Australia, California and Mexico. Freshwater inflows were shown to be significant in determining the behaviour of the inlet mouth and the balance between these inflows and wave events were shown to govern the opening/closure of the mouth of a particular estuary.

2.3 Forecasting for the future

The inherent complexity and unbounded nature of estuarine and coastal systems makes physical and ecological responses especially challenging to predict. However, our capacity to make predictions is critical to the success of estuarine and coastal management and conservation in a rapidly changing world.

2.3.1 Global Sea Level Rise

The Fifth Assessment Report (AR5) of the IPCC projected, with medium confidence, that global mean sea levels rose by a rate of 3.2 (2.8 to 3.6) mm yr^{-1} from 1993 to 2010 and are projected to increase by a further 44-74 cm by 2100 (IPCC, 2013). An alternative estimate which considers the uncertainties around Greenland and Antarctica ice sheet loss suggest that sea-level could rise by up to 1.8 m by 2100 (Jevrejeva *et al.*, 2014, Church *et al.*, 2013). In some regions, the addition of vertical movements of the land (e.g. through glacio-isostatic adjustment, tectonic uplift and geological subsidence) significantly contribute to changes in sea levels relative to the land (Relative Sea Level Rise (RSLR); Nicholls and Cazenave, 2010). This acceleration in Global Sea Level Rise (GSLR) will have a significant impact on estuarine and coastal ecosystems (IPCC, 2014). In this SI, Ciro Aucelli *et al*. (2016), Little *et al*. (2016) and Angus (2016) focussed on evaluating the future effects of RSLR, through the impacts of marine transgression and saline incursion on estuaries and coasts.

Ciro Aucelli *et al*. (2016) evaluated the effects of future RSLR on the Volturno River Plain in southern Italy; a plain characterised by its high economic and ecological value, low topography and severe land subsidence. Using topographical information and RSLR scenarios, Ciro Aucelli *et al*. (2016) determined that the areas prone to inundation would increase by approximately 50% and 60% by the years 2065 and 2100 respectively and would include areas of current infrastructure and agriculture.

Little *et al*. (2016) demonstrated that RSLR projections for southeast England will increase estuarine salinities and drive saline incursion into freshwater tidal areas, which in addition to projected changes in freshwater river flow, will have important consequences on upper estuarine structure and functioning. The study identified that the benthic freshwater fauna inhabiting these upper estuarine zones may demonstrate greater tolerance to salinity change than is currently recognised, and may persist where salinity increases are gradual and zones unbounded. Angus (2016) investigated the impacts and challenges of climate change on Scottish saline lagoons and their specialist lagoon fauna. Rising sea levels are predicted to result in a loss of lagoon habitat through either marine transgression (through removal of impoundment) and/or increasing salinities. Despite the wide salinity tolerances of lagoonal species, they may be out-competed by marine species and their limited dispersal capabilities may restrict their ability to move to compensated lagoon habitats (i.e. previously freshwater inland water bodies).

In addition to surface saline incursion and marine transgression, seawater intrusion into groundwater aquifers is predicted to increase with climate change (i.e. RSLR and increased abstraction of freshwater for irrigation and domestic use). Since the 1970s, over-extraction of fresh groundwater for agriculture in the Korba coastal plain (northeast Tunisia) has led to seawater intrusion in the aquifer. In this SI, Slama and Bouhlila (2016) investigated the hydrochemical processes that occur when freshwater and seawater mix, in order to use these as indicators of seawater intrusion progression and freshwater flushing into seawater accompanying the discharge of groundwater to sea (the Submarine Groundwater Discharge). These indicators are important in order to monitor and assess groundwater saline intrusion progression. Increasing salinization of coastal aquifers may result in the loss of access to fresh groundwater for more than one billion people living in coastal regions (Ferguson and Gleeson, 2012).

2.3.2 Integrated management approaches

In this SI, Lillebø *et al*. (2016) discusses lessons learned from the development of an integrated management approach of coastal lagoons and their catchments based on scientific strategies and a decision support framework developed in collaboration with local stakeholders. As part of a collaborative project, integrated scenarios of possible economic development and environmental impacts were developed for four European lagoons (Vistula lagoon on the Baltic Sea, Ria de Aveiro lagoon on the Atlantic Ocean, Tyligulskyi Liman lagoon on the Black Sea and Mar Menor lagoon on the Mediterranean Sea). These were discussed with local stakeholders, developing specific management recommendations for each study lagoon. These recommendations were translated into policy guidelines concerning management implementation in a local-regional-European setting. Lillebø (2016) highlighted the importance of enhancing the connectivity between research and policymaking in this way and identified a need to better recognise the connectivity between land, streams, rivers, lagoons and coastal zones. Lillebø (2016) proposed a single coordinating unit for coastal management on a European scale in view of projected changes in climate and socio-economic development.

3. Conclusions

The papers presented in this SI have clearly shown that global change is altering the structure and functioning of our estuaries and coastal seas. However, establishing impacts and assigning cause to the many pressures of global change is and will continue to be a formidable challenge in these systems, due in part to: (1) their complexity and unbounded nature; (2) difficulties distinguishing between human-induced changes and natural variations and; (3) multiple pressures and effects. This SI has explored a number of these issues over a range of disciplines; contributing to our understanding and assessment of the impacts of global change, highlighting methods for essential management/mitigation of the consequences and providing a set of directions, ideas and observations for future work.

Notably, there is an urgent need to consider the effects of multiple pressures. Studies that investigate the impact/s of individual pressures on ecosystem structure and functioning provide key pieces of information for understanding a larger puzzle.However, it is the cumulative, synergistic and antagonistic effects of multiple pressures (e.g. over-exploitation, habitat loss and climate change effects) that have been shown to be most significant in the loss, depletion and turnover of species in estuaries and coastal seas (Lotze *et al.*, 2006, Scavia *et al.*, 2002, Burney and Flannery, 2005, Peer and Miller, 2014, Bentley *et al.*, 2017). The environmental complexity of estuarine and coastal systems and the intricacy of underlying drivers means that the effects of multiple pressures (on a series of ecosystem components and levels of biological organisation; Parmesan *et al*., 2013) must be understood in order to assess the overall impacts of global change. Functional group and ecological network analyses which are interpreted using an integrated approach may prove key here (Schuckel *et al.*, 2015, Syvitski *et al.*, 2005, Bentley *et al.*, 2017).

The position and role of estuaries within the unbounded aquatic continuum means that exogenic pressures acting on adjoining ecosystems (terrestrial, freshwater and marine) also act on estuaries. However, the resultant impacts on estuarine functioning will have reciprocal effects throughout the aquatic continuum through the loss and alteration of trophic subsidies (i.e. flow and transfer of energy, matter and organisms between ecosystems; the ‘outwelling hypothesis’, Savage *et al*., 2012). It is therefore critically important in the face of global change, that we view and manage these systems as a single continuum. As such, much greater research focus is required on understanding the importance of this connectivity on the health and resilience of these interlinked ecosystems (Hyndes *et al.*, 2014).

Research projects which combine palaeo/ historic, contemporary and future modelling approaches to investigate the effects of multiple pressures on ecosystem functioning at a catchment-scale (i.e. land, streams, rivers, lagoons and coastal seas) could therefore be a powerful tool to manage and mitigate global change through adaptive management plans formed in conjunction with local stakeholders. Just like our unbounded study systems, this requires scientists to reach beyond traditional discipline boundaries and scales. ECSA international conferences provide this platform, enabling estuarine and marine researchers and professionals from these different disciplines to meet, disseminate their research and collaborate through global research networks.

Even with mitigation of the drivers and pressures (exogenic and endogenic) of global change in the near future, estuarine and coastal baselines will continue to shift. For example, even with the complete cessation of CO_2 emissions by 2100, global climate change has been shown to be irreversible on centennial to millennial timescales (Katarzyna and Kirsten, 2015). In this scenario, whilst global mean temperature might remain more constant (Solomon *et al.*, 2009), substantial regional changes in temperature, precipitation and ocean warming would continue (Gillett *et al.*, 2011) and thermostatic sea levels would rise for several centuries to come (Katarzyna and Kirsten, 2015). In some systems (e.g. coral reefs; Hughes *et al*., 2017b), returning to past configurations or maintaining a current state (i.e. achieving ‘Good Environmental Status’; Elliott *et al*., 2015), may no longer be an option and may require radical changes to how we view, manage and govern these systems (Hughes et al., 2017b). Whilst this SI and most research in this field assesses the threats and negative impacts of global change on estuaries and coastal seas, such changes could also present new opportunities. For example, the unbounded boundaries of these systems may result in novel assemblages and configurations of organisms in the near future, as native species are lost, move or adapt and joined or replaced by mobile non-natives (due to rising temperatures, ocean acidification and species introductions; Rius *et al*., 2014). These new species may, in some cases, support or even enrich functional biodiversity and as such, play a key role in the maintenance of ecosystem services (Walther *et al.*, 2009). The global challenge here is to accept and adapt to these changes if mitigation is untenable, recognising that securing essential ecosystem services into the future will require scientific developments, innovative technology and adaptive integrated management and governance of estuaries and coastal seas (Richardson *et al.*, 2012).

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