Factors of ecological resilience in global temperate estuaries: A systematic review

By

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COMMITTEE APPROVAL

The members of Joy Sherlock's Thesis Committee certify that they have read the thesis titled Factors of ecological resilience in global temperate estuaries: A systematic review and recommend that it be accepted as fulfilling the thesis requirements for the Degree of MASTER OF SCIENCE IN ENVIRONMENT AND MANAGEMENT:

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Abstract

Estuaries in temperate regions represent the confluence or transition of three major biomes: terrestrial ecosystems, freshwater outflows, and nearshore habitats and they face a variety of external stressors. To help mitigate the impacts of external stressors on temperate estuaries, this systematic literature review identified and synthesized the spatial and temporal scales of ecological functions, the main stressors, and factors supporting resilience in estuaries. Dominant stressors were water quality threats, coastal modification, and hydrology changes. Temporal and spatial scales of stressors varied, with anthropogenic stressors generally occupying larger spatial scales and shorter temporal scales than natural processes. Functional redundancy, habitat complexity, and healthy food webs were identified as indicators of resilience at multiple scales. My research identifies tools available for measuring resilience to guide localized management of external stressors in temperate estuaries. Importantly, management actions should consider ecological functional integrity as a critical measure of the success of those actions.

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times), and navigating changes in our personal lives throughout the process. This work would not have been possible without all of those mentioned here.

Introduction

Estuaries represent the confluence or transition of three major biomes: terrestrial ecosystems, freshwater outflows, and near-shore marine habitats. The ecosystems found in estuaries are globally important providers of coastal protection, nutrient cycling, habitat for migratory species, and a rich source of ecological productivity (Boerema & Meire, 2017). In temperate regions, estuaries are characterized by key habitat features such as seagrass, marshes, rocky shores, oyster reefs, and intertidal flats that provide critical habitat for species such as salmonids during particular phases of their life cycle (Levings, 2016). Estuarine ecosystems are subject to a variety of anthropogenic stressors as they also are a preferred location for human settlement and focal point of shipping routes (Lotze et al., 2006). The resilience of estuaries to the array of stressors they face is critical to continued provision of their essential ecosystem services.

To date, most resilience-based estuarine research has focussed on specific stressors and ecosystem responses. Few studies have attempted to synthesize estuarine stressors and the ecosystem processes that operate to manage the impact of those stressors (eg. Basso et al., 2018; Smith et al., 2020; Teodoro & Nairn, 2020). Identifying metrics that can be used to understand resilience in estuaries offers a valuable management tool for assessing estuarine health and defining restoration targets. The development of such a resilience framework requires clear definitions of the functional components of temperate estuaries, understandings of how resilience can be measured in the estuarine context, and a detailed knowledge of the ecosystem stressors.

Defining estuaries and their features

Estuaries are generally defined by the following characteristics: coastal waterbodies that are semi-enclosed with access to open ocean through tidal inundation, and dilution coming from a terrestrial fresh-water source such as a river or stream (Levings, 2016; Long et al., 2018; Simenstad et al., 1982). Estuaries are an example of a landscape edge feature where multiple landscapes interact and share nutrients and resources with one another (Long et al., 2018). The interaction between seasonal influences of variable freshwater discharge and daily influences of saltwater inundation from the tides determines the residence time of water in the estuary, which is constantly flushing (Levings, 2016). These defining characteristics allow for organic and inorganic materials to be shared among freshwater, ocean, and terrestrial landscapes (Long et al., 2018). The large quantities of nutrient exchange found in estuaries helps to explain why estuaries contain some of the most productive ecosystems on earth (Potter et al., 1990; Rodrigues & Pardal, 2015; Schelske & Odum, 1961; Turner et al., 2003)

An additional feature of estuaries that supports high productivity levels is the daily draining regime created by the tidal cycle, causing estuaries to maintain a fertile state of early succession (Odum, 1969). Tides act as external, acute disturbances that prevent the development of late successional phases (Kominoski et al., 2018; Odum, 1969). The features of early succession that can be witnessed in this regime include a food chain that is relatively simple and linear (from primary producer to secondary, tertiary, and quaternary consumer), high net primary production yield, and r-strategist species dominance (Borja et al., 2012; Odum, 1969). In contrast to k-strategist species, r-strategist species favour higher population size over individual fitness to survive in environments like estuaries with variable mortality factors (Adams, 1980). To accommodate these regular disturbances, these organisms reproduce at higher rates but have a shorter life-span and higher mortality rates than k-strategists (Adams, 1980). By supporting this species composition, regular disturbances act as stabilizing features of estuaries that help to maintain ecosystem function, creating what can be referred to as *pulse stability* or *pulse dynamic*s (Jentsch & White, 2019; Odum, 1969). Therefore, the study of resilience in estuaries must distinguish between the stabilizing forces of regular pulse dynamics that create ecological niches, and additional stressors that can accumulate and threaten those niches.

Functional components of temperate estuarine landscapes

The simplest generally accepted model of a global climate system is informed by the Köppen-Geiger climate classification system, which was developed in the 1930s based on the annual air temperature and precipitation cycles for any given region (Cui et al., 2021). Climate is one of the most critical determinants of ecosystem types and functions (Cui et al., 2021). The map shown in Figure 1 displays the coastal temperate regions of the world, including the following, as numbered on the map:

1. the west coast of North America south of Alaska and north of Baja California,
2. the east coast of North America north of Florida and along the eastern seaboard of the United States and Canada,
3. coastal south-central parts of South America,
4. most of western Europe and the Mediterranean,
5. the eastern part of South Africa,
6. most of China and Japan,
7. southern sections of Australia, including Tasmania, and

8. all of New Zealand.

Figure 1

Temperate Coastlines of the World Based on Köppen-Geiger Climate Classification (adapted from Cui et al, 2021)

The varying hydraulic regimes of temperate estuaries create a predictable and recognizable structure of ecosystems and landscape features that generate vertical dynamics of estuaries along a tidal gradient (Chust et al., 2013; Levings, 2016). Dominant habitats of temperate estuaries tend to include brackish marshes in the aquatic regions closest to the freshwater source, high salt marshes on the areas closest to land and, less frequently tidally inundated mudflats and sand flats, and intertidal and subtidal seagrass meadows towards the mouth of the estuary closest to the open ocean (Levings, 2016). Each of these vegetative components provide important carbon sinks and coastal protection as well as extensive habitat and foraging opportunities for a variety of organisms (Borja et al., 2012; Levings, 2016; Lovelock & Reef, 2020). Each habitat type and its associated biotic assemblages has high tolerance to variability in thresholds of environmental conditions such as salinity levels, temperature, dissolved oxygen and other physical and chemical features (Elliott & Quintino, 2007).

Estuarine vegetative communities, sand flats, and mud flats act as host to a variety of other important aquatic and avian organisms. Dominant aquatic invertebrate organisms within the assemblages of these features tend to be small in size, have short lifespans, large populations per species, and are acclimatized to regular environmental variations, e.g., oligochaetes and nereid polychaetes (Borja et al., 2012). These dominant organisms make estuaries good environments for migratory birds in search of habitat and foraging opportunities (Ma et al., 2006).

The habitat and foraging opportunities are also significant for a large number of fish species, including anadromous salmonids which have adapted to freshwater and marine environments and use estuaries as transitional areas between life history phases (Levings, 2016; Simenstad et al., 1982). Salmonid species have high economic value for human populations (Bottom et al., 2005), act as an indicator of ecosystem health for a large number of other species (Levings, 2016), and are important for transporting nutrients and materials between freshwater and marine habitats (Naiman et al., 2002). Temperate estuaries are critical in supporting the transition of life history phases of migratory salmonids, including rearing habitat for juveniles of many species (Bottom et al., 2005; Levings, 2016; Simenstad et al., 1982). These are a few examples of the functional components of temperate estuaries that are examined in this research.

Resilience and its application to estuaries

The concept of resilience was introduced to ecological study in the early 1970's by C.S. Holling (Gunderson, 2000). Holling (1973) described ecosystem resilience as its capacity to absorb environmental changes without dramatically altering its state of equilibrium or set of governing relationships and functions. Specifically, he notes that resilience is "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973, p. 14). Further, the study of resilience capacity required the holistic analysis of interconnected living and non-living relationships within the ecosystem rather than disconnected studies of specific aspects of that system. This holistic analysis can be juxtaposed against the classical physics-based reductionist approach in which the focus of study is on one set of dependent and independent variables that exist within an environment that is assumed to remain constant (Gunderson, 2000; Holling, 1973). A relationship-based approach is useful when investigating the cumulative impacts of multiple ecosystem stressors in temperate estuaries.

The resilience approach to ecological analysis and environmental management has increased in popularity since it was introduced (Brand, 2009; Spears et al., 2015). Resilience is now well-established as a key component of ecosystem health (Costanza, 2012), likely due to the understanding that it is unrealistic to assume an environmental medium of study that does not face fluctuations or changing conditions (Holling, 1973). The challenge ahead of estuarine environmental managers is to positively influence the ecological capacity of estuaries to absorb inevitable ecological stressors in order to allow ecosystem functions to persist (Jentsch & White, 2019). Given this challenge, resilience is a useful concept to support environmental managers in prioritization and plan development.

Summary of stressors and influencers in estuaries

When studying resilience in estuaries, it is important to acknowledge that estuarine ecosystems are naturally prone to, and stabilized by, regular disturbance. Due to the highly variable nature of estuarine environments, the composition of estuaries' fauna is comprised of species that are naturally resilient to changing aquatic conditions that vary with their changing hydraulic regimes (Borja et al., 2012). If organisms are to survive in estuaries, they must be adaptable to variation in dissolved oxygen, temperature, turbidity, salinity, and sedimentation (Borja et al., 2012). Because of the variable nature of estuaries, they tend to support ecosystems that would otherwise appear heavily disturbed or stressed in other contexts, making it difficult to use standard tools to determine the level of destabilizing stress that an estuary is subject to (Elliott & Quintino, 2007). As a result, it can be difficult to distinguish whether an estuarine ecosystem has been destabilized by external factors, or whether it is showing its naturally evolved homeostatic conditions, a situation titled the "estuarine quality paradox" (Borja et al., 2012; Elliott & Quintino, 2007). Due to this paradox, there is a need to develop indicators of resilience that are specific to the estuarine environment as we consider the importance of regular disturbances to estuarine ecosystems.

The natural disturbances described above are often combined with anthropogenic stressors in estuaries. Examples of significant anthropogenic stressors imposed on estuaries include:

- coastal modification (Chust et al., 2013),
- dredging (Borja et al., 2012),
- resource exploitation (Borja et al., 2012; Chust et al., 2013),
- invasive species introduction (Borja et al., 2012; Chust et al., 2013),
- upstream flow modification (Bottom et al., 2005; Cole Ekberg et al., 2017),
- leached chemicals and nutrients from local, upstream, and marine sources (Cabral et al., 2019; Chust et al., 2013), and
- the persistent impacts of climate change and sea-level rise (Cabral et al., 2019; Chust et al., 2013; Cole Ekberg et al., 2017; Rodrigues & Pardal, 2015).

While anthropogenic stressors are ubiquitous across landscape types, when compared to inland regions, coastal areas and estuaries are particularly vulnerable to stressors associated with artificialization and urbanization resulting from human settlement trends and preferences (Chust et al., 2013; Lotze et al., 2006). Artificialization in this context includes the transformation of coastal landscapes past a threshold that alters the existing ecological dynamics of that landscape (Ferreira et al., 2009). A list of typical natural and anthropogenic stressors on estuarine ecosystems are described in Table 1 and

Table ***2***. The purpose of these tables is to provide some examples of how natural and anthropogenic external pressures influence estuaries for greater context.

Table 1

Natural Stressors in Temperate Estuaries

Natural Stressor	Description
Fluctuations of tidal inundations	Also termed “fluctuating water level ecosystems”, the action of changing water marks increases rate of decomposition during dry periods, creating optimum conditions for productivity when water levels rise (Odum, 1969).
Saline fluctuations	Changing salt concentrations and stratification (Levings, 2016)
Sedimentation	Movement of sediment loads from freshwater riverine transportation (Levings, 2016). Can lead to additional phenomenon of turbidity, nutrient transfer, and mudflat generation
• turbidity	Increased concentrations of suspended particulate matter, causing changes in light attenuation which impacts primary production (Burchard & Baumert, 1998; Glover et al., 2019)
• nutrient transfer	Import of terrestrial nutrient flow carried through freshwater and sediment from rivers into the estuary and eventually the ocean through ongoing flushing (Long et al., 2018)
• mudflat creation	Development of flats from sediment that has settled on the benthic floor of the estuary (Levings, 2016)
Temperature fluctuations	Water temperature changes due to mixing freshwater and seawater in the estuary (Levings, 2016)
pH fluctuations	Water acidity levels changing due to mixing freshwater and seawater in the estuary (Levings, 2016)

Table 2

Anthropogenic Stressors in Temperate Estuaries

Anthropogenic Stressor	Description
Coastal modification	Modifying the natural coastal structures in the estuary through hardening shorelines (eg. Gittman et al., 2015), and replacing natural with artificial structures to support human activity (Macura et al., 2019; Siemes et al., 2020).
Dredging	Removal of benthic sediment, including sand and substrate (Demir et al., 2004).
Resource exploitation	Removal of ecosystem components such as fish and shellfish for human consumption (Borja et al., 2012).
Invasive species introduction	Importation of species into estuarine landscapes that outcompete native species (eg. Kennedy et al., 2018)
Upstream flow modification	Typically occurs through development of dams designed to divert water from regular river-estuary flow to land-based use, providing freshwater supply to human communities (Palinkas et al., 2019).

Leached chemicals and nutrients	Release of industrial, agricultural, and human waste chemicals and nutrients into estuaries (Adams et al., 2020; Cabral et al., 2019; Detenbeck et al., 2019)
Silviculture	Release of woody debris and prevention of access of sub-surface and benthic organisms to sunlight from the use of estuaries for log storage and handling. (Robb, 2014). Impacts also include creating niches for species that would otherwise not be present. (eg. Reid, 1980)
Climate change	The persistent impacts of increased atmospheric greenhouse gases worldwide, including increased temperature and sea levels, lower ocean pH levels, and an overall increased water temperature (Borchert et al., 2018; Borja et al., 2020; Cabral et al., 2019)

Research Question

The overarching objective of this thesis is to determine the features of temperate estuaries that indicate resilience to natural and anthropogenic disturbance, and to develop a framework for the application of resilience metrics / indices in support of temperate estuary management. My focal research questions are:

1) What are the dominant ecosystem stressors in temperate estuaries?
2) What are the indicators of resilience for estuaries in temperate climates?
3) What are the temporal and spatial scales of influencers on temperate estuaries?

The outcomes of this research will support ecosystem managers navigating the changing ecologies of temperate estuaries. Understanding and anticipating the temporal and spatial scales of impacts will support prioritization for short- and long-term impact mitigation strategies and resource allocation planning.

Methods

This study's research questions were addressed through a systematic review of the primary, peer-reviewed literature specific to indicators of resilience in estuaries.

Article collection

Journal articles were collected from a search of the Aquatic Sciences and Fisheries Abstracts and the Pro-quest databases using the search terms "estuar* + resilien*" to capture all results using both word stems of estuary and resilience to include terms that may come up in the literature such as estuarine and/or resilient. "estuar* + temperate + resilien*" was used in the next search to try to narrow the results to those located in temperate climates. "estuar* + adaptive capacity" was used in the next search, treating adaptive capacity as a synonym for resilience. Finally, "coastal habitat + restoration" was used to capture articles that included estuaries as a subset of coastal habitat, and those that inferred resilience through restoration.

Using each combination of search terms in the two databases, a total of eight searches were completed for this research. Results were filtered to only include articles that had been peer reviewed. If any of the searches yielded more than 200 articles, only the first 200 articles were included based on relevance as identified by the database search engine. Relevance is determined by the search engines' algorithms based on the number of times the search terms appeared in each record and where they appeared within the record (ProQuest, 2023). This process yielded a total of 1407 articles to review.

Selection process

Covidence software was used as a collaborative platform for systematic review (Covidence, n.d.) and all articles that were finally selected were moved to an excel spreadsheet for further analysis, referred to as the data collection spreadsheet. All 1407 articles were imported into Covidence, which provided a display of titles and abstracts of all articles for review. During this phase, two persons examined titles and abstracts of peer reviewed articles for relevance and a joint decision was made to either include or exclude each article. Articles were excluded if they did not meet all three of the following criteria:

- Specific to estuarine ecology
- Specific to temperate locations
- Identified pressure and response mechanisms within estuaries

Similarly, articles were excluded if they:

- studied locations that did not have temperate climates,
- studied solely marine (non-estuarine) or terrestrial/freshwater aquatic phenomena,
- did not focus on ecology, or
- did not effectively identify external pressures/changes and subsequent responses

Because temperate estuaries have specific ecological traits, as discussed in the introduction, it was important to select articles that could address the research questions as they relate to the features of temperate estuaries. Therefore, any study that was in a tropical, subtropical, sub-polar, or polar setting was excluded. Estuaries in these settings may face similar pressures, and in some cases show similar responses, but they could respond differently because they exhibit different ecological profiles.

Studies that were focused on purely marine or freshwater habitats were also excluded from the final selection. Although both habitats exchange resources with estuaries, and therefore have relevance to estuaries, studies removed from estuarine locations did not capture ecological responses relevant to estuaries specifically and therefore did not provide information on the pressures and response mechanisms, and thus, resilience, of estuaries.

A common profile of studies in the literature reviewed was a multidisciplinary approach that focused on the human and management aspects of coastal resilience such as policy, economics, and community building. Although many of these studies referenced scientific data, they did not have an ecological context and therefore did not provide data useful to my research questions. These types of study were also excluded from the analysis.

Using Covidence, each reviewer separately reviewed the title and abstract of each article and chose whether to include or exclude it based on the criterion above. If a conflict arose due to the two reviewers choosing differently, the conflict was discussed and a resolution to either include or exclude the article was reached. Through the title and abstract screening process, 1090 articles were eliminated, leaving 317 to review.

Selected articles were subject to full text review. Using Covidence, both reviewers examined the full text of the remaining 317 articles to determine whether the article fit the criteria as discussed above. The same conflict resolution process discussed above was followed to achieve consensus on whether to include an article if the two reviewers had selected differently. This process eliminated 121 additional studies, yielding 196 studies for data extraction.

Final selection

During the process of inputting data into the data collection table during the data extraction process, further studies were selected for removal if they did not match the criteria described previously and had missed being identified for elimination. I also determined at this stage that only primary research articles should be included. This inclusion criteria allowed for information to be collected on the full context of the data provided in the scoping section of the data collection table. This approach contrasted with the option of collecting information that had already been synthesized to support overarching reviews or arguments and would be three times removed from the context of the original data source once the information was input into the data collection table for this exercise. We therefore engaged in a third process of elimination, whereby overarching reviews, secondary research, and special issue introductions were removed from the data collection process, once reviewed by both parties. Through this final elimination, an additional 73 articles were removed, leaving a final inclusion count of 124 articles.

Data extraction

For data collection, the list of articles was taken from Covidence, which was then retired from the process. All 124 remaining articles were then added as line items to the data collection table. Within the table, data were extracted from each article and recorded (See Appendix 1 – Data Collection Table for complete table). To address research question 1, the table included a column for stressors studied. If multiple stressors were studied, new line items were made citing that article to capture all stressors. To address research question 2, the scope of each study was considered, including the variables being measured and their methods of measurement. This provided information related to typical methods of measurement that could be applied to a resilience framework. To address research question 3, information was further extracted based on the estuary features that were studied, and timeline information was collected to showcase the duration of each study. Estuary features were then divided based on whether they were related to the whole estuary, a habitat within the estuary, or a biological community occupying a habitat within an estuary. The purpose of this was to better understand the temporal and spatial scales of factors that affect change within estuaries, and how those scales apply to factors of resilience within estuaries.

Data Analysis

Using the data extraction table, the data analysis included a review of primary locations of research, estuary features, stressors, and metrics used. A simple article count that tallied the totals of each category used in each article was used to accomplish this. To better understand which stressors were most commonly applied to which estuarine features, a count was completed to determine the number of cross references between stressors and estuary features and analyzed in the form of a heat map. To better understand which metrics were most used to understand each stressor, a count was completed to determine the number of cross references between stressors and metrics.

I used the “results” column of the data collection table to summarize the information collected from each study and reviewed that information to assess how changes occur in estuaries over time. I used the “pressure” column to identify which pressures influencing the overall estuarine system were reviewed by each article. I then sought connections within each of the estuary features to better understand common and contrasting stressors and responses across studies. This allowed me to take note of how stressors and responses reveal themselves in different scenarios and at different scales within the estuary. Finally, I attempted to contextualize the information in terms of how resilience is defined in this research, to understand how this information can be applied in a way that recognized the full collection of relationships and ecological functions within estuaries.

Limitations

A limitation of this research is that it only included articles that followed a western scientific method, which excluded other methods of acquiring ecological knowledge such as indigenous observations, oral histories, or other methods not considered here. This research could therefore be enhanced by integrating the information presented here with other research using a diverse set of tools for acquiring knowledge.

Also, because this research was conducted at a Canadian English-speaking University, the data collection process only included articles that were written in or translated to the English language, and the search engines used conducted article searches in English. Due to the global nature of the research, articles that were written in different languages native to their region would have automatically been excluded before I had the chance to review them for relevance.

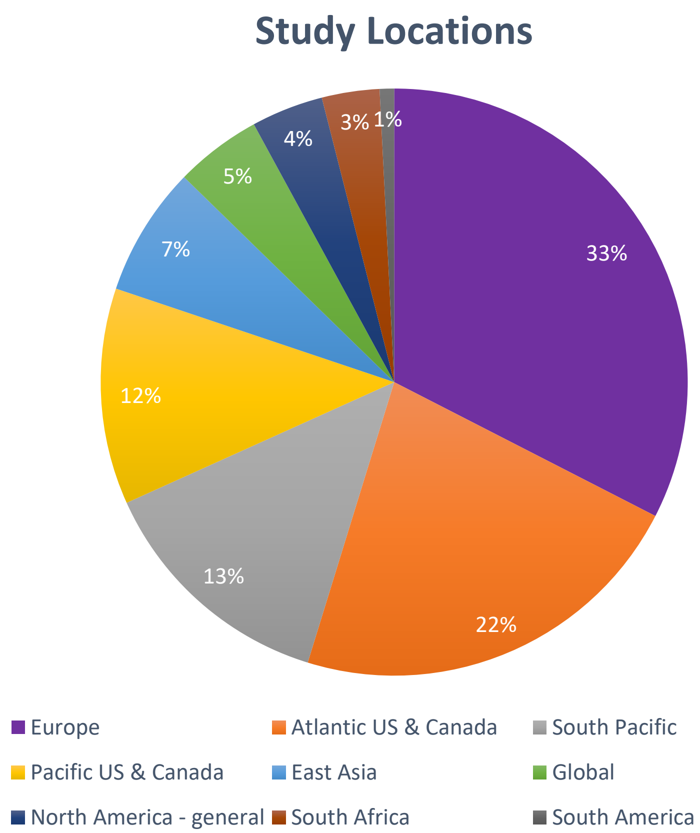
Results

Study Locations

The published English-language research related to estuary resilience was globally distributed (Figure 2), with a strong presence of studies from Europe (including UK) (33%), Atlantic US and Canada (22%), the South Pacific (Australia, New Zealand, Tasmania; 13%), and the Pacific US and Canada (12%). There was very low representation from temperate estuaries in South America (only 1 article). All other locations together had ≤ 7% representation. Not surprisingly, African temperate estuaries were poorly represented; only a short section of coastline in South Africa is considered temperate. However, there is a much larger coastline in South America, with approximately 3100 km of coastline on the Atlantic side and 2900 km of temperate coastline on the Pacific side that could have been better represented (Cui et al., 2021). This could be because of the limitation that only English language articles were used rather than Spanish, Portuguese, or other languages indigenous to South America. There were a few studies with wide geographic distribution, represented in the pie chart as Global (5%) and North America – general (4%), but all others were localized to a single estuary or few estuaries within the same geographic region.

Figure 2

Proportional Distribution of the 124 Articles Isolated Through the Review Process among Geographic Regions.



The literature covered a range of estuarine features (i.e., components that make up estuaries) at multiple scales, including the whole estuary, habitat scales, and biological scales (

Table ***3***). Water (22) was the most studied feature of the whole estuary category. The estuarine habitat most represented in the literature was salt marsh (40), followed by seagrass (24). The organism groups most represented were fish (15), bivalves (14), and microbiome (12).

Table 3

Literature Coverage of Estuarine Features.

Category	Feature	Article Count
Whole Estuary	Water	22
	Morphology	14
	Food Web	12
Habitat	Salt Marsh	40
	Seagrass	24
	Mudflats	15
	Sand Flats	6
	Oyster reefs	4
Biological	Fish	15
	Bivalves	14
	Microbiome	12
	Birds	9
	Invertebrates	9
	Zooplankton	6
	Phytoplankton	5
	Macroalgae	4

Dominant Ecosystem Stressors in Temperate Estuaries

The dominant ecosystem stressor categories for estuaries identified in the reviewed literature were water quality threats, coastal modification, and hydrology changes (~ 30% each), followed by biological changes (9%), and changing sedimentation regimes (4%) (Figure 3).

The most studied water quality threat in the literature was eutrophication (Table 4; 15 studies). The most studied coastal modification threat was land reclamation (7). Within hydrology changes, water temperature increase (14) was the most studied. Within biological changes, invasive species (8) was the most frequently studied. Comparatively little research has focused on sediment fluxes (4), and this category did not have sub-categories.

The heat map provided in Table 5 provides an overview of the dominant stressors most frequently studied in relation to each estuary feature. The numbers can be different from the totals found in Table 4 because most articles covered multiple features and stressors. The heat map presents the cross-referencing of stressors and features as they showed up in the literature, which happened more often than each individual stressor. For instance, if one article studied the impacts of both land reclamation and upstream modification on salt marshes, the article would be referenced twice on the heat map instead of once, so the total number of cross-references to each stressor and feature in the heat map will exceed the total number of articles that reference each as shown in Tables 3 and 4. The heat map in Table 5 shows that while the literature identifies important stressors in a dominant way for some features (e.g. sea-level rise and its relationship to salt marshes is clearly a dominant connection in the heat map), dominantly-studied stressors can be much less clear for other features (e.g. mudflats has a variety of stressors studied with no clear dominance in the literature).

Figure 3

Most Studied Temperate Estuary Ecosystem Stressor Categories Identified from the Literature

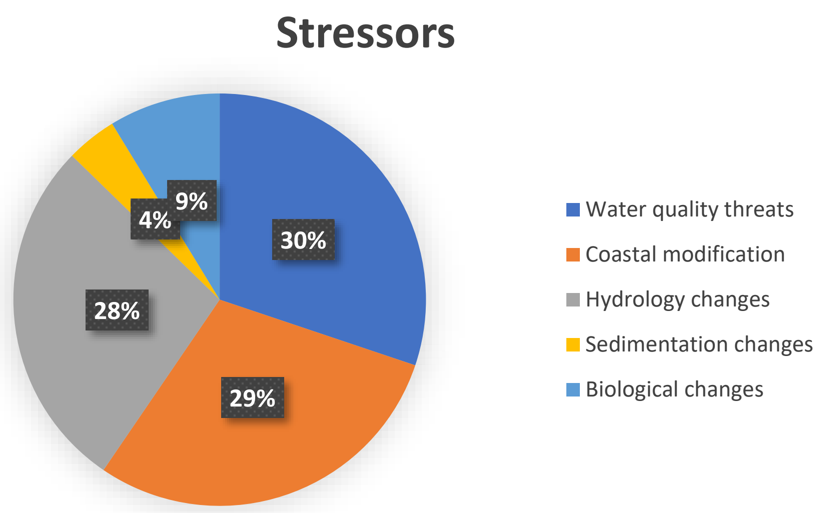


Table 4

Dominant Estuary Ecosystem Stressors within Categories

Stressor Category	Stressors	Defined as	Article Count
Water Quality Threats	Eutrophication	Increased nutrient supply in the water, often a result of human effluent discharge or agricultural runoff, that causes an increase of autotrophic organisms such as phytoplankton, cyanobacteria, and filamentous algae.	15
	Pollution	Discharge into an estuary resulting from anthropogenic activity. Includes discharge into flowing freshwater upstream of the estuary (e.g. Agricultural runoff, wastewater discharge, industrial tailings releases)	10
	Ocean acidification	Reduction of ocean water pH, largely driven by oceanic absorption of increased anthropogenic CO_2 from the atmosphere	9

Stressor Category	Stressors	Defined as	Article Count
	Turbidity	The increase in suspended particles in the water, reducing light penetration and visibility.	3
Coastal modification	Land reclamation	Converting transitional area along the land-water interface of an estuary (e.g. salt marshes and flats) into terrestrial area through draining the waterways and buffering the elevation with material import	7
	Modification - general	Total overarching landscape-based impact of anthropogenic changes to an estuary and its immediate land-base	4
	Marsh grazing / mowing	Use of livestock on marshland to consume marsh grasses or agricultural equipment to cut marsh grasses shorter	3
	Hardened coastal defences	Use of hard material such as stone and concrete to buffer shorelines to protect the landforms behind it from storm surges and water damage. Examples include dykes, seawalls, and riprap	3
	Shoreline realignment	Modification to the main shoreline along the edge of the estuary	3
	Channelization	Simplifying and redirecting water flows either within marshes and flats or directly to the freshwater input to the estuary, often to support coastal development. Involves reduction of the total number of channels through drainage modification and decreased complexity through sinuosity.	2
	Dredging	Removing and relocating sediment and all its associated life-forms from its original location to a new location, often to make room for shipping routes	2
Hydrology Changes	Water temperature increase	Increase in the temperature of the water within the estuary. Could be due to a combination of reduced flow and increased atmospheric temperatures.	14
	Sea-level rise	Increase in seawater elevation due to increased global glacial melt. Causes increased tidal inundation time and higher tides.	11

Stressor Category	Stressors	Defined as	Article Count
	Upstream modification	Changes to freshwater sources and associated natural structure of river inputs upstream of the estuary. Typically refers to dams and freshwater diversions.	9
	Freshwater flows / precipitation	Increased amount of freshwater entering the estuary. Includes changes in upstream snowmelt, precipitation patterns, reduced groundwater, and riverine flow.	8
	Drought	Extended period of reduced precipitation, causing parts of the estuary to become dry.	6
	Currents	Changes in the magnitude, volume, and velocity of currents from offshore, either through tidal or wave sources.	2
Sedimentation changes	Sediment fluxes	Sediment movement into, away from, and within the estuary.	4
Biological Changes	Invasive species	Introduced species that can thrive in the environment more successfully than endemic species, thus out-competing them and taking over their niches.	8
	Diversity loss	Reduction in variety of species types and genetic information.	1
	Aquaculture	Farming of aquatic organisms for human use within the estuarine setting.	1

Table 5 (*Overleaf*)

Heat Map Showing Number of Cross References between Stressors and Estuarine Features.

Stressor Category	Stressors	Features															
		Morphology	Water	Food Web	Mudflats	Oyster Reef	Salt marsh	Sand flats	Seagrass	Fish	Birds	Bivalves	Invertebrates	Macroalgae	Phytoplankton	Zooplankton	Microbiome
Water Quality	Eutrophication		7	1	3		1	2	7			1	7	2	2	1	2
	Pollution		3		3		3		1	1	2		1				
	Ocean acidification		4	1	1					1		5		1	2	1	
	Turbidity		2						3					1	1		
Coastal Modification	Land reclamation	3			1		9				1	1					
	Modification - general						4		3	1	2						2
	Marsh grazing / mowing	2					3		1								
	Hardened coastal defences	1					1				1						
	Shoreline realignment	1					3										
	Channelization	1	2				1									2	
	Dredging	1		1	1		1						1				
Hydrological Changes	Water temperature increase	3	7	1	1	1			4	4		3		1	3	4	2
	Sea-level rise	3	1		1		12		1	1	5						
	Upstream modification	1	4	1	2		1			2		1	1			1	
	Freshwater flows / precipitation	1	2	2	2			3	3			2	2			1	

	Drought		1	1			1	2	2	1	1	1	1				1
	Currents					1						1					
Sediment Fluxes	Sediment fluxes				2		2	1	1		1	2					1
Biological Changes	Invasive species			1	2		7		3		5		1				
	Diversity loss			1	1		1		1	1	1						1
	Aquaculture			1								1					

Note: Higher level of colour saturation indicates larger number of cross-references.

Metrics –Measuring the Effects of Stressors on Estuary Features

The variables or metrics used to measure the effect of stressors on estuarine features can be used to indicate resilience by assessing which characteristics support or harm ecological function. Habitat distribution, organism responses, water quality, and species composition were most frequently used in the literature to assess how stressors impact or influence estuarine features (Table 6). The typical variables and metrics used varied based on the stressors being measured (

Table *7*). As with Table 5, articles show up more than once in the heat map due to multiple cross-references that can be present within one study; the heat map (

Table *7*) shows the frequency of cross-references between metrics and stressors.

Table 6

Variables used as Metrics to Measure the Effect of Stressors on Estuarine Features

Metric	**Definition**	**Typical measures**	**Article Count**
Habitat distribution	Spatial profile of habitats and habitat types.	Areal extent and locations of salt marshes, seagrass meadows, and other main habitat groups. Could be measured in habitat coverage per square meter.	30
Organism response	Reactions of organisms to pressures or changing conditions within an estuary	Animal physiological and behavioural responses; survival rates; changes in abundance; changes in functional performance.	27
Water quality	Physical and chemical properties of the water within the estuary, with quality determined by the state of unimpacted water parameters to support ecological function for its location	Ratios of nitrogen, phosphorus, sulfur, and carbon dioxide within the water; concentrations of nutrients; levels of salinity (g/kg), alkalinity (pH), and aragonite saturation (Ω)	26

Metric	Definition	Typical measures	Article Count
Species composition	Diversity and ratio of species present within the estuary	Modelling studies using software that simulates processes using count and categorization of species present; total counts of benthic invertebrates or micro-organisms within core samples; bird counts; plankton type and composition found within water samples.	22
Biodiversity	Number and proportion of variation between species and within species gene pools within a study area.	Species richness and evenness; genetic richness and evenness	17
Plant density	Number of plants within a study area	Number of shoots present within a unit area	14
Restoration / recovery	Ability of habitats and biota to recover because of human intervention	Area, Shoot density, % cover, and genetic diversity within restored seagrass beds; area, % cover, diversity, and sheer strength within restored salt marshes;	14
Sediment fluxes	Sediment movement into, away from, and within the estuary.	Changes in area, spatial configuration, and elevation of mudflats, salt marshes, sand flats, and seagrass meadows; sediment characteristics as they relate to terrestrial or marine sources; often measured in relation to current and projected sea-level rise	13
Currents / discharge / hydrology	The overarching hydrological regimes within estuaries, including both tidal and seasonal changes. This includes rainfall, river discharge, waves, tidal currents, stagnation, and/or evaporation	hydrodynamic responses to pressures (typically modelled using software); water levels; estuary flushing; wave dynamics; tidal amplitude.	10
Accretion	As it pertains to salt marshes, the rate at which marsh elevation increases due to gradual sediment deposition	Increase in marsh height	7

Metric	Definition	Typical measures	Article Count
Elevation	As it pertains to salt marshes, their vertical location in relation to water levels throughout the estuary	Marsh height	7
Habitat connectivity	Spatial connection between habitats, relevant for migratory species who journey across multiple habitats	Landscape style patch mosaic of habitats and where they connect to each other. Patchiness as measured by length of habitat perimeters, size of habitat areas, number of distinct habitats present, and distance between habitats.	7
Microbial response / survival	Changes in abundance and composition of microbial species within a study area.	Microbial species occurrence and abundances	7
Plant diversity	Variability in species and genetic makeup of plants; used for saltmarsh and seagrass analyses.	Species composition and genetic profile composition of plants.	6
Plant response / survival	Reactions of saltmarsh or seagrass plants to pressures or changing conditions within an estuary	Physiological changes such as shoot height and width; plant die-off	6
Light access / attenuation	Light penetration into water column; typically studied in relation to seagrass productivity but also used to assess submerged macroalgae	Photosynthetically active radiation (PAR); Particulates; phytoplankton; algae; dissolved organic matter; turbidity;	5
Primary Production	Biomass of photoautotrophs in an estuary	Levels of chlorophyll-a; biomass of primary producers within a study area; kg / Ha	4
Sediment quality	Physical and chemical properties of sediment. Quality determined by the relationship between sediment properties and their ability to support ecological processes.	Quantity and / or proportion of silt, sand, and gravel; O_2 content; H_2S content; carbon and nitrogen content; pore water salinity	4
Harmful algal blooms	Over-production of algae and organisms that have similar effects (e.g. cyanobacteria), that is toxic to the normal functioning of aquatic systems;	Biomass / density of harmful algae; percent cover;	2

Metric	Definition	Typical measures	Article Count
	often associated with eutrophic conditions		
General health	Overarching synthesis of pre-determined indicators of healthy estuaries	Estuary habitat stressor model; estuary habitat assessment framework	2

Table 7 (*Overleaf*)

Heat Map Showing Number of Articles Using each Metric Type to Measure Each Stressor.

		Metrics																		
Stressor Category	Stressor	Algal Blooms	Animal Response / Survival	Biodiversity	Currents / Discharge / Hydrology	Elevation	General Health	Habitat Connectivity	Habitat Distribution	Light Access / attenuation	Microbial response / survival	Plant Density	Plant Diversity	Plant Response / Survival	Productivity	Restoration / Recovery	Sediment fluxes	Sediment Quality	Species Composition	Water Quality
Water Quality	Pollution	2	3	3	1	1	1		3					1					1	7
	Eutrophication	1	6	3		1				1	1	2		2	1	3	1		4	6
	Ocean Acidification		6	1					1						1				1	7
	Turbidity									3		1		2						1
Coastal Modification	Modification – General		2	3		2	1		4		1			2		1		1		
	Grazing / mowing				1				1			3	2		1	2				
	Channelization		1	1				2	2							1			1	
	Shoreline realignment				1	1			2								2			
	Land reclamation		1		1	2	1	2	7			1	1			2	3			1
	Dredging		1														1		1	
	Hardened coastal defences		1					1	1							1				
Hydrological Changes	Upstream modification		3		1		1		1	1						1	1	1	1	1
	Freshwater flows / precipitation		5	2	2							1				2			2	2
	Increased Currents				1	1			1								1			
	Water temperature increase		6	1	2			2	4	1		3		1		1			4	8
	Drought		3	1	1				1		1	1				1			1	3

	Sea-level rise		5		3	4		3	6			3	1	1		2	3	1		
Sediment Fluxes	**Sediment fluxes**		1		1				2	1	1	1					2	1		1
Biological Changes	**Diversity loss**			1					2			1					1	1		
	Climate Change – General							1	1											
	Invasive Species		4	2	1				3		1	1	1		1	1			1	1
	Aquaculture		1																1	

Note: Higher level of colour saturation indicates larger number of cross-references.

To better understand how resilience relates to the scale and timeline of estuarine features, the section below presents the findings on indicators of resilience in terms of their spatial footprint. The section starts with estuarine features that are omnipresent throughout the estuary (water, morphology, and food webs), moving to habitats within the estuary, and then organism groups that can be found within those habitats (as per the categorical breakdown in provided in

Table 3). Within each feature description there is also reference to how timelines are reflected in the stressors threatening ecological resilience. Information about scale and timelines has implications for impact assessment on proposed commercial, residential, or industrial activity to better understand what the true size and timeline of an impact may be. Scale and timeline information also has implications for restoration, compensation, and associated monitoring programs, including how large the effects of intervention should be and for how long it will be expected to take to achieve the restored ecological functions desired. Research questions two and three are therefore addressed here.

Scale: Whole Estuary

Water

Water within estuaries provides the main setting for all life assemblages within and between each of the habitats below the high-water line. The quality of the water is important for all organisms that live within and among it. According to the reviewed literature, the most common stressors impacting water quality are eutrophication (7), increased water temperatures (7), and ocean acidification (4) (Table 5). Common metrics used to measure these stressors include water quality, organism responses, habitat distribution, and species composition (

Table *7*).

Water quality can change very rapidly in an estuary – up to multiple times a day – as water flushes with the tides and riverine flow. Studies showed water quality changes resulting from changes in pollution levels to occur almost immediately to within a few months (e.g. Zeldis et al., 2020). The exception to this is estuaries that are starved of upstream sources of freshwater due to drought conditions or dams, or have sandbars that prevent tidal flow (e.g. Adams et al., 2020). Overall changes to temperature and acidity due to climate change were witnessed as progressive change over 1 or more years within the Salish Sea, British Columbia and Arauco Gulf, Chile (Bednaršek et al., 2020; Osma et al., 2020).

1. Stressor category: water quality

Anthropogenic nutrient enhancement, referred to as eutrophication, is often due to pollution from agricultural fertilizer inputs into freshwater that is then transported to the estuary, and direct pollution from human waste in coastal communities (Detenbeck et al., 2019; Greene et al., 2015). Eutrophication can lead to increased biomass of small photoautotrophs such as filamentous algae, cyanobacteria, phytoplankton, and others that thrive on increased levels of nutrients, such as nitrogen and phosphorus, in the aquatic system. These organisms compete for access to light with other aquatic primary producers such as seagrass and macroalgae that form important habitat in the estuary, (Adams et al., 2020; Detenbeck et al., 2019). Eutrophication can also lead to hypoxia i.e., zones with limiting levels of oxygen (Adams et al., 2020) and acidification (Bednarsek et al., 2020). This occurs when harmful blooms of the small photoautotrophs described above decompose after die-off, free dissolved oxygen is consumed and the release of carbon dioxide into the water results in acidification.

Most estuaries in the contiguous United States have experienced an increase in point-source nitrogen loads due to ongoing agricultural activity and an increase in wastewater and urban runoff (Detenbeck et al., 2019). However, water quality can recover from pollution very rapidly (within a quarter year) once pollution stops (e.g. Barr et al., 2020; Zeldis et al., 2020). Therefore, water quality is naturally resilient because removing ongoing pollution sources can have a rapid positive impact on water quality.

Ocean acidification is caused by additional CO_2 dissolved in the water, mostly from the atmosphere, which reduces the pH of the water. The most common studies of acidification in estuaries reviewed its negative impact on shell formation and early juvenile life stages for shelled species like bivalves and crustaceans (Bednaršek et al., 2020; Boulais et al., 2017; Fitzer et al., 2019; Pereira et al., 2015; Stapp et al., 2017). Conversely, phytoplankton appear to be resilient to changing pH conditions in estuaries (Osma et al., 2020).

Bednaršek et al. (2020) showed that plants (and macroalgal life to a smaller extent) in estuaries are directly related to the state of acidification: as CO_2 is assimilated by plants during photosynthesis, pH increases thus reducing acidification. Their study found that darker, deeper waters without plant life had higher levels of acidity. In the short term, eutrophic photoautotrophs such as plankton, filamentous algae and cyanobacteria create the same effect by consuming CO_2 and increasing the pH; however, they have short lifespans, and when they die, they releases the CO_2 back into the water thereby increasing the acidity again (Bednaršek et al., 2020). Plants from habitats such as salt marshes and seagrass meadows can sequester the CO_2 in dead material, removing it from the aquatic zone and reducing the likelihood of acidic water conditions (Alldred et al., 2020; Boudouresque et al., 2016); organisms that thrive in eutrophic conditions are unable to accomplish this. Therefore, non-eutrophic shallow estuaries with long-term plant life are most likely to be resilient to the acidification of local estuarine waters.

Morphology

In this context, the morphology of the estuary refers to the spatial profile of the estuary, including, but not limited to

- size and form;
- features of interfaces between the estuary center and river, land, habitats, and open ocean;
- tidal prism; and
- bathymetry.

The morphology of the estuary provides a setting for the establishment and maintenance of ecological processes, habitats, and biota they support. Morphology plays a part in determining protection from external influences through land and habitat placement in a way that can absorb and dissipate potentially harmful events (e.g., storms and currents). Resilience of morphology in this context refers to the ability to establish and maintain a formation that supports and protects the overarching ecological function within the estuary in the face of stressors. According to the literature, the most common stressors impacting morphology fall under the category coastal modification (10 out of a total of 18 articles reviewing morphology), including land reclamation (3), sea-level rise (3), and water temperature increase (3) (Table 5). Common metrics used to measure the impacts of each stressor include habitat distribution, sediment fluxes, organism responses, elevation, water quality, and species composition (

Table *7*).

On a temporal scale, morphological changes can occur over a variety of timelines. Changes due to intense storm surges and/or anthropogenic impact such as land reclamation can happen very quickly, within a few days, depending on the event (Bennett et al., 2020). Processes causing ongoing modification such as accretion (Oosterlee et al., 2018), sea level rise (Leuven et al., 2019)., and complexification (Elmilady et al., 2020) can take 10 to 100 years or longer before having significant impact on the structures supporting ecosystems.

1. Stressor category: coastal modification

Coastal modification is linked directly to estuary morphology through anthropogenic changes to the structural components of the estuary. For instance, hardened coastal structures such as dykes and jetties used for navigation and coastal land defense change the structure of the estuary and have been shown to be linked to an increase in the shear stress (or parallel force threatening the vertical estuarine structures) of tidal flow (Khangaonkar et al., 2017). This increase can threaten the built structures as well as the landforms they intend to protect. The natural solution of restoring tidal flow to blocked areas was demonstrated to be more likely to provide long-term structural resilience to existing landforms than hardened coastal structures (Khangaonkar et al., 2017).

Land reclamation is a form of modification where salt marshes and mudflats are drained and claimed as land to be used for human activity such as livestock grazing and arable use. Grazing and mowing have been shown to decrease shear strength, making the reclaimed land more susceptible to erosive forces (Bennett et al., 2020). While reclaimed land can be restored to the estuary through breaching tidal barriers, the structural complexity does not re-establish immediately (Brooks et al., 2015). Engineered complexity in restored marshes such as artificially excavated watercourses were shown to support structural resilience through increased shear strength (Brooks et al., 2015).

2. Stressor category: hydrological changes

Hydrological changes are linked to estuary morphology through ongoing sedimentation. A continuous flow of sediment transport from riverine and marine sources provides structure and material to build the surface and sub-surface habitat structures that buffer the shoreline, protecting it from sea-level rise (Elmilady et al., 2020; Palinkas et al., 2019). Estuaries with mature stages of infill are at greater risk of experiencing the impacts of sea-level rise because there will be insufficient terrestrial-sourced sediment transport to allow accretion to keep pace with predicted increased sea-levels (Rogers & Woodroffe, 2016). Sediment transport to estuaries is also threatened by sea-level rise because sediment transport requires sufficient riverine flow velocity, which is reduced under higher sea levels (Melo et al., 2020).

Sedimentation changes are also caused by modification upstream of the estuary and can also be linked to morphology. Upstream flow changes from damming rivers for municipal supply and hydro-electricity cause sediment to get trapped behind the dam (Palinkas et al., 2019). When the sediment is released through flooding events, it gets trapped in suspension due to higher velocity, preventing sediment accumulation in the estuary, and therefore preventing the natural development of structural components within the estuary (Palinkas et al., 2019).

The size of the estuary, ratio of salt marshes to shoreline, and tidal amplitude (vertical range between flood and ebb levels) all have implications for resilience to sea-level rise. In a study that simulated sea-level rise against a variety of different morphologies, it was found that estuary size and salt marsh presence were indicators of sensitivity to sea-level rise (Leuven et al., 2019). Larger estuaries (from measurements that ranged between 0.1 km^2 and 1000 km^2) with high tidal amplitude are less likely to experience increased tidal amplitude due to sea-level rise and therefore, tend to be more resilient to its impacts than smaller estuaries with low tidal amplitude (Leuven et al., 2019). Large estuaries combined with extensive salt marshes support resilience of the estuary-terrestrial shoreline to increased pressure from sea-level rise, as the salt marshes can absorb and attenuate tidal flow more effectively than if they were not present (Leuven et al., 2019). Large size combined with existing high tidal amplitude and a sufficient ratio of marshes can thus be indicators of morphological resilience to sea-level rise.

A wide estuary mouth is associated with a large intertidal zone where salt marshes can establish, but when simulating the impacts of widening an estuary mouth, the tidal amplitude was increased as a result (Leuven et al., 2019). Increased tidal amplitude can increase inundation times at high tides, which, combined with sea-level rise can prevent the successful establishment of salt marshes (Ganju et al., 2020; Leuven et al., 2019). However, marshes with wide shallow channels and submerged vegetation were shown to decrease tidal velocity, thereby protecting shorelines and other marshes (Fleri et al., 2019). Wide shallow channels are also more proficient at releasing suspended sediment that can then accrete in other parts of the estuary, such as other salt marshes in the intertidal zone (Fleri et al., 2019). This shows that while a wider mouth into the estuary from the ocean interface can be more impacted by sea-level rise than sheltered estuary types, an intertidal zone with extensive marshes with wide channels can mitigate those impacts.

Change to flow levels was also an important pressure interacting with water quality, mainly with regards to dissolved oxygen levels. One study found that dams preventing river flow reduced the amount of dissolved oxygen in the water to the point where it was no longer able to sustain aquatic life downstream of the dam (Gordon et al., 2015). Changes in freshwater flow also change the salinity profile of the estuary, impacting the stratification of the water column and its associated biological assemblages (e.g. Karlsson et al., 2018; Windham et al., 2019).

Food Webs

Estuarine food webs refer to the energy pathways throughout the estuary biome, which defines how energy is transferred between biotic factors throughout the estuary. Studies focused on estuarine food webs provided insight into the factors contributing to the ecological functional integrity of the system, and important metrics of resilience. The quantity of energy pathways through the food web can indicate functional redundancy (number of species or estuarine features that perform similar roles) within the ecosystem, which is an important feature of resilience (Bueno-Pardo et al., 2018; Pelletier et al., 2020). Resilience is indicated if the loss of one energy pathway can easily be replaced by others making the system less dependent on any one energy pathway (Pelletier et al., 2020).

Biomass within the estuarine food web is dominated by primary producers and detritus (e.g. Bueno-Pardo et al., 2018). The dominant primary producers in a temperate system are salt marsh halophytes and seagrass with supplementary presence of phytoplankton and microphytobenthos (Bueno-Pardo et al., 2018). Detritus is mainly in the form of decomposed plant matter, which is consumed through multiple channels including suspension feeders and deposit feeders (Bueno-Pardo et al., 2018). Different components of the food web change and recover in response to stressors and restoration with different timelines, depending on the organisms and the niche they fill.

The whole food web shifts in tandem with the organisms that have the most influence on energy channels, and resilience is likely to depend upon the trajectories of the keystone species. Keystone, in this context, refers to species that have the greatest interactive effects due to the abundance of interactions they have with other species within the food web (Jordán, 2009). The keystone index was a tool used within an ecosystem simulation software program to calibrate the total number of connections across energy pathways within the ecosystem. The functional groups of organisms with the highest number of connections were considered “keystone”. Keystone indices for one estuary suggests that piscivorous birds, detritivorous fish, and zooplankton have the highest number of pathways to other biological life forms throughout the food web, making them critical to the resilience of all biological assemblages through the estuary (Bueno-Pardo et al., 2018).

There were 12 articles that studied food webs as an estuary feature (

Table 3). Timelines for food web changes are highly dependent on the nature of the stressor, which organisms are responding to the stressor, and their trophic level within the food web. Species with more resilience due to greater abundance and functional redundancy such as r-strategists, are likely to withstand pressure more easily, thus not quickly impacting the rest of the food web (Borja et al., 2012). Literature on the stressors impacting food webs was generally evenly distributed (Table 5). The most common category of stressors was hydrological changes (4 of 10). Biological changes were also a prominent stressor identified in three studies. The most common metric for articles that studied food webs was species composition (e.g. Bueno-Pardo et al., 2018; Gao et al., 2020; Mittermayr et al., 2014; Schaffner, 2010; Woo et al., 2019). Timelines for processes representing stressors and resilience varied based on the stressor type, the presence of cumulative stressors, and the portion of the food web being assessed. Timing ranged from 1.5 years for macrobenthic diversity recovery to 10 + years for witnessing trends in losses of production, biomass, and food web diversity; and for restoration of food web stability while sustaining cumulative effects such as eutrophication, floods, and droughts.

1. Stressor category: hydrological changes

Hydrological changes impacting the food web included flooding events triggered by increased precipitation, increased water temperatures, upstream modification, and drought. Changes to hydrology discussed here are connected to uncharacteristic events, different from the normal hydrological regime for the watershed that drains into the estuary.

Abnormally heavy precipitation events were shown to temporarily decrease macrobenthos density, particularly in detritovores (Cardoso et al., 2008). However, these species were able to steadily recover over the course of two years following the heavy precipitation events. Increased freshwater flows due to release from upstream dams have been shown to negatively impact mysid and other benthic invertebrate prey species abundance, but positively impact species that favour freshwater, with nekton in general showing strong resilience (Gonzalez-Ortegon et al., 2012). Increased freshwater flows therefore alter the estuarine food web in different ways. Resilience to increased pressure from freshwater inputs is indicated by the diversity of euryhaline species.

Water temperature increase was a commonly studied stressor, caused by an increase in global atmospheric temperatures due to climate change (e.g. Garthwin et al., 2014). In the past 100 years, global sea surface temperatures have increased by 0.74°C and are expected to increase a further 2-3°C by 2050 (Garthwin et al., 2014). Increased water temperatures have been connected to reduced diversity and density of phytoplankton, micro- and mesozooplankton, which reduces the number of energy pathways through the system (Horn et al., 2020) and that ultimately reduces resilience by limiting functional redundancy within the system.

Warmer water temperatures have also been shown to cause changes in physiological and behavioural traits of estuarine organisms, including changes in bivalve suspension feeding behaviour (Graiff et al., 2015), increased seahorse metabolism (Aurelio et al., 2013), increased clam burrowing behaviour (Clements et al., 2017), and changes in oyster filtration rates (Eymann et al., 2020). Warmer temperatures are also linked to decreased secondary and primary production for many biotic components of the estuary, including loss of zooplankton biomass (Horn et al., 2020), loss of seagrass density (Kim et al., 2020), loss of oyster biomass (McFarland & Hare, 2018), and general loss of estuarine biotic factors (Scapin et al., 2018). Temperate organisms tend to have a higher tolerance to a larger range of temperatures than other organisms (Froelich et al., 2016).

Increased water temperature is also connected to acidification. Waters with increased temperature are also more likely to have higher acidity levels (Graiff et al., 2016; Evans et al., 2019). Therefore, estuarine organisms must respond to both stressors at the same time as temperature and acidification can have interactive effects. Unfortunately, for many organisms such as the copepod *Eurytemora affinis*, an increase in temperature has been shown to also increase the organism's vulnerability to ocean acidification, decreasing its resilience (Karlsson et al., 2018). Resilience for organisms impacted by both increased water temperature and acidification will require locations of refuge within the estuary to support their resilience.

Upstream modification through hydrological dams can also act as a stressor to food webs. In one 12 year study, it was found that the presence of an upstream dam was related to decreased mysid abundance, which are important contributors to secondary production in food webs (Gonzalez-Ortegon et al., 2012).

Finally, drought conditions can increase the salinity levels of the estuary, shifting the entire food web to favour saline-tolerant species (James et al., 2017). Drought is also connected with loss of bird migration habitat, and therefore potential loss of avian influence on estuaries (Galbraith et al., 2014). As increased precipitation events, increased water temperature, and increased drought events continue to change the conditions of an estuary more quickly and dramatically due to climate change, there will be less time for the estuarine food web to recover from each event, thereby reducing its resilience.

2. Stressor category: biological changes

Biological changes to food webs discovered in this review include aquaculture, diversity loss, and invasive species. One study showed that increasing the biomass of oysters via aquaculture had a negative impact on species richness and evenness throughout the entire estuary (Gao et al., 2020). The diversity of energy pathways throughout the estuary were also reduced as a result of the introduced species (Gao et al., 2020). Food web resilience can be indicated by dietary plasticity in the face of diversity loss, particularly within omnivore populations to allow a similar number of energy pathways to continue with fewer species present (Mittermayr et al., 2014).

3. Stressor category: coastal modification

Modification to coastal habitat is also a stressor to food web assemblages. One study found that macrobenthic communities impacted by dredging recovered at different rates depending on the severity of the disturbance, with depth of sedimentation events being a determinant factor in their recovery (Schaffner, 2010). Macrobenthic communities on dredged sediments recovered to become similar to a control group within approximately 1.5 years of disturbance (Schaffner, 2010), suggesting that food web resilience is supported by removing coastal modifying stressors or through establishing new habitat that can serve as a setting for new food webs to develop.

Finally, Woo et al. (2019) linked dietary plasticity for upper trophic levels such as salmonids to a diverse habitat patch mosaic, which allowed for different prey varieties to be available for migratory species within the estuary. In this case, dietary plasticity within the higher trophic levels was connected to a diversity of available prey resources and a diversity of habitats that support those resources. Food web resilience can therefore be associated with prevention of any coastal modification that simplifies the patchwork of habitats within the estuary landscape.

Scale: Habitat Features

Salt Marshes

Salt marshes are intertidal marshlands where halophytes thrive under the influence of saline and brackish conditions. Salt marshes often take the form of small coastal islands or coastal lowlands with extensive grasses atop a thick layer of mud, roots, and peat which sits on top of a range of substrates. Marshes are inundated during high tide but depend on exposure to sunlight and air during low tide for survival. Salt marshes provide habitat for a variety of estuarine species, including providing refuge for juvenile stages of migratory fish, and for birds at a variety of life stages during their migrations. Salt marshes also protect coastlines from the erosive forces of tides and currents by providing a physical barrier between open water and land and sequester carbon by absorbing atmospheric carbon and transferring it to its root system below the sediment. Salt marshes can be degraded quickly through coastal modification (as quickly as < one day) and restoring or constructing salt marshes can take up to five years for it to develop a healthy canopy, and up to 20 years to develop soil quality and a mature biodiversity of species.

Salt marshes were the most heavily researched estuarine feature within the literature reviewed, with 40 articles that focused on salt marshes (

Table 3). The most-studied stressors to salt marshes within the literature were sea-level rise (12), land reclamation (9), and invasive species (7) (Table 5). Common metrics used to measure the effects of these dominant stressors are organism responses, habitat distribution, elevation, and sediment fluxes (

Table *7*). Coastal modification was the most studied stressor category (23). Other stressor categories in the literature were hydrological changes (13) and biological changes (8).

1. Stressor category: coastal modification

Every stressor within the coastal modification category was represented at least once in the salt marsh literature (Table 5). The main stressors represented in this category were land reclamation (9), shoreline realignment (3), and grazing/mowing (3). Trends in land reclamation show that globally, much of the original temperate salt marshes have been converted to non-estuarine features such as agricultural use, urban areas, and open space (Baily & Pearson, 2007; Stein et al., 2020; Xie et al., 2011). This human intervention has caused widespread loss of salt marsh area.

Salt marshes were the only habitat feature to be impacted by grazing and mowing, as salt marshes have been used for livestock grazing, and mowing has also been applied to some marshes (Bennett et al., 2020; Brooks et al., 2015; Chen et al., 2020). While both practices have been shown to support overall halophyte diversity (Chen et al., 2020), this practice has also led to reduced shear strength (strength against parallel force, for salt marshes this would be tidal force that could cause a shearing effect on the soil structures, reducing their lateral extent and overall stability), decreasing resilience to erosive storm events (Bennett et al., 2020).

Shoreline realignment to support built coastlines was identified as a contributing factor to overall loss of salt marsh area across the United Kingdom and Tasmania (Baily & Pearson, 2007; Prahalad, 2014). It is also one of the contributors to reduced resilience to storm events (e.g. Bennett et al., 2020). The simplification and hardening of coastal structures associated with shoreline realignment is associated with vulnerability in the studies completed across the U.K. and Tasmania, and so survival of salt marshes and resilience of shorelines can therefore be associated with higher degrees of complexity.

While coastal modification is a significant stressor for salt marshes, it has also been used to the benefit of salt marshes through restoration and ecological rehabilitation programs. Ecological resilience of salt marshes within estuaries can be inferred by the success of restored sites to offer the same ecological values as reference sites. An assessment of ecosystem integrity of restored marshes compared to established reference marshes was applied across a variety of sites in Texas (restoration methods not specified) (Staszak & Armitage, 2013). The authors found that generally, restored sites had slightly lower ecosystem integrity than reference sites. The main differences in ecological integrity were attributed to lower epifaunal density within the salt marsh, lower vegetation diversity, and lower soil stability.

The overall structural stability of constructed salt marshes is generally vulnerable at early stages due to a lack of below-ground plant matter. In a study of constructed salt marshes at different phases of development, Alldred et al., (2020) found that older constructed salt marshes tended to have more stable soils. In this study, higher levels of below-ground plant matter via root systems allowed for more oxygen to move through the sediment and helps to stabilize sediment by preventing acidification through H_2S build-up (Alldred et al., 2020).

Managed realignment is a technique used to restore salt marshes by breaching previously erected barriers and re-establishing tidal flow (Spencer et al., 2008). Spencer et al. (2008) studied sediment layers eight years after one managed realignment event and showed that 6-8 cm of sediment was accreted on top of the area after breaching. There was poor water and nutrient transfer between the new layers of sediment and the previous landform, and new marsh roots could not reasonably permeate the layer from the previous landform (Spencer et al., 2008). Managed realignment practices could therefore benefit from additional intervention to improve permeability in the original layer of soil.

Marshes that are constructed or realigned in conjunction with or behind existing sand spits, stone sills, or other protective structures tend to establish structural integrity and resilience rapidly (Alldred et al., 2020; Currin et al., 2008; Schuerch et al., 2018). The provision of a barrier between the marsh and the ocean through trapping sediment allows for successive mutual reinforcement of both structures due to sediment movement between the structures, rather than away from them (Schuerch et al., 2018).

Other significant features contributing to resilience of salt marshes were drainage networks and elevation diversity, which can be accomplished through a network of sinuous creeks and channels (Brooks et al., 2015). Drainage networks help to prevent waterlogging in marshes (Brooks et al., 2015; Taylor et al., 2020). Elevation diversity supports diversity in marsh plant communities as species vary across salinity levels and tidal inundation levels (Brooks et al., 2015). Elevation diversity was also shown to support the structural stability of the marshes as was demonstrated through shear strength tests (Brooks et al., 2015). Creating and restoring structural complexity within marshes is therefore a key component of their resilience.

2. Stressor category: hydrology changes

Sea-level rise was the most-researched stressor in the hydrology change category (Table 5); this stressor will increase tidal inundation time frames for all marshes, causing a variety of impacts. First, it increases sediment H_2S content that increases the acidity of the soil, making it less stable and less able to support above-ground plant matter (Alldred et al., 2020). Plant root density can support resilience to sea-level rise by helping to transfer oxygen through the sediment, preventing H_2S-caused acidification while also supporting soil stability (Alldred et al., 2020).

Another impact of sea-level rise is decreased marsh area available for birds to nest, forage, and seek refuge. For example, the salt marsh sparrow nests in salt marsh vegetation, and nests must be at a high enough elevation to not to get flooded during high tides, but low enough to have adequate canopy to prevent predation (Benvenuti et al., 2018). Sea-level rise will cause a vertical squeeze on viable bird habitat area. A habitat mapping exercise found that vegetation density, distance to anthropogenic disturbance, and elevation are indicators of resilience for a salt marsh to provide adequate bird habitat (Ivajnšič et al., 2016).

Other studies have linked elevation capital (marsh height) to marsh resilience due to its capacity to help marshes avoid increased periods of tidal inundation (Cole Ekberg et al., 2017; Ganju et al., 2020; Liu et al., 2020). Capacity for ongoing sediment accretion to support elevation capital will be important to support marsh resilience to sea-level rise (Raw et al., 2020).

3. Stressor category: biological changes

The literature identifies invasive species as a significant stressor to salt marshes (Table 5). Due to the ability of some invasive marsh plants to colonize new areas quickly, much of the growth in salt marshes that have previously been degraded is due to the influx of colonizer species to non-native areas, including *Spartina spp.* And *Phragmites spp.*, which have spread rapidly from their native areas across the globe (Kennedy et al., 2018; Mackenzie et al., 2015). While invasive species have contributed to areas that have shown increases in marshland area, colonization of invasive plants has made it difficult for already threatened native species to re-establish and is associated with low levels of diversity and ecological integrity (Kennedy et al., 2018; Li et al., 2019).

Similarly, species that are native to salt marshes can become harmful under conditions where salt marshes are already vulnerable. Pettengill et al. (2018) showed that normal salt marsh inhabitants can further degrade salt marshes that are already threatened. In this study, the crab species *Sesarma reticulatum*, which is endemic to the region of the study in Cape Cod, MA, and Narragansett Bay, RI, caused damage when grazing and burrowing on marsh sites that were declining due to erosion and loss of marsh grasses, but healthy sites were not impacted by this species, showing that native species can become particularly harmful as a cumulative effect of additional pressures.

Additionally, as global temperatures increase, temperate marsh communities that exist near the sub-tropical border are starting to be replaced by sub-tropical plant varieties (Osland et al., 2019). Ongoing warming will likely result in a long-term poleward shift of temperate species and replacement by sub-tropical species at the equatorward edge of the temperate biome.

4. Stressor category: water quality

Another threat that impacts resilience of salt marshes is pollution, mainly from industrial sources. Schutte et al. (2020) reviewed the impact of an oil spill on salt marsh performance, and found those marshes impacted by an oil spill showed a similar capacity to cycle nitrogen as did marshes with lower elevation and a longer tidal inundation time frame. As discussed in the hydrological changes section, increased tidal inundation across salt marshes is associated with degraded ecological integrity, including reduction of the nitrogen filtration capacity of salt marshes that provides resilience against eutrophication (Schutte et al., 2020).

Seagrass

Seagrass describes a collection of grasses that thrive in subtidal estuarine waters. Seagrass forms underwater meadows or beds through both clonal reproductive methods and seed dispersion, depending on the species. Seagrass provides important habitat for many estuarine species and influences dampening and dispersion of strong waves and currents, water quality enhancement through removal of CO_2 during photosynthesis, and sediment trapping. Many studies found that seagrass meadows are associated with increased overall diversity of species

(Bordalo et al., 2011; Cardoso et al., 2008; Carroll et al., 2019; Dabrowska et al., 2016; Dolbeth et al., 2007; Trevathan-Tackett et al., 2020). Seagrass meadows, like salt marshes, can be rapidly impacted (< two months) by reduction of water quality (e.g. Gladstone-Gallagher et al., 2018; Kim et al., 2020; Plaisted et al., 2020), but take longer to become re-established after disturbance (> six years) (e.g. Chust et al., 2013; Verdelhos et al., 2014). The most frequently studied stressor to seagrass meadows in the literature was eutrophication (7) while the stressor categories most represented were water quality (11) and hydrology changes (10) (Table 5). Common metrics used to understand these impacts were organism response/survival, ecological diversity, habitat distribution, light attenuation, restoration/recovery, and plant density (

Table *7*).

1. Stressor category: water quality threats

Seagrass meadows require adequate water transparency to allow light penetration to occur (Biber et al., 2008; Bordalo et al., 2011; Kim et al., 2020; Wong et al., 2020); they need a minimum of 22% irradiance to survive, but higher levels are more suitable (Biber et al., 2008). Turbidity and increased amounts of phytoplankton cause loss of irradiance contributing to overall seagrass loss (Biber et al., 2008). Reduced light availability is associated with lower levels of seagrass production, reduced shoot numbers, and reduced numbers of leaves per shoot (Kim et al., 2020; Plaisted et al., 2020). Any impact to water quality that reduces light access, such as turbidity and eutrophication, is therefore a significant stressor to seagrass.

In addition to the impact of light availability, seagrass meadows are also threatened by the increased amount of nitrogen in the water associated with eutrophication. One study found that increased nitrogen levels were correlated with low seagrass cover and low biomass

(Gladstone-Gallagher et al., 2018). The same study also found that resilience to the impact of increased nitrogen was associated with macrofaunal density and diversity, suggesting that the biological communities supported by seagrass meadows contribute to their resilience (Gladstone-Gallagher et al., 2018).

2. Stressor category: hydrology changes

Within the hydrology changes category, the most frequently studied stressor was water temperature increase (Table 5). Scapin et al. (2018) found that warmer temperatures were associated with lower seagrass cover and lower overall seagrass canopy. There was only one study that did not find a significant difference in growth rates between sites at warmer temperatures than others (Garthwin et al., 2014). One way in which warmer temperatures can impact seagrass is through reduced ability to defend against fouling bacteria (Guan et al., 2020). Seagrass meadow resilience to water temperature increase is improved by light availability; in one experiment, it was shown that plots of seagrass with full light access were more resilient to the impacts of warming temperatures than those with shaded areas (Wong et al., 2020). However, the combined impact of shading and increased temperatures can have detrimental effects (Kim et al., 2020).

Another hydrological stressor studied was increased freshwater flows and precipitation. Recovery of seagrass meadows in a restored area was shown to be negatively affected by extreme weather events with high flows and precipitation levels (Verdelhos et al., 2014). Flooding events also impacted the ability of seagrass to provide viable habitat to macrobenthic organisms. Two studies noted that macrobenthic organism abundance and diversity was reduced following flooding events (Bordalo et al., 2011; Cardoso et al., 2008); however, removing eutrophic impacts allowed seagrass beds in the Mondego Estuary, Portugal, to continue a trajectory of recovery over 10+ years despite increased temperatures and extreme freshwater flow events (Bordalo et al., 2011; Cardoso et al., 2008). The interactive relationships between seagrass and its macrobenthic community can mitigate against the impacts of hydrological changes when eutrophic impacts are not present. Greater resilience to flooding, drought, and increased temperature is therefore conferred on seagrass meadows by reduced eutrophication.

3. Stressor category: biological changes

There were four studies that looked at the impact of biological changes, such as diversity loss and invasive species on seagrass meadows and their ecosystems. Seagrass is globally vulnerable to seagrass wasting disease, a condition caused by the protist *Labyrinthula spp.*, which causes black lesions on its surface and can be detrimental to entire seagrass beds (Martin et al., 2016). A global study tested the pathogenicity of the protist and found pathogenicity to be high throughout all samples, with differing abilities to cross-infect hosts across seagrass species from different regions globally (Martin et al., 2016). Regional and climactic differences appear to be as influential if not more influential than genetic diversity in influencing the host capacity to resist damage from *Labyrinthula* strains (Martin et al., 2016), suggesting that the variability in hydraulic regimes that occurs in estuaries may support seagrass resilience to wasting disease.

Seagrass itself is generally not grazed upon by other organisms in temperate estuaries (Mittermayr et al., 2014). However, Dos Santos et al. (2013) found seagrass to be vulnerable to grazing pressures of the black swan. In their study of the black swan's influence on seagrass meadows, once high intensity grazing pressure stopped, seagrass cover, but not biomass, recovered completely within a year. After being subjected to low intensity grazing, both seagrass biomass and cover recovered within a year (Dos Santos et al., 2013), suggesting a natural resilience to grazing pressures, provided the stressor is removed or depending on the intensity of the grazing.

Another potential biological stressor is predation of seeds, which could impact seagrass recruitment and therefore expansion of existing seagrass meadows. Seeds can be predated upon by a variety of organisms such as crustaceans, echinoderms, and fish (Carroll et al., 2019). Seed predation is most likely to occur within the center of healthy seagrass beds because the existing seagrass provides protection to organisms seeking refuge from higher trophic-level predators (Carroll et al., 2019). Seeds on nearby unvegetated sandy areas are therefore more likely to establish, showing natural capacity for seagrass meadows to expand into new territory and establish resiliency to predatory behaviour of resident organisms (Carroll et al., 2019). Previously established seagrass meadows are also naturally resilient to herbivory, as seagrass is not a preferred carbon source for many of the primary consumers within the seagrass meadow food web (Garthwin et al., 2014; Mittermayr et al., 2014).

The ability of seagrass to naturally establish and colonize unvegetated areas lends to its resilience to localized stressors. Seed-based reproduction allows for higher genetic diversity than self-cloning, supporting higher levels of resilience to environmental perturbations, but meadow growth tends to be slower than clonal reproduction (Bekkby et al., 2020). Genetic diversity is also associated with higher levels of physical connectivity between patches of seagrass beds. However, connectivity is typically limited to the area within an estuary; thus, there is low connectivity between estuaries (Bekkby et al., 2020; Chust et al., 2013). Genetic diversity was also shown to support the resilience of seagrass beds to eutrophic pressures (Plaisted et al., 2020).

Clonal reproductive methods allow seagrass to re-establish quickly after disturbance (Bekkby et al., 2020). However, clonal populations are more likely to be isolated and have lower genetic diversity (Bekkby et al., 2020; Chefaoui et al., 2016). The lack of genetic diversity makes entire, isolated seagrass meadows more vulnerable to external perturbations (Bekkby et al., 2020) because genetic diversity within seagrass is highly correlated with phenotypic diversity, which allows certain strains to withstand stress better than others (Bekkby et al., 2020; Chust et al., 2013; Evans et al., 2016)

Mudflats

Mudflats are shallow, intertidal platforms mainly consisting of soft sediment that has been deposited from terrestrial sources through freshwater exchange and which act as important habitat for a variety of microorganisms, primary producers (microphytobenthos), invertebrates, and larvae that support higher trophic levels throughout the food web (Bueno-Pardo et al., 2018; Woo et al., 2019). The biological assemblages that inhabit mudflats are naturally resilient to environmental changes including dramatic flooding and sedimentation events, as well as periods of desiccation (Cardoso et al., 2008; Daggers et al., 2020; Gerwing et al., 2016; McKew et al., 2011), as displayed through rapid recovery times of less than 1 year for most soft sediment inhabitants (Gerwing et al., 2016).

The most frequently studied stressors to mudflats were pollution (3), eutrophication (3), freshwater flows/precipitation (2), and upstream modification (2; Table 5). Common metrics used to understand these stressors included water quality, diversity, and organism responses (

Table 7). However, stressors were relatively evenly distributed throughout the categories, with water quality and hydrological changes being the most prominent categories (7 out of 22 each; Table 5).

1. Stressor category: water quality

Mudflats have been shown to be impacted more heavily than other estuarine habitats by pollution (Dai et al., 2013). Soft sediments of mudflats have been shown to absorb and retain organic matter, nitrogen, and carbon when near pollution sources (Zeldis et al., 2020). Biomass within mudflats has shown declines associated with pollution and eutrophication (Cardoso et al., 2008). Removal of pollution sources and eutrophication has been associated with rapid recovery of some organisms while overall species richness and evenness can increase steadily over the course of 10 years (Cardoso et al., 2008).

Mudflats are also vulnerable to acidification. Organisms like clams that burrow in mudflats can be particularly vulnerable to acidification, especially when combined with increased sea-surface temperatures (e.g. Clements et al., 2017). Increased temperatures can lead to increased burrowing depth into sediment that is acidic and therefore harmful to the carbonate shells of burrowing bivalves (Clements et al., 2017).

2. Stressor category: hydrological changes

The most frequently studied hydrological stressors to mudflats were upstream modifications impacting freshwater flows, and overall variability in freshwater flows. The impact of changes to freshwater flows is variable depending on how the change presents itself. de Juan and Hewitt (2014) demonstrated that some variability in salinity levels is beneficial for mudflats and their biological assemblages. The diversity of benthic organisms that inhabit mudflats is enhanced by variability of wave exposure, mixing of sand and mud, and changing levels of salinity and temperature (de Juan & Hewitt, 2014). A certain amount of variability in the hydrological environment should therefore be maintained to support diversity, and thus resilience, of mudflat communities.

However, there is a threshold for how much variability living organisms within mudflats can withstand. Increased variability in freshwater flows is linked to loss of clam populations. Windham et al. (2019) demonstrated that reduced freshwater flow associated with increased salinity caused by drought conditions was linked to reduced population size of *Rangia cuneata* clam populations that are endemic to Galveston Bay, Texas.

Increased flow variability due to the presence of operational dams upstream of an estuary is also linked to negative impacts from changes in typical nutrient and sediment exchange between rivers and estuary mudflats (Palinkas et al., 2019). Measurements of sediment and nutrient changes related to dams located upstream of the Chesapeake Bay, Virginia, showed that high variability of freshwater flows into the estuary limited sediment and nutrient transport that would have otherwise contributed to the estuarine mudflats and their biological assemblages (Palinkas et al., 2019).

Given that increased variability in freshwater flows can be harmful to mudflat communities, the removal of upstream modifications was hypothesized to negatively alter estuarine mudflat communities through a single event with a dramatic change in freshwater flows. However, Gerwing et al. (2016) showed that removing spillway gates along a watercourse did not negatively impact a mudflat community in the estuary. With the complete release of spillway gates from the previously modified Petitcodiac River, New Brunswick (Canada), the immediate change in freshwater discharge showed no significant impact on mudflat faunal communities, demonstrating that mudflat organisms can be naturally very resilient to one event involving dramatically increased freshwater flows (Gerwing et al., 2016). This demonstrates that extreme changes in freshwater flows can also have a neutral effect on mudflat communities when limited to one event. In summary, there is variability in the effects on mudflat communities of changes in freshwater flows depending on the severity and frequency of the changes.

3. Stressor category: sediment fluxes

Bird presence on mudflats is a factor that contributes to estuary resilience. Bird foraging on mudflats helps to disrupt the accumulation of biofilms (Booty et al., 2020), which can prevent movement of sediment and nutrients, particularly nitrogen, through the estuarine system (Booty et al., 2020). This disruption of biofilm supported by bird foraging activity in mudflats indicates that functional integrity within mudflats is enhanced by bird presence. Reclaiming mud flat area has also been shown to enhance bird populations. Li et al. (2019) found that the wintering population of *Grus japonensis* – the red-crowned crane – increased substantially in response to increased reclamation of mudflat habitats in estuaries.

Sand Flats and Sandy Shoals

Sand flats and sandy shoals are most notably identified in the literature as important habitat for bivalves, as well as benthic organisms. The combination of sand flats and seagrass habitat provide optimal conditions for some bivalves due to the combined habitats' ability to support multiple life phases (Verdelhos et al., 2014). Bivalve presence is important for mediating nutrient fluxes in sand flat sediments (Magni et al., 2014). Sand flats are host to similar benthic species types as mud flats. Isopods contribute to secondary production within sand flat ecosystems and provide important energy pathways through the estuarine food web (Bordalo et al., 2011).

Sand flat ecosystems can change very quickly, within one to two days or less than a few months, in congruence with extreme weather and sedimentation events (e.g. Anderson et al., 2019; Bordalo et al., 2011; Verdelhos et al., 2014). The natural development and establishment of sand flats through accretion can take much longer, from two to 200 years (Elmilady et al., 2020). The most frequently studied stressor to sand flats was freshwater flows/precipitation (3) (Table 5). This stressor was commonly measured by organism responses (

Table *7*). Hydrological change was the most studied stressor category (5) followed by water quality (2), and sediment fluxes (1).

1. Stressor category: hydrological changes

Within this stressor category, freshwater flows/precipitation and drought were the two studied variables. Authors found that both drought and dramatic increases in freshwater flows were harmful to the ability of sand flats to support their inhabitants, including bivalves and isopods (Bordalo et al., 2011; Verdelhos et al., 2014). Like mudflats, Windham et al. (2019) found that decreases in clam abundance in sand flats were associated with a dramatic increase in freshwater variability.

2. Stressor category: water quality

Water quality was represented by eutrophication as a stressor. The reviewed studies concluded that eutrophic conditions were harmful to sand flat communities. Removal of eutrophic conditions resulted in increases in sand flat biota, but recovery was stalled by extreme weather events (Bordalo et al., 2011; Verdelhos et al., 2014), showing that extreme weather events can undermine restoration attempts when removing point-source stressors. However, both studies showed that post-restoration, biota did eventually increase after extreme events, so there is some natural resilience that occurs when eutrophication is removed.

3. Stressor category: sediment fluxes

Heavy sedimentation events are often associated with extreme freshwater flow events as the freshwater discharge often brings a large amount of sediment with it. This increased freshwater flow can cause deep burial of sand dwelling organisms such as cockles (Anderson et al., 2019). This study on cockles' response to burial showed that while cockles are generally able to re-orient when disoriented and resurface when buried, repeated deep burial events can cause harm to populations of cockles as they lose the energy to resurface (Anderson et al., 2019).

However, like salt marshes, sand flats and sandy shoals are made structurally resilient through normal continued accretion from regular deposits (Elmilady et al., 2020). In the case of sand flats, these deposits are often brought into the estuary through ocean currents rather than terrestrial sources (e.g. Schuerch et al., 2018). Resilience can therefore be inferred by the regularity of ongoing sedimentation rather than through extreme sedimentation events.

Oyster Reefs

Oyster reefs are features that allow for oysters and other bivalves to create a rocky or sill-like structure by fixing themselves vertically to other oyster shells below (Zhu et al., 2020). They were poorly represented in the literature with only two references that studied them as an estuary feature (McFarland & Hare, 2018; Zhu et al., 2020). Both articles studied hydrological changes (increased currents and increased water temperature), and both ran over two the course of two years, assuming the development of oyster populations would occur naturally during that time depending on whether the conditions were favourable at that location. Metrics used to measure both included restoration/recovery, organism response/survival, and currents/discharge (

Table *7*). However, neither study looked at the impact of stressors or targeted human intervention through restoration and the impact that can have on timelines for reef establishment and degradation.

1. Stressor category: hydrological changes

Constructed oyster reefs were studied for their ability to attenuate wave energy to provide coastline protection from strong currents. Zhu et al's. (2020) findings suggest that living reefs are effective at dampening wave energy, reducing their intensity. This dampening effect is useful for protecting shorelines from the erosive forces of regular currents. However, intense swell energy during high wave events was not effectively dampened by the oyster reefs (Zhu et al., 2020). Oyster reefs may therefore support resilience for the estuary and coastline through protection from erosion during regular hydrological events, but these features would benefit from having other habitat features to act as additional barriers for wave attenuation to support overall estuary resilience during more extreme events.

McFarland and Hare (2018) looked for the best location to create restored oyster reefs by measuring survival at different temperature and salinity gradients within an estuary and found that sheltered area closest to the ocean provided the best opportunity for oyster reefs to re-establish. The ability to rehabilitate oyster reefs in this context is indicated by a higher salinity level along the estuarine salinity gradient with nearby structural features to provide a buffer for re-establishment. In this example, assuming that resilience of the estuary is enhanced by the presence of oyster reefs, they can better provide resilience to the estuary when adjacent to other habitat and structural features.

Scale: Biological communities

Fish

Fish species often use estuaries as nursery and feeding grounds for juveniles between life history phases (Colombano et al., 2020). Fish can be present in estuaries intermittently during migration, but some species are present year-round (Colombano et al., 2020). Detritivorous fish were shown to be a relevant keystone functional group in a Mediterranean estuarine food web (Bueno-Pardo et al., 2018). Other functional groups of fish, such as omnivorous and piscivorous fish, were also considered important contributors to the estuarine food web (Bueno-Pardo et al., 2018). Larger, slow growing species tend to be resilient within estuaries because they have wider temperature range tolerance and lower minimum dissolved oxygen tolerance (Froehlich et al., 2016). However, these larger, slow growing varieties often are at a higher trophic level, so tend to be less resilient and more vulnerable to the impacts of fisheries due to lower rates of reproduction and development (Froehlich et al., 2016).

The most frequently studied stressors to fish included water temperature increase (4) and upstream modification (2) (Table 5). Common metrics used to measure these stressors included organism response, water quality, habitat distribution, species composition, and diversity (

Table *7*). The most dominant stressor categories were hydrological changes (7) followed by coastal modification (3). Lincoln et al. (2018) demonstrated that removal of upstream dams was associated with dramatic and short-term population increases. Timelines for changes to estuarine fish populations due to other stressors were not available in much of the literature reviewed.

1. Stressor category: hydrological changes

The most frequently studied impact of hydrological change to fish was related to an increase in water temperature, which is negatively correlated with fish presence as well as fish habitat suitability (Huber & Carlson, 2020; Scapin et al., 2018). Even though many fish varieties can survive at higher temperatures (Aurelio et al., 2013; Froehlich et al., 2016), they are likely to retreat to cooler areas if available (e.g. Huber & Carlson, 2020). A study on seahorses from the Mediterranean suggested higher metabolism and ventilation rates at water temperatures above 18^{o} C. with significant impacts to survival above 28^{o} C (Aurelio et al., 2013).

Also within the hydrological changes category were sea-level rise and drought. Sea-level rise impacts fish because it is associated with a net-loss of fish habitat such as salt marshes (Crozier et al., 2019). Drought negatively impacts fish because it is associated with increased salinity and decreased overall water quality due to lower dissolved oxygen levels and lower pH values (Huber & Carlson, 2020). Salinity increase is due to reduced freshwater inputs, and this reduces transitional habitat for migratory fish to adjust their osmoregulation between saltwater and freshwater environments (Huber & Carlson, 2020). Decreased water quality was shown to increase fish movement through the estuary, likely in search of places of refuge (Huber & Carlson, 2020). Resilience for fish is therefore indicated by availability of habitat with cooler water to give fish a location for refuge from increased temperatures.

Reduced freshwater inputs due to upstream river damming can also disrupt the osmoregulatory adaptation of anadromous species as they transition between freshwater and saltwater habitats (Gonzalez-Ortegon et al., 2012). For fish that inhabit the estuary year-round, reduction of freshwater inputs can cause conditions that are too saline for their survival; removal of dams has been shown to increase fish presence throughout the estuary (Lincoln et al., 2018). Removal of upstream dams consequently contributes to resilience of estuarine fish species.

2. Stressor category: coastal modification

Important estuarine habitat for fish include seagrass, saltmarshes, large woody debris, vertical cliff faces, kelp, rocky shores, sand/mud flats, and tidal forests (Currin et al., 2008; Huber & Carlson, 2020; Meyer & Posey, 2019; Seitz et al., 2014; Woo et al., 2019). Sand bar formations and other barriers between rivers and estuaries can prevent river access for anadromous salmonids, limiting their spawning grounds to estuaries (Crozier et al., 2019). In the context of coastal modification, increasing the quantity and diversity of fish habitat in estuaries will be important because resilience of fish is positively correlated with level of habitat protection within estuaries (Vasconcelos et al., 2017). Any planned coastal modification in estuaries should thus either increase available fish habitat or ensure no net loss to estuarine fish habitat to support fish species resilience.

The rate of habitat loss within estuaries, broadly speaking, is currently a significant threat to fish, especially migratory fish such as salmonids that have longer residence times in estuaries (Crozier et al., 2019). However, fish presence has not been found to vary significantly between restored/constructed habitat and well-established habitats within estuaries (Currin et al., 2008), suggesting there is opportunity to create resilience for fish species in places that are managed for fish habitat. In a study of fish presence within different marsh habitats, Meyer and Posey (2019) found that diversity of sub-habitats within extensive fringe marshes provided for higher density and species richness of nekton varieties. Small marsh islands and a lower ratio of area to perimeter was also indicative of good habitat for finfish (Meyer & Posey, 2019).

3. Stressor category: water quality

Water quality is also an important determinant of fish survival and resilience. Fish that inhabit estuaries intermittently for migration require a sufficient amount of freshwater inputs to allow them to acclimatize to changing salinities (Froehlich et al., 2016).

Other important water quality factors impacting fish in estuaries are dissolved oxygen and pH. Fish biomass within temperate estuaries tends to be negatively correlated with higher salinity levels, and positively correlated with pH where it varies within the estuary (Froehlich et al., 2016; Huber & Carlson, 2020; Scapin et al., 2018).

A factor impacting resilience of fish species was noise pollution. Fish stress levels increase when subjected to continuous sounds with irregular amplitudes and frequencies, while regular continuous sound can cause fish to experience masking (when noise pollution prevents fish from sending and receiving communication signals and acoustic prompts) and hearing loss (de Jong et al., 2020). These impacts can prevent fish from entering areas subject to intensive industrial or commercial activity where noise pollution increases stress levels, masking, and hearing loss. In some situations, noise pollution avoidance can prevent fish from entering traditional spawning and foraging grounds, which can influence their reproductive capacity (de Jong et al., 2020). Resilience for fish species who use estuaries for spawning or migratory routes towards spawning grounds can therefore be inferred by increased fish habitat availability with sufficient refuge from noise pollution.

Bivalves

Bivalves such as mussels, oysters, and clams are important contributors to the resilience of many estuarine features, including sediment, morphology, the water column, and the overall food web. Oysters mediate water quality through feeding on different varieties of plankton in the water column (Gedan et al., 2014). Sediment nutrient fluxes were shown to be connected to seasonal activity of bivalves located in sediment (Magni et al., 2014). Bivalves can also provide unique habitat features through the establishment of oyster reefs, which can also support mediation of sedimentation accumulation within estuaries (see habitat features section on oyster reefs). Supporting bivalves in estuaries is therefore an important component of supporting functional resilience of the entire estuary.

The most frequently assessed stressors to bivalves as reported in the literature were ocean acidification (5) and water temperature increase (3) (Table 5). Common metrics used to measure the impact of these stressors included organism response, water quality, and habitat distribution (

Table *7*). The most prominent stressor categories in the literature were hydrological changes (7) and water quality (6). Timelines are variable depending on which aspect of bivalve resilience is being studied. Many lab studies lasted approximately 1 week to 1 month, which was sufficient time to determine individual level responses to acute stressors such as changes to temperature, acidity, and sedimentation in the absence of cumulative stressors or additional ecological variables (e.g. Gedan et al., 2014; Pereira et al., 2015; Stapp et al., 2017). However, population level changes within the regular ecosystem were more accurately determined over the course of 6 years to multiple decades (e.g. Verdelhos et al., 2014; Windham et al., 2019).

1. Stressor category: hydrological changes

One important hydrological stressor is water temperature increase, which has been linked to increased heart rate and increased numbers of anaerobic metabolites in bivalves (Eymann et al., 2020). An increase in water temperature can also increase the vulnerability of bivalves to ocean acidification. Clements et al. (2017) demonstrated that increased temperature for sediment-dwelling bivalves heightened the impacts of acidity by triggering a neural response that encourages them to burrow, often burrowing further into harmful acidified sediment. However, oysters have a natural resilience to water temperature increase, with water filtration capacity optimized between 18°C and 26°C, and survival up to 30°C (Eymann et al., 2020).

Another important hydrological stressor to bivalves is changes in freshwater flows. In a study that lasted 31 years, Windham et al. (2019) determined that overall decreased bivalve populations were associated with increased variability in freshwater flows driven by extreme events of drought and precipitation. However, in a different study, it was shown that submerged seagrass vegetation supported bivalve resilience to extreme weather events (Verdelhos et al., 2014). Sheltering structures can also support bivalve resilience. Oyster success was found to be linked to a naturally sheltered part of the estuary near the ocean interface (McFarland & Hare, 2018). Resilience of bivalve populations can therefore be enhanced long-term through reduced instances of extreme variability in freshwater flows, the presence of seagrass, and the presence of sheltering habitat.

2. Stressor category: water quality

The most persistent external threat to bivalves discussed in the literature is ocean acidification. Acidity has been shown to reduce the success of hatching larvae, and can cause deformities in larvae that develop (Pereira et al., 2015). pH levels between 7.1 and 6.7 were shown to disrupt gametogenesis required for reproduction and prevent early larval success (Boulais et al., 2017). A lab study focused on the impact of acidity on larvae of *Donax trunculus,* the wedge shell clam, showed high rates of mortality and the study was terminated early due to such high death and abnormality rates (Pereira et al., 2015); however, Fitzer et al. (2019) and Stapp et al. (2017) demonstrated that some oysters can be selectively bred to be more resilient to ocean acidification than wild type varieties.

Presence of oysters and mussels contribute to improved water quality due to their filtration capacity through consumption of micro-phytoplankton (Gedan et al., 2014). When located together, mussels and oysters consume twice as much micro-plankton as oysters alone due to specialized feeding behaviours (Gedan et al., 2014), suggesting that bivalves perform better when contributing to improved water quality when situated with complementary species.

3. Stressor category: biological changes

Bivalves are commercially important species, so farming bivalves in estuaries has become a common practice. Due to the benefits of bivalves as discussed above, bivalve aquaculture has the potential to add value to the estuary, depending on how it’s implemented. Aquaculture for bivalves can be used to selectively breed varieties that are more resilient to some of the harmful effects of acidification (Fitzer et al., 2019); however, it’s also possible for farmed bivalves to exceed the carrying capacity of the estuary, altering the food web in a way that is damaging to other functional components (e.g. Gao et al., 2020). Breeding bivalves can therefore support estuarine resilience but only if done in a way that considers and supports the functional needs of the estuary. Food web modelling tools such as Ecopath can be useful to understand the potential impacts of changing the dynamics in the food web prior to implementing any changes (e.g. Gao et al., 2020).

4. Stressor category: sediment fluxes

Bivalve success and resilience have been shown to be linked to sediment fluxes. Cockles were shown to be naturally resilient to extreme weather events that cause burial through sedimentation but were less resilient when sustaining multiple ongoing burial events (Anderson et al., 2019). Bivalve activity is linked to filtration of nutrients in sediment; pore-water nutrients, sedimentary acid-volatile sulfide, and benthic chlorophyll-α have been shown to fluctuate naturally in connection with bivalve filtration activity (Magni et al., 2014). Estuarine structures, habitats and bivalves therefore work together to mutually re-enforce resilience.

Microbiome

Microbial communities that make up the microbiome within estuaries are the bacteria, fungi, protists, and other microscopic eucaryotes that inhabit estuarine communities. Included in this category is microphytobenthos (MPBs), the photoautotrophs that often colonize mudflats and rocky shores, contribute to nutrient cycling, and act as primary producers in multiple food webs (Booty et al., 2020; Harris et al., 2020). Also included are the microorganisms that contribute to organic content in the soil beneath salt marsh plants and seagrass beds, as well as the epiphyte assemblages that colonize seagrass leaves and are significant contributors to the seagrass food web (Mittermayr et al., 2014). One study found that differences in epiphyte loads on seagrass leaves were a phenotypic indicator of genetic diversity of seagrass within a meadow (Evans et al., 2016). Microbial communities are the first to respond to changing conditions and can therefore indicate the trajectory and resilience of certain estuarine features early (Lynum et al., 2020; McKew et al., 2011).

The most common stressors impacting the microbiome in the literature were eutrophication (2) and water temperature increase (2) (Table 5). Common metrics used to measure these stressors included water quality, organism responses, habitat distribution, and species composition (

Table *7*). The most common pressure categories were hydrological changes (3), water quality (2), and coastal modification (2) (Table 5). Timelines ranged from 1-3 months to capture seasonal patterns and information from microbial communities.

1. Stressor category: hydrological changes

The main stressors to the microbiome related to hydrological changes were drought and freshwater flows/precipitation. In a period of desiccation and rewetting in a salt marsh, biomass of microphytobenthos and bacterial activity were significantly decreased during desiccation but immediately recovered biomass and activity after rewetting (McKew et al., 2011). Epiphytic bacteria tend to be resilient to heat-wave treatments, but are more likely to vary based on regular seasonal changes associated with water temperature change (Guan et al., 2020). Alpha and beta diversity of epiphytic bacteria and fungi is linked to differing salinity levels and freshwater sources (Trevathan-Tackett et al., 2020). It is suggested that appropriate biome species protect seagrasses from extreme saline and freshwater conditions, thus promoting their resilience to extreme flow changes (Trevathan-Tackett et al., 2020)

2. Stressor category: water quality

Microphytobenthos (MPBs) can be vulnerable to eutrophication and regular seasonal variation. Toxic algal blooms and increased nitrate content associated with eutrophication have been found to be correlated with reduced MPB biomass (Harris et al., 2020; Lemley et al., 2018). High density levels within patches of MPBs on mudflats have been found to be less likely to disappear or change location with changing seasons than patches with lower density (Daggers et al., 2020). Understanding microbial communities is important to understand the changing trajectories of estuarine habitats such as salt marshes, mudflats, sand flats, and seagrass beds.

3. Stressor category: coastal modification

Study of microbial communities can be an effective way to determine the trajectory of restoration from coastal modification. In a salt marsh that had a road and culvert system removed that was previously blocking tidal flow from reaching the salt marsh, the fungal and bacterial communities shifted quickly and dramatically to become more reflective of the communities found in a reference marsh that was not previously subject to restricted tidal flow (Lynum et al., 2020). Similarly, it was found that diversity of epiphytic microbial communities on seagrass leaves can be used to indicate nutrient availability for the seagrass bed ecosystem (Trevathan-Tackett et al., 2020). Microbial communities could therefore be useful as a metric for restoration success in newly planted salt marshes and seagrass beds.

Birds

Birds use estuaries as migratory and nesting habitat, and bird presence can be used as an indicator of estuarine integrity (e.g. Benvenuti et al., 2018; Dai et al., 2013; Prosser, Nagel, et al., 2018). A food web study of an estuarine ecosystem identified piscivorous birds as potential keystone species for the estuarine food web (Bueno-Pardo et al., 2018). Bird foraging behaviour in mudflats can positively support sediment and nitrogen cycles within estuaries (Booty et al., 2020). In addition to mudflats, salt marshes and shallow subtidal regions are also important habitat for many bird species (Benvenuti et al., 2018; Prosser, Nagel, et al., 2018; Rosencranz et al., 2018). Birds are resilient when provided with nesting and foraging habitat that is buffered from human influence (Dai et al., 2013; Ivajnšič et al., 2016; Li et al., 2019).

The most prominently studied stressors impacting birds were sea-level rise (5) and invasive species (5) (Table 5). Common metrics that were used to measure the impact of these stressors were organism response, habitat distribution, and sediment fluxes (

Table *7*). Hydrological changes (6) and biological changes (6) were the most frequently studied stressor categories, followed by coastal modification (4). Timelines for changes in bird populations are variable and often occur in congruence with changes to habitat availability (e.g. Li et al., 2019; Rosencranz et al., 2018).

1. Stressor category: hydrological changes

Sea-level rise combines with coastal modification to impact bird habitat through coastal squeeze, defined as "...intertidal habitat loss which arises due to the high water mark being fixed by a defence and the low water mark migrating landwards in response to sea level rise" (Pontee, 2013). This squeeze would normally move bird habitat further inland, but due to anthropogenic development along shorelines, there is no room for estuarine habitats to re-establish (Raw et al., 2020). Loss of estuarine habitats due to sea-level rise and drought are predicted to increase the risk of extinction for up to 87% of shorebird species (Galbraith et al., 2014). In that study, risk was determined based on changing availability of breeding habitat, degree of dependence on ecological synchronicities, migration distance, and degree of habitat specialization. Habitats are predicted to become more linear and reduced in area if sea-level rise trends remain on current trajectories (Ivajnšič et al., 2016). Managing for shorebird resilience will therefore require protection and development of bird habitat with elevation capital to account for sea-level rise.

2. Stressor category: biological changes

Another pressure causing vulnerability in bird populations is invasive species that are not local to the region being occupied by birds. A waterbird survey suggested a negative correlation between waterbirds and *Spartina alterniflora* found in locations where it is not native to the area (Zou et al., 2016). *Phragmites australis* can take over estuarine marshes outside of its original range, reducing habitat quality and function for birds (Prosser, Nagel, et al., 2018). To achieve resilience for bird species, availability of native habitat types e.g., marshes that are dominated by native species as opposed to invasive species, is thus relevant.

3. Stressor category: coastal modification

Modifications in the form of hardened coastal defenses (bulkheads, hardened shorelines, and armoured beaches) have been linked to negative trends in bird presence (Prosser, Nagel, et al., 2018). Availability of natural, undeveloped shorelines as well as distance from anthropogenically modified landscapes were found to be important indicators of bird population integrity (Ivajnšič et al., 2016; Prosser, Nagel, et al., 2018). Reclamation and restoration of estuarine habitat has been positively linked to improvements in bird populations (Li et al., 2019).

Invertebrates

Assemblages of invertebrates (excluding bivalves) are often used as indicators of health and resilience in mudflats, sand flats and salt marshes within estuaries (Bordalo et al., 2011;

Mackenzie et al., 2015; Schaffner, 2010; Zeldis et al., 2020). Different assemblages can either indicate healthy or unhealthy ecosystems. Density and biomass of invertebrates tend to be greater in low marsh as compared to higher marsh settings (Mackenzie et al., 2015) and also tend to be resilient to fluctuating water and sediment flows (Gerwing et al., 2016; Schaffner, 2010).

The most frequently studied stressors to non-bivalve invertebrates were eutrophication (7) and freshwater flows / precipitation (2) (Table 5). Common metrics used to measure each of these stressors were water quality and organism responses (

Table *7*) Water quality was the stressor category most represented (8), followed by hydrological changes (4) (Table 5). Timelines were 1-3 years for overall population level responses to changing levels of eutrophication (e.g. Dolbeth et al., 2007; Leite et al., 2014).

1. **Stressor category: water quality**

Invertebrate diversity has been shown to be positively correlated with improved water quality post-eutrophication (Cardoso et al., 2008). Invertebrates can also be used as an indicator of poor estuarine conditions, depending on the type being studied. For example, deposit-feeding polychaetes have been associated with eutrophic conditions created by wastewater (Zeldis et al., 2020). In this example, diminished density of deposit-feeding polychaetes was an indicator of functional integrity. Abundances of deposit-feeding polychaetes were reduced to about a quarter of eutrophic levels after removal of eutrophic inputs (Zeldis et al., 2020).

The removal of eutrophic inputs was associated with increased biomass, density, and diversity of invertebrates in the Mondego estuary (Portugal) (Cardoso et al., 2008). Diversity of invertebrates within sediment is linked to sites with healthy seagrass beds in contrast to eutrophic areas (Dabrowska et al., 2016; Dolbeth et al., 2007). Since resilience is linked to diversity, removal of eutrophic inputs can enhance resilience of invertebrate communities.

2. Stressor category: hydrological changes

The hydrological changes category was represented by modification of freshwater flows and drought. Increased precipitation and drought both contributed to reduced density and diversity of invertebrates; however, once conditions normalized, invertebrate density and diversity recovered (Bordalo et al., 2011). Increased freshwater flows associated with removal of upstream modifications also showed that invertebrate density can be resilient to increased freshwater. Gerwing et al. (2016) found that faunal communities were able to maintain density after multiple spillway gate removals upstream of the estuary. Invertebrate populations are resilient to hydrological extremes; however, persistent extreme conditions could be threatening to invertebrate density and diversity.

Zooplankton

Zooplankton in estuaries form the next building block of the food web after phytoplankton and are an important source of nutrients for carnivores and omnivores within the system, including fish (Breckenridge et al., 2020; Bueno-Pardo et al., 2018). They inhabit the water column and can therefore be influenced by the water features within an estuary. For example, ocean changes due to the North Atlantic Oscillation were shown to have a significant impact on the zooplankton assemblages of the Mondego estuary in Portugal (Marques et al., 2018). Within the same estuary, restoration of water quality after eutrophication supported a spike in zooplankton densities of more than double their value in eutrophic waters, suggesting natural recovery and resilience (Falcao et al., 2012). Due to their critical role in the food web, zooplankton were used as ecosystem indicators in a few of the studies (Breckenridge et al., 2020; Falcao et al., 2012). Food web resilience is thus closely linked to zooplankton communities in estuaries.

The most frequently studied stressor to zooplankton was water temperature increase (4) followed by channelization (2). Common metrics used to measure the impact of these stressors included organism responses, water quality, habitat distribution, species composition, and currents/discharge/hydrology (

Table *7*). Stressor categories represented in the literature were hydrological changes (5) followed by coastal modification (3) and water quality (2) (Table 5). Timelines ranged from 1-3 months to measure responses to the impacts of warming temperatures, acidification and channelization (Breckenridge et al., 2020; Horn et al., 2020), to 9 years to measure responses to the impacts of changing ocean currents due to climate change (Marques et al., 2018).

1. Stressor category: hydrological changes

Increased water temperatures in estuaries can have variable effects on zooplankton. Overall abundance and biomass were correlated with seasonally increased temperatures in the Fraser River Estuary, British Columbia (Breckenridge et al., 2020). However, in the Kiel Fjord Estuary, a nutrient-depleted estuary in Germany, warmer temperatures simulated in a microcosm within the estuary were associated with decreased biomass for all zooplankton groups except for microzooplankton, and reduced diversity for all zooplankton groups (Horn et al., 2020). Increased freshwater inputs resulting from extreme weather events were also linked to decreases in copepod zooplankton (Karlsson et al., 2018). This could be true of changes to freshwater inputs from upstream dams as well. Zooplankton resilience is therefore linked to maintenance of regular site-specific seasonal hydrological parameters within estuaries.

2. Stressor category: water quality

Warming temperatures are also linked to zooplankton sensitivity to water quality variables. For example, increased salinity and temperatures combined have been shown to increase rate of development of copepod *Eurytemora affinis* hatchlings where they are endemic in Swedish estuaries; however, lower salinity levels combined with higher temperatures had a detrimental effect on adult survival rates (Karlsson et al., 2018). In another example, increased acidity levels was related to overall decreased zooplankton biomass (Horn et al., 2020). Resilience for zooplankton is conferred by normal thresholds of variability for pH, salinity and temperature that is typical for each individual estuary.

3. Stressor category: coastal modification

Habitat features are also an important factor in determining zooplankton densities. Zooplankton are more likely to congregate in sections with slow-moving waters such as sloughs, rather than faster moving channels (Breckenridge et al., 2020). Disruption of previous channelization practices through re-complexification of upstream habitat has been associated with more than doubling of density values and population size in zooplankton (Falcao et al., 2012). In this example, zooplankton was used as an indicator of restoration effectiveness. Therefore, increased channelization of rivers can lead to decreased resilience in zooplankton communities whereas complexification of upstream sources can increase resilience.

Dabrowska et al. (2016) found that zooplankton species richness can be higher in seagrass or vegetated areas. Habitat variety and complexity within estuaries therefore contributes to zooplankton resilience.

Phytoplankton

Phytoplankton is an estuarine feature that can either support the resilience of or cause harm to the estuarine system, depending on whether it's acting as a component of a thriving food web alongside critical habitat or causing harm to habitats and food web components due to overabundance from eutrophication (Biber et al., 2008). Phytoplankton is one of the first building blocks of the estuarine food web; they are omnipresent as a physically small but numerically important primary producer within the system (Bueno-Pardo et al., 2018; Horn et al., 2020; Lemley et al., 2018; Mittermayr et al., 2014). Phytoplankton tends to have highest abundance towards the middle of the estuary rather than closer to marine or freshwater flows, suggesting that estuarine phytoplankton varieties are specialized to mesohaline conditions (Osma et al., 2020).

The most frequently studied stressor to phytoplankton was water temperature increase (3), followed by eutrophication (2) and ocean acidification (2) (Table 5). Common metrics used to understand each of these stressors included organism response, water quality, habitat distribution, and species composition (

Table *7*). Stressor categories represented were water quality (5) and hydrological changes (3). The timelines were up to one month to measure responses to the impacts of temperature and acidification (Horn et al., 2020; Lemley et al., 2018), two seasons to measure seasonal changes to phytoplankton assemblages and impacts of coastal upwelling (Osma et al., 2020), and one year to measure responses to water and hydrological impacts to plankton (Schallenberg & Burns, 2003).

1. Stressor category: water quality changes

As primary producers, phytoplankton can benefit from increased CO_2, which would normally be associated with ocean acidification harmful to other species groups growing calcareous shells (Horn et al., 2020). In certain circumstances, phytoplankton can contribute to vulnerability of other estuarine features; for example, phytoplankton blooms can prevent light attenuation through the water, negatively impacting seagrass and other macrophytes (Biber et al., 2008). Also, abundances of some species of phytoplankton are increased alongside the harmful effects of eutrophication, contributing to increased levels of acidification as dead phytoplankton decomposes (Bednaršek et al., 2020; Biber et al., 2008). However, phytoplankton assemblages are more likely to be influenced by nutrient inputs than acidification (Osma et al., 2020). Phytoplankton is therefore not an indicator of vulnerability in the food web when the food web can effectively transfer the carbon sources to upper trophic levels, rather than blooming beyond the capacity of upper trophic levels to digest (e.g. Mittermayr et al., 2014). Phytoplankton's contribution as a main food source to higher trophic levels helps to maintain a clear water column with sufficient light penetration, while also taking up CO_2 that can lead to acidification.

2. Stressor category: hydrological changes

Assemblages of phytoplankton will mostly be determined by temperatures and nutrient content within the water (Osma et al., 2020). Primary production from phytoplankton tends to be highest during warmer temperatures in the summer, but diversity tends to be highest during cooler temperatures in the winter (Osma et al., 2020). One could infer from this that a more resilient estuarine ecosystem is one where blooms of phytoplankton commonly associated with eutrophication do not occur, and that estuaries would be more vulnerable to this in the summer months due to the increased primary production.

Schallenberg and Burns (2003) also found that an estuary influenced by upwelling currents had higher chlorophyll-α levels associated with phytoplankton density than one that did not. Groundwater flow conditions can also influence phytoplankton assemblages and abundance. Schallenberg and Burns (2003) found that nutrients transferred from groundwater sources were as important as those from riverine sources in their impacts on phytoplankton assemblages.

Macroalgae

Macroalgae was not heavily studied in the literature, as it is not always common in estuaries; however, it does have presence in some estuarine environments. Macroalgae can act as habitat for some species (Leite et al., 2014), and can contribute to pCO_2 absorption, supporting estuarine resilience to ocean acidification (Graiff et al., 2015). The four stressors related to macroalgae studied in the literature included eutrophication (2), ocean acidification (1), turbidity (1), and water temperature increase (1) (Table 5). Common metrics used to understand these stressors included water quality, organism response, and light access/attenuation (

Table *7*). Water quality was the most studied stressor category (4). Study timelines were 1-2 years depending on which stressor macroalgae was responding to.

1. **Stressor category: water quality**

Macroalgae face the same stressors as seagrass as it relates to photosynthetic activity that is vulnerable to decreases in light attenuation, which can occur from suspended riverine sediment that can then be re-suspended through wave action (Glover et al., 2019). This stressor was found to be more impactful than other stressors including sand scouring and substrate changes (Glover et al., 2019). Resilience can be inferred through the ability to adapt to or recover from decreased water transparency in estuaries.

In some cases, macroalgae can have negative impacts on water and can be associated with eutrophication in estuaries. Decomposing macroalgae associated with eutrophic blooms can be harmful to water quality or otherwise associated with the creation of habitat for mobile invertebrates and small fishes (Harris et al., 2020). Deposits of decomposing macroalgae in the intertidal regions of estuaries can also add a physical barrier that limits flow and stabilizes sediments and can alter the macrofaunal assemblages in the sediment (Harris et al., 2020). Macroalgae can therefore either contribute to the resilience or the vulnerability of the estuary and its features, depending on the circumstance.

Macroalgae such as *Fucus vesticulosis* (rockweed) is naturally resilient to increased sea surface temperatures as well as higher levels of acidity, as it tends towards increased growth rates in these environments (Graiff et al., 2015). Algae in estuaries can also provide habitat to other organisms such as *Echinogammarus marinus*, which has also shown high levels of resilience to increased temperatures (Leite et al., 2014). However, eutrophic conditions can reduce the temperature threshold at which both macroalgae and its associated biota can survive (Leite et al., 2014).

Discussion

Through systematic review of the primary literature, this study assessed the range of stressors that temperate estuaries are subject to, and how the response and resilience to these stressors' scales to estuary features in space and time. Resilience was defined in terms of ecological function, and the focus of the research was therefore to identify the processes that must be supported to maintain ecological function. Stressors to estuaries were diverse and included water quality threats, coastal modification, hydrology changes, sedimentation changes, and biological changes. Key threats driving these stressors are eutrophication, land reclamation, water temperature increase, and invasive species. Below, I discuss how these threats and stressors impact temperate estuary resilience, the indicators of resilience as a function of the features of the estuary, the scale of those features, and the timeframes associated with pressures and responses.

Indicators of resilience – whole estuary scale

At the whole estuary scale, water quality is indicated by surface irradiance and balanced physical-chemical properties such as dissolved oxygen, nitrogen and phosphorus concentrations, and pH (Bordalo et al., 2011; Lemley et al., 2018; Osma et al., 2020; Schutte et al., 2020; Wong et al., 2020; Zeldis et al., 2020). These metrics tend to improve under protection from human pollution across the watershed and regular flushing within the estuary (e.g. Bordalo et al., 2011). Resilience to change is supported by the presence of long-term primary producers such as native marsh and seagrass species that can remove excess nutrients and CO_2 from the water (Bednaršek et al., 2020) indicating that supporting those ecological features can be used as a technique to manage acidification locally within an estuary. Stressors of eutrophication and acidification can be managed locally at the estuary scale. For instance, removal of pollution sources away from the estuary was shown to have dramatic effects on water quality (Zeldis et al., 2020). Removal of upstream dams to restore regular water flow can also support water quality through regular flushing (e.g. Lincoln et al., 2018), assuming the river water has not been polluted. My results also indicate that oyster beds and reefs have an important water filtration function which can be helpful in polluted estuaries, especially when oysters are combined with other bivalves such as mussels (Gedan et al., 2014).

Geomorphological resilience is measured in terms of shear strength and coastal erosion protection. Resilience through the estuary is enhanced through structural complexity of both the coastline and estuarine habitats such as salt marshes (Brooks et al., 2015; Leuven et al., 2019). Structural complexity supports overall shear strength when faced with pressures associated with wave and tidal velocity (e.g. Brooks et al., 2015). This is true for salt marshes protecting shorelines as well, as shown by Fagherazzi et al. (2012) in a modeling study focusing on resilience of salt marshes. Structural complexity and plant density in that study were demonstrated to support continuous sediment accretion rates which protected shorelines from sea-level rise and helped to dissipate erosive energy from strong currents (Fagherazzi et al., 2012). In salt marshes, complexity is represented through a combination of main channels, sinuous creeks, and elevation diversity.

The literature in my review did not speak directly to the structural contribution of seagrass; however, seagrass can also contribute to the structural resiliency of coastlines and landscapes. One example of this is the Mediterranean seagrass *Posidonia oceanica*, which has been shown to alter bathymetry through trapping sediment and growing vertically within the trapped sediment (Boudouresque et al., 2016). *P. oceanica* can also attenuate flow velocity, protecting shorelines from erosion; it develops complex assemblages of matte, which can be washed up on shorelines in the form of banquettes, which protect shorelines from erosion and sea-level rise by trapping sand and sediment (Boudouresque et al., 2016).

Since complexification is important for estuarine resilience, it can be inferred that loss of resilience can occur due to simplification of structures and habitats. Simplification can occur through channelization, dredging, shoreline hardening, and land reclamation (Grossman et al., 2020; Healy & Hickey, 2002; O'Donnell, 2017; Ralston et al., 2019). Dredging and channelization works conducted to support navigation have been shown to increase tidal flow velocity towards the shoreline making it more vulnerable to erosive forces (Ralston et al., 2019). Channelization also alters sedimentation fluxes such that sediment is more likely to move offshore than contribute to estuarine habitats as it otherwise would (Grossman et al., 2020). Simplification through hardening of coastal shorelines by constructing bulkheads, seawalls, groins, and revetments is used in support of land reclamation to protect coastal land use such as private property (O'Donnell, 2017). However, these simplified structures have been shown to increase the risk of erosion and alter estuarine sediment flows, as well as reduce habitat viability and water quality (O'Donnell, 2017; Prosser, Jordan, et al., 2018).

Many estuaries have historically been subject to land reclamation for agricultural purposes through converting salt marshes to freshwater grasslands for grazing (Healy & Hickey, 2002). Estuaries are also subject to land reclamation for urban-industrial and recreational purposes, which has significantly altered the hydrological and sedimentation dynamics and negatively impacted biological assemblages of estuaries (eg. Healy & Hickey, 2002). Avoiding these activities reduces vulnerability and thus enhances landscape resilience.

Indicators of resilience – habitat scale

At the habitat scale, natural resilience to external perturbations occurs within certain limits. For instance, mudflat assemblages were able to re-establish and become re-colonized quickly after large sedimentation events and periods of desiccation (Bordalo et al., 2011; Schaffner, 2010). Seagrass is naturally resilient to herbivory and can re-establish quickly with improved water quality (Bordalo et al., 2011; Cardoso et al., 2008; Carroll et al., 2019). Salt marshes have been found to naturally re-establish after managed shoreline realignment by breaching constructed barriers and seawalls (Spencer et al., 2008). However, salt marsh habitats showed vulnerability to perturbations such as poor water quality (Schutte et al., 2020), coastal anthropogenic disturbance (Bennett et al., 2020), increased sea-level rise (Cole Ekberg et al., 2017), and erosion (Brooks et al., 2015).

For salt marsh habitats, one of the most important factors supporting resilience is continuous water and sediment flows through the estuary (e.g. Harvey et al., 2020). Sediment flows can come from either riverine discharge or tidal influx and require an equal or greater amount of natural sediment accretion to match the increased tidal high-water mark associated with sea-level rise (Fagherazzi et al., 2012; Goodman et al., 2007). The results suggest that in some estuaries, the increased tidal flux of sediment is not sufficient to offset the loss of riverine sediment discharge from sea-level rise (Liu et al., 2020). Riverine sediment discharge was also suggested to be threatened by upstream river dams and diversions. To foster greater resilience, sediment accretion can be supported by dense vegetation on salt marshes (Alldred et al., 2020).

Higher density plant communities can trap sediment better than low density plant communities and can also contribute to complexification of the marshes, protecting them from erosion (Fagherazzi et al., 2012). Maintaining resilience of salt marshes will therefore require local understanding of water and sediment fluxes and supporting plant density on the marshes themselves.

Also important for salt marshes is their location relative to other protective structures within the estuary. For example, enclosing marshes behind protected bays, stone sills, and oyster reefs supports their natural development through erosion protection and mutual re-enforcement of sediment trapping (e.g. Schuerch et al., 2018). Fivash et al. (2021) suggested that oyster reefs can also benefit from proximity of salt marshes due to both the marsh and the reef's ability to stabilize sediment, promoting establishment of both when subject to tidal and wave currents.

Another theme in the literature related to habitat resilience is diversity. Genetic diversity and species diversity were both shown to support resilience of habitats to external perturbations. For example, genetic diversity in seagrass was shown to support resilience to water quality changes including increased temperatures, acidification, pollution, and seagrass wasting disease (Bekkby et al., 2020; Chefaoui et al., 2016; Martin et al., 2016). Additional studies suggest that genetic diversity in seagrass can support resistance of seagrass to grazing impacts, as well as enhancing shoot density under warming temperatures (Ehlers et al., 2008; Hughes & Stachowicz, 2004). Similarly, Salt marshes can also show increased resilience to pressures with greater genetic diversity (Hughes, 2014). In another study, species diversity within mudflats and sandflats was shown to support their resilience through enhanced nutrient cycling (Magni et al., 2014). These findings are consistent with Pelletier et al. (2020), who suggested that diversity in aquatic systems is one of the main supports and indicators of resilient ecosystems.

Indicators of resilience – biological community scale

Diversity, complexity, and connectivity of habitats and sub-habitats supports the diversity of biological assemblages that are required for maintaining ecological processes (Breckenridge et al., 2020; Dabrowska et al., 2016; Huber & Carlson, 2020; Ivajnšič et al., 2016). In many studies, organism responses at the biological community scale were used to measure the health of features at the habitat scale (e.g. Bordalo et al., 2011; Windham et al., 2019). Common metrics used to measure the impact of stressors on biological communities included water quality and habitat distribution (

Table *7*). These were used to assess the effect of several common stressors, including water temperature increase, sea-level rise, invasive species, and acidification.

Resilience of fish assemblages is supported by heterogeneity and connectivity of habitats with access to places of refuge from harmful conditions. Fish were shown to be more resilient to the impacts of changing water conditions including temperature, salinity, pH, and dissolved oxygen when provided with a variety of habitats and sub-habitats (e.g. Lincoln et al., 2018). Habitat complexity within salt marsh and seagrass beds in an estuary is important as migratory habitat for estuarine fish (Leslie et al., 2017). A study of pacific salmon suggests that diversity of habitats is needed to support diverse life stages and genetic profiles (Weitkamp et al., 2014). Depending on seasonality and variety, salmon will make use of shallow, nearshore habitats and deep, fast-moving channels (Weitkamp et al., 2014).

Diversity of habitats was also important for other biological communities. The diversity of zooplankton increased with complexity of water channels and sloughs (Breckenridge et al., 2020). For birds, a combination of mudflats and marshes were shown to be important for their population stability (e.g. Booty et al., 2020; Dai et al., 2013). Birds were shown to be more resilient when presented with extensive habitat with low human presence and overall coastal modification (Galbraith et al. (2014). Bivalve success was linked to a variety of habitats including seagrass and sand flats (Magni et al., 2014; Verdelhos et al., 2014). Other invertebrates showed higher diversity at the confluence of multiple sections of the estuary between sand and mud sediment mixtures and greater wave exposures (de Juan & Hewitt, 2014). Similarly, diversity within biological communities was often used as an indicator of resilience of habitat features. Diversity within the microbiome is an early indicator of restoration success (Lynum et al., 2020), and seagrass epiphytic diversity is indicative of diversity of energy transfers within the food web (Trevathan-Tackett et al., 2020). Seagrass epiphyte diversity can indicate diversity within the seagrass meadow ecosystem (Mittermayr et al., 2014).

Metrics to support management of temperate estuaries

The results suggest that estuarine habitat-based metrics are useful to determine overall resilience across the estuary. At the scale of the whole estuary, total habitat area and connectivity between habitats are useful metrics to understand overall resilience. My research would benefit from further studies that relate the habitat diversity to estuary size and degree of connectivity between habitats to support ecological processes. Further studies could help to establish some generalizations for how much habitat restoration and construction should be targeted by coastal managers. In the absence of quantification, it can be assumed that building and restoring more habitats and creating more connections between habitat types is a useful goal for estuary management, as the literature on the subject is generally in agreement that estuarine habitats are likely to continue facing net loss due to sea-level rise and other ongoing pressures in the absence of human intervention.

An important metric at the whole estuary scale is the species composition. Diversity and redundancy across functional groups within food webs across habitats allow for multiple pathways of energy transfer between trophic levels (Pelletier et al., 2020). For example, the main macrophyte-based habitats in estuaries (salt marshes and seagrass) tend to generate detritus-based food webs, so the species composition should reflect diverse species that can work through detritus (Bueno-Pardo et al., 2018). Managers could compare the microbiome of newly established or restored habitats to that of a healthy well-established habitat to better understand the future success of that habitat. Species profiling across different sections of the estuary can therefore indicate which energy pathways are strong, and which may require additional redundancies.

At the habitat scale, there are many useful metrics that can be used to support our understanding of resilience (Table 8). At the biological community scale, the most commonly used metrics to understand resilience were behavioural and physiological responses to stressors, as well as population dynamics.

Table 8

Metrics Indicating Resilience for major Habitat Types

Salt Marshes	**Seagrass**	**Mudflats and Sand flats**	**Oyster reefs**

Belowground plant biomass	Genetic diversity	Species composition	Habitat connectivity
Plant density	Shoot density	Sediment quality	Water quality
Plant diversity	Light availability	Sediment fluxes	
Shear strength	Epiphytic biomass and diversity		
Elevation	Water quality values		
Dominance of native species (as opposed to invasives)			
Structural complexity			

Management options

Temperate estuaries face a wide array of stressors, that span a range of spatial and temporal scales. While solving stressors associated with global CO_2 emissions (e.g., climate change, ocean acidification, and sea-level rise) requires concerted international action, there are localized actions that can be applied to support temperate estuary resilience. One management option to support processes contributing to resilience is protection of the estuary and its habitats from localized anthropogenic stressors. For instance, halting or diverting point-source pollution (e.g. Adams et al., 2020; Zeldis et al., 2020), or reducing use of inorganic nitrogen and phosphorous in agriculture upstream of the estuary (e.g. Detenbeck et al., 2019), can lead to a rapid improvement of water quality and have a positive feedback on salt marsh and seagrass habitats, and their associated biota. Limiting coastal squeeze can allow for high marshes to develop in support of habitat and coastline protection (Raw et al., 2020). Management actions that can achieve this include restricting development within a buffered area from the shoreline (Stein et al., 2020), or building coastal habitat through importing materials and planting endemic halophytes to create a larger buffer from the shoreline (Alldred et al., 2020).

Living shorelines are often cited as a management option for supporting coastal resilience and estuarine biota (Bilkovic et al., 2016; O'Donnell, 2017; Prosser, Jordan, et al., 2018). Living shorelines involves protection of shorelines by constructing or restoring coastal habitat to allow for the living ecological systems to absorb the impacts of sea-level rise and increased currents rather than installing hardened concrete structures that can result in further erosion (O'Donnell, 2017). Restoring and constructing coastal habitat can therefore protect coastal communities while also promoting ecological function (O'Donnell, 2017). Promoting estuarine habitats supports the resilience of the estuary and is therefore a useful tool to consider.

Managed realignment through breaching of hardened shoreline structures is a restoration strategy that can reverse estuarine sediment starvation and allow conditions for the natural re-establishment of salt marshes where they have been previously lost (Stein et al., 2020). This solution, in conjunction with ensuring appropriate fluvial sediment flow, is effective at mitigating shoreline pressures associated with sea-level rise (Stein et al., 2020). However, marsh communities may take more than 15 years to mature after first establishment and will tend to have low diversity levels and be at risk of invasive species development (Alldred et al., 2020; Ladd et al., 2019; Staszak & Armitage, 2013). Restored marshes therefore require ongoing management and intervention to establish a diversity of vegetation, prevent loss to grazers, and prevent invasive species from becoming established when they can disrupt endemic community maturation.

Re-planting macrophyte habitats is another option available for managing estuaries for resilience. Salt marsh area can be actively restored through human intervention, and this can be an effective means of re-establishing important temperate estuary habitat for birds, fish, crab and shrimp species, while also buffering the shoreline against erosive hydrological forces such as wave and tidal energy (Alldred et al., 2020; Benvenuti et al., 2018; Fagherazzi et al., 2012; Meyer & Posey, 2019; Pettengill et al., 2018). When constructing a marsh from scratch, it is likely possible to control for higher diversity through planting a variety of species. However, adequate below-ground biomass must be established to support resilience to coastal erosion, which can take ten to fifteen years (Alldred et al., 2020). Planting seagrass is another option for developing habitat and supporting the estuarine food web. Early transplanted and propagated seagrass is often missing the genetic diversity needed to ensure resilience (Williams, 2001); only once the seagrass expands naturally through seed dispersal can genetic diversity increase (Bekkby et al., 2020; Chust et al., 2013). Genetic diversity could potentially be supported through mixing eelgrass shoots of the same species from different locations when planting.

Removal of dams upstream within the watershed can be a very important management action for estuaries. Upstream barriers alter regular flows and reduce the transport of sediment required to support accretion and water quality within the estuary (Gonzalez-Ortegon et al., 2012; Gordon et al., 2015; Lincoln et al., 2018; Palinkas et al., 2019). Dams also have a direct impact on water quality in estuaries through reduction of dissolved oxygen (Gordon et al., 2015). Removal of dams helps to restore natural flows and supports migratory fish species adaptation to changing salinities through a more gradual transition between the terrestrial water sources and marine flows than they would experience with reduced freshwater flows (Lincoln et al., 2018).

Another aspect of ecosystem management that should be mentioned is the use of habitat compensation plans or restoration plans as offsets for planned harm to ecological features through industrial or commercial development. An example of this is section 34 of Canada's

Fisheries Act, which states that a permit can be granted to cause harm to fish habitat if an appropriate restoration or offsetting habitat is developed or invested in. When reviewing the timelines across each of the habitat features within the results, one of the key themes is that removal or destruction of habitat can happen very quickly but re-establishing the same habitat type to the same integrity level can take up to 20+ years. Basing restoration targets on habitat area alone can therefore leave a gap in restoration of ecological function that requires a mature and established habitat.

Research Gaps

Depending on the location of the temperate estuary in the world, and other factors that may be influencing it, the thresholds and parameters used to determine functional resilience within the estuary are likely to differ (e.g., temperature and tidal variability). As this was a global study, specific thresholds could not be defined in a way that could be applied in a widespread way across all temperate estuaries. Prioritizing data collection for each managed estuary is therefore necessary to determine the best pathway to resilience.

Further studies are required to resolve the interactions between industrial pressures and estuaries. For instance, in the Pacific Northwest, logging and mining are prevalent land-based activities that alter the sedimentation regime within estuaries downstream (Grossman et al., 2020). Based on the literature, some of the impacts of these activities can be inferred. For instance, any activities that negatively impact the water quality are likely to reduce the resilience of an estuary. For the logging and mining industries, poor water quality and altered freshwater flows can be influenced by these land-based industrial activities (Grossman et al., 2020). If estuaries are to be used as log booms, the logs will shade out the water below it, preventing photosynthesis and thus killing any existing seagrass on the estuary floor. While it is possible to infer the impacts of activities based on what is required for resilience, it would be useful if there were further studies specifically quantifying the industrial impacts on estuaries.

Further research is also warranted to explore the role of macrophytes in mitigating the combined impacts of acidification, eutrophication, sea-level rise, and potentially warming temperatures. Many of the studies in this review focused on the vulnerability of estuarine features to external perturbations, rather than focusing on how to use certain features to enhance the resilience of the estuary. The role of macrophytes shows promise as an approach to restore ecological function and protect estuaries from persistent, ongoing threats that are more difficult to manage on a larger scale.

There is also room for further research on the feedbacks between biological communities and the estuarine habitats that they use. To use the example of birds, there were a variety of studies that looked at which habitats are required to support bird resilience, but there was only one that looked at how birds contribute to the estuarine habitats that they use (Booty et al., 2020). There were also very few studies that looked at how migratory fish might provide feedbacks to their preferred habitats, e.g., through feeding, but many that were concerned with which habitats are needed to support fish populations. Such studies could provide further impetus for supporting and protecting biological communities.

Conclusions

Through systematic literature review, this thesis explored the features of temperate estuaries that support their resilience to natural and anthropogenic disturbance stressors, with goal to inform management actions. Temperate estuaries are shown to be dynamic, fluid biomes, and both they and the stressors that they face operate at a variety of spatial and temporal scales. Dominant stressors were related to water quality, coastal modification, hydrological changes, sediment fluxes, and biological changes. Temporal and spatial scales of stressors on estuaries varied, with anthropogenic stressors generally having larger spatial scales and shorter temporal scales than natural processes. Functional redundancy, habitat complexity, and diversity were three key themes that stood out in supporting estuarine resilience across spatial and temporal scales. Synthesis of resilience measures identified metrics that are appropriate across different spatial and temporal scales. Commonly referenced metrics included organism response and survival, habitat distribution, and water quality parameters. My research supports the use of tools available for measuring resilience to guide localized management of external stressors in temperate estuaries. Importantly, management actions should consider ecological functional integrity as a critical measure of the success of those actions

One of the biggest challenges of this work was to take a systems-based approach like resilience and have it informed by a compendium of research that takes a reductionist approach. The dichotomy of approaches is similar to that described by Holling (1998) as the analytical versus integrative approach when commenting on the culture of how biological ecology is practiced. It was difficult to categorize components of a system of actors, pressures, responses, and metrics in a way that distinguishes each component from other components due to their inherent interconnectedness within the system. This could be potentially remedied or at least understood better by learning how ecological science is practiced in other cultures, including indigenous cultures (e.g. Kimmerer, 2013), and finding ways to bridge the differing approaches.

Also difficult was trying to separate the influencers – whether that be stressors or metrics of resilience – from the features being impacted. In many instances, estuarine biota contributed to the resilience of other habitats within the estuary; for example, bivalves and birds were both shown to mediate nutrient fluxes and sediment movement in mudflats, but through quite different routes. Similarly, estuarine habitats and biota contribute to the morphology and water properties, such as sediment trapping by salt marshes causing an increased elevation and overall changes to the marsh's morphology. The guidance to take away from this is to view each feature more as a contributor to the overall system, with multiple functions and purposes, than a stand-alone item that is not active until it is responding to external stressors. Each component of the system is constantly dealing with external influences while at the same time influencing other parts of the system.

This synthesis showcased that a resilient system is one that has an abundance and diversity of functional features that can reinforce each other when faced with external pressures. This was shown through the benefits of having multiple habitat types near each other allowing biota to have access to suitable habitat over multiple life phases. That biota can then interact with their habitats in a way that promotes their regeneration, for instance, having mud flats and sand flats near each other supports certain bivalves throughout multiple life phases. The presence of bivalves then improves sediment quality, which could be useful in mitigating the impacts of pollution. Also, having salt marshes near stone sills or oyster reefs allows the marshes to exchange sediment within the estuary rather than having the sediment pulled out to sea. The more functional traits present, the more likely the system is to maintain ecological processes during external perturbations.

To better understand resilience as it applies to estuaries, I recommend shifting the focus of future studies from measuring the stressors and responses of single estuarine features to focusing on measurements that can be applied to the whole system. Cataloging the diversity and redundancy of functional components within temperate estuaries will provide a benchmark against which to assess impacts. Many of the articles reviewed found simulation software to be a useful tool to better understanding how estuaries are likely to shift over time based on cumulative changes.

My final recommendation is to increase databasing with baseline information on each of the estuaries, including basic information on all the features including abundances and diversity of biota; size, complexity, and diversity of habitats; and basic morphological, water, and food web characteristics. With these factors all understood, we will be better able to predict and assess the ways that human activity influences them before they are impacted. There have been attempts to do this across the United States, South Africa, and many European countries, but often this information is calculated only for specific impacts and only on estuaries that are already heavily modified with poor baseline information on less modified sites.

References

Adams, J. B., Taljaard, S., Van Niekerk, L., & Lemley, D. A. (2020). Nutrient enrichment as a threat to the ecological resilience and health of South African microtidal estuaries. *African Journal of Aquatic Science, 45*, 23-40. https://doi.org/10.2989/16085914.2019.1677212

Adams, P. B. (1980). Life history patterns in marine fishes and their consequences for fisheries management. *Fishery Bulletin*, *78*(1). https://fisherybulletin.nmfs.noaa.gov/content/life-history-patterns-marine-fishes-and-their-consequences-fisheries-management

Alldred, M., Borrelli, J. J., Hoellein, T., Bruesewitz, D., & Zarnoch, C. (2020). Marsh plants enhance coastal marsh resilience by changing sediment oxygen and sulfide concentrations in an urban, eutrophic estuary. *Estuaries and Coasts, 43*(4), 801-813. https://doi.org/http://dx.doi.org/10.1007/s12237-020-00700-9

Anderson, T., Barrett, H., & Morrisey, D. (2019). Effects of sediment deposition on the New Zealand cockle, *Austrovenus stutchburyi*. *New Zealand Journal of Marine and Freshwater Research, 53*(3), 363-376. https://doi.org/http://dx.doi.org/10.1080/00288330.2019.1580751

Aurelio, M., Faleiro, F., Lopes, V. M., Pires, V., Lopes, A. R., Pimentel, M. S., Repolho, T., Baptista, M., Narciso, L., & Rosa, R. (2013). Physiological and behavioral responses of temperate seahorses (*Hippocampus guttulatus*) to environmental warming. *Marine Biology, 160*(10), 2663-2670. https://doi.org/10.1007/s00227-013-2259-8

Baily, B., & Pearson, A. W. (2007). Change detection mapping and analysis of salt marsh areas of central southern england from Hurst Castle Spit to Pagham Harbour. *Journal of Coastal Research, 23*(6), 1549-1564. https://ezproxy.library.ubc.ca/login?url=https://www.proquest.com/docview/210842246?accountid=14656

Barr, N., Zeldis, J., Scheuer, K., & Schiel, D. (2020). Macroalgal bioindicators of recovery from eutrophication in a tidal lagoon following wastewater diversion and earthquake disturbance. *Estuaries and Coasts, 43*(2), 240-255. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00654-7

Basso, G., Vaudrey, J. M. P., O'Brien, K., & Barrett, J. (2018). Advancing coastal habitat resiliency through landscape-scale assessment. *Coastal Management, 46*(1), 19-39. https://doi.org/http://dx.doi.org/10.1080/08920753.2018.1405328

Bednaršek, N., Pelletier, G., Ahmed, A., & Feely, R. A. (2020). Chemical exposure due to anthropogenic ocean acidification increases risks for estuarine calcifiers in the Salish Sea: biogeochemical model scenarios. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00580

Bekkby, T., Papadopoulou, N., Fiorentino, D., McOwen, C. J., Rinde, E., Boström, C., Carreiro-Silva, M., Linares, C., Andersen, G. S., Bengil, E. G. T., Bilan, M., Cebrian, E., Cerrano, C., Danovaro, R., Fagerli, C. W., Fraschetti, S., Gagnon, K., Gambi, C., Gundersen, H., Kipson, S., Kotta, J., Morato, T., Ojaveer, H., Ramirez-Llodra, E., & Smith, C. J. (2020). Habitat features and their influence on the restoration potential of marine habitats in Europe. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00184

Bennett, W. G., van Veelen, T. J., Fairchild, T. P., Griffin, J. N., & Karunarathna, H. (2020). Computational modelling of the impacts of saltmarsh management interventions on hydrodynamics of a small macro-tidal estuary. *Journal of Marine Science and Engineering, 8*(5), 373. https://doi.org/http://dx.doi.org/10.3390/jmse8050373

Benvenuti, B., Walsh, J., O'Brien, K. M., & Kovach, A. I. (2018). Plasticity in nesting adaptations of a tidal marsh endemic bird. *Ecology and Evolution, 8*, 10780-10793. https://doi.org/10.1002/ece3.4528

Biber, P. D., Gallegos, C. L., & Kenworthy, W. J. (2008). Calibration of a bio-optical model in the North River, North Carolina (Albemarle-Pamlico Sound): a tool to evaluate water quality impacts on seagrasses. *Estuaries and Coasts, 31*(1), 177-191. https://doi.org/http://dx.doi.org/10.1007/s12237-007-9023-6

Bilkovic, D. M., Mitchell, M., Mason, P., & Duhring, K. (2016). The role of living shorelines as estuarine habitat conservation strategies. *Coastal Management, 44*(3), 161-174. https://doi.org/10.1080/08920753.2016.1160201

Boerema, A., & Meire, P. (2017). Management for estuarine ecosystem services: A review. *Ecological Engineering*, *98*, 172-182. https://doi.org/10.1016/j.ecoleng.2016.10.051

Booty, J. M., Underwood, G. J. C., Parris, A., Davies, R. G., & Tolhurst, T. J. (2020). Shorebirds affect ecosystem functioning on an intertidal mudflat. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00685

Borchert, S. M., Osland, M. J., & Enwright, N. M. (2018). Coastal wetland adaptation to sea level rise: Quantifying potential for landward migration and coastal squeeze. *Journal of Applied Ecology*, *55*, 2876-2887. https://doi.org/10.1111/1365-2664.13169

Bordalo, M. D., Ferreira, S. M. F., Cardoso, P. G., Leston, S., & Pardal, M. A. (2011). Resilience of an isopod population (*Cyathura carinata*) to multiple stress factors in a temperate estuarine system. *Hydrobiologia*, *671*(1), 13-25. https://doi.org/10.1007/s10750-011-0700-x

Borja, A., Andersen, J. H., Arvanitidis, C. D., Basset, A., Buhl-Mortensen, L., Carvalho, S., Dafforn, K. A., Devlin, M. J., Escobar-Briones, E. G., Grenz, C., Harder, T., Katsanevakis, S., Liu, D., Metaxas, A., Morán, X. A. G., Newton, A., Piroddi, C., Pochon, X., Queirós, A. M., Snelgrove, P. V. R., Solidoro, C., St John, M. A., & Teixeira, H. (2020). Past and future grand challenges in marine ecosystem ecology. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00362

Borja, A., Basset, A., Bricker, S., Dauvin, J.-C., Elliot, M., Harrison, T., Marques, J., Weisberg, S., & West, R. (2012). Classifying ecological quality and integrity of estuaries. In E. Wolanski & D. McLusky (Eds.), *Treatise on Estuarine and Coastal Science* (Vol. 1, pp. 125-162). Academic Press.

Bottom, D. L., Simenstad, C. A., Burke, J., Baptista, A. M., Jay, D. A., Jone, K. K., Casillas, E., & Schiewe, M. H. (2005). Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. 246.

Boudouresque, C. F., Pergent, G., Pergent-martini, C., Ruitton, S., Thibaut, T., & Verlaque, M. (2016). The necromass of the *Posidonia oceanica* seagrass meadow: fate, role, ecosystem services and vulnerability. *Hydrobiologia*, *781*(1), 25-42. https://doi.org/http://dx.doi.org/10.1007/s10750-015-2333-y

Boulais, M., Chenevert, K. J., Demey, A. T., Darrow, E. S., Robison, M. R., Roberts, J. P., & Volety, A. (2017). Oyster reproduction is compromised by acidification experienced seasonally in coastal regions. *Scientific Reports, 7*(13276). https://doi.org/10.1038/s41598-017-13480-3

Brand, F. (2009). Critical natural capital revisited: Ecological resilience and sustainable development. *Ecological Economics, 68*(3), 605-612. https://doi.org/10.1016/j.ecolecon.2008.09.013

Breckenridge, J., Pakhomov, E., Emry, S., & Mahara, N. (2020). Copepod assemblage dynamics in a snowmelt-dominated estuary. *Estuaries and Coasts, 43*(6), 1502-1518. https://doi.org/http://dx.doi.org/10.1007/s12237-020-00722-3

Brooks, K. L., Mossman, H. L., Chitty, J. L., & Grant, A. (2015). Limited vegetation development on a created salt marsh associated with over-consolidated sediments and lack of topographic heterogeneity. *Estuaries and Coasts, 38*(1), 325-336. https://doi.org/http://dx.doi.org/10.1007/s12237-014-9824-3

Bueno-Pardo, J., Garcia-Seoane, E., Sousa, A. I., Coelho, J. P., Morgado, M., Frankenbach, S., Ezequiel, J., Vaz, N., Quintino, V., Rodrigues, A. M., Leandro, S., Luis, A., Serodio, J., Cunha, M. R., Calado, A. J., Lillebo, A., Rebelo, J. E., & Queiroga, H. (2018, Jun). Trophic web structure and ecosystem attributes of a temperate coastal lagoon (Ria de

Aveiro, Portugal). *Ecological Modelling, 378*, 13-25. https://doi.org/10.1016/j.ecolmodel.2018.03.009

Burchard, H., & Baumert, H. (1998). The formation of estuarine turbidity maxima due to density Effects in the salt wedge: A hydrodynamic process study. *Journal of Physical Oceanography, 28*(2), 309-321. https://journals.ametsoc.org/view/journals/phoc/28/2/1520-0485_1998_028_0309_tfoetm_2.0.co_2.xml

Cabral, H., Fonseca, V., Sousa, T., & Costa Leal, M. (2019, Jul 31). Synergistic effects of climate change and marine pollution: An overlooked interaction in coastal and estuarine areas. *Int J Environ Res Public Health, 16*(15). https://doi.org/10.3390/ijerph16152737

Cardoso, P. G., Raffaelli, D., Lillebo, A. I., Verdelhos, T., & Pardal, M. A. (2008). The impact of extreme flooding events and anthropogenic stressors on the macrobenthic communities' dynamics. *Estuarine Coastal and Shelf Science, 76*(3), 553-565. https://doi.org/10.1016/j.ecss.2007.07.026

Carroll, J. M., Furman, B. T., Jackson, L. J., Hunter, E. A., & Peterson, B. J. (2019). Propagule risk in a marine foundation species: Seascape effects on *Zostera marina* seed predation. *The Journal of Ecology, 107*(4), 1982-1994. https://doi.org/http://dx.doi.org/10.1111/1365-2745.13154

Chefaoui, R. M., Assis, J., Duarte, C. M., & Serrão, E. A. (2016). Large-scale prediction of seagrass distribution integrating landscape metrics and environmental factors: The case of *Cymodocea nodosa* (Mediterranean-Atlantic). *Estuaries and Coasts, 39*(1), 123-137. https://doi.org/http://dx.doi.org/10.1007/s12237-015-9966-y

Chen, Q., Bakker, J. P., Alberti, J., & Smit, C. (2020). Long-term management is needed for conserving plant diversity in a Wadden Sea salt marsh. *Biodiversity & Conservation, 29*(7), 2329-2341. https://doi.org/http://dx.doi.org/10.1007/s10531-020-01976-w

Chust, G., Albaina, A., Aranburu, A., Borja, A., Diekmann, O. E., Estonba, A., Franco, J., Garmendia, J. M., Iriondo, M., Muxika, I., Rendo, F., Rodriguez, J. G., Ruiz-Larranaga, O., Serrao, E. A., & Valle, M. (2013). Connectivity, neutral theories and the assessment of species vulnerability to global change in temperate estuaries. *Estuarine Coastal and Shelf Science, 131*, 52-63. https://doi.org/10.1016/j.ecss.2013.08.005

Clements, J. C., Bishop, M. M., & Hunt, H. L. (2017). Elevated temperature has adverse effects on GABA-mediated avoidance behaviour to sediment acidification in a wide-ranging marine bivalve. *Marine Biology, 164*(3), 1-11. https://doi.org/10.1007/s00227-017-3085-1

Cole Ekberg, M. L., Raposa, K. B., Ferguson, W. S., Ruddock, K., & Watson, E. B. (2017). Development and application of a method to identify salt marsh vulnerability to sea level rise. *Estuaries and Coasts*, *40*(3), 694-710. https://doi.org/10.1007/s12237-017-0219-0

Colombano, D. D., Manfree, A. D., O'Rear, T. A., Durand, J. R., & Moyle, P. B. (2020). Estuarine-terrestrial habitat gradients enhance nursery function for resident and transient fishes in the San Francisco Estuary. *Marine Ecology Progress Series*, *637*, 141. https://doi.org/http://dx.doi.org/10.3354/meps13238

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Covidence. Veritas Health Innovation. www.covidence.org

Crozier, L. G., McClure, M. M., Beechie, T., Bograd, S. J., Boughton, D. A., Carr, M., Cooney, T. D., Dunham, J. B., Greene, C. M., Haltuch, M. A., Hazen, E. L., Holzer, D. M., Huff, D. D., Johnson, R. C., Jordan, C. E., Kaplan, I. C., Lindley, S. T., Mantua, N. J., Moyle, P. B., Myers, J. M., Nelson, M. W., Spence, B. C., Weitkamp, L. A., Williams, T. H., & Willis-Norton, E. (2019). Climate vulnerability assessment for Pacific salmon and steelhead in the California Current Large Marine Ecosystem. *PLoS One*, *14*(7), 1-49. https://doi.org/10.1371/journal.pone.021771

Cui, D., Liang, S., & Wang, D. (2021). Observed and projected changes in global climate zones based on Köppen climate classification. *WIREs Climate Change*, *12*(3). https://doi.org/10.1002/wcc.701

Currin, C. A., Delano, P. C., & Valdes-weaver, L. M. (2008). Utilization of a citizen monitoring protocol to assess the structure and function of natural and stabilized fringing salt marshes in North Carolina. *Wetlands Ecology and Management*, *16*(2), 97-118. https://doi.org/http://dx.doi.org/10.1007/s11273-007-9059-1

Dabrowska, A. H., Janas, U., & Kendzierska, H. (2016). Assessment of biodiversity and environmental quality using macrozoobenthos communities in the seagrass meadow (Gulf of Gdansk, southern Baltic). *Oceanological and Hydrobiological Studies, 45*(2), 286-294. https://doi.org/http://dx.doi.org/10.1515/ohs-2016-0024

Daggers, T. D., Herman, P. M. J., & van der Wal, D. (2020). Seasonal and spatial variability in patchiness of microphytobenthos on intertidal flats from sentinel-2 satellite imagery. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00392

Dai, X., Ma, J., Zhang, H., & Xu, W. (2013). Evaluation of ecosystem health for the coastal wetlands at the Yangtze Estuary, Shanghai. *Wetlands Ecology and Management, 21*(6), 433-445. https://doi.org/http://dx.doi.org/10.1007/s11273-013-9316-4 de Jong, K., Forland, T. N., Amorim Maria Clara, P., Rieucau, G., Slabbekoorn, H., & Sivle, L. D. (2020). Predicting the effects of anthropogenic noise on fish reproduction. *Reviews in Fish Biology and Fisheries*, *30*(2), 245-268. https://doi.org/http://dx.doi.org/10.1007/s11160-020-09598-9

de Juan, S., & Hewitt, J. (2014). Spatial and temporal variability in species richness in a temperate intertidal community. *Ecography, 37*(2), 183-190. https://doi.org/10.1111/j.1600-0587.2013.00048.x

Demir, H., Otay, E. N., Work, P. A., & Börekçi, O. S. (2004). Impacts of dredging on shoreline change. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, *130*(4), 170-178. https://doi.org/10.1061/(asce)0733-950x(2004)130:4(170)

Detenbeck, N. E., You, M., & Torre, D. (2019). Recent changes in nitrogen sources and load components to estuaries of the contiguous United States. *Estuaries and Coasts*, *42*(8), 2096-2113. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00614-1

Dolbeth, M., Cardoso, P. G., Ferreira, S. M., Verdelhos, T., Raffaelli, D., & Pardal, M. A. (2007). Anthropogenic and natural disturbance effects on a macrobenthic estuarine community over a 10-year period. *Marine Pollution Bulletin*, *54*(5), 576-585. https://doi.org/10.1016/j.marpolbul.2006.12.005

Dos Santos, V. M., Matheson, F. E., Pilditch, C. A., & Elger, A. (2013). Seagrass resilience to waterfowl grazing in a temperate estuary: A multi-site experimental study. *Journal of Experimental Marine Biology and Ecology*, *446*, 194-201. https://doi.org/10.1016/j.jembe.2013.05.030

Ehlers, A., Worm, B., & Reusch, T. B. H. (2008). Importance of genetic diversity in eelgrass Zostera marina for its resilience to global warming. *Marine Ecology Progress Series, 355*, 1-7. https://doi.org/10.3354/meps07369

Elliott, M., & Quintino, V. (2007, Jun). The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. *Mar Pollut Bull*, *54*(6), 640-645. https://doi.org/10.1016/j.marpolbul.2007.02.003

Elmilady, H., van der Wegen, M., Roelvink, D., & van der Spek, A. (2020). Morphodynamic evolution of a fringing sandy shoal: from tidal levees to sea level rise. *Journal of Geophysical Research. Earth Surface*, *125*(6). https://doi.org/http://dx.doi.org/10.1029/2019JF005397

Evans, S. M., Sinclair, E. A., Poore, A. G., Bain, K. F., & Verges, A. (2016). Genotypic richness predicts phenotypic variation in an endangered clonal plant. *Peerj*, *4*, e1633. https://doi.org/10.7717/peerj.1633

Eymann, C., Götze, S., Bock, C., Guderley, H., Knoll, A. H., Lannig, G., Sokolova, I. M., Aberhan, M., & Hans-O, P. (2020). Thermal performance of the European flat oyster, *Ostrea edulis* (Linnaeus, 1758)—explaining ecological findings under climate change. *Marine Biology, 167*(2). https://doi.org/http://dx.doi.org/10.1007/s00227-019-3620-3

Fagherazzi, S., Kirwan, M. L., Mudd, S. M., Guntenspergen, G. R., Temmerman, S., D'Alpaos, A., van de Koppel, J., Rybczyk, J. M., Reyes, E., Craft, C., & Clough, J. (2012). Numerical models of salt marsh evolution: Ecological, geomorphic, and climatic factors. *Reviews of Geophysics, 50*(1). https://doi.org/10.1029/2011rg000359

Falcao, J., Marques, S. C., Pardal, M. A., Marques, J. C., Primo, A. L., & Azeiteiro, U. M. (2012). Mesozooplankton structural responses in a shallow temperate estuary following restoration measures. *Estuarine Coastal and Shelf Science, 112*, 23-30. https://doi.org/10.1016/j.ecss.2011.06.007

Ferreira, J. C., Silva, L., & Polette, M. (2009). The coastal artificialization process: Impacts and challenges for the sustainable management of the coastal cities of Santa Catarina (Brazil). *Journal of Coastal Research*, 1209-1213. http://www.jstor.org.ezproxy.royalroads.ca/stable/25737979

Fitzer, S. C., McGill, R. A. R., Sergio Torres, G., Hughes, B., Dove, M., O'Connor, W., & Byrne, M. (2019). Selectively bred oysters can alter their biomineralization pathways, promoting resilience to environmental acidification. *Global Change Biology, 25*(12), 4105-4115. https://doi.org/http://dx.doi.org/10.1111/gcb.14818

Fivash, G. S., Stüben, D., Bachmann, M., Walles, B., van Belzen, J., Didderen, K., Temmink, R. J. M., Lengkeek, W., van der Heide, T., & Bouma, T. J. (2021). Can we enhance ecosystem-based coastal defense by connecting oysters to marsh edges? Analyzing the limits of oyster reef establishment. *Ecological Engineering*, *165*, 13. https://doi.org/10.1016/j.ecoleng.2021.106221

Fleri, J. R., Lera, S., Gerevini, A., Staver, L., & Nardin, W. (2019). Empirical observations and numerical modelling of tides, channel morphology, and vegetative effects on accretion in a restored tidal marsh: The Journal of the British Geomorphological Research Group. *Earth Surface Processes and Landforms, 44*(11), 2223-2235. https://doi.org/http://dx.doi.org/10.1002/esp.4646

Froehlich, H. E., Gentry, R. R., & Halpern, B. S. (2016). Synthesis and comparative analysis of physiological tolerance and life-history growth traits of marine aquaculture species. *Aquaculture*, *460*, 75-82. https://doi.org/10.1016/j.aquaculture.2016.04.018

Galbraith, H., DesRochers, D. W., Brown, S., & Reed, J. M. (2014). Predicting vulnerabilities of North American shorebirds to climate change. *PLoS One, 9*(9), e108899. https://doi.org/10.1371/journal.pone.0108899

Ganju, N. K., Defne, Z., & Fagherazzi, S. (2020). Are elevation and open-water conversion of salt marshes connected? *Geophysical Research Letters, 47*(3). https://doi.org/10.1029/2019gl086703

Gao, Y., Fang, J., Lin, F., Li, F., Li, W., Wang, X., Du, M., Fang, J., Jiang, W., Liu, H., Zhang, Y., Wang, J., & Jiang, Z. (2020). Simulation of oyster ecological carrying capacity in Sanggou Bay in the ecosystem context. *Aquaculture International*, *28*(5), 2059-2079. https://doi.org/10.1007/s10499-020-00576-3

Garthwin, R. G., Poore, A. G. B., & Verges, A. (2014). Seagrass tolerance to herbivory under increased ocean temperatures. *Marine Pollution Bulletin, 83*(2), 475-482. https://doi.org/10.1016/j.marpolbul.2013.08.010

Gedan, K. B., Kellogg, L., & Breitburg, D. L. (2014). Accounting for multiple foundation species in oyster reef restoration benefits. *Restoration Ecology, 22*(4), 517-524. https://doi.org/10.1111/rec.12107

Gerwing, T. G., Hamilton, D. J., Barbeau, M. A., Haralampides, K., & Yamazaki, G. (2016). Short-term response of a downstream marine system to the partial opening of a tidal-river causeway. *Estuaries and Coasts, 40*(3), 717-725. https://doi.org/10.1007/s12237-016-0173-2

Gittman, R. K., Fodrie, F. J., Popowich, A. M., Keller, D. A., Bruno, J. F., Currin, C. A., Peterson, C. H., & Piehler, M. F. (2015). Engineering away our natural defenses: an analysis of shoreline hardening in the US. *Frontiers in Ecology and the Environment*, *13*(6), 301-307. https://doi.org/10.1890/150065

Gladstone-Gallagher, R. V., Hughes, R. W., Douglas, E. J., & Pilditch, C. A. (2018). Biomass-dependent seagrass resilience to sediment eutrophication. *Journal of Experimental Marine Biology and Ecology*, *501*, 54-64. https://doi.org/10.1016/j.jembe.2018.01.002

Glover, H. E., Ogston, A. S., Miller, I. M., Eidam, E. F., Rubin, S. P., & Berry, H. D. (2019). Impacts of suspended sediment on nearshore benthic light availability following dam removal in a small mountainous river: In situ observations and statistical modeling. *Estuaries and Coasts*, *42*(7), 1804-1820. https://doi.org/10.1007/s12237-019-00602-5

Gonzalez-Ortegon, E., Subida, M. D., Arias, A. M., Baldo, F., Cuesta, J. A., Fernandez-Delgado, C., Vilas, C., & Drake, P. (2012). Nekton response to freshwater inputs in a temperate European estuary with regulated riverine inflow. *Sci Total Environ*, *440*, 261-271. https://doi.org/10.1016/j.scitotenv.2012.06.061

Goodman, J. E., Wood, M. E., & Gehrels, W. R. (2007). A 17-yr record of sediment accretion in the salt marshes of Maine (USA). *Marine Geology, 242*(1-3), 109-121. https://doi.org/10.1016/j.margeo.2006.09.017

Gordon, J., Arbeider, M., Scott, D., Wilson, S. M., & Moore, J. W. (2015). When the tdes don't turn: floodgates and hypoxic zones in the lower Fraser River, British Columbia, Canada. *Estuaries and Coasts, 38*(6), 2337-2344. https://doi.org/10.1007/s12237-014-9938-7

Graiff, A., Bartsch, I., Ruth, W., Wahl, M., & Karsten, U. (2015). Season exerts differential effects of ocean acidification and warming on growth and carbon metabolism of the seaweed *Fucus vesiculosus* in the western Baltic Sea. *Frontiers in Marine Science, 2*. https://doi.org/10.3389/fmars.2015.00112

Greene, C. M., Blackhart, K., Nohner, J., Candelmo, A., & Nelson, D. M. (2015). A national assessment of stressors to estuarine fish habitats in the contiguous USA. *Estuaries and Coasts, 38*(3), 782-799. https://doi.org/10.1007/sl2237-014-9855-9

Grossman, E. E., Stevens, A. W., Dartnell, P., George, D., & Finlayson, D. (2020). Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise, Skagit River Delta, Washington, USA. *Marine Geology, 430*. https://doi.org/10.1016/j.margeo.2020.106336

Guan, C., Saha, M., & Weinberger, F. (2020). Simulated heatwaves lead to upregulated chemical defense of a marine foundation macrophyte against microbial colonizers. *Frontiers in Marine Science, 7*. https://doi.org/10.3389/fmars.2020.00463

Gunderson, L. H. (2000). Ecological resilience - In theory and application. *Annual Review of Ecology and Systematics, 31*, 425-439. http://www.jstor.org/stable/221739

Harris, R. J., Niemand, C., & Pilditch, C. A. (2020). Decomposing macroalgae (Ulva spp.) impacts benthic macrofauna and surface sediment erosion. *Geo - Marine Letters, 40*(2), 281-294. https://doi.org/http://dx.doi.org/10.1007/s00367-019-00593-z

Harvey, M. E., Giddings, S. N., Stein, E. D., Crooks, J. A., Whitcraft, C., Gallien, T., Largier, J. L., Tiefenthaler, L., Meltzer, H., Pawlak, G., Thorne, K., Johnston, K., Ambrose, R., Schroeter, S. C., Page, H. M., & Elwany, H. (2020). Effects of Elevated Sea Levels and Waves on Southern California Estuaries During the 2015–2016 El Niño. *Estuaries and Coasts, 43*(2), 256-271. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00676-1

Healy, M. G., & Hickey, K. R. (2002). Historic land reclamation in the intertidal wetlands of the Shannon estuary, western Ireland. *Journal of Coastal Research, 36,* 365-373. https://doi.org/10.2112/1551-5036-36.sp1.365

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*, 1-23. http://www.jstor.org/stable/2096802

Holling, C. S. (1998). Two cultures of ecology. *Conservation Ecology*, *2*(2). http://www.consecol.org/vol2/iss2/art4/

Horn, H. G., Boersma, M., Garzke, J., Sommer, U., & Aberle, N. (2020). High CO2 and warming affect microzooplankton food web dynamics in a Baltic Sea summer plankton community. *Marine Biology*, *167*(5). https://doi.org/10.1007/s00227-020-03683-0

Huber, E. R., & Carlson, S. M. (2020). Environmental correlates of fine-scale juvenile steelhead trout (*Oncorhynchus mykiss*) habitat use and movement patterns in an intermittent estuary during drought. *Environmental Biology of Fishes*, *103*(5), 509-529. https://doi.org/10.1007/s10641-020-00971-y

Hughes, A. R. (2014). Genotypic diversity and trait variance interact to affect marsh plant performance. *Journal of Ecology*, *102*(3), 651-658. https://doi.org/10.1111/1365-2745.12244

Hughes, A. R., & Stachowicz, J. J. (2004). Genetic diversity enhances the resistance of a seagrass ecosystem to disturbance. *Proceedings of the National Academy of Sciences*, *101*(24), 5.

Ivajnšič, D., Lipej, L., Škornik, I., & Kaligarič, M. (2016). The sea level rise impact on four seashore breeding birds: the key study of Sečovlje Salina Nature Park. *Climatic Change, 140*(3-4), 549-562. https://doi.org/10.1007/s10584-016-1854-3

James, N. C., Lamberth, S. J., Midgley, C., & Whitfield, A. K. (2017). Resilience of fish assemblages in the Breede Estuary, South Africa, to environmental perturbations. *Environmental Biology of Fishes, 101*(1), 109-126. https://doi.org/10.1007/s10641-017-0685-z

Jentsch, A., & White, P. (2019). A theory of pulse dynamics and disturbance in ecology. *Ecology, 100*(7), e02734. https://doi.org/https://doi.org/10.1002/ecy.2734

Jordán, F. (2009). Keystone species and food webs. *Philosophical Transactions: Biological Sciences, 364*(1524), 1733-1741. https://www.jstor.org/stable/40485950

Karlsson, K., Puiac, S., & Winder, M. (2018). Life-history responses to changing temperature and salinity of the Baltic Sea copepod *Eurytemora affinis*. *Mar Biol, 165*(2), 30. https://doi.org/10.1007/s00227-017-3279-6

Kennedy, D. M., Konlechner, T., Zavadil, E., Mariani, M., Wong, V., Ierodiaconou, D., & Macreadie, P. (2018). Invasive cordgrass (*Spartina spp.*) in south-eastern Australia induces island formation, salt marsh development, and carbon storage. *Geographical Research, 56*(1), 80-91. https://doi.org/10.1111/1745-5871.12265

Khangaonkar, T., Nugraha, A., Hinton, S., Michalsen, D., & Brown, S. (2017). Sediment transport into the Swinomish navigation channel, Puget Sound-Habitat restoration versus navigation maintenance needs. *Journal of Marine Science and Engineering, 5*(2), 19. https://doi.org/http://dx.doi.org/10.3390/jmse5020019

Kim, M., Le-Zheng, Q., Kim, S. H., Song, H.-J., Kim, Y. K., & Lee, K.-S. (2020). Influence of water temperature anomalies on the growth of *Zostera marina* plants held under high and low irradiance levels. *Estuaries and Coasts, 43*(3), 463-476. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00578-2

Kimmerer, R. W. (2013). *Braiding sweetgrass: indigenous wisdom, scientific knowledge and the teachings of plants*. Milkweed Editions.

Kominoski, J. S., Gaiser, E. E., & Baer, S. G. (2018). Advancing theories of ecosystem development through long-term ecological research. *BioScience, 68*(8), 554-562. https://doi.org/10.1093/biosci/biy070

Ladd, C. J. T., Duggan-Edwards, M. F., Bouma, T. J., Pages, J. F., & Skov, M. W. (2019). Sediment Supply Explains Long-Term and Large-Scale Patterns in Salt Marsh Lateral

Expansion and Erosion. *Geophysical Research Letters, 46*(20), 11178-11187. https://doi.org/10.1029/2019GL083315

Leite, N., Guerra, A., Almeida, A., Marques, J. C., & Martins, I. (2014). Long term variation of an amphipod species' population secondary production as indicator of incomplete resilience in a temperate estuary. *Ecological Indicators, 36*, 324-333. https://doi.org/10.1016/j.ecolind.2013.08.001

Lemley, D. A., Nunes, M., & Adams, J. B. (2018). Estuarine algal responses to increasing nitrate concentrations during closed mouth conditions of oligotrophic systems: a laboratory microcosm experiment. *Botanica Marina, 61*(6), 559-572. https://doi.org/10.1515/bot-2018-0027

Leslie, T., James, N. C., Potts, W. M., & Rajkaran, A. (2017). The relationship between habitat complexity and nursery provision for an estuarine-dependent fish species in a permanently open South African Estuary. *Estuarine, Coastal and Shelf Science, 198*, 183-192. https://doi.org/10.1016/j.ecss.2017.09.013

Leuven, J. R. F. W., Pierik, H. J., Maarten van der, V., Bouma, T. J., & Kleinhans, M. G. (2019). Sea-level-rise-induced threats depend on the size of tide-influenced estuaries worldwide. *Nature Climate Change, 9*(12), 986-992. https://doi.org/http://dx.doi.org/10.1038/s41558-019-0608-4

Levings, C. D. (2016). *Ecology of Salmonids in Estuaries Around the World: Adaptations, habitats, and conservation*. UBC Press.

Li, N., Wang, Z., Lu, X., Feng, Y., Ling-qian, X., Ya-jun, Q., Xin-hai, L., Shu-qing, A., & Shu-bo, F. (2019). Effects of long-term coastal reclamation on suitable habitat and wintering population size of the endangered Red-crowned Crane, *Grus japonensis*. *Hydrobiologia, 827*(1), 21-29. https://doi.org/http://dx.doi.org/10.1007/s10750-017-3341-x

Lincoln, A. E., Shaffer, J. A., & Quinn, T. P. (2018). Opportunistic use of estuarine habitat by juvenile bull trout, *Salvelinus confluentus*, from the Elwha River before, during, and after dam removal. *Environmental Biology of Fishes, 101*(11), 1559-1569. https://doi.org/http://dx.doi.org/10.1007/s10641-018-0800-9

Liu, Z. C., de Lange, W. P., & Bryan, K. R. (2020). Estuary rejuvenation in response to sea level rise: an example from Tairua Estuary, New Zealand. *Geo - Marine Letters, 40*(2), 269-280. https://doi.org/http://dx.doi.org/10.1007/s00367-019-00603-0

Long, A., Xie, Q., Yu, X., Xiao, H., & Zhou, W. (2018). Nutrient exchange between sediments and overlying waters in the Modaomen Estuary (China) over a complete semidiurnal tide cycle: Implications of saltwater intrusion. *Journal of Coastal Research, 346*, 1439-1448. https://doi.org/10.2112/jcoastres-d-17-00104.1

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., Kidwell, S. M., Kirby, M. X., Peterson, C. H., & Jackson, J. B. C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science, 312*(5781), 1806. https://doi.org/10.1126/science.1128035

Lovelock, C. E., & Reef, R. (2020). Variable impacts of climate change on blue carbon. *One Earth, 3*(2), 195-211. https://doi.org/https://doi.org/10.1016/j.oneear.2020.07.010

Lynum, C. A., Bulseco Ashley, N., Dunphy, C. M., Osborne, S. M., Vineis, J. H., & Bowen, J. L. (2020). Microbial community response to a passive salt marsh restoration. *Estuaries and Coasts, 43*(6), 1439-1455. https://doi.org/http://dx.doi.org/10.1007/s12237-020-00719-y

Ma, Z., Gan, X., Choi, C., Jing, K., Tang, S., Li, B., & Chen, J. (2006). Wintering bird communities in newly-formed wetland in the Yangtze River estuary. *Ecological Research, 22*(1), 115-124. https://doi.org/10.1007/s11284-006-0193-7

Mackenzie, R. A., Dionne, M., Miller, J., Haas, M., & Morgan, P. A. (2015). Community structure and abundance of benthic infaunal invertebrates in Maine fringing marsh ecosystems. *Estuaries and Coasts, 38*(4), 1317-1334. https://doi.org/http://dx.doi.org/10.1007/s12237-015-9977-8

Macura, B., Byström, P., Airoldi, L., Eriksson, B. K., Rudstam, L., & Støttrup, J. G. (2019). Impact of structural habitat modifications in coastal temperate systems on fish recruitment: a systematic review. *Environmental Evidence, 8*(1). https://doi.org/10.1186/s13750-019-0157-3

Magni, P., Como, S., Montani, S., & Tsutsumi, H. (2014). Interlinked seasonal variation in biogenic nutrient fluxes and pore-water nutrient concentrations in intertidal sediments. *Marine Biology*, *161*(12), 2767-2779. https://doi.org/http://dx.doi.org/10.1007/s00227-014-2541-4

Marques, S. C., Pardal, M. A., Primo, A. L., Martinho, F., Falcao, J., Azeiteiro, U., & Molinero, J. C. (2018). Evidence for changes in estuarine zooplankton fostered by increased climate variance. *Ecosystems, 21*(1), 56-67. https://doi.org/10.1007/s10021-017-0134-z

Martin, D. L., Chiari, Y., Boone, E., Sherman, T. D., Ross, C., Wyllie-echeverria, S., Gaydos, J. K., & Boettcher, A. A. (2016). Functional, phylogenetic and host-geographic signatures of *Labyrinthula spp*. provide for putative species delimitation and a global-scale view of seagrass wasting disease. *Estuaries and Coasts*, *39*(5), 1403-1421. https://doi.org/http://dx.doi.org/10.1007/s12237-016-0087-z

McFarland, K., & Hare, M. P. (2018). Restoring oysters to urban estuaries: Redefining habitat quality for eastern oyster performance near New York City. *PLoS One*, *13*(11), e0207368. https://doi.org/10.1371/journal.pone.0207368

McKew, B. A., Taylor, J. D., McGenity, T. J., & Underwood, G. J. C. (2011). Resistance and resilience of benthic biofilm communities from a temperate saltmarsh to desiccation and rewetting. *Isme Journal*, *5*(1), 30-41. https://doi.org/10.1038/ismej.2010.91

Melo, W., Pinho, J., Iglesias, I., Bio, A., Avilez-Valente, P., Vieira, J., Bastos, L., & Veloso-Gomes, F. (2020). Hydro- and morphodynamic impacts of sea level rise: The Minho Estuary case study. *Journal of Marine Science and Engineering*, *8*(6), 441. https://doi.org/http://dx.doi.org/10.3390/jmse8060441

Meyer, D. L., & Posey, M. H. (2019). Salt marsh habitat size and location do matter: the influence of salt marsh size and landscape setting on nekton and estuarine finfish community structure. *Estuaries and Coasts*, *42*(5), 1353-1373. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00555-9

Mittermayr, A., Fox, S. E., & Sommer, U. (2014). Temporal variation in stable isotope composition (delta C-13, delta N-15 and delta S-34) of a temperate *Zostera marina* food web. *Marine Ecology Progress Series*, *505*, 95-105. https://doi.org/10.3354/meps10797

Naiman, R. J., Bilby, R. E., Schindler, D. E., & Helfield, J. M. (2002). Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. *Ecosystems, 5*(4), 399-417. http://www.jstor.org.ezproxy.royalroads.ca/stable/3658977

O'Donnell, J. E. D. (2017). Living shorelines: a review of literature relevant to New England coasts. *Journal of Coastal Research, 33*(2), 435-451. https://doi.org/http://dx.doi.org/10.2112/JCOASTRES-D-15-00184.1

Odum, E. P. (1969). The strategy of ecosystem development. *Science, 164*(3877), 262-270. https://doi.org/10.1126/science.164.3877.262

Oosterlee, L., Cox, T. J. S., Vandenbruwaene, W., Maris, T., Temmerman, S., & Meire, P. (2018). Tidal marsh restoration design affects feedbacks between inundation and elevation change. *Estuaries and Coasts, 41*(3), 613-625. https://doi.org/http://dx.doi.org/10.1007/s12237-017-0314-2

Osland, M. J., Grace, J. B., Guntenspergen, G. R., Thorne, K. M., Carr, J. A., & Feher, L. C. (2019). Climatic controls on the distribution of foundation plant species in coastal wetlands of the conterminous United States: Knowledge gaps and emerging research needs. *Estuaries and Coasts, 42*(8), 1991-2003. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00640-z

Osma, N., Latorre-Melín, L., Jacob, B., Contreras, P. Y., von Dassow, P., & Vargas, C. A. (2020). Response of phytoplankton assemblages from naturally acidic coastal ecosystems to elevated pCO2. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00323

Palinkas, C. M., Testa, J. M., Cornwell, J. C., Li, M., & Sanford, L. P. (2019). Influences of a river dam on delivery and fate of sediments and particulate nutrients to the adjacent estuary: Case study of Conowingo Dam and Chesapeake Bay. *Estuaries and Coasts, 42*(8), 2072-2095. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00634-x

Pelletier, M. C., Ebersole, J., Mulvaney, K., Rashleigh, B., Gutierrez, M. N., Chintala, M., Kuhn, A., Molina, M., Bagley, M., & Lane, C. (2020). Resilience of aquatic systems: Review and management implications. *Aquatic Sciences, 82*(2). https://doi.org/http://dx.doi.org/10.1007/s00027-020-00717-z

Pereira, A. M., Range, P., Campoy, A., Oliveira, A. P., Joaquim, S., Matias, D., Chícharo, L., & Gaspar, M. B. (2015). Larval hatching and development of the wedge shell (*Donax trunculus* L.) under increased CO2 in southern Portugal. *Regional Environmental Change, 16*(3), 855-864. https://doi.org/10.1007/s10113-015-0803-4

Pettengill, T. M., Crotty, S. M., Angelini, C., & Bertness, M. D. (2018). A natural history model of New England salt marsh die-off. *Oecologia, 186*(3), 621-632. https://doi.org/http://dx.doi.org/10.1007/s00442-018-4078-6

Plaisted, H. K., Novak, A. B., Weigel, S., Klein, A. S., & Short, F. T. (2020). Eelgrass genetic diversity influences resilience to stresses associated with eutrophication. *Estuaries and Coasts, 43*(6), 1425-1438. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00669-0

Pontee, N. (2013). Defining coastal squeeze: A discussion. *Ocean & Coastal Management, 84*, 204-207. https://doi.org/10.1016/j.ocecoaman.2013.07.010

Potter, I. C., Beckley, L. E., Whitfield, A. K., & Lenanton, R. C. J. (1990). Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environmental Biology of Fishes, 28*(1-4), 143-178. https://doi.org/10.1007/bf00751033

Prahalad, V. N. (2014). Human impacts and saltmarsh loss in the Circular Head coast, north-west Tasmania, 1952-2006: implications for management. *Pacific Conservation Biology, 20*(3), 272-285. https://doi.org/http://dx.doi.org/10.1071/PC140272

ProQuest. (2023). *ProQuest / LibGuides / ProQuest Platform / Results*. Retrieved February 5, 2023 from https://proquest.libguides.com/proquestplatform/results

Prosser, D. J., Jordan, T. E., Nagel, J. L., Seitz, R. D., Weller, D. E., & Whigham, D. F. (2018). Impacts of coastal land use and shoreline armoring on estuarine ecosystems: an introduction to a special issue. *Estuaries and Coasts, 41*(1), 2-18. https://doi.org/http://dx.doi.org/10.1007/s12237-017-0331-1

Prosser, D. J., Nagel, J. L., Howlin, S., Marbán, P. R., Day, D. D., & Erwin, R. M. (2018). Effects of local shoreline and subestuary watershed condition on waterbird community integrity: Influences of geospatial scale and season in the Chesapeake Bay. *Estuaries and Coasts, 41*(1), 207-222. https://doi.org/http://dx.doi.org/10.1007/s12237-017-0288-0

Ralston, D. K., Talke, S., Geyer, W. R., Al-Zubaidi, H. A. M., & Sommerfield, C. K. (2019). Bigger tides, less flooding: Effects of dredging on barotropic dynamics in a highly modified estuary. *Journal of Geophysical Research: Oceans, 124*(1), 196-211. https://doi.org/10.1029/2018jc014313

Raw, J. L., Riddin, T., Wasserman, J., Lehman, T. W. K., Bornman, T. G., & Adams, J. B. (2020). Salt marsh elevation and responses to future sea-level rise in the Knysna Estuary, South Africa. *African Journal of Aquatic Science, 45*(1-2), 49-64. https://doi.org/http://dx.doi.org/10.2989/16085914.2019.1662763

Reid, R. G. B. (1980). Aspects of the biology of a gutless species of Solemya (Bivalvia: Protobranchia). *Canadian Journal of Zoology*, *58*(3), 386-393.

Robb, C. K. (2014). Assessing the impact of human activities on British Columbia's estuaries. *PLoS One*, *9*(6), e99578. https://doi.org/10.1371/journal.pone.0099578

Rodrigues, E. T., & Pardal, M. Â. (2015). Primary productivity temporal fluctuations in a nutrient-rich estuary due to climate-driven events. *Estuaries and Coasts*, *38*(1), 1-12. http://www.jstor.org.ezproxy.library.ubc.ca/stable/44851272

Rogers, K., & Woodroffe, C. D. (2016). Geomorphology as an indicator of the biophysical vulnerability of estuaries to coastal and flood hazards in a changing climate. *Journal of Coastal Conservation*, *20*(2), 127-144. https://doi.org/10.1007/s11852-016-0424-1

Rosencranz, J. A., Thorne, K. M., Buffington, K. J., Takekawa, J. Y., Hechinger, R. F., Stewart, T. E., Ambrose, R. F., MacDonald, G. M., Holmgren, M. A., Crooks, J. A., Patton, R. T., & Lafferty, K. D. (2018). Sea-level rise, habitat loss, and potential extirpation of a salt marsh specialist bird in urbanized landscapes. *Ecol Evol*, *8*(16), 8115-8125. https://doi.org/10.1002/ece3.4196

Scapin, L., Zucchetta, M., Sfriso, A., & Franzoi, P. (2018). Local habitat and seascape structure influence seagrass fish assemblages in the Venice Lagoon: The importance of conservation at multiple spatial scales. *Estuaries and Coasts, 41*(8), 2410-2425. https://doi.org/http://dx.doi.org/10.1007/s12237-018-0434-3

Schaffner, L. C. (2010). Patterns and Rates of Recovery of Macrobenthic Communities in a Polyhaline Temperate Estuary Following Sediment Disturbance: Effects of Disturbance Severity and Potential Importance of Non-local Processes. *Estuaries and Coasts, 33*(6), 1300-1313. https://doi.org/10.1007/s12237-010-9301-6

Schallenberg, M., & Burns, C. W. (2003). A temperate, tidal lake-wetland complex - 2. Water quality and implications for zooplankton community structure. *New Zealand Journal of Marine and Freshwater Research, 37*(2), 429-447. https://doi.org/10.1080/00288330.2003.9517178

Schelske, C. L., & Odum, E. P. (1961). Mechanisms maintaining high productivity in Georgia estuaries. *Proceedings of the Gulf and Caribbean Fisheries Institute, 14*, 75-80.

Schuerch, M., Dolch, T., Bisgwa, J., & Vafeidis, A. T. (2018). Changing sediment dynamics of a mature backbarrier salt marsh in response to sea-level rise and storm events. *Frontiers in Marine Science, 5*. https://doi.org/10.3389/fmars.2018.00155

Schutte, C. A., Marton, J. M., Bernhard, A. E., Giblin, A. E., & Roberts, B. J. (2020). No evidence for long-term impacts of oil spill contamination on salt marsh soil nitrogen cycling processes. *Estuaries and Coasts*, *43*(4), 865-879. https://doi.org/http://dx.doi.org/10.1007/s12237-020-00699-z

Seitz, R. D., Wennhage, H., Bergstrom, U., Lipcius, R. N., & Ysebaert, T. (2014). Ecological value of coastal habitats for commercially and ecologically important species. *ICES Journal of Marine Science, 71*(3), 648-665. https://doi.org/http://dx.doi.org/10.1093/icesjms/fst152

Siemes, R. W. A., Borsje, B. W., Daggenvoorde, R. J., & Suzanne, J. M. H. H. (2020). Artificial structures steer morphological development of salt marshes: A model study. *Journal of Marine Science and Engineering, 8*(5), 326. https://doi.org/http://dx.doi.org/10.3390/jmse8050326

Simenstad, C. A., Fresh, K. L., & Salo, E. O. (1982). The role of Puget Sound and Washington coastal estuaries in the life history of pacific salmon: An unappreciated function. In V. S. Kennedy (Ed.), *Estuarine Comparisons* (pp. 343-364). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-404070-0.50026-0

Smith, C. S., Rudd, M. E., Gittman, R. K., Melvin, E. C., Patterson, V. S., Renzi, J. J., Wellman, E. H., & Silliman, B. R. (2020, 2020 Jun 10

2020-06-12). Coming to Terms With Living Shorelines: A Scoping Review of Novel Restoration Strategies for Shoreline Protection. *Frontiers in Marine Science*. https://doi.org/http://dx.doi.org/10.3389/fmars.2020.00434

Spears, B. M., Ives, S. C., Angeler, D. G., Allen, C. R., Birk, S., Carvalho, L., Cavers, S., Daunt, F., Morton, R. D., Pocock, M. J. O., Rhodes, G., Thackeray, S. J., & Cadotte, M. (2015). Effective management of ecological resilience - are we there yet? *Journal of Applied Ecology, 52*(5), 1311-1315. https://doi.org/10.1111/1365-2664.12497

Spencer, K. L., Cundy, A. B., Davies-Hearn, S., Hughes, R., Turner, S., & MacLeod, C. L. (2008). Physicochemical changes in sediments at Orplands Farm, Essex, UK following 8 years of managed realignment. *Estuarine, Coastal and Shelf Science, 76*(3), 608-619. https://doi.org/http://dx.doi.org/10.1016/j.ecss.2007.07.029

Stapp, L. S., Thomsen, J., Schade, H., Bock, C., Melzner, F., Portner, H. O., & Lannig, G. (2017). Intra-population variability of ocean acidification impacts on the physiology of Baltic blue mussels (*Mytilus edulis*): Integrating tissue and organism response. *J Comp Physiol B, 187*(4), 529-543. https://doi.org/10.1007/s00360-016-1053-6

Staszak, L. A., & Armitage, A. R. (2013). Evaluating salt marsh restoration success with an index of ecosystem integrity. *Journal of Coastal Research, 29*(2), 410-418. http://gw2jh3xr2c.search.serialssolutions.com/directLink?&atitle=Evaluating+Salt+Mars

h+Restoration+Success+with+an+Index+of+Ecosystem+Integrity&author=Staszak%2C+Lindsey+A%3BArmitage%2C+Anna+R&issn=07490208&title=Journal+of+Coastal+Research&volume=29&issue=2&date=2013-03-01&spage=410&id=doi:&sid=ProQ_ss&genre=article

Stein, E. D., Doughty, C. L., Lowe, J., Cooper, M., Sloane Evyan, B., & Bram, D. L. (2020). Establishing targets for regional coastal wetland restoration planning using historical ecology and future scenario analysis: The past, present, future approach. *Estuaries and Coasts*, *43*(2), 207-222. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00681-4

Taylor, L., Curson, D., Verutes, G. M., & Wilsey, C. (2020). Mapping sea level rise impacts to identify climate change adaptation opportunities in the Chesapeake and Delaware Bays, USA. *Wetlands Ecology and Management, 28*(3), 527-541. https://doi.org/http://dx.doi.org/10.1007/s11273-020-09729-w

Teodoro, J. D., & Nairn, B. (2020). Understanding the knowledge and data landscape of climate change impacts and adaptation in the Chesapeake Bay region: A systematic review. *Climate*, *8*(4), 58. https://doi.org/http://dx.doi.org/10.3390/cli8040058

Trevathan-Tackett, S. M., Allnutt, T. R., Sherman, C. D. H., Richardson, M. F., Crowley, T. M., & Macreadie, P. I. (2020). Spatial variation of bacterial and fungal communities of estuarine seagrass leaf microbiomes. *Aquatic Microbial Ecology*, *84*, 59. https://doi.org/http://dx.doi.org/10.3354/ame01926

Turner, N. J., Davidson-Hunt, I. J., & O'Flaherty, M. (2003). Living on the edge: Ecological and cultural edges as sources of diversity for social–ecological resilience. *Human Ecology, 31*(3), 439-461. https://www.jstor.org/stable/4603484

Vasconcelos, R. P., Batista, M. I., & Henriques, S. (2017). Current limitations of global conservation to protect higher vulnerability and lower resilience fish species. *Scientific Reports, 7*, Article 7702. https://doi.org/10.1038/s41598-017-06633-x

Verdelhos, T., Cardoso, P. G., Dolbeth, M., & Pardal, M. A. (2014). Recovery trends of *Scrobicularia plana* populations after restoration measures, affected by extreme climate events. *Marine Environmental Research*, *98*, 39-48. https://doi.org/10.1016/j.marenvres.2014.03.004

Weitkamp, L. A., Goulette, G., Hawkes, J., O'Malley, M., & Lipsky, C. (2014). Juvenile salmon in estuaries: comparisons between North American Atlantic and Pacific salmon populations. *Reviews in Fish Biology and Fisheries*, *24*(3), 713-736. https://doi.org/http://dx.doi.org/10.1007/s11160-014-9345-y

Williams, S. (2001). Reduced genetic diversity in Eelgrass transplantations affects both population growth and individual fitness. *Ecological Applications, 11*(5), 1472-1488. https://www.jstor.org/stable/3060933

Windham, R., Nunnally, A. P., & Quigg, A. (2019). Investigating *Rangia cuneata* clams as ecological response bioindicators to three decades of variable freshwater inflows. *Journal of Coastal Research, 35*(6), 1260-1270. https://doi.org/http://dx.doi.org/10.2112/JCOASTRES-D-18-00164.1

Wong, M. C., Griffiths, G., & Vercaemer, B. (2020). Seasonal response and recovery of eelgrass (*Zostera marina*) to short-term reductions in light availability. *Estuaries and Coasts, 43*(1), 120-134. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00664-5

Woo, I., Davis, M. J., Ellings, C. S., Hodgson, S., Takekawa, J. Y., Nakai, G., & Susan, E. W. D. L. C. (2019). A mosaic of estuarine habitat types with prey resources from multiple environmental strata supports a diversified foraging portfolio for juvenile chinook salmon. *Estuaries and Coasts, 42*(7), 1938-1954. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00613-2

Xie, Z., Liu, J., Zhu, G., Shao, Q., & Xu, X. (2011). Evaluating habitat change and boundary adjustment of a nature reserve in coastal wetlands: Case study of Beidagang Nature Reserve, China. *Journal of Coastal Research, 27*(5), 966-972.

http://gw2jh3xr2c.search.serialssolutions.com/directLink?&atitle=Evaluating+Habitat+Change+and+Boundary+Adjustment+of+a+Nature+Reserve+in+Coastal+Wetlands%3A+Case+Study+of+Beidagang+Nature+Reserve%2C+China&author=Xie%2C+Zhenglei%3BLiu%2C+Jiyuan%3BZhu%2C+Gaoru%3BShao%2C+Quanqin%3BXu%2C+Xuegong&issn=07490208&title=Journal+of+Coastal+Research&volume=27&issue=5&date=2011-09-01&spage=966&id=doi:&sid=ProQ_ss&genre=article

Zeldis, J. R., Depree, C., Gongol, C., South, P. M., Marriner, A., & Schiel, D. R. (2020). Trophic Indicators of Ecological Resilience in a Tidal Lagoon Estuary Following Wastewater Diversion and Earthquake Disturbance. *Estuaries and Coasts*, *43*(2), 223-239. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00637-8

Zhu, L., Chen, Q., Wang, H., Capurso, W., Niemoczynski, L., Hu, K., & Snedden, G. (2020). Field observations of wind waves in upper Delaware Bay with living shorelines. *Estuaries and Coasts*, *43*(4), 739-755. https://doi.org/http://dx.doi.org/10.1007/s12237-019-00670-7

Zou, Y.-a., Tang, C.-d., Niu, J.-y., Wang, T.-h., Xie, Y.-h., & Guo, H. (2016). Migratory Waterbirds Response to Coastal Habitat Changes: Conservation Implications from Long-term Detection in the Chongming Dongtan Wetlands, China. *Estuaries and Coasts*, *39*(1), 273-286. https://doi.org/http://dx.doi.org/10.1007/s12237-015-9991-x

Appendix 1 – Data Collection Table

ID	Author	Scale	Scope	Timeline	Results	Estuary Feature	Variable Studied	Pressure categories
1	Adams, J.B.; Taljaard, S., van Niekerk, L, Lemley, D.A.	Multiple Estuaries	comparison of water quality values in multiple estaries with respect to eutrophication from urban waste and farmland	1 time lit review data collection	Urban-industrial pollution impacts of eutrophication are greater than agricultural. Water quality is impacted by water residence time when there are ongoing pollution inputs.	Water	Algal Blooms	Pollution
1	Adams, J.B.; Taljaard, S., van Niekerk, L, Lemley, D.A.	Multiple Estuaries	comparison of water quality values in multiple estaries with respect to eutrophication from urban waste and farmland	1 time lit review data collection	Urban-industrial pollution impacts of eutrophication are greater than agricultural. Water quality is impacted by water residence time when there are ongoing pollution inputs.		Water Quality	
2	Alldred, M., Borrelli, J.J., Hoellein, T., Bruesewitz, D., Zarnoch, C.	One section of an estuary, multiple marshes	Core samples in marshes tested for oxygen, H2S, organic content, root density. Compared values between deteriorating and stable marsh. Compared values across constructed/ restored marshes of different ages. Discerned relationship between tidal inundation and H2S. Discerned relationship between belowground plant biomass, sediment oxygen, and sulfide dynamics	Data collected over roughly 2 years, 2015-2017. Estimation of constructed marsh performance over time based on review of marshes at different early ages. Cores collected during high tide and subject to 16-8 h light-dark cycle.	Existing stable marshes have double the plant matter below ground as constructed. Sediment H2S is positively correlated with tidal inundation timeframe/low elevation and negatively correlated with below-ground plant matter. Sediment oxygen is positively correlated with below-grade plant matter, marsh elevation	Salt Marsh	Sediment Quality	Modification - General
2	Alldred, M., Borrelli, J.J., Hoellein, T., Bruesewitz, D., Zarnoch, C.	One section of an estuary, multiple marshes	Core samples in marshes tested for oxygen, H2S, organic content, root density. Compared values between deteriorating and stable marsh. Compared values across constructed/ restored marshes of different ages. Discerned relationship between tidal inundation and H2S. Discerned relationship between belowground plant biomass, sediment oxygen, and sulfide dynamics	Data collected over roughly 2 years, 2015-2017. Estimation of constructed marsh performance over time based on review of marshes at different early ages. Cores collected during high tide and subject to 16-8 h light-dark cycle.	Existing stable marshes have double the plant matter below ground as constructed. Sediment H2S is positively correlated with tidal inundation timeframe/low elevation and negatively correlated with below-ground plant matter. Sediment oxygen is positively correlated with below-grade plant matter, marsh elevation		Restoration / Recove	Sea-level rise
2	Alldred, M., Borrelli, J.J., Hoellein, T., Bruesewitz, D., Zarnoch, C.	One section of an estuary, multiple marshes	Core samples in marshes tested for oxygen, H2S, organic content, root density. Compared values between deteriorating and stable marsh. Compared values across constructed/ restored marshes of different ages. Discerned relationship between tidal inundation and H2S. Discerned relationship between belowground plant biomass, sediment oxygen, and sulfide dynamics	Data collected over roughly 2 years, 2015-2017. Estimation of constructed marsh performance over time based on review of marshes at different early ages. Cores collected during high tide and subject to 16-8 h light-dark cycle.	Existing stable marshes have double the plant matter below ground as constructed. Sediment H2S is positively correlated with tidal inundation timeframe/low elevation and negatively correlated with below-ground plant matter. Sediment oxygen is positively correlated with below-grade plant matter, marsh elevation		Elevation	
2	Alldred, M., Borrelli, J.J., Hoellein, T., Bruesewitz, D., Zarnoch, C.	One section of an estuary, multiple marshes	Core samples in marshes tested for oxygen, H2S, organic content, root density. Compared values between deteriorating and stable marsh. Compared values across constructed/ restored marshes of different ages. Discerned relationship between tidal inundation and H2S. Discerned relationship between belowground plant biomass, sediment oxygen, and sulfide dynamics	Data collected over roughly 2 years, 2015-2017. Estimation of constructed marsh performance over time based on review of marshes at different early ages. Cores collected during high tide and subject to 16-8 h light-dark cycle.	Existing stable marshes have double the plant matter below ground as constructed. Sediment H2S is positively correlated with tidal inundation timeframe/low elevation and negatively correlated with below-ground plant matter. Sediment oxygen is positively correlated with below-grade plant matter, marsh elevation		Plant Response / Survival	
3	Anderson, T., Barrett, H., Morrisey, D.	Lab studies, specimens from multiple estuaries	Testing bivalve (Cockle) responses to different kinds of sediment inundation: -shallow and repeated (mimicking increased flood events) -deep burial (mimicking dramatic flooding) -disoriented (positioned upside down to mimic potential impac of flood)	Hourly/daily examination over 1 week per experiment	Cockles were slow to re-orient after sand burial but those in natural orientation surfaced quickly Repeated burial decreased capacity to resurface Cockles were resilient to deep burial	Sand Flats	Animal response / survival	Sediment fluxes
3	Anderson, T., Barrett, H., Morrisey, D.	Lab studies, specimens from multiple estuaries	Testing bivalve (Cockle) responses to different kinds of sediment inundation: -shallow and repeated (mimicking increased flood events) -deep burial (mimicking dramatic flooding) -disoriented (positioned upside down to mimic potential impac of flood)	Hourly/daily examination over 1 week per experiment	Cockles were slow to re-orient after sand burial but those in natural orientation surfaced quickly Repeated burial decreased capacity to resurface Cockles were resilient to deep burial	Bivalves		Sediment fluxes
4	Aurelio, M., Faleiro, F., Lopes, V.M., Pires, V., Lopes, A.R., Pimentel, M.S., Repolho, T., Baptista, M., Narciso, L., Rosa, R.	Lab studies, specimens from one estuary	Testing seahorse physiological responses to warming temperatures at four increased temperature scenarios	1 month for seahorses to acclimatize to lab conditions, O2 consumption rates tested over 6 hours for adults, 4-6 hours for juveniles. Food intake tested daily. Ventilation rates were tested twice daily before each feeding. Behavioural patterns were tested twice daily after feeding	Increased temperature caused an increased metabolism, particularly in juveniles from 18-28 degrees C, until the temperature was increased to 30 degrees at which point metabolism plateaued. Increased temperature caused increased ventilation. Food intake was not impacted	Water	Animal response / survival	Water Temperature increase

4	Aurelio, M., Faleiro, F., Lopes, V.M., Pires, V., Lopes, A.R., Pimentel, M.S., Repolho, T., Baptista, M., Narciso, L., Rosa, R.	Lab studies, specimens from one estuary	Testing seahorse physiological responses to warming temperatures at four increased temperature scenarios	1 month for seahorses to acclimatize to lab conditions, O2 consumption rates tested over 6 hours for adults, 4-6 hours for juveniles. Food intake tested daily. Ventilation rates were tested twice daily before each feeding. Behavioural patterns were tested twice daily after feeding	Increased temperature caused an increased metabolism, particularly in juveniles from 18-28 degrees C, until the temperature was increased to 30 degrees at which point metabolism plateaued. Increased temperature caused increased ventilation. Food intake was not impacted	Fish		
5	Baily, B., Pearson, A.W.,	Nine salt-marsh sites in six estuaries	Reviewing salt-marsh decline from 1970-2000 from photographic mapping exercise	30 years (1970-2000) - photos from sporadic intervals across the 30 year timespan	Loss of salt-marsh area ranged across the estuaries from 26.5% to 63% over the 30 years. Average loss rate of 2.13% per year across all. Dissection and fragmentation have occurred over time. Frontal erosion is coupled with widening creeks. [Interpretation] Loss can be attributed to shoreline re-alignment, land reclamation schemes. One harbour showed stability and slight increase due to ongoing sedimentation and accretion.	Salt Marsh	Habitat Distribution	Shoreline realignment
5	Baily, B., Pearson, A.W.,	Nine salt-marsh sites in six estuaries	Reviewing salt-marsh decline from 1970-2000 from photographic mapping exercise	30 years (1970-2000) - photos from sporadic intervals across the 30 year timespan	Loss of salt-marsh area ranged across the estuaries from 26.5% to 63% over the 30 years. Average loss rate of 2.13% per year across all. Dissection and fragmentation have occurred over time. Frontal erosion is coupled with widening creeks. [Interpretation] Loss can be attributed to shoreline re-alignment, land reclamation schemes. One harbour showed stability and slight increase due to ongoing sedimentation and accretion.		Sediment fluxes	Land reclamation
5	Baily, B., Pearson, A.W.,	Nine salt-marsh sites in six estuaries	Reviewing salt-marsh decline from 1970-2000 from photographic mapping exercise	30 years (1970-2000) - photos from sporadic intervals across the 30 year timespan	Loss of salt-marsh area ranged across the estuaries from 26.5% to 63% over the 30 years. Average loss rate of 2.13% per year across all. Dissection and fragmentation have occurred over time. Frontal erosion is coupled with widening creeks. [Interpretation] Loss can be attributed to shoreline re-alignment, land reclamation schemes. One harbour showed stability and slight increase due to ongoing sedimentation and accretion.		Sediment fluxes	
6	Barr, N., Zeldis, J., Scheuer, K., Schiel, D.	Multiple sites, one estuary	Water quality was studied (NH4-N, NO3-N, DIN, DRP) at 7 sites across Avon-Heathcote Estuary, New Zealand. Percent algal cover was studied at 17 sites within the same estuary, two of which included algal biochemistry monitoring to test for rate of recovery from the impacts of eutrophication after point-source waste dumping into the estuary ceased.	Seven years (2007-2014). Annual change immediately after waste discharge into the estuary ceased.	Clear reductions of NH4, DIN and DRP at most sites following wastewater diversion. Lower reduction of NO3 as it is sourced by the rivers but clear reduction nonetheless. Riverborne N loads appear to be increasing in frequency. Releases from the two earthquakes did not significantly impact reduction rates Clear reductions in seawater DIN concentrations, algal chlorophyll and algal tissue N-indices post-diversion. Clear reduction in algal percent cover post diversion.	Water	Algal Blooms	Pollution
6	Barr, N., Zeldis, J., Scheuer, K., Schiel, D.	Multiple sites, one estuary	Water quality was studied (NH4-N, NO3-N, DIN, DRP) at 7 sites across Avon-Heathcote Estuary, New Zealand. Percent algal cover was studied at 17 sites within the same estuary, two of which included algal biochemistry monitoring to test for rate of recovery from the impacts of eutrophication after point-source waste dumping into the estuary ceased.	Seven years (2007-2014). Annual change immediately after waste discharge into the estuary ceased.	Clear reductions of NH4, DIN and DRP at most sites following wastewater diversion. Lower reduction of NO3 as it is sourced by the rivers but clear reduction nonetheless. Riverborne N loads appear to be increasing in frequency. Releases from the two earthquakes did not significantly impact reduction rates Clear reductions in seawater DIN concentrations, algal chlorophyll and algal tissue N-indices post-diversion. Clear reduction in algal percent cover post diversion.		Water Quality	Eutrophication
7	Basso, G., Vaudrey, J. M. P., O'Brien, K., Barrett, J.	Multiple Estuaries	Applying a habitat assessment framework, including metrics for measuring ecosystem health for priority estuarine habitats, to determine overall health of LIS estuaries	One time data collection from records	Tidal wetlands, eelgrass, and coastal forests are in poor condition, coastal embayments are in fair condition. 3 basins range in terms of tidal flushing, population density, nutrient loads, and impervious cover. In west/central basins, eelgrass has the lowest health, next to wetlands and then forests. In the east, forests have lowest health, next to wetlands.	Salt Marsh	General Health	Modification - General
7	Basso, G., Vaudrey, J. M. P., O'Brien, K., Barrett, J.	Multiple Estuaries	Applying a habitat assessment framework, including metrics for measuring ecosystem health for priority estuarine habitats, to determine overall health of LIS estuaries	One time data collection from records	Tidal wetlands, eelgrass, and coastal forests are in poor condition, coastal embayments are in fair condition. 3 basins range in terms of tidal flushing, population density, nutrient loads, and impervious cover. In west/central basins, eelgrass has the lowest health, next to wetlands and then forests. In the east, forests have lowest health, next to wetlands.	Seagrass	Habitat Distribution	
8	Bednarsek, N., Pelletier, G., Ahmed, A., Feely, R. A.	Sea connecting multiple estuaries	Use of biogeochemical model (Salish Sea Model or SSM) to assess changes in chemical exposure since pre-industrial era using atmospheric CO2 and nutrient-caused eutrophication. Determining exposure and sensitivity for pteropods and dungeness crabs	2008 vs. hypothetical pre-industrial conditions of CO2, DIC, anthropogenic nutrient sources. Assumed values across 1780-2100.	Due to atmospheric CO2 and nutrient intake, ΩAR levels pre-industrially were higher than current (2008). Higher towards more shallow depths. PH levels have decreased. Early spring and late autumn periods show highest change in nutrient uptake. Eutrophication driven primary-production helps to increase ΩAR in the short term, but when phytoplankton decompose, further release of CO2 through respiration occurs, decreasing pH levels and ΩAR. However, majority of change is due to atmospheric CO2 uptake. Eutrophication had highest impact in small, stratified bays. CO2 uptake has highest impact in deep basins. Lower values suggest decreased ability of pteropods and larval crabs to develop exoskeletons. Future projections suggest conditions that will be lethal to larval crabs and pteropods.	Water		Ocean Acidification
8	Bednarsek, N., Pelletier, G., Ahmed, A., Feely, R. A.	Sea connecting multiple estuaries	Use of biogeochemical model (Salish Sea Model or SSM) to assess changes in chemical exposure since pre-industrial era using atmospheric CO2 and nutrient-caused eutrophication. Determining exposure and sensitivity for pteropods and dungeness crabs	2008 vs. hypothetical pre-industrial conditions of CO2, DIC, anthropogenic nutrient sources. Assumed values across 1780-2100.	Due to atmospheric CO2 and nutrient intake, ΩAR levels pre-industrially were higher than current (2008). Higher towards more shallow depths. PH levels have decreased. Early spring and late autumn periods show highest change in nutrient uptake. Eutrophication driven primary-production helps to increase ΩAR in the short term, but when phytoplankton decompose, further release of CO2 through respiration occurs, decreasing pH levels and ΩAR. However, majority of change is due to atmospheric CO2 uptake. Eutrophication had highest impact in small, stratified bays. CO2 uptake has highest impact in deep basins. Lower values suggest decreased ability of pteropods and larval crabs to develop exoskeletons. Future projections suggest conditions that will be lethal to larval crabs and pteropods.	crustaceans	Water Quality	Eutrophication
8	Bednarsek, N., Pelletier, G., Ahmed, A., Feely, R. A.	Sea connecting multiple estuaries	Use of biogeochemical model (Salish Sea Model or SSM) to assess changes in chemical exposure since pre-industrial era using atmospheric CO2 and nutrient-caused eutrophication. Determining exposure and sensitivity for pteropods and dungeness crabs	2008 vs. hypothetical pre-industrial conditions of CO2, DIC, anthropogenic nutrient sources. Assumed values across 1780-2100.	Due to atmospheric CO2 and nutrient intake, ΩAR levels pre-industrially were higher than current (2008). Higher towards more shallow depths. PH levels have decreased. Early spring and late autumn periods show highest change in nutrient uptake. Eutrophication driven primary-production helps to increase ΩAR in the short term, but when phytoplankton decompose, further release of CO2 through respiration occurs, decreasing pH levels and ΩAR. However, majority of change is due to atmospheric CO2 uptake. Eutrophication had highest impact in small, stratified bays. CO2 uptake has highest impact in deep basins. Lower values suggest decreased ability of pteropods and larval crabs to develop exoskeletons. Future projections suggest conditions that will be lethal to larval crabs and pteropods.		Animal Response / Survival	

9	Bekkby, T., Papadopoulou, N., Fiorentino, D., Owen,C. J., Rinde, E., Bostrom, C., Carreiro-Silva, M., Linares, C., Sogn-Andersen, G., Bengil, E. G. T., Bilan, M., Cebrian, E., Cerrano, C., Danovaro, R.	Mediterranean Sea, Baltic Sea, North-East Atlantic Ocean	Study of impact of biological and ecological features on restoration of habitat types (seagrass, kelp, macroalgal beds, coralligenous assemblages, cold-water coral)	One workshop with a range of experts. Conducted liturature review style research together to come up with restoration impacts	Slow-growing seagrass species require more recovery time but tend to be enduring. Populations with high connectivity tend to have higher genetic diversity, leading to higher levels of resilience to environmental purturbations. Isolated populations of clonal species tend to be more vulnerable. Wide spatial distribution associated with resilience due to higher capacity for genetic drift suggests large-scal planting for restoration efforts. Removal of anthropogenic stressors, including pollution and habitat destruction as well as maintaining populations of associated species (ie. predators) are important restoration goals.	Seagrass	Habitat Distribution	Pollution
9	Bekkby, T., Papadopoulou, N., Fiorentino, D., Owen,C. J., Rinde, E., Bostrom, C., Carreiro-Silva, M., Linares, C., Sogn-Andersen, G., Bengil, E. G. T., Bilan, M., Cebrian, E., Cerrano, C., Danovaro, R.	Mediterranean Sea, Baltic Sea, North-East Atlantic Ocean	Study of impact of biological and ecological features on restoration of habitat types (seagrass, kelp, macroalgal beds, coralligenous assemblages, cold-water coral)	One workshop with a range of experts. Conducted liturature review style research together to come up with restoration impacts	Slow-growing seagrass species require more recovery time but tend to be enduring. Populations with high connectivity tend to have higher genetic diversity, leading to higher levels of resilience to environmental purturbations. Isolated populations of clonal species tend to be more vulnerable. Wide spatial distribution associated with resilience due to higher capacity for genetic drift suggests large-scal planting for restoration efforts. Removal of anthropogenic stressors, including pollution and habitat destruction as well as maintaining populations of associated species (ie. predators) are important restoration goals.		Biodiversity	Modification - General
9	Bekkby, T., Papadopoulou, N., Fiorentino, D., Owen,C. J., Rinde, E., Bostrom, C., Carreiro-Silva, M., Linares, C., Sogn-Andersen, G., Bengil, E. G. T., Bilan, M., Cebrian, E., Cerrano, C., Danovaro, R.	Mediterranean Sea, Baltic Sea, North-East Atlantic Ocean	Study of impact of biological and ecological features on restoration of habitat types (seagrass, kelp, macroalgal beds, coralligenous assemblages, cold-water coral)	One workshop with a range of experts. Conducted liturature review style research together to come up with restoration impacts	Slow-growing seagrass species require more recovery time but tend to be enduring. Populations with high connectivity tend to have higher genetic diversity, leading to higher levels of resilience to environmental purturbations. Isolated populations of clonal species tend to be more vulnerable. Wide spatial distribution associated with resilience due to higher capacity for genetic drift suggests large-scal planting for restoration efforts. Removal of anthropogenic stressors, including pollution and habitat destruction as well as maintaining populations of associated species (ie. predators) are important restoration goals.		Plant Response / Survival	
10	Bennett, W. G., van Veelen, T. J., Fairchild, T. P., Griffin, J. N., Karunarathna, H	Taf Estuary, south-west Wales	Modelling study of hydrodynamic responses to coastal defense intervention during selected storm conditions. Interventions included hard defences, managed realignment, and altered lan use of saltmarshes	One-time study using coastal modelling software	Southwest storm: Water level changes as a result of interventions are insignificant. Wave heights are significantly increased on sites with grazed marshes and managed realignment. Ebb and flow velocities are significantly increased with grazed salt marshes. Easterly storm: Peak storm wave height, ebb and flow velocities are also most significantly impacted by grazing on the salt-marshes.	Morphology	Currents / Discharge / Hydrology	Grazing / mowing
10	Bennett, W. G., van Veelen, T. J., Fairchild, T. P., Griffin, J. N., Karunarathna, H	Taf Estuary, south-west Wales	Modelling study of hydrodynamic responses to coastal defense intervention during selected storm conditions. Interventions included hard defences, managed realignment, and altered lan use of saltmarshes	One-time study using coastal modelling software	Southwest storm: Water level changes as a result of interventions are insignificant. Wave heights are significantly increased on sites with grazed marshes and managed realignment. Ebb and flow velocities are significantly increased with grazed salt marshes. Easterly storm: Peak storm wave height, ebb and flow velocities are also most significantly impacted by grazing on the salt-marshes.	Salt Marsh		Shoreline realignment
11	Benvenuti, B., Walsh, J., O'Brien, K. M., Kovach, A. I.	536 saltmarsh sparrow nests, New Hampshire, Maine, and Massachusetts.	Review of levels of nest resilience based on different characteristics of nests. Sparrow behaviour in location placement and building type of nests	Nesting season over five years (2011-2015)	5% of nests experienced partial flooding and depredation. Successful and depredated nests were built a higher elevations than flooded. Fledged nests more likely to have full or partial canopy than flooded. Females exhibit high fidelity in nest sites and are likely to change site selection and structure if previous attempts failed.	Salt Marsh	Animal Response / Survival	Sea-level rise
11	Benvenuti, B., Walsh, J., O'Brien, K. M., Kovach, A. I.	536 saltmarsh sparrow nests, New Hampshire, Maine, and Massachusetts.	Review of levels of nest resilience based on different characteristics of nests. Sparrow behaviour in location placement and building type of nests	Nesting season over five years (2011-2015)	5% of nests experienced partial flooding and depredation. Successful and depredated nests were built a higher elevations than flooded. Fledged nests more likely to have full or partial canopy than flooded. Females exhibit high fidelity in nest sites and are likely to change site selection and structure if previous attempts failed.	Birds		Modification - General
12	Biber, P. D., Gallegos, C. L., Kenworthy, W. J.	Nine water quality sampling stations and three seagrass deep-edge locations in North Carolina's North River Estuary	Measurement of water quality for optical properties to test seagrass access to light. Includes nonalgal particulates, phytoplankton, and colored dissolved organic matter (Kpar value).	Two years. Monthly intervals from September 2002 to late August 2004.	Seagrass requires a minimum of 22% surface irradiance or higher at any given depth to survive. Turbidity has largest impact on light attenuation, followed by CDOM, and then phytoplankton, but each provide significant contributions. Turbidity is positively related to non-algal particulate absorption and particulate scattering. Chlorophyll A is positively correlated to absorption by phytoplankton. Seasonal changes were site specific, but summer generally had higher turbidity and chlorophyl a levels.	Seagrass	Light access / attenuation	Turbidity
12	Biber, P. D., Gallegos, C. L., Kenworthy, W. J.	Nine water quality sampling stations and three seagrass deep-edge locations in North Carolina's North River Estuary	Measurement of water quality for optical properties to test seagrass access to light. Includes nonalgal particulates, phytoplankton, and colored dissolved organic matter (Kpar value).	Two years. Monthly intervals from September 2002 to late August 2004.	Seagrass requires a minimum of 22% surface irradiance or higher at any given depth to survive. Turbidity has largest impact on light attenuation, followed by CDOM, and then phytoplankton, but each provide significant contributions. Turbidity is positively related to non-algal particulate absorption and particulate scattering. Chlorophyll A is positively correlated to absorption by phytoplankton. Seasonal changes were site specific, but summer generally had higher turbidity and chlorophyl a levels.	Water	Plant Response / Surv	Eutrophication
12	Biber, P. D., Gallegos, C. L., Kenworthy, W. J.	Nine water quality sampling stations and three seagrass deep-edge locations in North Carolina's North River Estuary	Measurement of water quality for optical properties to test seagrass access to light. Includes nonalgal particulates, phytoplankton, and colored dissolved organic matter (Kpar value).	Two years. Monthly intervals from September 2002 to late August 2004.	Seagrass requires a minimum of 22% surface irradiance or higher at any given depth to survive. Turbidity has largest impact on light attenuation, followed by CDOM, and then phytoplankton, but each provide significant contributions. Turbidity is positively related to non-algal particulate absorption and particulate scattering. Chlorophyll A is positively correlated to absorption by phytoplankton. Seasonal changes were site specific, but summer generally had higher turbidity and chlorophyl a levels.	Phytoplankton		
13	Booty, J. M., Underwood, G. J. C., Parris, A., Davies, R. G., Tolhurst, T. J.	400m2 mudflat in Essex, UK.	20 1m2 plots established, 10 unmanipulated, and 10 bamboo exclosures to prevent use by shorebirds. Measured values for erosion protection and nutrient cycling	3.5 months, from January 20 to April 3, 2017	surface chlorophyl a biofilm was measured to be higher in bird exclusion plots during times of high bird density Sediment critical erosion threshold was measured to be smaller in shorebird presence vs. higher during absence Higher nitrate influx occurred in plots of bird absence. No significant changes were found in phosphate or DOC fluxes. No significant difference was found in macrofaunal density of the sites	Mudflats	Sediment Quality	Diversity Loss
13	Booty, J. M., Underwood, G. J. C., Parris, A., Davies, R. G., Tolhurst, T. J.	400m2 mudflat in Essex, UK.	20 1m2 plots established, 10 unmanipulated, and 10 bamboo exclosures to prevent use by shorebirds. Measured values for erosion protection and nutrient cycling	3.5 months, from January 20 to April 3, 2017	surface chlorophyl a biofilm was measured to be higher in bird exclusion plots during times of high bird density Sediment critical erosion threshold was measured to be smaller in shorebird presence vs. higher during absence Higher nitrate influx occurred in plots of bird absence. No significant changes were found in phosphate or DOC fluxes. No significant difference was found in macrofaunal density of the sites	Birds	Microbial response / survival	Sediment fluxes

13	Booty, J. M., Underwood, G. J. C., Parris, A., Davies, R. G., Tolhurst, T. J.	400m2 mudflat in Essex, UK.	20 1m2 plots established, 10 unmanipulated, and 10 bamboo exclosures to prevent use by shorebirds. Measured values for erosion protection and nutrient cycling	3.5 months, from January 20 to April 3, 2017	surface chlorophyl a biofilm was measured to be higher in bird exclusion plots during times of high bird density Sediment critical erosion threshold was measured to be smaller in shorebird presence vs. higher during absence Higher nitrate influx occurred in plots of bird absence. No significant changes were found in phosphate or DOC fluxes. No significant difference was found in macrofaunal density of the sites	Microbiome	Sediment fluxes	
14	Bordalo, M.D., Ferreira, S.M.F., Cardoso, P.G., Leston, S., Pardal, M.A.	3 sections of the Mondego estuary, including a Z. noltii bed, a recovering mudflat (previously a Z. noltii bed), and a sand flat area	Macrobenthic sampling at all plots, including sediment cores, plant matter (macroalgae and z. nolteii), and animal data of cyathura carinata (isopod - sex, length, and density), climate data also collected	2 distinct periods: -Jan 1993-Sept1995 (2.75 years) prior to restoration from eutrophication -Feb 1999-Nov 2008 (9.75 years) after restoration, Monthly samples	weather showed hotter and drier averages in the post-millennial decade compared to the previous decade. Seagrass beds showed clear deterioration before restoration and improvement after restoration, which included increasing water transparency, reducing water residence time, and reducing nutrient loading i 1998. Macroalgal blooms no longer evident on sand flat after restoration and seagrass was recolonizing the mudflat. Cyathura carinata was most abundant in the sand flat, showed consistent seasonal density patterns, an populations in the z.noltii and sandflat increased after restoration. However, they decreased immediately following extreme weather events of a heat wave and drought. Density was most highly correlated with salinity and organic matter in the z.noltii bed and in the intermediate area, plant biomass, DO, PH, and temp were important. In the sand flat, precipitation and temp (both water and air) were correlated with density. Populations decreased during heat waves, droughts, floods, and macroalgal blooms.	Seagrass	Animal response / survival	Eutrophication
14	Bordalo, M.D., Ferreira, S.M.F., Cardoso, P.G., Leston, S., Pardal, M.A.	3 sections of the Mondego estuary, including a Z. noltii bed, a recovering mudflat (previously a Z. noltii bed), and a sand flat area	Macrobenthic sampling at all plots, including sediment cores, plant matter (macroalgae and z. nolteii), and animal data of cyathura carinata (isopod - sex, length, and density), climate data also collected	2 distinct periods: -Jan 1993-Sept1995 (2.75 years) prior to restoration from eutrophication -Feb 1999-Nov 2008 (9.75 years) after restoration, Monthly samples	weather showed hotter and drier averages in the post-millennial decade compared to the previous decade. Seagrass beds showed clear deterioration before restoration and improvement after restoration, which included increasing water transparency, reducing water residence time, and reducing nutrient loading i 1998. Macroalgal blooms no longer evident on sand flat after restoration and seagrass was recolonizing the mudflat. Cyathura carinata was most abundant in the sand flat, showed consistent seasonal density patterns, an populations in the z.noltii and sandflat increased after restoration. However, they decreased immediately following extreme weather events of a heat wave and drought. Density was most highly correlated with salinity and organic matter in the z.noltii bed and in the intermediate area, plant biomass, DO, PH, and temp were important. In the sand flat, precipitation and temp (both water and air) were correlated with density. Populations decreased during heat waves, droughts, floods, and macroalgal blooms.	Sand Flats	Restoration / Recovery	Drought
14	Bordalo, M.D., Ferreira, S.M.F., Cardoso, P.G., Leston, S., Pardal, M.A.	3 sections of the Mondego estuary, including a Z. noltii bed, a recovering mudflat (previously a Z. noltii bed), and a sand flat area	Macrobenthic sampling at all plots, including sediment cores, plant matter (macroalgae and z. nolteii), and animal data of cyathura carinata (isopod - sex, length, and density), climate data also collected	2 distinct periods: -Jan 1993-Sept1995 (2.75 years) prior to restoration from eutrophication -Feb 1999-Nov 2008 (9.75 years) after restoration, Monthly samples	weather showed hotter and drier averages in the post-millennial decade compared to the previous decade. Seagrass beds showed clear deterioration before restoration and improvement after restoration, which included increasing water transparency, reducing water residence time, and reducing nutrient loading i 1998. Macroalgal blooms no longer evident on sand flat after restoration and seagrass was recolonizing the mudflat. Cyathura carinata was most abundant in the sand flat, showed consistent seasonal density patterns, an populations in the z.noltii and sandflat increased after restoration. However, they decreased immediately following extreme weather events of a heat wave and drought. Density was most highly correlated with salinity and organic matter in the z.noltii bed and in the intermediate area, plant biomass, DO, PH, and temp were important. In the sand flat, precipitation and temp (both water and air) were correlated with density. Populations decreased during heat waves, droughts, floods, and macroalgal blooms.	Invertebrates	Biodiversity	Freshwater flows / precipitation
14	Bordalo, M.D., Ferreira, S.M.F., Cardoso, P.G., Leston, S., Pardal, M.A.	3 sections of the Mondego estuary, including a Z. noltii bed, a recovering mudflat (previously a Z. noltii bed), and a sand flat area	Macrobenthic sampling at all plots, including sediment cores, plant matter (macroalgae and z. nolteii), and animal data of cyathura carinata (isopod - sex, length, and density), climate data also collected	2 distinct periods: -Jan 1993-Sept1995 (2.75 years) prior to restoration from eutrophication -Feb 1999-Nov 2008 (9.75 years) after restoration, Monthly samples	weather showed hotter and drier averages in the post-millennial decade compared to the previous decade. Seagrass beds showed clear deterioration before restoration and improvement after restoration, which included increasing water transparency, reducing water residence time, and reducing nutrient loading i 1998. Macroalgal blooms no longer evident on sand flat after restoration and seagrass was recolonizing the mudflat. Cyathura carinata was most abundant in the sand flat, showed consistent seasonal density patterns, an populations in the z.noltii and sandflat increased after restoration. However, they decreased immediately following extreme weather events of a heat wave and drought. Density was most highly correlated with salinity and organic matter in the z.noltii bed and in the intermediate area, plant biomass, DO, PH, and temp were important. In the sand flat, precipitation and temp (both water and air) were correlated with density. Populations decreased during heat waves, droughts, floods, and macroalgal blooms.		Plant Density	
15	Boulais, M., Chenevert, K.J., Demey, A.T., Darrow, E.S., Robison, M.R., Roberts, J.P., Volety, A.	Oysters collected from hatchery and tested in lab setting in North Carolina	Subjecting oysters to different pH levels to determine impact on gametogenesis, fertilization, and early larval development success	5 weeks with regular monitoring in lab setting	oogenesis was more sensitive to severe OA than spermatogenesis, with significant differences occurring at pH = 7.1-6.7. Gametogenesis was showing delays at 7.1, and complete inhibition at 6.7. Sex ratios were different at 6.7	Bivalves	Animal Response / Survival	Ocean Acidification
15	Boulais, M., Chenevert, K.J., Demey, A.T., Darrow, E.S., Robison, M.R., Roberts, J.P., Volety, A.	Oysters collected from hatchery and tested in lab setting in North Carolina	Subjecting oysters to different pH levels to determine impact on gametogenesis, fertilization, and early larval development success	5 weeks with regular monitoring in lab setting	oogenesis was more sensitive to severe OA than spermatogenesis, with significant differences occurring at pH = 7.1-6.7. Gametogenesis was showing delays at 7.1, and complete inhibition at 6.7. Sex ratios were different at 6.7		Water Quality	

16	Breckenridge, J., Pakhomov, E., Emry, S., Mahara, N.	Five slough and channel areas of the Fraser River Estuary	Zooplankton (copepod) biomass and production compared against salinity/stratification, temperature, turbidity, fluorescence, and productivity	bi-weekly to monthly sampling over 3 years (33 months, 2015-2018). Assessment of seasonal impacts	Channel areas showed generally higher salinity levels than slough areas. Chlorophyl α = peaked in May but showed higher numbers between March and July (channels) and Feb to Aug (slough). Minimum copepod abundances at channel stations occurred April through June at, peak abundances occurred in August and Sept Mean copepod abundances were highest at slough stations over channel, where min abundances occurred in Dec, and peak abundances occurred in sept, with lower peak in Apr-May. Copepod abundance and biomass increased with temperature, but less significantly in channels than sloughs. Abundance and biomass decreased with discharge. More estuarine specific copepods were found in sloughs compared to channels, which had more freshwater and marine specific organisms.	Water	Species Composition	Channelization
16	Breckenridge, J., Pakhomov, E., Emry, S., Mahara, N.	Five slough and channel areas of the Fraser River Estuary	Zooplankton (copepod) biomass and production compared against salinity/stratification, temperature, turbidity, fluorescence, and productivity	bi-weekly to monthly sampling over 3 years (33 months, 2015-2018). Assessment of seasonal impacts	Channel areas showed generally higher salinity levels than slough areas. Chlorophyl α = peaked in May but showed higher numbers between March and July (channels) and Feb to Aug (slough). Minimum copepod abundances at channel stations occurred April through June at, peak abundances occurred in August and Sept Mean copepod abundances were highest at slough stations over channel, where min abundances occurred in Dec, and peak abundances occurred in sept, with lower peak in Apr-May. Copepod abundance and biomass increased with temperature, but less significantly in channels than sloughs. Abundance and biomass decreased with discharge. More estuarine specific copepods were found in sloughs compared to channels, which had more freshwater and marine specific organisms.	Morphology	Biodiversity	Water temperature increase
16	Breckenridge, J., Pakhomov, E., Emry, S., Mahara, N.	Five slough and channel areas of the Fraser River Estuary	Zooplankton (copepod) biomass and production compared against salinity/stratification, temperature, turbidity, fluorescence, and productivity	bi-weekly to monthly sampling over 3 years (33 months, 2015-2018). Assessment of seasonal impacts	Channel areas showed generally higher salinity levels than slough areas. Chlorophyl α = peaked in May but showed higher numbers between March and July (channels) and Feb to Aug (slough). Minimum copepod abundances at channel stations occurred April through June at, peak abundances occurred in August and Sept Mean copepod abundances were highest at slough stations over channel, where min abundances occurred in Dec, and peak abundances occurred in sept, with lower peak in Apr-May. Copepod abundance and biomass increased with temperature, but less significantly in channels than sloughs. Abundance and biomass decreased with discharge. More estuarine specific copepods were found in sloughs compared to channels, which had more freshwater and marine specific organisms.	Zooplankton	Habitat Distribution	
16	Breckenridge, J., Pakhomov, E., Emry, S., Mahara, N.	Five slough and channel areas of the Fraser River Estuary	Zooplankton (copepod) biomass and production compared against salinity/stratification, temperature, turbidity, fluorescence, and productivity	bi-weekly to monthly sampling over 3 years (33 months, 2015-2018). Assessment of seasonal impacts	Channel areas showed generally higher salinity levels than slough areas. Chlorophyl α = peaked in May but showed higher numbers between March and July (channels) and Feb to Aug (slough). Minimum copepod abundances at channel stations occurred April through June at, peak abundances occurred in August and Sept Mean copepod abundances were highest at slough stations over channel, where min abundances occurred in Dec, and peak abundances occurred in sept, with lower peak in Apr-May. Copepod abundance and biomass increased with temperature, but less significantly in channels than sloughs. Abundance and biomass decreased with discharge. More estuarine specific copepods were found in sloughs compared to channels, which had more freshwater and marine specific organisms.		Habitat Connectivity	
17	Brooks, K. L., Mossman, H.L., Chitty, J. L., Grant, A.	Salt marsh area in Abbotts Hall, located in Blackwater Estuary, UK.	Site previously reclaimed for grazing (18th century) and arable use (1943-1970) was realigned to allow tidal flow (1994). Two sites within the restored marshland and one outside the restoration area were assessed. One of the sites in the restored marshland had an artificially excavated creek. 100 samples taken from each site to assess vegetation, soil characteristics, elevation, redox potential, soil shear strength, soil water content, organic matter content.	One round of sampling in August, 2009.	Reference marsh had significantly different plant community composition than both restored marsh sites, although the engineered creek showed more similarities to the reference marsh than the site with no engineered watercourse. Reference marsh had complete vegetation cover at elevation, whereas both restored sites had partial vegetation cover. Elevation was static on non-engineered restored site but varied on the engineered restored site (with largest range) and the highest diversity in elevation was on the reference site. Redox potential was higher on non-engineered site. Shear strength highest on engineered site (>80kPa), then non-engineered (still >80kPa), then reference (<40kPa). Water content decreased with increased elevation on both restored sites but remained high on the reference marsh. Reference marsh had higher organic content than both restored sites.	Salt Marsh	Restoration / Recovery	Grazing / mowing
17	Brooks, K. L., Mossman, H.L., Chitty, J. L., Grant, A.	Salt marsh area in Abbotts Hall, located in Blackwater Estuary, UK.	Site previously reclaimed for grazing (18th century) and arable use (1943-1970) was realigned to allow tidal flow (1994). Two sites within the restored marshland and one outside the restoration area were assessed. One of the sites in the restored marshland had an artificially excavated creek. 100 samples taken from each site to assess vegetation, soil characteristics, elevation, redox potential, soil shear strength, soil water content, organic matter content.	One round of sampling in August, 2009.	Reference marsh had significantly different plant community composition than both restored marsh sites, although the engineered creek showed more similarities to the reference marsh than the site with no engineered watercourse. Reference marsh had complete vegetation cover at elevation, whereas both restored sites had partial vegetation cover. Elevation was static on non-engineered restored site but varied on the engineered restored site (with largest range) and the highest diversity in elevation was on the reference site. Redox potential was higher on non-engineered site. Shear strength highest on engineered site (>80kPa), then non-engineered (still >80kPa), then reference (<40kPa). Water content decreased with increased elevation on both restored sites but remained high on the reference marsh. Reference marsh had higher organic content than both restored sites.	Morphology	Plant Diversity	Land reclamation

17	Brooks, K. L., Mossman, H.L., Chitty, J. L., Grant, A.	Salt marsh area in Abbotts Hall, located in Blackwater Estuary, UK.	Site previously reclaimed for grazing (18th century) and arable use (1943-1970) was realigned to allow tidal flow (1994). Two sites within the restored marshland and one outside the restoration area were assessed. One of the sites in the restored marshland had an artificially excavated creek. 100 samples taken from each site to assess vegetation, soil characteristics, elevation, redox potential, soil shear strength, soil water content, organic matter content.	One round of sampling in August, 2009.	Reference marsh had significantly different plant community composition than both restored marsh sites, although the engineered creek showed more similarities to the reference marsh than the site with no engineered watercourse. Reference marsh had complete vegetation cover at elevation, whereas both restored sites had partial vegetation cover. Elevation was static on non-engineered restored site but varied on the engineered restored site (with largest range) and the highest diversity in elevation was on the reference site. Redox potential was higher on non-engineered site. Shear strength highest on engineered site (>80kPa), then non-engineered (still >80kPa), then reference (<40kPa). Water content decreased with increased elevation on both restored sites but remained high on the reference marsh. Reference marsh had higher organic content than both restored sites.		Plant Density	
17	Brooks, K. L., Mossman, H.L., Chitty, J. L., Grant, A.	Salt marsh area in Abbotts Hall, located in Blackwater Estuary, UK.	Site previously reclaimed for grazing (18th century) and arable use (1943-1970) was realigned to allow tidal flow (1994). Two sites within the restored marshland and one outside the restoration area were assessed. One of the sites in the restored marshland had an artificially excavated creek. 100 samples taken from each site to assess vegetation, soil characteristics, elevation, redox potential, soil shear strength, soil water content, organic matter content.	One round of sampling in August, 2009.	Reference marsh had significantly different plant community composition than both restored marsh sites, although the engineered creek showed more similarities to the reference marsh than the site with no engineered watercourse. Reference marsh had complete vegetation cover at elevation, whereas both restored sites had partial vegetation cover. Elevation was static on non-engineered restored site but varied on the engineered restored site (with largest range) and the highest diversity in elevation was on the reference site. Redox potential was higher on non-engineered site. Shear strength highest on engineered site (>80kPa), then non-engineered (still >80kPa), then reference (<40kPa). Water content decreased with increased elevation on both restored sites but remained high on the reference marsh. Reference marsh had higher organic content than both restored sites.		Habitat Distribution	
18	Bueno-Pardo, J., Garcia-Seoane, E., Sousa, A.I., Coelho, J.P., Morgado, M., Frankenbach, S., Ezequiel, J, Vaz, N., Quintino, V., Rodrigues, A.M., Leandro, S., Luis, A., Serodio, J., Cunha, M.R., Calado, A.J., Lillebo, A., Rebelo, J.E., Queiroga, H.	Sub and intertidal zones of Ria de Aveiro, Portugal	Use of Ecopath modelling software to develop trophic model of biomass using 26 functional groups (producers to top predators) and 3 different fisheries.	Data was collected from the years 2004-2014	Only half of planktivorous production was predated within the system but almost all of the zooplankton was predated (95%) by secondary consumers. Biomass accumulation was high for sediment organic matter and halophyte litter and was highly exploited by zoobenthivorous fish, omnivorous fish, and cephalopods. Main flows to detritus were halophytes and microphytobenthos as well as gastropods and annelids. System is dominated by primary producers followed by detritus. Invertebrates link organic sediments and predators. Artisanal and leisure fisheries have strong impacts on the system. As functional groups, bivalves, amphipods, isopods, cumaceans, tanaidaceans, gastropods, decapods, and phytoplankton have strong positive impacts on the food web Keystone indices showed relevance of piscivorous birds, detritivorous fish, and zooplankton	Food Web	Biodiversity	Baseline assessment
19	Cardoso, P.G. Raffaeli, D., Lillebo, A.I., Verdelhos, T., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between.	Macrobenthic sampling drilling 6 to 10 (13.5cm) cores to depth of 20cm at each sampling site to assess changes in macrobenthic densities, biomass, species richness. Gleaned impacts of flooding events on each	Jan 1993 to Sep 1995 (prior to restoration from eutrophication) and Feb 1999 to Dec 2002 (after restoration). Biweekly samples for first 18 months and monthly samples thereafter	Three events of higher than average precipitation occurred during the sampling period: autumn 1993/1994, winter 1995/1006, winter 2000/2001. Macrobenthic density fluctuated seasonally in the Z. noltii bed pre-restoration, biomass increased. Density and biomass fluctuated seasonally in eutrophic area due to algal blooms. Post restoration, biomass recovered faster than density but was impacted by flooding events. Detritovores and herbivores were most representative groups. Detritovores dominated by surface deposit feeders. Detritovores declined alongside z. noltii due to eutrophication but recovered concurrently after restoration. Detritovores also showed decline after 2001 flood in seagrass bed. Sub-surface deposit feeders showed steady increase over 10 year period in eutrophic area. In intermediate area, omnivores increased steadily while detritovores decreased. Seagrass bed generally provided better species richness but lower evenness over 10 years than other sites. Diversity increased steadily after restoration from eutrophication but declined after the floods.	Seagrass	Restoration / Recovery	Eutrophication
19	Cardoso, P.G. Raffaeli, D., Lillebo, A.I., Verdelhos, T., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between.	Macrobenthic sampling drilling 6 to 10 (13.5cm) cores to depth of 20cm at each sampling site to assess changes in macrobenthic densities, biomass, species richness. Gleaned impacts of flooding events on each	Jan 1993 to Sep 1995 (prior to restoration from eutrophication) and Feb 1999 to Dec 2002 (after restoration). Biweekly samples for first 18 months and monthly samples thereafter	Three events of higher than average precipitation occurred during the sampling period: autumn 1993/1994, winter 1995/1006, winter 2000/2001. Macrobenthic density fluctuated seasonally in the Z. noltii bed pre-restoration, biomass increased. Density and biomass fluctuated seasonally in eutrophic area due to algal blooms. Post restoration, biomass recovered faster than density but was impacted by flooding events. Detritovores and herbivores were most representative groups. Detritovores dominated by surface deposit feeders. Detritovores declined alongside z. noltii due to eutrophication but recovered concurrently after restoration. Detritovores also showed decline after 2001 flood in seagrass bed. Sub-surface deposit feeders showed steady increase over 10 year period in eutrophic area. In intermediate area, omnivores increased steadily while detritovores decreased. Seagrass bed generally provided better species richness but lower evenness over 10 years than other sites. Diversity increased steadily after restoration from eutrophication but declined after the floods.	Mudflats	Biodiversity	Freshwater flows / precipitation

19	Cardoso, P.G. Raffaeli, D., Lillebo, A.I., Verdelhos, T., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between.	Macrobenthic sampling drilling 6 to 10 (13.5cm) cores to depth of 20cm at each sampling site to assess changes in macrobenthic densities, biomass, species richness. Gleaned impacts of flooding events on each	Jan 1993 to Sep 1995 (prior to restoration from eutrophication) and Feb 1999 to Dec 2002 (after restoration). Biweekly samples for first 18 months and monthly samples thereafter	Three events of higher than average precipitation occurred during the sampling period: autumn 1993/1994, winter 1995/1006, winter 2000/2001. Macrobenthic density fluctuated seasonally in the Z. noltii bed pre-restoration, biomass increased. Density and biomass fluctuated seasonally in eutrophic area due to algal blooms. Post restoration, biomass recovered faster than density but was impacted by flooding events. Detritovores and herbivores were most representative groups. Detritovores dominated by surface deposit feeders. Detritovores declined alongside z. noltii due to eutrophication but recovered concurrently after restoration. Detritovores also showed decline after 2001 flood in seagrass bed. Sub-surface deposit feeders showed steady increase over 10 year period in eutrophic area. In intermediate area, omnivores increased steadily while detritovores decreased. Seagrass bed generally provided better species richness but lower evenness over 10 years than other sites. Diversity increased steadily after restoration from eutrophication but declined after the floods.	Food Web		
19	Cardoso, P.G. Raffaeli, D., Lillebo, A.I., Verdelhos, T., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between.	Macrobenthic sampling drilling 6 to 10 (13.5cm) cores to depth of 20cm at each sampling site to assess changes in macrobenthic densities, biomass, species richness. Gleaned impacts of flooding events on each	Jan 1993 to Sep 1995 (prior to restoration from eutrophication) and Feb 1999 to Dec 2002 (after restoration). Biweekly samples for first 18 months and monthly samples thereafter	Three events of higher than average precipitation occurred during the sampling period: autumn 1993/1994, winter 1995/1996, winter 2000/2001. Macrobenthic density fluctuated seasonally in the Z. noltii bed pre-restoration, biomass increased. Density and biomass fluctuated seasonally in eutrophic area due to algal blooms. Post restoration, biomass recovered faster than density but was impacted by flooding events. Detritovores and herbivores were most representative groups. Detritovores dominated by surface deposit feeders. Detritovores declined alongside z. noltii due to eutrophication but recovered concurrently after restoration. Detritovores also showed decline after 2001 flood in seagrass bed. Sub-surface deposit feeders showed steady increase over 10 year period in eutrophic area. In intermediate area, omnivores increased steadily while detritovores decreased. Seagrass bed generally provided better species richness but lower evenness over 10 years than other sites. Diversity increased steadily after restoration from eutrophication but declined after the floods.	Invertebrates	Species Composition	
20	Carroll, J.M., Furman, B.T., Jackson, L.J., Hunter, E.A., Peterson, B.J.	Patchy Zostera marina meadow in Shinnecock Bay, New York	Seed predation units installed (wood board with 10 fastened seeds) in 158 patches and 53 in adjacent unvegetated patches for 7-15 days. SPUs were placed at the interior and edge of the 40 largest patches. Predator abundance was tested at three sites by suction dredging. Objective was to identify characteristics of seed predation in seagrass meadow	1-2 weeks over Summer of 2012. One time data collection of predator abundance	Seed predation was highest within the z. marina patches and lowest in the unvegetated sandy plots. Seed predation was lower in larger patch sizes and higher within the center of the patch versus the edge. slight negative relationship between patch size and predator density, as well as % cover and predator density slight positive relationship between patch size and isopod density/prey density. slight negative relationship between % cover and isopod density/prey density	Seagrass	Habitat Distribution	Invasive Species
20	Carroll, J.M., Furman, B.T., Jackson, L.J., Hunter, E.A., Peterson, B.J.	Patchy Zostera marina meadow in Shinnecock Bay, New York	Seed predation units installed (wood board with 10 fastened seeds) in 158 patches and 53 in adjacent unvegetated patches for 7-15 days. SPUs were placed at the interior and edge of the 40 largest patches. Predator abundance was tested at three sites by suction dredging. Objective was to identify characteristics of seed predation in seagrass meadow	1-2 weeks over Summer of 2012. One time data collection of predator abundance	Seed predation was highest within the z. marina patches and lowest in the unvegetated sandy plots. Seed predation was lower in larger patch sizes and higher within the center of the patch versus the edge. slight negative relationship between patch size and predator density, as well as % cover and predator density slight positive relationship between patch size and isopod density/prey density. slight negative relationship between % cover and isopod density/prey density		Plant Response / Survival	
20	Carroll, J.M., Furman, B.T., Jackson, L.J., Hunter, E.A., Peterson, B.J.	Patchy Zostera marina meadow in Shinnecock Bay, New York	Seed predation units installed (wood board with 10 fastened seeds) in 158 patches and 53 in adjacent unvegetated patches for 7-15 days. SPUs were placed at the interior and edge of the 40 largest patches. Predator abundance was tested at three sites by suction dredging. Objective was to identify characteristics of seed predation in seagrass meadow	1-2 weeks over Summer of 2012. One time data collection of predator abundance	Seed predation was highest within the z. marina patches and lowest in the unvegetated sandy plots. Seed predation was lower in larger patch sizes and higher within the center of the patch versus the edge. slight negative relationship between patch size and predator density, as well as % cover and predator density slight positive relationship between patch size and isopod density/prey density. slight negative relationship between % cover and isopod density/prey density	Fish		
21	Chefaoui, R.M., Assis, J., Duarte, C.M., Serrao, E.A.	Entire habitat range of Cymodocea nodosa seagrass, including mediterranean sea, NE atlantic coasts, and Black Sea	Performing algorithms on ecological data to establish niche values and suitable habitats for C. nodosa. Develop large scale distribution niche modelling to determine which variables explain global seagrass distribution of C. nodosa	Sometime prior to 2015 (timeline not identified in methods)	Environmental predictors three times more significant than landscape metrics. Notable predictors included salinity, summer SST (sea surface temperature), winter SST, pH, mean winter wave height, Phosphate and Nitrate	Seagrass	Habitat Distribution	Baseline assessment
22	Chen, Q., Bakker, J.P., Alberti, J., Smit, C.	Wadden Sea Salt Marshes off the coast of Schiermonnikoog, the Netherlands	Four study blocks were established in 1972 and studied until 2017, two in high marsh and two in low marsh. Each block had 8 treatments: control, mowing (early, late, both), grazing, grazing + mowing (early, late, both). Evaluated the impact of mowing (haymaking) and cattle grazing on salt marsh species diversity. Includes plant community composition, expansion of dominant Elytrigia atherica grass and Festuca rubra grass.	46 year study - 1972 to 2017	E. atherica dominanted in the control plots, and was significantly decreased in all other plots. F. rubra increased in mowing and grazing treatments and decreased in control. Species richness increased in all treatments except control. After 1989, both early and late mowing treatments also showed decreased richness. Species compositions changed dramatically after 15 years in control treatment, with species dominance structure changing significantly after15 years in all treatments.	Salt Marsh	Plant Diversity	Grazing / mowing
22	Chen, Q., Bakker, J.P., Alberti, J., Smit, C.	Wadden Sea Salt Marshes off the coast of Schiermonnikoog, the Netherlands	Four study blocks were established in 1972 and studied until 2017, two in high marsh and two in low marsh. Each block had 8 treatments: control, mowing (early, late, both), grazing, grazing + mowing (early, late, both). Evaluated the impact of mowing (haymaking) and cattle grazing on salt marsh species diversity. Includes plant community composition, expansion of dominant Elytrigia atherica grass and Festuca rubra grass.	46 year study - 1972 to 2017	E. atherica dominanted in the control plots, and was significantly decreased in all other plots. F. rubra increased in mowing and grazing treatments and decreased in control. Species richness increased in all treatments except control. After 1989, both early and late mowing treatments also showed decreased richness. Species compositions changed dramatically after 15 years in control treatment, with species dominance structure changing significantly after15 years in all treatments.		Plant Density	

23	Cho, J.S., Lee, J.S., Kim, J.K.	west and south coastline of South Korea	Analysis of distribution and environmental factors impacting Phragmites australis in four brackish water sites in South Korea (also included fresh and seawater). Examined soil near roots to 15cm depth to determine salinity, moisture content, organic matter content, pH, available phosphorus (a-p), total nitrogen, soil particle size. Examined water environment for dissolved oxygen, salinity, soil pH, and conductivity	Sometime prior to 2015 (timeline not identified in methods).	Mean growth rate is 211.3cm/year. Mean density is 145 shoots/m2 (highest in brackish vs sea or freshwater. Mean moisture content was 22.16%. Soil organic matter content was 3.07%. Soil pH average was 6.91. Soil salinity was 3ppt. Conductivity was 5.74millisiemens per centimeter. Total nitrogen was .71. Average soil a-p was 310.23 microgram/g. Sand Silt and clay contents were 82.30%, 12.34%, and 5.34%. Dissolved oxygen in water awas 12.23 mg/L. Water pH was 8.04. Salinity was 8.9ppt, conductivity was 14,304millisiemens/cm. Study area included 8 taxa and 5 families in brackish water (lowest in brackish vs sea or freshwater)	Salt Marsh	Plant Growth	Baseline assessment
23	Cho, J.S., Lee, J.S., Kim, J.K.	west and south coastline of South Korea	Analysis of distribution and environmental factors impacting Phragmites australis in four brackish water sites in South Korea (also included fresh and seawater). Examined soil near roots to 15cm depth to determine salinity, moisture content, organic matter content, pH, available phosphorus (a-p), total nitrogen, soil particle size. Examined water environment for dissolved oxygen, salinity, soil pH, and conductivity	Sometime prior to 2015 (timeline not identified in methods).	Mean growth rate is 211.3cm/year. Mean density is 145 shoots/m2 (highest in brackish vs sea or freshwater. Mean moisture content was 22.16%. Soil organic matter content was 3.07%. Soil pH average was 6.91. Soil salinity was 3ppt. Conductivity was 5.74millisiemens per centimeter. Total nitrogen was .71. Average soil a-p was 310.23 microgram/g. Sand Silt and clay contents were 82.30%, 12.34%, and 5.34%. Dissolved oxygen in water awas 12.23 mg/L. Water pH was 8.04. Salinity was 8.9ppt, conductivity was 14,304millisiemens/cm. Study area included 8 taxa and 5 families in brackish water (lowest in brackish vs sea or freshwater)		Plant Density	
24	Chust, G., Albaina, A., Aranburu, A., Borja, A., Diekman, O.E., Estonba, A., Franco, J., Garmendia, J.M., Iriondo, M., Muxika I., Rendo, F., Rodriguez, J., Ruiz-Larranaga, O., Serrao, E.A.,	Thirteen estuaries along 150km of the Basque Country coast in Northeast Spain	Estimate degree of species and genetic connectivity between structural estuarine species - plants and macroinvertebrates - to infer community vulnerability to global climate change. Analysis of genomes for heterozygosity, inbreeding, and allelic richness from: -Zostera noltei populations from 9 estuaries (three basque, six other northern Spain and France due to limited availability in Basque); -Cerastoderma edule from five estuaries in Basque Inventory of salt marsh plants, seagrass beds, and soft-bottom macroinvertebrates was obtained through existing literature	6 years from 2002 to 2008. Samples retrieved once a year in winter	Heterozygosity of z.noltei ranged from .29 to .81. There was a range between clear clonal dominance and high genetic diversity across the estuaries studied. There was no correlation identified between genetic distance and geographic distance, indicating low connectivity between estuaries. Heterozygosity of c. edule ranged from .418 to .902. There was no correlation identified between genetic distance and geographic distance. For salt marsh plants and seagrass beds, there was a correlation between species similarity and oceanographic distance, but there was no similar correlation for soft bottom macroinvertebrates suggesting high connectivity	Seagrass	Biodiversity	Baseline assessment
24	Chust, G., Albaina, A., Aranburu, A., Borja, A., Diekman, O.E., Estonba, A., Franco, J., Garmendia, J.M., Iriondo, M., Muxika I., Rendo, F., Rodriguez, J., Ruiz-Larranaga, O., Serrao, E.A.,	Thirteen estuaries along 150km of the Basque Country coast in Northeast Spain	Estimate degree of species and genetic connectivity between structural estuarine species - plants and macroinvertebrates - to infer community vulnerability to global climate change. Analysis of genomes for heterozygosity, inbreeding, and allelic richness from: -Zostera noltei populations from 9 estuaries (three basque, six other northern Spain and France due to limited availability in Basque); -Cerastoderma edule from five estuaries in Basque Inventory of salt marsh plants, seagrass beds, and soft-bottom macroinvertebrates was obtained through existing literature	6 years from 2002 to 2008. Samples retrieved once a year in winter	Heterozygosity of z.noltei ranged from .29 to .81. There was a range between clear clonal dominance and high genetic diversity across the estuaries studied. There was no correlation identified between genetic distance and geographic distance, indicating low connectivity between estuaries. Heterozygosity of c. edule ranged from .418 to .902. There was no correlation identified between genetic distance and geographic distance. For salt marsh plants and seagrass beds, there was a correlation between species similarity and oceanographic distance, but there was no similar correlation for soft bottom macroinvertebrates suggesting high connectivity	Salt Marsh	Habitat Connectivity	
25	Clements, J.C., Bishop, M.M., Hunt, H.L.	A mudflat in the Bay of Fundy in southwest New Brunswick, Canada	Juvenile Mya arenaria (clams) collected and placed in 2 buckets (400 each) acclimatized over 10 days at 18 or 21 degrees C, then samples from each bucket were released onto sediment from the collection site and sediment that had been manipulated for increased acidity. Juvenile m. arenaria collected and placed in 2 buckets (400 each) acclimatized over 10 days at 16 degrees C. One bucket had gabazine (neural receptor interference impacting behaviour, CO2 creates similar impact) administered to the clams prior to the expleriment.	2 months - exp1 = early August, 2015. exp2 = late sept, 2015	Clams held at 18 degrees were less likely to burrow into acidified sediment than clams held at 21 degrees. Clams held at 16 degrees but had been administered gabazine had similar burrowing behaviour to thos held at higher temperatures, being more likely to burrow in low pH sediment than the clams that were not administered gabazine.	Mudflats	Animal Response / Survival	Water temperature increase
25	Clements, J.C., Bishop, M.M., Hunt, H.L.	A mudflat in the Bay of Fundy in southwest New Brunswick, Canada	Juvenile Mya arenaria (clams) collected and placed in 2 buckets (400 each) acclimatized over 10 days at 18 or 21 degrees C, then samples from each bucket were released onto sediment from the collection site and sediment that had been manipulated for increased acidity. Juvenile m. arenaria collected and placed in 2 buckets (400 each) acclimatized over 10 days at 16 degrees C. One bucket had gabazine (neural receptor interference impacting behaviour, CO2 creates similar impact) administered to the clams prior to the expleriment.	2 months - exp1 = early August, 2015. exp2 = late sept, 2015	Clams held at 18 degrees were less likely to burrow into acidified sediment than clams held at 21 degrees. Clams held at 16 degrees but had been administered gabazine had similar burrowing behaviour to thos held at higher temperatures, being more likely to burrow in low pH sediment than the clams that were not administered gabazine.	Bivalves		Ocean Acidification
26	Cole Ekberg, M.L., Raposa, K.B., Ferguson, W.S., Ruddock, K., Watson, E.B.	39 marsh units across 31 marshes across coastal rhode island (Narragansett Bay)	Development of vulnerability indices for marshes to sea level rise. Classification of marsh community types, marsh soil integrity, marsh elevation. Identification of model outputs (Sea Level Affecting Marshes Model or SLAMM) accounting for accretion rate against SLR. Vulnerability incides developed based on marsh height, vegetation, Spartina alterniflora height, and predicted loss under sea level rise scenarios.	One time field study sometime prior to 2017 (timeline not identified in methods)	Significant factors impacting vulnerability included median marsh elevation above mean high water, mean marsh elevation, projected loss under .3m of sea level rise, perennial turfgrass vegetation, and percentage of low marsh vegetation	Salt Marsh	Elevation	Sea-level rise

26	Cole Ekberg, M.L., Raposa, K.B., Ferguson, W.S., Ruddock, K., Watson, E.B.	39 marsh units across 31 marshes across coastal rhode island (Narragansett Bay)	Development of vulnerability indices for marshes to sea level rise. Classification of marsh community types, marsh soil integrity, marsh elevation. Identification of model outputs (Sea Level Affecting Marshes Model or SLAMM) accounting for accretion rate against SLR. Vulnerability incides developed based on marsh height, vegetation, Spartina alterniflora height, and predicted loss under sea level rise scenarios.	One time field study sometime prior to 2017 (timeline not identified in methods)	Significant factors impacting vulnerability included median marsh elevation above mean high water, mean marsh elevation, projected loss under .3m of sea level rise, perennial turfgrass vegetation, and percentage of low marsh vegetation		Habitat Distribution	
26	Cole Ekberg, M.L., Raposa, K.B., Ferguson, W.S., Ruddock, K., Watson, E.B.	39 marsh units across 31 marshes across coastal rhode island (Narragansett Bay)	Development of vulnerability indices for marshes to sea level rise. Classification of marsh community types, marsh soil integrity, marsh elevation. Identification of model outputs (Sea Level Affecting Marshes Model or SLAMM) accounting for accretion rate against SLR. Vulnerability incides developed based on marsh height, vegetation, Spartina alterniflora height, and predicted loss under sea level rise scenarios.	One time field study sometime prior to 2017 (timeline not identified in methods)	Significant factors impacting vulnerability included median marsh elevation above mean high water, mean marsh elevation, projected loss under .3m of sea level rise, perennial turfgrass vegetation, and percentage of low marsh vegetation		Plant Density	
27	Columbano, D.D., Manfree, A.D., O'Rear, T.A., Durand, J.R., Moyle, P.B.	Managed saltmarshes along three arms of the Suisun Marsh of the San Francisco Estuary	Fish collection data from monthly otter trawl surveys and compared against habitat types near the survey locations to determine habitat usage as nursery and species-habitat relationships	Monthly from 1995 to 2017 (22 years). Assessing seasonal variations	Tule perch present year round. Striped bass and starry flounder found in summer and autumn. Splittail, striped bass, and tule perch prefer dead-end shallow sloughs as nursery habitat. Tule perch more abundant in interior sloughs during low flow periods. Conditions favorable to small fish include large areas of tidal marsh drained by shallow, sinuous channels connecting to grassland.	Fish	Habitat Distribution	Baseline assessment
28	Crozier, L.G., McClure, M.M., Beechie, T., Bograd, S.J., Boughton, D.A., Carr, M., Cooney, T.D., Dunham, J.B., Greene, C.M., Haltuch, M.A., Hazen, E.L., Holzer, D.M., Huff, D.D., Johnson, R.C., Jordan, C.E., Kaplan, I.C., Lindley, S.T., Mantua, N.J., Moyle, P.B., Myers, J.M., Nelson, M.W., Spence, B.C., Weitkamp	All anadramous pacific salmon and steelhead populations in the California Current Large Marine Ecosystem from California to Washington	Application of climate vulnerability assessment method to determine vulnerability of each population. Use of exposure, sensitivity, probability of directional shift, and net direction of climate effects.	One time data collection from experts providing opinion	Vulnerability was higher for fish that had longer residence time in the estuary. Estuary vulnerability linked to sea-level rise as it is associated with net loss of estuarine habitat. Estuaries that are seasonally blocked by sand-bar formations prevent salmonid access to their watershed for spawning. For Chinook subyearlings that lack access to snow-cooled juvenile habitat, they are more dependent on estuaries and therefore more vulnerable to sea-level rise.	Fish	Habitat Connectivity	Sea-level rise
28	Crozier, L.G., McClure, M.M., Beechie, T., Bograd, S.J., Boughton, D.A., Carr, M., Cooney, T.D., Dunham, J.B., Greene, C.M., Haltuch, M.A., Hazen, E.L., Holzer, D.M., Huff, D.D., Johnson, R.C., Jordan, C.E., Kaplan, I.C., Lindley, S.T., Mantua, N.J., Moyle, P.B., Myers, J.M., Nelson, M.W., Spence, B.C., Weitkamp	All anadramous pacific salmon and steelhead populations in the California Current Large Marine Ecosystem from California to Washington	Application of climate vulnerability assessment method to determine vulnerability of each population. Use of exposure, sensitivity, probability of directional shift, and net direction of climate effects.	One time data collection from experts providing opinion	Vulnerability was higher for fish that had longer residence time in the estuary. Estuary vulnerability linked to sea-level rise as it is associated with net loss of estuarine habitat. Estuaries that are seasonally blocked by sand-bar formations prevent salmonid access to their watershed for spawning. For Chinook subyearlings that lack access to snow-cooled juvenile habitat, they are more dependent on estuaries and therefore more vulnerable to sea-level rise.		Habitat Distribution	Climate Change - General
29	Currin, C.A., Delano, P.C., Valdes-Weaver, L.M.	Outer banks section of North Carolina, three constructed fringing marsh sites where S. alterniflora were planted. In and around the Newport River Estuary in the North section of	Samples taken to compare each constructed site with a natural marsh reference site nearby. Seawalls and breakwaters replaced with stone sills and buffered with marsh plants (Spartina alterniflora and Spartina patens) Measurement of surface elevation, sediment characteristics, and vegetation. Fyke nets used to determine fish usage	Data collected during spring and fall each year from 2001 to 2004. Included time after Hurricane Isabel hit north coast of North Carolina in 2003	Increase in elevation at both natural and restored sites after restoration. Accretion was higher at the center of the marsh than at the outer fringes. Slope was unaffected. Sediment salinity did not vary between sites. Low sediment organic content throughout but higher at reference sites than restored. Silt and gravel higher at reference sites. Organic matter was increased with distance from marsh edge. Size and density of vegetation much lower at restored sites but increased quickly over the years of study. Fish, crab, and shrimp usage of sites did not vary between natural and restored, and this variable was most impacted by seasonality.	Salt Marsh	Restoration / Recovery	
29	Currin, C.A., Delano, P.C., Valdes-Weaver, L.M.	Outer banks section of North Carolina, three constructed fringing marsh sites where S. alterniflora were planted. In and around the Newport River Estuary in the North section of	Samples taken to compare each constructed site with a natural marsh reference site nearby. Seawalls and breakwaters replaced with stone sills and buffered with marsh plants (Spartina alterniflora and Spartina patens) Measurement of surface elevation, sediment characteristics, and vegetation. Fyke nets used to determine fish usage	Data collected during spring and fall each year from 2001 to 2004. Included time after Hurricane Isabel hit north coast of North Carolina in 2003	Increase in elevation at both natural and restored sites after restoration. Accretion was higher at the center of the marsh than at the outer fringes. Slope was unaffected. Sediment salinity did not vary between sites. Low sediment organic content throughout but higher at reference sites than restored. Silt and gravel higher at reference sites. Organic matter was increased with distance from marsh edge. Size and density of vegetation much lower at restored sites but increased quickly over the years of study. Fish, crab, and shrimp usage of sites did not vary between natural and restored, and this variable was most impacted by seasonality.	Fish		
29	Currin, C.A., Delano, P.C., Valdes-Weaver, L.M.	Outer banks section of North Carolina, three constructed fringing marsh sites where S. alterniflora were planted. In and around the Newport River Estuary in the North section of	Samples taken to compare each constructed site with a natural marsh reference site nearby. Seawalls and breakwaters replaced with stone sills and buffered with marsh plants (Spartina alterniflora and Spartina patens) Measurement of surface elevation, sediment characteristics, and vegetation. Fyke nets used to determine fish usage	Data collected during spring and fall each year from 2001 to 2004. Included time after Hurricane Isabel hit north coast of North Carolina in 2003	Increase in elevation at both natural and restored sites after restoration. Accretion was higher at the center of the marsh than at the outer fringes. Slope was unaffected. Sediment salinity did not vary between sites. Low sediment organic content throughout but higher at reference sites than restored. Silt and gravel higher at reference sites. Organic matter was increased with distance from marsh edge. Size and density of vegetation much lower at restored sites but increased quickly over the years of study. Fish, crab, and shrimp usage of sites did not vary between natural and restored, and this variable was most impacted by seasonality.	Crustaceans	Sediment fluxes	
30	Dabrowska, A.H., Janas, U., Kendzierska, H.	One sandy shoal along the Hel Peninsula in the Baltic Sea (Poland)	Macrozoobenthos collected at 16 stations, some from top sections of plants, some from sandy bottom covered with vascular plants, some on bare sand close to vegetation	One time data collection	Flora was dominated by Zostera marina but Z. palustris and P pectinatus were also present. Filamentous algae was attached to the plants but with low biomass. 33 taxa from 9 phyla of zoobenthos were observed. Biodiversity was higher where plants were located.	Seagrass	Biodiversity	Baseline assessment
30	Dabrowska, A.H., Janas, U., Kendzierska, H.	One sandy shoal along the Hel Peninsula in the Baltic Sea (Poland)	Macrozoobenthos collected at 16 stations, some from top sections of plants, some from sandy bottom covered with vascular plants, some on bare sand close to vegetation	One time data collection	Flora was dominated by Zostera marina but Z. palustris and P pectinatus were also present. Filamentous algae was attached to the plants but with low biomass. 33 taxa from 9 phyla of zoobenthos were observed. Biodiversity was higher where plants were located.	Food Web		
30	Dabrowska, A.H., Janas, U., Kendzierska, H.	One sandy shoal along the Hel Peninsula in the Baltic Sea (Poland)	Macrozoobenthos collected at 16 stations, some from top sections of plants, some from sandy bottom covered with vascular plants, some on bare sand close to vegetation	One time data collection	Flora was dominated by Zostera marina but Z. palustris and P pectinatus were also present. Filamentous algae was attached to the plants but with low biomass. 33 taxa from 9 phyla of zoobenthos were observed. Biodiversity was higher where plants were located.	Zooplankton	Species Composition	

31	Daggers, T.D., Herman, P.M.J., van der Wal, D.	Mudflats across the Westerschelde Estuary, the Netherlands	Use of Sentinel-2 imagery to determine biomass, patchiness, and seasonality of microphytobenthos throughout the mudflats	Seasonal assessment over four years (2016-2019)	Total biomass increased from spring to summer. Biomass during winter varied across the four year assessment. Patch size of microphytobenthos with high biomass index did not change seasonally but some patches with lower biomass disappeared and locations of patches changed through changing seasons. Higher patch size and degree of patchiness was found on relatively sandy mid-channel tidal flats versus silt-rich fringing tidal flats.	Mudflats	Microbial response / survival	Baseline assessment
31	Daggers, T.D., Herman, P.M.J., van der Wal, D.	Mudflats across the Westerschelde Estuary, the Netherlands	Use of Sentinel-2 imagery to determine biomass, patchiness, and seasonality of microphytobenthos throughout the mudflats	Seasonal assessment over four years (2016-2019)	Total biomass increased from spring to summer. Biomass during winter varied across the four year assessment. Patch size of microphytobenthos with high biomass index did not change seasonally but some patches with lower biomass disappeared and locations of patches changed through changing seasons. Larger patch size and higher degree of patchiness was found on relatively sandy mid-channel tidal flats versus silt-rich fringing tidal flats.	Microbiome	Productivity	
32	Dai, X., Zhang, H.	Chongming Dongtan Wetlands in the Yangtze Estuary, Shanghai	Application of Pressure-State-Response framework to determine health of the wetlands in a highly urbanized and modified estuary. Use of ecosystem mapping techniques and imagery against health indicators: pollution, invasion of non-native varieties, vegetation cover, benthos biomass, patch density, diversity of rare species, wetland ecological economic output	One time data collection around 2008.	Areas protected from human influence had more suitable habitat for rare and migratory bird populations. Tidal flats experienced higher pressure (pollution) than salt marshes. Outputs of heavy metals from industrial activity were associated with poor health. However, 75% of the area studied was considered healthy.	Salt Marsh	Habitat Distribution	Pollution
32	Dai, X., Zhang, H.	Chongming Dongtan Wetlands in the Yangtze Estuary, Shanghai	Application of Pressure-State-Response framework to determine health of the wetlands in a highly urbanized and modified estuary. Use of ecosystem mapping techniques and imagery against health indicators: pollution, invasion of non-native varieties, vegetation cover, benthos biomass, patch density, diversity of rare species, wetland ecological economic output	One time data collection around 2008.	Areas protected from human influence had more suitable habitat for rare and migratory bird populations. Tidal flats experienced higher pressure (pollution) than salt marshes. Outputs of heavy metals from industrial activity were associated with poor health. However, 75% of the area studied was considered healthy.	Mudflats	Water Quality	
32	Dai, X., Zhang, H.	Chongming Dongtan Wetlands in the Yangtze Estuary, Shanghai	Application of Pressure-State-Response framework to determine health of the wetlands in a highly urbanized and modified estuary. Use of ecosystem mapping techniques and imagery against health indicators: pollution, invasion of non-native varieties, vegetation cover, benthos biomass, patch density, diversity of rare species, wetland ecological economic output	One time data collection around 2008.	Areas protected from human influence had more suitable habitat for rare and migratory bird populations. Tidal flats experienced higher pressure (pollution) than salt marshes. Outputs of heavy metals from industrial activity were associated with poor health. However, 75% of the area studied was considered healthy.	Birds	Animal Response / Survival	Pollution
32	Dai, X., Zhang, H.	Chongming Dongtan Wetlands in the Yangtze Estuary, Shanghai	Application of Pressure-State-Response framework to determine health of the wetlands in a highly urbanized and modified estuary. Use of ecosystem mapping techniques and imagery against health indicators: pollution, invasion of non-native varieties, vegetation cover, benthos biomass, patch density, diversity of rare species, wetland ecological economic output	One time data collection around 2008.	Areas protected from human influence had more suitable habitat for rare and migratory bird populations. Tidal flats experienced higher pressure (pollution) than salt marshes. Outputs of heavy metals from industrial activity were associated with poor health. However, 75% of the area studied was considered healthy.		Biodiversity	
33	de Jong, K., Forland, T.N., Amorim, M.C.P., Rieucau, G., Slabbekoorn, H., Silve, L.D.	Global	Literature search to determine impact of noise onto fish stress, masking, and hearing-loss on reproductive traits	One time literature search	Continuous sounds with irregular amplitude and/or frequency content most likely to cause stress. Continuous sounds most likely to cause masking and hearing loss. Fish with reproductive behaviour requiring sound communication are most vulnerable to noise pollution. Fish with ability to reallocate reproduction away from noise have most resilience.	Fish	Animal response / su	Pollution
34	de Juan, S., Hewitt, J.	Five study sites of intertidal regions along the Mahurangi Harbour, in New Zealand North Island	Collection of core samples of intertidal mud flats to identify organisms and measure diversity by species richness. Sediment samples were collected for grain size annually in April	Seasonally, four times per annum for 12 years starting in July 1994 until 2005	Spatial structure was not associated with species richness, as it did not appear to have an impact on species found. Community patterns more likely to be impacted by environmental variables. Higher richness was found on the site with less mud content and greater wave exposure. Differences between sites changed seasonally	Mudflats	Biodiversity	Baseline assessment
34	de Juan, S., Hewitt, J.	Five study sites of intertidal regions along the Mahurangi Harbour, in New Zealand North Island	Collection of core samples of intertidal mud flats to identify organisms and measure diversity by species richness. Sediment samples were collected for grain size annually in April	Seasonally, four times per annum for 12 years starting in July 1994 until 2005	Spatial structure was not associated with species richness, as it did not appear to have an impact on species found. Community patterns more likely to be impacted by environmental variables. Higher richness was found on the site with less mud content and greater wave exposure. Differences between sites changed seasonally	Invertebrates	Habitat Distribution	
35	Detenbeck, N.E., You, M., Torre, D.	365 Estuaries throughout the contiguous United States. Assessed regional differences	Use of modelling software to estimate nitrogen and phosphorous loads based on output data of terrestrial nutrient sources that can reach and be absorbed by streams delivering nutrients to estuaries. Also assesses direct atmospheric deposition to estuaries	2002 data was compared against 2011 data	Overall, most estuaries experienced an increase in estimated point-source delivered nitrogen loads but there was great variation between estuaries. Wastewater and urban runoff appear to increasing across estuaries. Agricultural activity appears to be decreasing but not enough to offset urban runoff.		Water Quality	Pollution
36	Dolbeth, M., Cardoso, P.G., Ferreira, S.M., Verdelhos, T., Raffaelli, D., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between	Sediment cores taken at each site to a depth of 20cm to determine biomass of secondary production.	samples were collected fortnightly in the morning at low tide for the first 18 months and monthly thereafter. Data was collected from 1993 to 1996 and then from 1999 to 2002	The seagrass bed supported more secondary producers than the intermediate area and the eutrophic area. Production levels gradually increased after mitigations but decreased after the floods in 2001. Significant differences were demonstrated in production characteristics between sites with the seagrass bed providing most species richness and productivity.	Seagrass	Productivity	Eutrophication
36	Dolbeth, M., Cardoso, P.G., Ferreira, S.M., Verdelhos, T., Raffaelli, D., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between	Sediment cores taken at each site to a depth of 20cm to determine biomass of secondary production.	samples were collected fortnightly in the morning at low tide for the first 18 months and monthly thereafter. Data was collected from 1993 to 1996 and then from 1999 to 2002	The seagrass bed supported more secondary producers than the intermediate area and the eutrophic area. Production levels gradually increased after mitigations but decreased after the floods in 2001. Significant differences were demonstrated in production characteristics between sites with the seagrass bed providing most species richness and productivity.	Mudflats		
36	Dolbeth, M., Cardoso, P.G., Ferreira, S.M., Verdelhos, T., Raffaelli, D., Pardal, M.A.	Three sampling sites within Mondego Estuary, Portugal, including a seagrass (z. noltii) bed, a eutrophic area upstream, and an intermediate area in between	Sediment cores taken at each site to a depth of 20cm to determine biomass of secondary production.	samples were collected fortnightly in the morning at low tide for the first 18 months and monthly thereafter. Data was collected from 1993 to 1996 and then from 1999 to 2002	The seagrass bed supported more secondary producers than the intermediate area and the eutrophic area. Production levels gradually increased after mitigations but decreased after the floods in 2001. Significant differences were demonstrated in production characteristics between sites with the seagrass bed providing most species richness and productivity.	Invertebrates		

37	Dos Santos, V.M., Matheson, F.E., Pilditch, C.A., Elger, A.	Four sites in one large temperate estuary (Tauranga Harbour, New Zealand, 201km2)	Establishment of plots to create a seagrass grazing simulation experiment mimicking activities of the black swan including high intensity grazing, low intensity grazing, non-treated control plots, and non-treated initial plots that had been disturbed prior to simulation. Tested factors include proportion of biomass recovered including above ground vs. below ground as well as regeneration rates.	Monthly intervals for a year from February 2009	High intensity grazing plots did not fully recover biomass, which maintained values significantly lower than low-intensity grazing and control. However, seagrass cover recovered within a year. The low intensity grazing plots recovered biomass within a year.	Seagrass	Restoration / Recovery	Invasive Species
37	Dos Santos, V.M., Matheson, F.E., Pilditch, C.A., Elger, A.	Four sites in one large temperate estuary (Tauranga Harbour, New Zealand, 201km2)	Establishment of plots to create a seagrass grazing simulation experiment mimicking activities of the black swan including high intensity grazing, low intensity grazing, non-treated control plots, and non-treated initial plots that had been disturbed prior to simulation. Tested factors include proportion of biomass recovered including above ground vs. below ground as well as regeneration rates.	Monthly intervals for a year from February 2009	High intensity grazing plots did not fully recover biomass, which maintained values significantly lower than low-intensity grazing and control. However, seagrass cover recovered within a year. The low intensity grazing plots recovered biomass within a year.	Birds	Plant Density	
37	Dos Santos, V.M., Matheson, F.E., Pilditch, C.A., Elger, A.	Four sites in one large temperate estuary (Tauranga Harbour, New Zealand, 201km2)	Establishment of plots to create a seagrass grazing simulation experiment mimicking activities of the black swan including high intensity grazing, low intensity grazing, non-treated control plots, and non-treated initial plots that had been disturbed prior to simulation. Tested factors include proportion of biomass recovered including above ground vs. below ground as well as regeneration rates.	Monthly intervals for a year from February 2009	High intensity grazing plots did not fully recover biomass, which maintained values significantly lower than low-intensity grazing and control. However, seagrass cover recovered within a year. The low intensity grazing plots recovered biomass within a year.		Productivity	
38	Elmilady, H., van der Wegen, M., Roelvink, D., van der Spek, A.	Sandy-shoal system in the Western Scheldt Estuary (Netherlands)	Modelling study of mophodynamics of a fringing sandy shoal to determine mechanisms driving its evolution across time.	One time modelling type data collection	Most mophodynamic changes due to fluctuating ocean movements (tide, waves) occur at the edges of the sandy shoal while the interior maintained stability. The sandy shoal emerges from the center of the channel and accretes vertically and landwards horizontally. Wave and tidal motions cause erosion from the top of the shoal	Sand Flats	Sediment fluxes	Baseline assessment
38	Elmilady, H., van der Wegen, M., Roelvink, D., van der Spek, A.	Sandy-shoal system in the Western Scheldt Estuary (Netherlands)	Modelling study of mophodynamics of a fringing sandy shoal to determine mechanisms driving its evolution across time.	One time modelling type data collection	Most mophodynamic changes due to fluctuating ocean movements (tide, waves) occur at the edges of the sandy shoal while the interior maintained stability. The sandy shoal emerges from the center of the channel and accretes vertically and landwards horizontally. Wave and tidal motions cause erosion from the top of the shoal	Morphology		
39	Evans, S.M., Sinclair, E.A., Poore, A.G.B., Bail, K.F., Verges, A.	12 estuaries across New South Wales, Australia's southeast coast	Collection of 30 shoots of Posidonia australis seagrass per location in 12 locations (n=360) on Australia's east coast. Genetic and phenotypic diversity were measured across shoots within and between geographically distinct locations. Genetic diversity was determined by studying allE96:O97eles. Phenotypic diversity was determined by collecting data on surface area, biomass, productivity, and epiphyte load.	One time extraction	Positive linear relationships were found between genotypic and phenotypic diversity. Strongest correlation was between genotype and surface area/biomass per shoot. No correlation was found between genotypic richness and shoot density or productivity. However there was a correlation between genotypic richness and variation in shoot productivity. Genotypic richness was associated with variation in epiphyte biomass. Herbivory levels were not associated with genotypic richness.	Seagrass	Biodiversity	Baseline assessment
39	Evans, S.M., Sinclair, E.A., Poore, A.G.B., Bail, K.F., Verges, A.	12 estuaries across New South Wales, Australia's southeast coast	Collection of 30 shoots of Posidonia australis seagrass per location in 12 locations (n=360) on Australia's east coast. Genetic and phenotypic diversity were measured across shoots within and between geographically distinct locations. Genetic diversity was determined by studying alleles. Phenotypic diversity was determined by collecting data on surface area, biomass, productivity, and epiphyte load.	One time extraction	Positive linear relationships were found between genotypic and phenotypic diversity. Strongest correlation was between genotype and surface area/biomass per shoot. No correlation was found between genotypic richness and shoot density or productivity. However there was a correlation between genotypic richness and variation in shoot productivity. Genotypic richness was associated with variation in epiphyte biomass. Herbivory levels were not associated with genotypic richness.	Microbiome	Plant Density	
39	Evans, S.M., Sinclair, E.A., Poore, A.G.B., Bail, K.F., Verges, A.	12 estuaries across New South Wales, Australia's southeast coast	Collection of 30 shoots of Posidonia australis seagrass per location in 12 locations (n=360) on Australia's east coast. Genetic and phenotypic diversity were measured across shoots within and between geographically distinct locations. Genetic diversity was determined by studying alleles. Phenotypic diversity was determined by collecting data on surface area, biomass, productivity, and epiphyte load.	One time extraction	Positive linear relationships were found between genotypic and phenotypic diversity. Strongest correlation was between genotype and surface area/biomass per shoot. No correlation was found between genotypic richness and shoot density or productivity. However there was a correlation between genotypic richness and variation in shoot productivity. Genotypic richness was associated with variation in epiphyte biomass. Herbivory levels were not associated with genotypic richness.	Microbiome	Plant Diversity	
40	Evans, W., Pocock, K., Hare, A., Weekes, C., Hales, B., Jackson, J., Gurney-Smith, H., Mathis, J.T., Alin, S.R., Feely, R.A.	Seawater collected from Sawmill Bay, Fanny Bay	Seawater samples collected across the North Salish Sea through citizen science collaboratives. relationships were examined between depth, CO2, salinity, alkalinity, and aragonite saturation	Long-term collection over four years from 2014 to 2018	Strong correlation between salinity and alkalinity. Salinity and alkalinity tend to increase at depth until about 250m. pCO2 levels have inverse relationship with SST, with low values in summertime and high values in winter. Aragonite saturation and pHT have same seasonal tendencies as SST, with highest values during the summer and low during the winter. SST highly influenced by wind.	Water	Water Quality	Ocean Acidification
40	Evans, W., Pocock, K., Hare, A., Weekes, C., Hales, B., Jackson, J., Gurney-Smith, H., Mathis, J.T., Alin, S.R., Feely, R.A.	Seawater collected from Sawmill Bay, Fanny Bay	Seawater samples collected across the North Salish Sea through citizen science collaboratives. relationships were examined between depth, CO2, salinity, alkalinity, and aragonite saturation	Long-term collection over four years from 2014 to 2018	Strong correlation between salinity and alkalinity. Salinity and alkalinity tend to increase at depth until about 250m. pCO2 levels have inverse relationship with SST, with low values in summertime and high values in winter. Aragonite saturation and pHT have same seasonal tendencies as SST, with highest values during the summer and low during the winter. SST highly influenced by wind.			Water temperature increase
41	Eymann, C., Gotze, S., Bock, C., Guderley, H., Knoll, A.H., Lannig, G. Sokolova, I.M., Aberhan, M., Portner, H.O.	Raft cultured oysters collected from Vigo Estuary, Spain	Oysters were brought into lab from estuary and acclimatized. Temperature was increased by 2 degrees celcius every 48 hours starting at 12 degrees and going to 36 degrees C. Filtration rate, heart rate, and metabolites were studied	One time collection, spring 2017	All oysters died within 18 hours of reaching 36 degrees but mortality was negligible up to 34 degrees. Filtration rates were optimized at between 18 and 26 degrees. Heart rate increased linearly up to 30 degrees and then decreased. Increasing temperatures increased numbers of anaerobic metabolites	Lab	Animal Response / Survival	Water temperature increase

41	Eymann, C., Gotze, S., Bock, C., Guderley, H., Knoll, A.H., Lannig, G. Sokolova, I.M., Aberhan, M., Portner, H.O.	Raft cultured oysters collected from Vigo Estuary, Spain	Oysters were brought into lab from estuary and acclimatized. Temperature was increased by 2 degrees celcius every 48 hour starting at 12 degrees and going to 36 degrees C. Filtration rate, heart rate, and metabolites were studied	One time collection, spring 2017	All oysters died within 18 hours of reaching 36 degrees but mortality was negligible up to 34 degrees. Filtration rates were optimized at between 18 and 26 degrees. Heart rate increased linearly up to 30 degrees and then decreased. Increasing temperatures increased numbers of anaerobic metabolites	Bivalves		
42	Falcao, J., Marques, S.C., Pardal, M.A., Marques, J.C., Primo, A.L., Azeiteiro, U.	Five sampling stations within the Mondego Estuary: one at the mouth of the estuary, and four upstream (two south, two north)	Restoration efforts to reconnect two arms of the freshwater flows to the estuary after them having been separated through channelization and potable water extraction, as well as subject to eutrophication. Effectiveness of efforts were tested by measuring the amount of mesozooplankton at each of the sampling stations. Temperature, salinity, and productivity (chlorophyl A) were also measured.	Collections were made monthly from Jan 2003 to Dec 2009. Seasonal changes were noted.	Temp, salinity, and productivity tended to be higher in summer months than other times of year. Zooplankton abundance was seasonally variable throughout the experiment but higher levels of abundance occurred after the restoration intervention than before (highest value 815 ind more than doubled to 2045). Higher densities were also recorded post-intervention and density was also seasonally variable.	Water	Animal Response / Survival	Channelization
42	Falcao, J., Marques, S.C., Pardal, M.A., Marques, J.C., Primo, A.L., Azeiteiro, U.	Five sampling stations within the Mondego Estuary: one at the mouth of the estuary, and four upstream (two south, two north)	Restoration efforts to reconnect two arms of the freshwater flows to the estuary after them having been separated through channelization and potable water extraction, as well as subject to eutrophication. Effectiveness of efforts were tested by measuring the amount of mesozooplankton at each of the sampling stations. Temperature, salinity, and productivity (chlorophyl A) were also measured.	Collections were made monthly from Jan 2003 to Dec 2009. Seasonal changes were noted.	Temp, salinity, and productivity tended to be higher in summer months than other times of year. Zooplankton abundance was seasonally variable throughout the experiment but higher levels of abundance occurred after the restoration intervention than before (highest value 815 ind more than doubled to 2045). Higher densities were also recorded post-intervention and density was also seasonally variable.	Zooplankton	Restoration / Recovery	Eutrophication
42	Falcao, J., Marques, S.C., Pardal, M.A., Marques, J.C., Primo, A.L., Azeiteiro, U.	Five sampling stations within the Mondego Estuary: one at the mouth of the estuary, and four upstream (two south, two north)	Restoration efforts to reconnect two arms of the freshwater flows to the estuary after them having been separated through channelization and potable water extraction, as well as subject to eutrophication. Effectiveness of efforts were tested by measuring the amount of mesozooplankton at each of the sampling stations. Temperature, salinity, and productivity (chlorophyl A) were also measured.	Collections were made monthly from Jan 2003 to Dec 2009. Seasonal changes were noted.	Temp, salinity, and productivity tended to be higher in summer months than other times of year. Zooplankton abundance was seasonally variable throughout the experiment but higher levels of abundance occurred after the restoration intervention than before (highest value 815 ind more than doubled to 2045). Higher densities were also recorded post-intervention and density was also seasonally variable.			Upstream modification
43	Fitzer, S.C., McGill, R.A.R., Gabarda, S.T., Hughes, B., Dove, M., O'Connor, W., Byrne, M.	Bred oysters collected from two estuaries in Australia: Wallis Lake and Port Stephens	Oysters from families selectively bred for fast growth or disease resistance and wild type oysters were collected from one control site and one acidified site per estuary (4 sites). The acidified sites were influenced by sulphate soil acidification. They were tested for ability to form carbonite shells in acidified conditions.	One time oyster collection	Selectively bred oysters were better able to cope with the lower carbon availability for shell growth in acidified conditions than wild type oysters. Shell growth appears to be most proficient in oysters bred for disease resistance	Bivalves	Animal Response / Survival	Ocean Acidification
44	Fleri, J.R., Lera, S., Gerevini, A., Staver, S., Nardin, W.	One tidal marsh on Poplar Island (active restoration site in Chesapeake Bay, USA)	Man-made low-energy tidal marsh constructed from previously dredged materials was examined for impacts by tidal currents, development of channel morphology, and impact of vegetation on sediment dynamics. Tidal fluxes, sediment fluxes, and morphology were measured to determine what factors influence sediment distribution and accretion in the context of rising sea levels.	Every 3 minutes over the course of 1 week to ascertain changes occurring during daily tidal cycles	Water transport occurred mostly through box culverts on site, ebb tides were dominant over flood tides. Velocities increased further inland. Channel morphology and vegetation impacted the effects of tidal cycles and overall stability of the marsh. Velocities were decreased in locations where there were wide, shallow channels and dense submerged vegetation. These factors also influenced accretion rates by releasing suspended sediment.	Salt Marsh	Sediment fluxes	Dredging
44	Fleri, J.R., Lera, S., Gerevini, A., Staver, S., Nardin, W.	One tidal marsh on Poplar Island (active restoration site in Chesapeake Bay, USA)	Man-made low-energy tidal marsh constructed from previously dredged materials was examined for impacts by tidal currents, development of channel morphology, and impact of vegetation on sediment dynamics. Tidal fluxes, sediment fluxes, and morphology were measured to determine what factors influence sediment distribution and accretion in the context of rising sea levels.	Every 3 minutes over the course of 1 week to ascertain changes occurring during daily tidal cycles	Water transport occurred mostly through box culverts on site, ebb tides were dominant over flood tides. Velocities increased further inland. Channel morphology and vegetation impacted the effects of tidal cycles and overall stability of the marsh. Velocities were decreased in locations where there were wide, shallow channels and dense submerged vegetation. These factors also influenced accretion rates by releasing suspended sediment.	Morphology		
45	Froelich, H.E., Gentry, R.R., Halpern, B.S.,	Not location specific. Lit-review type data collection	Collection of data on tolerance levels of 178 different aquaculture species to temperature, dissolved oxygen, growth, trophic level, taxon, region, and market value. Assessment of relationships between variables discussed.	One time data collection	Inverse relationship was found between temperature tolerance and minimum DO tolerance. Larger, slow growing species tend to have larger temperature range tolerance and lower minimum DO tolerance, but are at a higher trophic level so tend to be less sustainable. Temperate species tend to have higher ranges than tropical species.	Fish	Animal Response / Su	Water temperature increase
46	Galbraith, H., DesRochers, D.W., Brown, S., Reed, M.	Shorebirds across Canada and the US	Application of risk model against 49 shorebird species to determine the impact that climate change is having on their growth and survival rates. Risk assessment included the following factors: breeding, migration, non-breeding habitat, degree of dependence on ecological synchronicities, migration distance, and degree of habitat specialization.	One time data collection	Eighty seven percent of species are predicted to exhibit an increased extinction risk when adding climat change to current existing vulnerabilities. Species were at risk of loss of breeding habitat (estuaries), loss of coastal and inland migration stopover habitats due to sea-level rise and drought, and loss of coastal wintering habitat due to sea-level rise. It is concluded that shorebirds are highly vulnerable to the impacts of climate change.	Birds	Animal Response / Su	Sea-level rise
46	Galbraith, H., DesRochers, D.W., Brown, S., Reed, M.	Shorebirds across Canada and the US	Application of risk model against 49 shorebird species to determine the impact that climate change is having on their growth and survival rates. Risk assessment included the following factors: breeding, migration, non-breeding habitat, degree of dependence on ecological synchronicities, migration distance, and degree of habitat specialization.	One time data collection	Eighty seven percent of species are predicted to exhibit an increased extinction risk when adding climat change to current existing vulnerabilities. Species were at risk of loss of breeding habitat (estuaries), loss of coastal and inland migration stopover habitats due to sea-level rise and drought, and loss of coastal wintering habitat due to sea-level rise. It is concluded that shorebirds are highly vulnerable to the impacts of climate change.			Drought
47	Ganju, N.K., Defne, Z., Fagherazzi, S.	Four estuarine marsh systems of the eastern US: Chincoteague Bay, Maryland/Virginia; Great South Bay, New York; Cape Cod, Massachusetts, Plum Island Estuary	Use of geospatial dataset to determine relationship between elevation and unvegetated-vegetated ratio (UVVR) of estuarine salt marshes	One time data collection	Elevations were lowest in fringing marshes closer to open water. Unvegetated areas decreased with increased elevation. Increased lifespan was found in areas of higher elevation as well.	Salt Marsh	Elevation	Sea-level rise

47	Ganju, N.K., Defne, Z., Fagherazzi, S.	Four estuarine marsh systems of the eastern US: Chincoteague Bay, Maryland/Virginia; Great South Bay, New York; Cape Cod, Massachusetts, Plum Island Estuary	Use of geospatial dataset to determine relationship between elevation and unvegetated-vegetated ratio (UVVR) of estuarine salt marshes	One time data collection	Elevations were lowest in fringing marshes closer to open water. Unvegetated areas decreased with increased elevation. Increased lifespan was found in areas of higher elevation as well.		Plant Density	
48	Gao, Y., Fang, J., Li, F., Li, W., Wang, X., Du, M., Fang, J., Jiang, W., Liu, H., Zhang, Y., Wang, J., Jiang, Z.	18 sampling stations in Sanggou Bay, Shandong Peninsula, China. An estuary used heavily for aquaculture, including oysters, scallops, and kelp	Use of ecopath modelling software to determine the ecological carrying capacity of Sanggou Bay. 24 functional groups were identified. Assessed the impact of potential growth in use of the bay for oyster aquaculture against the carrying capacity of the ecosystem.	Four separate cruises (one for each season) during 2017-2018 were used to collect survey data for inputs into the model.	The system identified high primary production levels. Increase in oyster biomass had a negative effect on biodiversity and evenness. Ecopath also identified a decrease in diversity of energy flows through th system. Primary production decreased, and efficiency of energy transfer decreased. It also showed a general decrease in biomass for each of the other functional groups - species that oysters feed on decreased due to feeding, oyster competitors decreased due to food depletion, and biomass of higher predators decreased.	Food Web	Species Composition	Aquaculture
48	Gao, Y., Fang, J., Li, F., Li, W., Wang, X., Du, M., Fang, J., Jiang, W., Liu, H., Zhang, Y., Wang, J., Jiang, Z.	18 sampling stations in Sanggou Bay, Shandong Peninsula, China. An estuary used heavily for aquaculture, including oysters, scallops, and kelp	Use of ecopath modelling software to determine the ecological carrying capacity of Sanggou Bay. 24 functional groups were identified. Assessed the impact of potential growth in use of the bay for oyster aquaculture against the carrying capacity of the ecosystem.	Four separate cruises (one for each season) during 2017-2018 were used to collect survey data for inputs into the model.	The system identified high primary production levels. Increase in oyster biomass had a negative effect on biodiversity and evenness. Ecopath also identified a decrease in diversity of energy flows through th system. Primary production decreased, and efficiency of energy transfer decreased. It also showed a general decrease in biomass for each of the other functional groups - species that oysters feed on decreased due to feeding, oyster competitors decreased due to food depletion, and biomass of higher predators decreased.	Bivalves	Animal Response / Survival	
49	Garthwin, R.G., Poore, A.G.B., Verges, A.	Four zostera muelleri meadows in Lake Macquarie, Australia, an estuary on the southeast coast. One of the sample locations has warmer temperatures due to a	Quantification of natural herbivory rates and seagrass growth at all four sites to determine whether herbivory and/or growth show differences at the site with warmer temperatures	April-June, 2012.	Rates of leaf loss to herbivory was low across all locations, and there wasn't any significant difference between the site with warmer temperatures and other sites. There was also no significant difference in growth rates at the site with warmer temperatures, indicating general resilience to warming temperatures.	Seagrass	Plant Density	Water temperature increase
49	Garthwin, R.G., Poore, A.G.B., Verges, A.	Four zostera muelleri meadows in Lake Macquarie, Australia, an estuary on the southeast coast. One of the sample locations has warmer temperatures due to a	Quantification of natural herbivory rates and seagrass growth at all four sites to determine whether herbivory and/or growth show differences at the site with warmer temperatures	April-June, 2012.	Rates of leaf loss to herbivory was low across all locations, and there wasn't any significant difference between the site with warmer temperatures and other sites. There was also no significant difference in growth rates at the site with warmer temperatures, indicating general resilience to warming temperatures.		Habitat Distribution	
50	Gedan, K.B., Kellogg, L., Breitburg, D.L.	Experimental tanks (lab setting). Oyster samples collected from two oyster reef locations, one in Edgewater, MD, and one in Grasonville, MD. Hooked mussel species	Study of hooked mussel (Ischadium recurvum) as secondary ecosystem engineer to oyster reefs comprising of the eastern oyster (Crassostrea virginica) to inform restoration efforts. Examined water filtration rates and phytoplankton control both alone and together across a range of temperatures mimicking seasonal differences.	One time data collection over 16 hours	Oyster clearance rates equalied or exceeded mussel clearance rates at all temperatures. Oyster filtration rates optimized at 28 degrees C, whereas mussels optimised at 26.6. Both fed minimally at 10 degrees and lower. Mussels more efficient at clearing picoplankton. Adding mussel filtration to oyster filtration into the control model more than doubled the total filtration, indicating they are complementary species to be included together in restoration efforts.	Food Web		
50	Gedan, K.B., Kellogg, L., Breitburg, D.L.	Experimental tanks (lab setting). Oyster samples collected from two oyster reef locations, one in Edgewater, MD, and one in Grasonville, MD. Hooked mussel species	Study of hooked mussel (Ischadium recurvum) as secondary ecosystem engineer to oyster reefs comprising of the eastern oyster (Crassostrea virginica) to inform restoration efforts. Examined water filtration rates and phytoplankton control both alone and together across a range of temperatures mimicking seasonal differences.	One time data collection over 16 hours	Oyster clearance rates equalied or exceeded mussel clearance rates at all temperatures. Oyster filtration rates optimized at 28 degrees C, whereas mussels optimised at 26.6. Both fed minimally at 10 degrees and lower. Mussels more efficient at clearing picoplankton. Adding mussel filtration to oyster filtration into the control model more than doubled the total filtration, indicating they are complementary species to be included together in restoration efforts.	Bivalves	Species Composition	Baseline assessment
50	Gedan, K.B., Kellogg, L., Breitburg, D.L.	Experimental tanks (lab setting). Oyster samples collected from two oyster reef locations, one in Edgewater, MD, and one in Grasonville, MD. Hooked mussel species	Study of hooked mussel (Ischadium recurvum) as secondary ecosystem engineer to oyster reefs comprising of the eastern oyster (Crassostrea virginica) to inform restoration efforts. Examined water filtration rates and phytoplankton control both alone and together across a range of temperatures mimicking seasonal differences.	One time data collection over 16 hours	Oyster clearance rates equalied or exceeded mussel clearance rates at all temperatures. Oyster filtration rates optimized at 28 degrees C, whereas mussels optimised at 26.6. Both fed minimally at 10 degrees and lower. Mussels more efficient at clearing picoplankton. Adding mussel filtration to oyster filtration into the control model more than doubled the total filtration, indicating they are complementary species to be included together in restoration efforts.		Water Quality	
51	Gerwing, T.G., Hamilton, D.J., Barbeau, M.A., Haralampides, K., Yamazaki, G.	Five intertidal mudflats along Chignecto Bay, New Brunswick: two near where the petitcodiac discharges into the Bay of Fundy, and three sites in Cumberland Basin and Marys point assumed to be protected from the causeway opening	A causeway was built in 1968 along the petitcodiac river, which caused the decimation of a population of atlantic salmon and extirpation of two other species, as well as erosion and increased water velocity. The spillway gates were opened in 2010 permanently to promote fish passage, and caused increased discharge into the bay of Fundy. The study reviewed short term impacts on intertidal mudflats of the gates opening on fauna and sediment properties.	Every 3 weeks from June to Sept in 2009 and 2010.	No significant short-term impacts on the faunal communities, sediment conditions, or productivity wer found immediately after opening the spillgates. Year-over-year comparison in each site did not yield significant differences. It was hypothesized that the faunal community would be negatively impacted b the erosion associated with the new regime but the hypothesis was not supported by the data.	Mudflats	Animal Response / Survival	Upstream modification
51	Gerwing, T.G., Hamilton, D.J., Barbeau, M.A., Haralampides, K., Yamazaki, G.	Five intertidal mudflats along Chignecto Bay, New Brunswick: two near where the petitcodiac discharges into the Bay of Fundy, and three sites in Cumberland Basin and Marys point assumed to be protected from the causeway opening	A causeway was built in 1968 along the petitcodiac river, which caused the decimation of a population of atlantic salmon and extirpation of two other species, as well as erosion and increased water velocity. The spillway gates were opened in 2010 permanently to promote fish passage, and caused increased discharge into the bay of Fundy. The study reviewed short term impacts on intertidal mudflats of the gates opening on fauna and sediment properties.	Every 3 weeks from June to Sept in 2009 and 2010.	No significant short-term impacts on the faunal communities, sediment conditions, or productivity wer found immediately after opening the spillgates. Year-over-year comparison in each site did not yield significant differences. It was hypothesized that the faunal community would be negatively impacted b the erosion associated with the new regime but the hypothesis was not supported by the data.	Invertebrates	Sediment Quality	
52	Gladstone-Gallagher, R.V., Hughes, R.W., Douglas, E.J., Pilditch, C.A.	Six plots within Tauranga Harbour, New Zealand	Six intertidal seagrass sites were experimentally treated with nitrogen inputs using urea-based fertilizer pellets to mimic the impacts of eutrophication and examine the effects on seagrass. Sites varied based on sediment mud content, seagrass morphological properties, and macrofaunal communities.	60 days after eutrophication impacts	C:N ratios of the grass leaves decreased due to enrichment at all sites. Sites that showed the strongest impact of the nigrogen treatments were correlated with low seagrass cover and biomass. Sites that showed no effects of enrichment on seagrass morphology correlated positively with macrofaunal density and diversity.	Seagrass	Plant Response / Survival	Eutrophication

52	Gladstone-Gallagher, R.V., Hughes, R.W., Douglas, E.J., Pilditch, C.A.	Six plots within Tauranga Harbour, New Zealand	Six intertidal seagrass sites were experimentally treated with nitrogen inputs using urea-based fertilizer pellets to mimic the impacts of eutrophication and examine the effects on seagrass. Sites varied based on sediment mud content, seagrass morphological properties, and macrofaunal communities.	60 days after eutrophication impacts	C:N ratios of the grass leaves decreased due to enrichment at all sites. Sites that showed the strongest impact of the nigrogen treatments were correlated with low seagrass cover and biomass. Sites that showed no effects of enrichment on seagrass morphology correlated positively with macrofaunal density and diversity.		Biodiversity	
52	Gladstone-Gallagher, R.V., Hughes, R.W., Douglas, E.J., Pilditch, C.A.	Six plots within Tauranga Harbour, New Zealand	Six intertidal seagrass sites were experimentally treated with nitrogen inputs using urea-based fertilizer pellets to mimic the impacts of eutrophication and examine the effects on seagrass. Sites varied based on sediment mud content, seagrass morphological properties, and macrofaunal communities.	60 days after eutrophication impacts	C:N ratios of the grass leaves decreased due to enrichment at all sites. Sites that showed the strongest impact of the nigrogen treatments were correlated with low seagrass cover and biomass. Sites that showed no effects of enrichment on seagrass morphology correlated positively with macrofaunal density and diversity.		Species Composition	
52	Gladstone-Gallagher, R.V., Hughes, R.W., Douglas, E.J., Pilditch, C.A.	Six plots within Tauranga Harbour, New Zealand	Six intertidal seagrass sites were experimentally treated with nitrogen inputs using urea-based fertilizer pellets to mimic the impacts of eutrophication and examine the effects on seagrass. Sites varied based on sediment mud content, seagrass morphological properties, and macrofaunal communities.	60 days after eutrophication impacts	C:N ratios of the grass leaves decreased due to enrichment at all sites. Sites that showed the strongest impact of the nigrogen treatments were correlated with low seagrass cover and biomass. Sites that showed no effects of enrichment on seagrass morphology correlated positively with macrofaunal density and diversity.		Water Quality	
53	Glover, H.E., Ogston, A.S., Eidam, E.F., Rupin, S.P., Berr, H.D.,	Elwha River Estuary, Washington, USA	Deployment of 7 benthic light monitoring platforms periodically over 2016 and 2017. Purpose was to understand the impact of sediment input from rivers whose dams were removed on macroalgal mortality and growth by looking at light attenuation in relation to river discharge.	Monthly over two years	Suspended sediment from the river was determined to be the principal driver of light attenuation. The next main drivers was resuspension from waves, and then clearance through tidal flushing. light attentuation was determined to be the main factor limiting macroalgal growth and promoting mortality as the other two options (sand scouring and substrate change) did not appear to impact macroalgae substantially.	Macroalgae	Light access / attenuation	Turbidity
53	Glover, H.E., Ogston, A.S., Eidam, E.F., Rupin, S.P., Berr, H.D.,	Elwha River Estuary, Washington, USA	Deployment of 7 benthic light monitoring platforms periodically over 2016 and 2017. Purpose was to understand the impact of sediment input from rivers whose dams were removed on macroalgal mortality and growth by looking at light attenuation in relation to river discharge.	Monthly over two years	Suspended sediment from the river was determined to be the principal driver of light attenuation. The next main drivers was resuspension from waves, and then clearance through tidal flushing. light attentuation was determined to be the main factor limiting macroalgal growth and promoting mortality as the other two options (sand scouring and substrate change) did not appear to impact macroalgae substantially.	Water		
54	Gonzales-Ortegon, E., Subida, M.D., Arias, A.M., Faldo, F., Cuesta, J.A., Fernandez-Delgado, C., Vilas, C., Drake, P.	Three sampling locations along Guadalquivir river estuary, Iberian Peninsula, Spain	Assessment of faunal communities at the three sampling locations within the estuary to understand impacts of salinity changes, temperature, and turbidity related to anthropogenic impacts of hydrodam located 110km upstream.	Monthly over 12 years from May 1997 to November 2009	Freshwater discharge from the dam has significant long-term decreasing trend associated with changes in mysid abundance, impacting prey availability. Freshwater inputs have positive correlation with diadramous species (eels) but negative correlation with marine straggler species (anchovy, shrimp). Nekton showed strong resilience to freshwater inputs.	Food Web		
54	Gonzales-Ortegon, E., Subida, M.D., Arias, A.M., Faldo, F., Cuesta, J.A., Fernandez-Delgado, C., Vilas, C., Drake, P.	Three sampling locations along Guadalquivir river estuary, Iberian Peninsula, Spain	Assessment of faunal communities at the three sampling locations within the estuary to understand impacts of salinity changes, temperature, and turbidity related to anthropogenic impacts of hydrodam located 110km upstream.	Monthly over 12 years from May 1997 to November 2009	Freshwater discharge from the dam has significant long-term decreasing trend associated with changes in mysid abundance, impacting prey availability. Freshwater inputs have positive correlation with diadramous species (eels) but negative correlation with marine straggler species (anchovy, shrimp). Nekton showed strong resilience to freshwater inputs.	Water	Species Composition	Upstream modification
54	Gonzales-Ortegon, E., Subida, M.D., Arias, A.M., Faldo, F., Cuesta, J.A., Fernandez-Delgado, C., Vilas, C., Drake, P.	Three sampling locations along Guadalquivir river estuary, Iberian Peninsula, Spain	Assessment of faunal communities at the three sampling locations within the estuary to understand impacts of salinity changes, temperature, and turbidity related to anthropogenic impacts of hydrodam located 110km upstream.	Monthly over 12 years from May 1997 to November 2009	Freshwater discharge from the dam has significant long-term decreasing trend associated with changes in mysid abundance, impacting prey availability. Freshwater inputs have positive correlation with diadramous species (eels) but negative correlation with marine straggler species (anchovy, shrimp). Nekton showed strong resilience to freshwater inputs.	Fish		
55	Gordon, J., Arbeider, M., Scott, D., Wilson, S.M., Moore, J.W.	Six sites along the tidal creek system of the lower Fraser River watershed, three with flood-gates, and three control. All six sites had both upstream and downstream components	Measurement of water quality downstream and upstream of floodgates and at control sites to determine the impact of restricting water flow on water quality. Variables measured were dissolved oxygen, temperature, conductivity, salinity, and pH. Dissolved oxygen was the main indicator of water quality.	Eleven days at dawn and dusk from July 31 to Aug 10, 2013 at all sites and from April to August at upstream locations	Dissolved oxygen was lower upstream of floodgates than downstream and in reference sites. DO levels upstream of floodgates were all below the minimum provincial (BC) criteria of 5ml for the protection of aquatic life. Reference sites had higher DO levels than both upstream and downstream floodgate locations. DO was most significantly predicted by water temperature, depth, stream type, and distance from floodgate. Undeveloped land surrounding the sites was also correlated with higher DO levels. Late summer DO levels were lower than early summer. Salinity/conductivity levels were lower at downstream and control sites	Water	Water Quality	Upstream modification
56	Graiff, A., Bartsch, I., Ruth, W., Wahl, M., Karsten, U.	Within Kiel Ford, Germany, on the western section of the Baltic Sea	Fucus vesticulosis (f. vesticulosis - rockweed/bladder wrack) specimens were collected and transported to an outdoor lab. Lab studies included sampling of the specimens after manual manipulations to both pCO2 and temperature. Specimens were submerged in conditions similar to local conditions appropriate for the season with associated micro- and macroepiphytes and mesograzers to stimulate similar environment.	Collections were taken once per season. Four experiments were taken over the course of each season.	F. vesticulosis growth rates followed similar patterns under increased temperature and pCO2 conditions. Increased temp conditions generally caused an increase in growth rates at all times of the year except for early summer. increased temp and pCO2 had a positive impact on growth rates most of the year except for late spring, where growth rates were lower than those of just increased temp. Some specimens died at the elevated temperature during summer months.	Macroalgae	Water Quality	Water temperature increase
56	Graiff, A., Bartsch, I., Ruth, W., Wahl, M., Karsten, U.	Within Kiel Ford, Germany, on the western section of the Baltic Sea	Fucus vesticulosis (f. vesticulosis - rockweed/bladder wrack) specimens were collected and transported to an outdoor lab. Lab studies included sampling of the specimens after manual manipulations to both pCO2 and temperature. Specimens were submerged in conditions similar to local conditions appropriate for the season with associated micro- and macroepiphytes and mesograzers to stimulate similar environment.	Collections were taken once per season. Four experiments were taken over the course of each season.	F. vesticulosis growth rates followed similar patterns under increased temperature and pCO2 conditions. Increased temp conditions generally caused an increase in growth rates at all times of the year except for early summer. increased temp and pCO2 had a positive impact on growth rates most of the year except for late spring, where growth rates were lower than those of just increased temp. Some specimens died at the elevated temperature during summer months.			Ocean Acidification
57	Greene, C.M., Blackhart, K., Nohner, J., Candelmo, A., Nelson, D.M.	All estuaries across the contiguous USA.	Use of a nationwide dataset to assess estuarine habitat stressors across the US to determine prioritization of watershed and estuarine restoration and protection.	One time data collection	Land development was generally most common on estuary shorelines, whereas agriculture was more common interior to the watershed. River flow alteration was correlated with altered land use and eutrophication. Pollution was correlated positively with altered land use.		General Health	Upstream modification
57	Greene, C.M., Blackhart, K., Nohner, J., Candelmo, A., Nelson, D.M.	All estuaries across the contiguous USA.	Use of a nationwide dataset to assess estuarine habitat stressors across the US to determine prioritization of watershed and estuarine restoration and protection.	One time data collection	Land development was generally most common on estuary shorelines, whereas agriculture was more common interior to the watershed. River flow alteration was correlated with altered land use and eutrophication. Pollution was correlated positively with altered land use.			Land reclamation

57	Greene, C.M., Blackhart, K., Nohner, J., Candelmo, A., Nelson, D.M.	All estuaries across the contiguous USA.	Use of a nationwide dataset to assess estuarine habitat stressors across the US to determine prioritization of watershed and estuarine restoration and protection.	One time data collection	Land development was generally most common on estuary shorelines, whereas agriculture was more common interior to the watershed. River flow alteration was correlated with altered land use and eutrophication. Pollution was correlated positively with altered land use.			Pollution
58	Guan, C., Saha, M., Weinberger, F.	Within Kiel Ford, Germany, on the western section of the Baltic Sea	Zostera marina (z. marina - eelgrass sp.) specimens were collected and transported to an outdoor in-situ lab where heatwaves were stimulated in four of the six tanks, two in May, July, and August lasting 7 days each (to stimulate ongoing warming event) and two only in August (to stimulate one shock warming event). The other two were control. Z. marina in each tank were tested for surface bacteria that cause fouling.	Summer months to correspond with heat wave events	Bacterial density on Z. marina surface was unaffected by heatwave treatments. Heatwave treatments significantly influenced defense capacity of Z. marina. However, regular seasonal variation was correlated more highly with bacterial settlement than heatwave treatments.	Seagrass	Plant Density	Water temperature increase
58	Guan, C., Saha, M., Weinberger, F.	Within Kiel Ford, Germany, on the western section of the Baltic Sea	Zostera marina (z. marina - eelgrass sp.) specimens were collected and transported to an outdoor in-situ lab where heatwaves were stimulated in four of the six tanks, two in May, July, and August lasting 7 days each (to stimulate ongoing warming event) and two only in August (to stimulate one shock warming event). The other two were control. Z. marina in each tank were tested for surface bacteria that cause fouling.	Summer months to correspond with heat wave events	Bacterial density on Z. marina surface was unaffected by heatwave treatments. Heatwave treatments significantly influenced defense capacity of Z. marina. However, regular seasonal variation was correlated more highly with bacterial settlement than heatwave treatments.	Microbiome	Microbial response / survival	
59	Harris, R.J., Niemand, C., Pildich, C.A.	Two mid-intertidal sites within Tauranga Harbour, New Zealand.	To assess the impact of decomposing macroalgae from toxic blooms on sedimentation and macrofauna, three types of 1m2 plots were studied in the two intertidal regions: one with mesh bag full of macroalgae (Ulva spp.), one with empty mesh bag, and one control with nothing. Sediment samples were collectec to determine sediment erosion, macrofauna, microphytobenthos biomass, and conductivity. One site was dominated by suspension feeding clam (Austrovenus stutchburyi - species rich, functionally diverse macrofauna area and another dominated by deposit-feeding bivalve (Macomona liliana - less diversity and biomass associated)	Treatments lasted 30 days, one sample was collected the day after the treatments were removed. Another sample was collected 14 days later.	There were no significant differences between the two sites in sediment properties or MPB biomass. However, control plots showed higher MPB biomass than the Ulva sites (suggesting light limiting impact). At both sites, there was a difference in the macrofaunal feeding groups on the ulva plots compared to control. However, at the Austrovenus site, the difference did not persist into the second sample, yet it did persist to the 14 day sample at the Macomona site. Surface erosion was reduced in the Ulva plots during both samples at the Macomona site. Surface erosion increased in the Ulva plots at the Austrovenus site but the impact was diminished by day 14 after removal.	Macroalgae	Sediment fluxes	Eutrophication
59	Harris, R.J., Niemand, C., Pildich, C.A.	Two mid-intertidal sites within Tauranga Harbour, New Zealand.	To assess the impact of decomposing macroalgae from toxic blooms on sedimentation and macrofauna, three types of 1m2 plots were studied in the two intertidal regions: one with mesh bag full of macroalgae (Ulva spp.), one with empty mesh bag, and one control with nothing. Sediment samples were collectec to determine sediment erosion, macrofauna, microphytobenthos biomass, and conductivity. One site was dominated by suspension feeding clam (Austrovenus stutchburyi - species rich, functionally diverse macrofauna area and another dominated by deposit-feeding bivalve (Macomona liliana - less diversity and biomass associated)	Treatments lasted 30 days, one sample was collected the day after the treatments were removed. Another sample was collected 14 days later.	There were no significant differences between the two sites in sediment properties or MPB biomass. However, control plots showed higher MPB biomass than the Ulva sites (suggesting light limiting impact). At both sites, there was a difference in the macrofaunal feeding groups on the ulva plots compared to control. However, at the Austrovenus site, the difference did not persist into the second sample, yet it did persist to the 14 day sample at the Macomona site. Surface erosion was reduced in the Ulva plots during both samples at the Macomona site. Surface erosion increased in the Ulva plots at the Austrovenus site but the impact was diminished by day 14 after removal.	Water	Microbial response / survival	
59	Harris, R.J., Niemand, C., Pildich, C.A.	Two mid-intertidal sites within Tauranga Harbour, New Zealand.	To assess the impact of decomposing macroalgae from toxic blooms on sedimentation and macrofauna, three types of 1m2 plots were studied in the two intertidal regions: one with mesh bag full of macroalgae (Ulva spp.), one with empty mesh bag, and one control with nothing. Sediment samples were collectec to determine sediment erosion, macrofauna, microphytobenthos biomass, and conductivity. One site was dominated by suspension feeding clam (Austrovenus stutchburyi - species rich, functionally diverse macrofauna area and another dominated by deposit-feeding bivalve (Macomona liliana - less diversity and biomass associated)	Treatments lasted 30 days, one sample was collected the day after the treatments were removed. Another sample was collected 14 days later.	There were no significant differences between the two sites in sediment properties or MPB biomass. However, control plots showed higher MPB biomass than the Ulva sites (suggesting light limiting impact). At both sites, there was a difference in the macrofaunal feeding groups on the ulva plots compared to control. However, at the Austrovenus site, the difference did not persist into the second sample, yet it did persist to the 14 day sample at the Macomona site. Surface erosion was reduced in the Ulva plots during both samples at the Macomona site. Surface erosion increased in the Ulva plots at the Austrovenus site but the impact was diminished by day 14 after removal.	Microbiome	Water Quality	
59	Harris, R.J., Niemand, C., Pildich, C.A.	Two mid-intertidal sites within Tauranga Harbour, New Zealand.	To assess the impact of decomposing macroalgae from toxic blooms on sedimentation and macrofauna, three types of 1m2 plots were studied in the two intertidal regions: one with mesh bag full of macroalgae (Ulva spp.), one with empty mesh bag, and one control with nothing. Sediment samples were collectec to determine sediment erosion, macrofauna, microphytobenthos biomass, and conductivity. One site was dominated by suspension feeding clam (Austrovenus stutchburyi - species rich, functionally diverse macrofauna area and another dominated by deposit-feeding bivalve (Macomona liliana - less diversity and biomass associated)	Treatments lasted 30 days, one sample was collected the day after the treatments were removed. Another sample was collected 14 days later.	There were no significant differences between the two sites in sediment properties or MPB biomass. However, control plots showed higher MPB biomass than the Ulva sites (suggesting light limiting impact). At both sites, there was a difference in the macrofaunal feeding groups on the ulva plots compared to control. However, at the Austrovenus site, the difference did not persist into the second sample, yet it did persist to the 14 day sample at the Macomona site. Surface erosion was reduced in the Ulva plots during both samples at the Macomona site. Surface erosion increased in the Ulva plots at the Austrovenus site but the impact was diminished by day 14 after removal.		Species Composition	
60	Harvey, M.E., Giddings, S.N., Stein, E.D., Crooks, J.A., Whitcraft, C., Gallien, T., Largier, J.L., Tiefenthaler, L., Meltzer, H., Pawlak, G., Thorne, K., Johnston, K., Ambrose, R., Schroeter, S.C., [illegible]	13 Estuaries in Southern California	Study of the impacts of 2015-2016 el nino event as a basis for identifying oceanic factors that will impact low inflow estuarine morphology under warming and sea-level rise scenarios. Use of existing estuarine monitoring programs to collect data on water levels, waves, atmospheric and river discharge data.	One year of abnormally warm temperatures from 2015-2016	Water levels were above average across all estuaries studied during El Nino event, and the increase in water levels was higher in intermittently closed estuaries. Intermittently closed estuaries did not fully flush during low tide events due to wave generated sand-berms that trapped tidewater within the estuary.	Morphology	Currents / Discharge / Hydrology	Water temperature increase

60	Harvey, M.E., Giddings, S.N., Stein, E.D., Crooks, J.A., Whitcraft, C., Gallien, T., Largier, J.L., Tiefenthaler, L., Meltzer, H., Pawlak, G., Thorne, K., Johnston, K., Ambrose, R., Schroeter, S.C., Page	13 Estuaries in Southern California	Study of the impacts of 2015-2016 el nino event as a basis for identifying oceanic factors that will impact low inflow estuarine morphology under warming and sea-level rise scenarios. Use of existing estuarine monitoring programs to collect data on water levels, waves, atmospheric and river discharge data.	One year of abnormally warm temperatures from 2015-2016	Water levels were above average across all estuaries studied during El Nino event, and the increase in water levels was higher in intermittently closed estuaries. Intermittently closed estuaries did not fully flush during low tide events due to wave generated sand-berms that trapped tidewater within the estuary.	Morphology		Sea-level rise
61	Hesse, C., Stefanova, A., Krysanova, V.	Four coastal lagoon type estuaries in Europe - Ria de Aveiro, Portugal; Mar Menor, Spain; Tyligulskyi Liman, Ukraine; Vistula Lagoon, Poland	Use of eco-hydrological model (Soil-Water-Assessment-Tool, SWIM) to generate a impact assessment on hydrology in the four lagoons. Impacts studied included climate and land use changes. Three climate scenarios were applied.	One time data collection.	Rising temperatures are expected at all four locations in all three scenarios. Precipitation percentage is expected to increase at the Vistula lagoon in all three scenarios but decrease or remain close to zero in all three other lagoons, with wide variability in intensity. Solar radiation levels are negatively correlated to precipitation percentage. This is aligned with a trend in increasing precipitation in northern europe and decreasing precipitation in the south.	Morphology	Currents / Discharge / Hydrology	Water temperature increase
61	Hesse, C., Stefanova, A., Krysanova, V.	Four coastal lagoon type estuaries in Europe - Ria de Aveiro, Portugal; Mar Menor, Spain; Tyligulskyi Liman, Ukraine; Vistula Lagoon, Poland	Use of eco-hydrological model (Soil-Water-Assessment-Tool, SWIM) to generate a impact assessment on hydrology in the four lagoons. Impacts studied included climate and land use changes. Three climate scenarios were applied.	One time data collection.	Rising temperatures are expected at all four locations in all three scenarios. Precipitation percentage is expected to increase at the Vistula lagoon in all three scenarios but decrease or remain close to zero in all three other lagoons, with wide variability in intensity. Solar radiation levels are negatively correlated to precipitation percentage. This is aligned with a trend in increasing precipitation in northern europe and decreasing precipitation in the south.			Freshwater flows / precipitation
62	Horn, H., Moersma, M., Garzke, J., Sommer, U., Aberle, N.	Kiel Fjord Ecosystem, nutrient deplete	Microzooplankton were collected from the Kiel Fjord and transferred to a lab where they were studied under two temperatures and a gradient of CO2 to measure acidification. Samples of mesocosm water were taken and tested for nutrients, nanoflagellates, phytoplankton, and microzooplankton. Phytoplankton, microzooplankton and mesozooplankton were also studied to understand taxonomy, biomass, growth, and grazing.	Monthly over 12 years from May 1997 to November 2009	Increase in CO2 had a positive effect on phytoplankton biomass but warming had a negative impact. All treatments showed decreased biomass. Initial decrease was followed by blooms on day 10 in cold treatment and day 5 in warm treatment but decreased again after the bloom. Warming treatment had most notable decrease of mesozooplankton biomass but acidification did not show any changes. Temperature had positive impact on microzooplankton but acidification had negative impact. Ciliate (microzooplankton) diversity decreased while dinoflagellate diversity increased.	Food Web		
62	Horn, H., Moersma, M., Garzke, J., Sommer, U., Aberle, N.	Kiel Fjord Ecosystem, nutrient deplete	Microzooplankton were collected from the Kiel Fjord and transferred to a lab where they were studied under two temperatures and a gradient of CO2 to measure acidification. Samples of mesocosm water were taken and tested for nutrients, nanoflagellates, phytoplankton, and microzooplankton. Phytoplankton, microzooplankton and mesozooplankton were also studied to understand taxonomy, biomass, growth, and grazing.	Collection of specimens on August 15. Observations occurred regularly over 28 days from August 16 to Sept 13	Increase in CO2 had a positive effect on phytoplankton biomass but warming had a negative impact. All treatments showed decreased biomass. Initial decrease was followed by blooms on day 10 in cold treatment and day 5 in warm treatment but decreased again after the bloom. Warming treatment had most notable decrease of mesozooplankton biomass but acidification did not show any changes. Temperature had positive impact on microzooplankton but acidification had negative impact. Ciliate (microzooplankton) diversity decreased while dinoflagellate diversity increased.	Water	Species Composition	Water Temperature increase
62	Horn, H., Moersma, M., Garzke, J., Sommer, U., Aberle, N.	Kiel Fjord Ecosystem, nutrient deplete	Microzooplankton were collected from the Kiel Fjord and transferred to a lab where they were studied under two temperatures and a gradient of CO2 to measure acidification. Samples of mesocosm water were taken and tested for nutrients, nanoflagellates, phytoplankton, and microzooplankton. Phytoplankton, microzooplankton and mesozooplankton were also studied to understand taxonomy, biomass, growth, and grazing.	Collection of specimens on August 15. Observations occurred regularly over 28 days from August 16 to Sept 13	Increase in CO2 had a positive effect on phytoplankton biomass but warming had a negative impact. All treatments showed decreased biomass. Initial decrease was followed by blooms on day 10 in cold treatment and day 5 in warm treatment but decreased again after the bloom. Warming treatment had most notable decrease of mesozooplankton biomass but acidification did not show any changes. Temperature had positive impact on microzooplankton but acidification had negative impact. Ciliate (microzooplankton) diversity decreased while dinoflagellate diversity increased.	Phytoplankton	Water Quality	Ocean Acidification
62	Horn, H., Moersma, M., Garzke, J., Sommer, U., Aberle, N.	Kiel Fjord Ecosystem, nutrient deplete	Microzooplankton were collected from the Kiel Fjord and transferred to a lab where they were studied under two temperatures and a gradient of CO2 to measure acidification. Samples of mesocosm water were taken and tested for nutrients, nanoflagellates, phytoplankton, and microzooplankton. Phytoplankton, microzooplankton and mesozooplankton were also studied to understand taxonomy, biomass, growth, and grazing.	Collection of specimens on August 15. Observations occurred regularly over 28 days from August 16 to Sept 13	Increase in CO2 had a positive effect on phytoplankton biomass but warming had a negative impact. All treatments showed decreased biomass. Initial decrease was followed by blooms on day 10 in cold treatment and day 5 in warm treatment but decreased again after the bloom. Warming treatment had most notable decrease of mesozooplankton biomass but acidification did not show any changes. Temperature had positive impact on microzooplankton but acidification had negative impact. Ciliate (microzooplankton) diversity decreased while dinoflagellate diversity increased.	Zooplankton	Microbial response / survival	
63	Huber, E.R., Carlson, S.M.	500k fish locations within Pescadero intermittent estuary, San Mateo county, California	Fish were seined and tagged around the middle of the estuary. 35 fish were implanted with acoustic transmitters linked to receivers placed in the estuary. Abiotic factors were measured throughout the experiment to see if they impacted fish use. Fish movement and locations were measured throughout the study.	Fish collection occurred Sept 9, 2013. Monitoring occurred September 9 to December 22.	Tagged trout showed strong site fidelity and overall increasing upstream movement. Preferred microhabitat included large woody debris structure at night time, and a lower area with a tall vertical cliff face. Tagged fish detections were negatively correlated with water temperature and salinity and positively correlated with pH and DO. Movement increased as water quality conditions decreased.	Fish	Water Quality	Drought
63	Huber, E.R., Carlson, S.M.	500k fish locations within Pescadero intermittent estuary, San Mateo county, California	Fish were seined and tagged around the middle of the estuary. 35 fish were implanted with acoustic transmitters linked to receivers placed in the estuary. Abiotic factors were measured throughout the experiment to see if they impacted fish use. Fish movement and locations were measured throughout the study.	Fish collection occurred Sept 9, 2013. Monitoring occurred September 9 to December 22.	Tagged trout showed strong site fidelity and overall increasing upstream movement. Preferred microhabitat included large woody debris structure at night time, and a lower area with a tall vertical cliff face. Tagged fish detections were negatively correlated with water temperature and salinity and positively correlated with pH and DO. Movement increased as water quality conditions decreased.		Habitat Distribution	Water temperature increase
63	Huber, E.R., Carlson, S.M.	500k fish locations within Pescadero intermittent estuary, San Mateo county, California	Fish were seined and tagged around the middle of the estuary. 35 fish were implanted with acoustic transmitters linked to receivers placed in the estuary. Abiotic factors were measured throughout the experiment to see if they impacted fish use. Fish movement and locations were measured throughout the study.	Fish collection occurred Sept 9, 2013. Monitoring occurred September 9 to December 22.	Tagged trout showed strong site fidelity and overall increasing upstream movement. Preferred microhabitat included large woody debris structure at night time, and a lower area with a tall vertical cliff face. Tagged fish detections were negatively correlated with water temperature and salinity and positively correlated with pH and DO. Movement increased as water quality conditions decreased.			Ocean Acidification
64	Ivajnšič, D., Lipej, L., Škornik, I., Kaligarič, M.	Sečovlje Salina Nature Park along the Slovenian-Croatian border	Potential change in breeding area due to sea-level rise for four estuarine breeding birds was modeled. Birds included Kentish Plover, Litter Lern, Common Tern, and Black-winged Stilt. Data on bird nesting was collected for the area to inform the model.	Model information was collected in the field from 2004-2013	Vegetation density and distance to anthropogenic disturbance were the strongest predictors of breedin area for Kentish Plover and the Black-winged stilt, which was also impacted by elevation and salt marsh habitat type. Common tern was most impacted by elevation and salt marsh habitat type. Each species had a unique breeding response to each impact type. Habitats are predicted to become more linear anc reduced if sea-level rise trends remain along current trajectories.	Salt Marsh	Animal Response / Survival	Sea-level rise

64	Ivajnšič, D., Lipej, L., Škornik, I., Kaligarič, M.	Sečovlje Salina Nature Park along the Slovenian-Croatian border	Potential change in breeding area due to sea-level rise for four estuarine breeding birds was modeled. Birds included Kentish Plover, Litter Lern, Common Tern, and Black-winged Stilt. Data on bird nesting was collected for the area to inform the model.	Model information was collected in the field from 2004-2013	Vegetation density and distance to anthropogenic disturbance were the strongest predictors of breedin area for Kentish Plover and the Black-winged stilt, which was also impacted by elevation and salt marsh habitat type. Common tern was most impacted by elevation and salt marsh habitat type. Each species had a unique breeding response to each impact type. Habitats are predicted to become more linear anc reduced if sea-level rise trends remain along current trajectories.	Birds	Elevation	Modification - General
64	Ivajnšič, D., Lipej, L., Škornik, I., Kaligarič, M.	Sečovlje Salina Nature Park along the Slovenian-Croatian border	Potential change in breeding area due to sea-level rise for four estuarine breeding birds was modeled. Birds included Kentish Plover, Litter Lern, Common Tern, and Black-winged Stilt. Data on bird nesting was collected for the area to inform the model.	Model information was collected in the field from 2004-2013	Vegetation density and distance to anthropogenic disturbance were the strongest predictors of breedin area for Kentish Plover and the Black-winged stilt, which was also impacted by elevation and salt marsh habitat type. Common tern was most impacted by elevation and salt marsh habitat type. Each species had a unique breeding response to each impact type. Habitats are predicted to become more linear anc reduced if sea-level rise trends remain along current trajectories.		Habitat Distribution	
65	James, N.C., Lamberth, S.J., Midgley, C., Whitfield, A.K.	Breede Estuary South Africa - permanently open	Seining was completed and taxonomic distribution was analyzed for species richness and evenness. Data was collected during low-flow periods.	Summer sampling over ten years from February 2002 to February 2012	Interannual variation did not occur significantly in salinity or flow levels. Species assemblage did not show interannual variation. One subtropical species Rediobius dewaali made its way into this temperat estuary from 2004 onwards. Salinity was most dominant environmental variable impacting fish assemblage	Food Web		
65	James, N.C., Lamberth, S.J., Midgley, C., Whitfield, A.K.	Breede Estuary South Africa - permanently open	Seining was completed and taxonomic distribution was analyzed for species richness and evenness. Data was collected during low-flow periods.	Summer sampling over ten years from February 2002 to February 2012	Interannual variation did not occur significantly in salinity or flow levels. Species assemblage did not show interannual variation. One subtropical species Rediobius dewaali made its way into this temperat estuary from 2004 onwards. Salinity was most dominant environmental variable impacting fish assemblage	Water	Species Composition	Drought
65	James, N.C., Lamberth, S.J., Midgley, C., Whitfield, A.K.	Breede Estuary South Africa - permanently open	Seining was completed and taxonomic distribution was analyzed for species richness and evenness. Data was collected during low-flow periods.	Summer sampling over ten years from February 2002 to February 2012	Interannual variation did not occur significantly in salinity or flow levels. Species assemblage did not show interannual variation. One subtropical species Rediobius dewaali made its way into this temperat estuary from 2004 onwards. Salinity was most dominant environmental variable impacting fish assemblage		Water Quality	Freshwater flows / precipitation
65	James, N.C., Lamberth, S.J., Midgley, C., Whitfield, A.K.	Breede Estuary South Africa - permanently open	Seining was completed and taxonomic distribution was analyzed for species richness and evenness. Data was collected during low-flow periods.	Summer sampling over ten years from February 2002 to February 2012	Interannual variation did not occur significantly in salinity or flow levels. Species assemblage did not show interannual variation. One subtropical species Rediobius dewaali made its way into this temperat estuary from 2004 onwards. Salinity was most dominant environmental variable impacting fish assemblage		Currents / Discharge / Hydrology	
66	Janousek, C.N., Folger, C.L.	Four estuaries in Oregon: the Yaquina, Netarts, Alsea, and Coquille.	Conducted a vegetative classification of marshes throughout the four estuaries in Oregon to weigh field investigations against the current classification system of the National Wetlands Inventory for tidal emergent marsh classes, including low estuarine marsh, high estuarine marsh, and tidal palustrine marsh.	Summer sampling in 2010 from June to September	Pore water salinity varied strongly across marsh classes. sediment carbon and nitrogen also varied but less strongly. Common plant cover differed across classes, and there were a large number of plant assemblages not captured by the national wetland inventory classification system.	Salt Marsh	Plant Diversity	Baseline assessment
66	Janousek, C.N., Folger, C.L.	Four estuaries in Oregon: the Yaquina, Netarts, Alsea, and Coquille.	Conducted a vegetative classification of marshes throughout the four estuaries in Oregon to weigh field investigations against the current classification system of the National Wetlands Inventory for tidal emergent marsh classes, including low estuarine marsh, high estuarine marsh, and tidal palustrine marsh.	Summer sampling in 2010 from June to September	Pore water salinity varied strongly across marsh classes. sediment carbon and nitrogen also varied but less strongly. Common plant cover differed across classes, and there were a large number of plant assemblages not captured by the national wetland inventory classification system.		Sediment Quality	
67	Karlsson, K., Puiac, S., Winder, M.	Stockholm archipelago, Bothnian Bay, and Gulf of Riga	Studied the diversity of reactions of the copepod Eurytemora affinis within populations to stimulus of increasing freshwater inputs and increasing temperatures.	Spring and Autumn of 2014	Salinity and temperature had a significant interactive impact on copepod hatching success. Sensitivity t changing salinity changed at different temperatures. Increased salinity and temperatures increased rate of development. Both had an effect on adult survival, where lower salinity levels were detrimental and higher temperatures negatively impact survival rates but not as strongly as salinity changes.	Water	Animal Response / Survival	Freshwater flows / precipitation
67	Karlsson, K., Puiac, S., Winder, M.	Stockholm archipelago, Bothnian Bay, and Gulf of Riga	Studied the diversity of reactions of the copepod Eurytemora affinis within populations to stimulus of increasing freshwater inputs and increasing temperatures.	Spring and Autumn of 2014	Salinity and temperature had a significant interactive impact on copepod hatching success. Sensitivity t changing salinity changed at different temperatures. Increased salinity and temperatures increased rate of development. Both had an effect on adult survival, where lower salinity levels were detrimental and higher temperatures negatively impact survival rates but not as strongly as salinity changes.	Zooplankton	Water Quality	Water temperature increase
68	Kennedy, D.M., Konlechner, T., Zavadil, E., Mariani, M., Wong, V., Ierodiaconou, D., Macreadie, P.	Venus Bay, Anderson Inlet, Victoria, Australia	Study of the impact of habitat changes caused by invasive Spartina spp. using core samples and aerial photo analysis. LiDAR data was used to capture images of the area from elevations of +10 to -25m. Historical photos from 1950, 1981, 2010, and 2015 were used to determine marsh habitat change over time. Coring was completed to determine carbon and organic content of the soil.	Aerial imagery collected in 2007. Core samples were collected in 2015. Images allowed for study over 65 years	Small marsh islands grew substantially since the 1950s on three distinct sites. Additionally, many more islands emerged since the 1950s. Much of this was attributed to european colonization and the subsequent expansion of Spartina, which dominated the marshes.	Salt Marsh	Habitat Distribution	Invasive Species
69	Khangaonkar, T., Nugraha, A., Hinton, S., Michalsen, D., Brown, S.	Swinomish Navigation Channel in the Skagit River Estuary, Puget Sound, Washington	In an effort to find the best restoration option to allow navigation channels to be re-established following erosion of existing dykes and jetties, different options were modelled using Finite Volume Community Ocean Model. Preferred optior would allow access for fishing and recreational craft while also maintaining fish habitat connectivity and enhancing estuarine brackish water habitat. The model used oceanographic data studying currents, salinity, temperature, and acoustic and optical backscatter. Suspended sediment concentrations were also measured. One restoration option was to repair the jetty, another was to breach the causeway.	Data was used from a study conducted in May, 2006. Other data was used from a different study undertaken in 2009 as inputs into the model.	The jetty repair option did not appear to impact salinity distribution in a strong way. Bottom shear stress was increased by this option. The repaired jetty prevents tidal flow from accessing one section of tidal flats, and increases shear stress of tidal flow in the other section. Total suspended sediment is decreased from entering the Swinomish channel in this option, but not by a noticable amount, suggesting the repair might not achieve the effect intended.	Morphology	Restoration / Recovery	Hardened coastal defences

69	Khangaonkar, T., Nugraha, A., Hinton, S., Michalsen, D., Brown, S.	Swinomish Navigation Channel in the Skagit River Estuary, Puget Sound, Washington	In an effort to find the best restoration option to allow navigation channels to be re-established following erosion of existing dykes and jetties, different options were modelled using Finite Volume Community Ocean Model. Preferred optior would allow access for fishing and recreational craft while also maintaining fish habitat connectivity and enhancing estuarine brackish water habitat. The model used oceanographic data studying currents, salinity, temperature, and acoustic and optical backscatter. Suspended sediment concentrations were also measured. One restoration option was to repair the jetty, another was to breach the causeway.	Data was used from a study conducted in May, 2006. Other data was used from a different study undertaken in 2009 as inputs into the model.	The jetty repair option did not appear to impact salinity distribution in a strong way. Bottom shear stress was increased by this option. The repaired jetty prevents tidal flow from accessing one section of tidal flats, and increases shear stress of tidal flow in the other section. Total suspended sediment is decreased from entering the Swinomish channel in this option, but not by a noticable amount, suggesting the repair might not achieve the effect intended.			Land reclamation
70	Kim, M., Qin, L., Kim, S.H., Song, H.J., Kim, Y.K., Lee, K.S.	Lab cultures were collected from Koje Bay, South Korea	Zostera marina shoots from core samples were collected and cultured in a lab setting to stimulate two anomalous events: colder water temperatures from summer upwelling and warmer temperatures from autumn heat waves. There were four experimental units comprising of temperatures at 20 and 27 degrees and photon irradiance at 150 and 500 mmol photons m-2s-1.	One experiment was conducted in fall 2014 and another in summer of 2015. Data was collected biweekly seven times over the course of each season.	Increased light treatment in the fall with no temperature increase showed increased shoot density and leaf productivity by a small amount. Increased temperature with low light availability in the fall caused an extreme decrease in shoot density. In the summer, shoot density increased significantly with sudden temperature decrease, but shoot density decreased with the ambient high temperature. High temperatures and low light availability combined had detrimental effects. Low temperatures and light availability had positive combined effects on leaf productivity and shoot density.	Seagrass	Light Access / Attenuation	Water temperature increase
70	Kim, M., Qin, L., Kim, S.H., Song, H.J., Kim, Y.K., Lee, K.S.	Lab cultures were collected from Koje Bay, South Korea	Zostera marina shoots from core samples were collected and cultured in a lab setting to stimulate two anomalous events: colder water temperatures from summer upwelling and warmer temperatures from autumn heat waves. There were four experimental units comprising of temperatures at 20 and 27 degrees and photon irradiance at 150 and 500 mmol photons m-2s-1.	One experiment was conducted in fall 2014 and another in summer of 2015. Data was collected biweekly seven times over the course of each season.	Increased light treatment in the fall with no temperature increase showed increased shoot density and leaf productivity by a small amount. Increased temperature with low light availability in the fall caused an extreme decrease in shoot density. In the summer, shoot density increased significantly with sudden temperature decrease, but shoot density decreased with the ambient high temperature. High temperatures and low light availability combined had detrimental effects. Low temperatures and light availability had positive combined effects on leaf productivity and shoot density.		Plant Density	Turbidity
70	Kim, M., Qin, L., Kim, S.H., Song, H.J., Kim, Y.K., Lee, K.S.	Lab cultures were collected from Koje Bay, South Korea	Zostera marina shoots from core samples were collected and cultured in a lab setting to stimulate two anomalous events: colder water temperatures from summer upwelling and warmer temperatures from autumn heat waves. There were four experimental units comprising of temperatures at 20 and 27 degrees and photon irradiance at 150 and 500 mmol photons m-2s-1.	One experiment was conducted in fall 2014 and another in summer of 2015. Data was collected biweekly seven times over the course of each season.	Increased light treatment in the fall with no temperature increase showed increased shoot density and leaf productivity by a small amount. Increased temperature with low light availability in the fall caused an extreme decrease in shoot density. In the summer, shoot density increased significantly with sudden temperature decrease, but shoot density decreased with the ambient high temperature. High temperatures and low light availability combined had detrimental effects. Low temperatures and light availability had positive combined effects on leaf productivity and shoot density.		Plant Response / Survival	
70	Kim, M., Qin, L., Kim, S.H., Song, H.J., Kim, Y.K., Lee, K.S.	Lab cultures were collected from Koje Bay, South Korea	Zostera marina shoots from core samples were collected and cultured in a lab setting to stimulate two anomalous events: colder water temperatures from summer upwelling and warmer temperatures from autumn heat waves. There were four experimental units comprising of temperatures at 20 and 27 degrees and photon irradiance at 150 and 500 mmol photons m-2s-1.	One experiment was conducted in fall 2014 and another in summer of 2015. Data was collected biweekly seven times over the course of each season.	Increased light treatment in the fall with no temperature increase showed increased shoot density and leaf productivity by a small amount. Increased temperature with low light availability in the fall caused an extreme decrease in shoot density. In the summer, shoot density increased significantly with sudden temperature decrease, but shoot density decreased with the ambient high temperature. High temperatures and low light availability combined had detrimental effects. Low temperatures and light availability had positive combined effects on leaf productivity and shoot density.		Water Quality	
71	Ladd, C.J.T., Duggan-Edwards, M.F., Bouma, T.J., Pages, J.F., Skov, M.W.	25 estuaries and embayments in six regions across Great Britain (19 000 ha)	Salt marsh area was quantified for each estuary over time using historical imagery. Net sediment flux per unit area was calculated for each estuary, and frequency of storm events was identified. Archives were collected on major infrastructure projects. Wave fetch length information was also included. All data was collected to identify variable factors leading to lateral changes in salt marshes over time.	Modelling was conducted once. Data included information from 1846 to 2016, at 30-year intervals	Land reclamation caused major loss of marsh areas, but most recovered and expanded historically. In many cases, marsh area increases have been due to the invasion of Spartina cordgrass. Concurrent increase of sediment flux and fetch length led to the increase of marsh area. Large scale, long term trends are most related to sediment supply. Longer wave fetch lengths are related to wider foreshores, which can effectively attenuate waves, preventing marsh area reduction from erosion.	Salt Marsh	Habitat Distribution	Land reclamation
71	Ladd, C.J.T., Duggan-Edwards, M.F., Bouma, T.J., Pages, J.F., Skov, M.W.	25 estuaries and embayments in six regions across Great Britain (19 000 ha)	Salt marsh area was quantified for each estuary over time using historical imagery. Net sediment flux per unit area was calculated for each estuary, and frequency of storm events was identified. Archives were collected on major infrastructure projects. Wave fetch length information was also included. All data was collected to identify variable factors leading to lateral changes in salt marshes over time.	Modelling was conducted once. Data included information from 1846 to 2016, at 30-year intervals	Land reclamation caused major loss of marsh areas, but most recovered and expanded historically. In many cases, marsh area increases have been due to the invasion of Spartina cordgrass. Concurrent increase of sediment flux and fetch length led to the increase of marsh area. Large scale, long term trends are most related to sediment supply. Longer wave fetch lengths are related to wider foreshores, which can effectively attenuate waves, preventing marsh area reduction from erosion.		Currents / Discharge / Hydrology	Invasive Species
71	Ladd, C.J.T., Duggan-Edwards, M.F., Bouma, T.J., Pages, J.F., Skov, M.W.	25 estuaries and embayments in six regions across Great Britain (19 000 ha)	Salt marsh area was quantified for each estuary over time using historical imagery. Net sediment flux per unit area was calculated for each estuary, and frequency of storm events was identified. Archives were collected on major infrastructure projects. Wave fetch length information was also included. All data was collected to identify variable factors leading to lateral changes in salt marshes over time.	Modelling was conducted once. Data included information from 1846 to 2016, at 30-year intervals	Land reclamation caused major loss of marsh areas, but most recovered and expanded historically. In many cases, marsh area increases have been due to the invasion of Spartina cordgrass. Concurrent increase of sediment flux and fetch length led to the increase of marsh area. Large scale, long term trends are most related to sediment supply. Longer wave fetch lengths are related to wider foreshores, which can effectively attenuate waves, preventing marsh area reduction from erosion.			Sediment fluxes
72	Leite, N., Guerra, A., Almeida, A., Marques, J.C., Martins, I.	Mondego Estuary, Portugal, three locations	Echinogammarus marinus (leach) was tested for population dynamics and productivity levels through a monthly field sampling program in the Mondego estuary. The sampling program included collection of fucus algae and extracting leach biomass and information about other species. Results were compared with similar programs completed in the same location during pre-eutrophic (1980s) and eutrophic (1990s) regimes that occurred.	Field sampling was collected monthly from April 2009 to March 2010	Pre-eutrophication, E. marinus density was positively correlated temperature and dissolved oxygen, fecundity - temp and salinity, and sex-ratio - dissolved oxygen and negative correlation with nitrite. During eutrophication, density was negatively correlated with temperature and salinity. biomass was positively correlated with macroalgae density. Post-eutrophication, density was positively related to salinity and dissolved oxygen and negatively to ammonia and phosphate. Biomass was positively correlated with salinity and negatively with ammonia. Population parameters were highest pre-eutrophication and lowest during eutrophication. Results indicate post-eutrophication recovery but no yet to pre-eutrophic levels.	Macroalgae	Animal Response / Survival	Eutrophication

72	Leite, N., Guerra, A., Almeida, A., Marques, J.C., Martins, I.	Mondego Estuary, Portugal, three locations	Echinogammarus marinus (leach) was tested for population dynamics and productivity levels through a monthly field sampling program in the Mondego estuary. The sampling program included collection of fucus algae and extracting leach biomass and information about other species. Results were compared with similar programs completed in the same location during pre-eutrophic (1980s) and eutrophic (1990s) regimes that occurred.	Field sampling was collected monthly from April 2009 to March 2010	Pre-eutrophication, E. marinus density was positively correlated temperature and dissolved oxygen, fecundity - temp and salinity, and sex-ratio - dissolved oxygen and negative correlation with nitrite. During eutrophication, density was negatively correlated with temperature and salinity. biomass was positively correlated with macroalgae density. Post-eutrophication, density was positively related to salinity and dissolved oxygen and negatively to ammonia and phosphate. Biomass was positively correlated with salinity and negatively with ammonia. Population parameters were highest pre-eutrophication and lowest during eutrophication. Results indicate post-eutrophication recovery but no yet to pre-eutrophic levels.	Invertebrates	Animal Response / Survival	
73	Lemley, D.A., Nunes, M., Adams, J.B.	Collection from Maitland Estuary, South Africa, and moved to lab for simuilated microcosm experiment	Estuarine water filled with micro primary producers (filamentous algae, phytoplankton, and microphytobenthos) was collected from a warm-temperate oligohaline estuary that was temporarily closed from open ocean due to a naturally occurring sandbar. In lab setting, primary producers were exposed to increased concentrations of nitrate. Inorganic nitrogen and phosphorous levels were measured along with salinity, temperature, and dissolved oxygen. Primary producer biomass, communities and structures were noted. All tanks were exposed to environmental variables of sunlight and temperature.	Specimens were collected May 17, 2017 and studied in lab environment for 28 days after.	Salinity remained constant at low levels. Temperature was variable but generally showed a gradual increase. Dissolved oxygen generally showed a gradual decrease throughout. phytoplankton and microphytobenthos remained low across all treatments. Higher nitrate concentrations had significantly less phytoplankton and MPB biomass than the other two treatments. Filamentous algae showed dramatic increases across all treatments, prominently in week 3 for the high nitrate treatment and in week 4 for the other two treatments.	Water	Microbial response / survival	Eutrophication
73	Lemley, D.A., Nunes, M., Adams, J.B.	Collection from Maitland Estuary, South Africa, and moved to lab for simuilated microcosm experiment	Estuarine water filled with micro primary producers (filamentous algae, phytoplankton, and microphytobenthos) was collected from a warm-temperate oligohaline estuary that was temporarily closed from open ocean due to a naturally occurring sandbar. In lab setting, primary producers were exposed to increased concentrations of nitrate. Inorganic nitrogen and phosphorous levels were measured along with salinity, temperature, and dissolved oxygen. Primary producer biomass, communities and structures were noted. All tanks were exposed to environmental variables of sunlight and temperature.	Specimens were collected May 17, 2017 and studied in lab environment for 28 days after.	Salinity remained constant at low levels. Temperature was variable but generally showed a gradual increase. Dissolved oxygen generally showed a gradual decrease throughout. phytoplankton and microphytobenthos remained low across all treatments. Higher nitrate concentrations had significantly less phytoplankton and MPB biomass than the other two treatments. Filamentous algae showed dramatic increases across all treatments, prominently in week 3 for the high nitrate treatment and in week 4 for the other two treatments.	Phytoplankton		Water temperature increase
73	Lemley, D.A., Nunes, M., Adams, J.B.	Collection from Maitland Estuary, South Africa, and moved to lab for simuilated microcosm experiment	Estuarine water filled with micro primary producers (filamentous algae, phytoplankton, and microphytobenthos) was collected from a warm-temperate oligohaline estuary that was temporarily closed from open ocean due to a naturally occurring sandbar. In lab setting, primary producers were exposed to increased concentrations of nitrate. Inorganic nitrogen and phosphorous levels were measured along with salinity, temperature, and dissolved oxygen. Primary producer biomass, communities and structures were noted. All tanks were exposed to environmental variables of sunlight and temperature.	Specimens were collected May 17, 2017 and studied in lab environment for 28 days after.	Salinity remained constant at low levels. Temperature was variable but generally showed a gradual increase. Dissolved oxygen generally showed a gradual decrease throughout. phytoplankton and microphytobenthos remained low across all treatments. Higher nitrate concentrations had significantly less phytoplankton and MPB biomass than the other two treatments. Filamentous algae showed dramatic increases across all treatments, prominently in week 3 for the high nitrate treatment and in week 4 for the other two treatments.	Microbiome		
74	Leuven, J.R.F.W., Pierik, H.J., van der Vegt, M., Bouma, T.J., Kleinhans, M.G.	Model of 36 estuaries across the world.	Used simulation models to calculate hydrodynamic response to sea-level rise in estuaries ranging in size from .1 to 1000 kilometers squared. Three scenarios were used. 1: increase in SLR of 1m over 100 years. Scenario 2: changing tidal amplitude at the estuary mouth between -.25m and .5m. Scenario 3: changing estuary width.	One time data collection	Impacts of sea-level rise vary between small, shallow and damping estuaries versus large, deep, and amplifying estuaries. Size was the strongest indicator of sensitivity. Large, amplified estuaries are less likely to be further amplified by an increase in SLR. tidal amplification impacts establishing salt marshes through inundation - widening of the estuary mouth increases the tidal prism moving salt marshes into the intertidal zone and creating more intertidal area. It also creates greater risk of flooding at high tides and loss of navigability during low tides. Decrease in adequate sediment supply in congruence with SLR is created in situations of lower tidal amplitude, but higher amplitude provides sufficient sediment. Small estuaries are less impacted by tidal amplitude. Managed realignment is appropriate as a management technique for large estuaries to counteract sediment starvation.	Morphology	Currents / Discharge / Hydrology	Sea-level rise
74	Leuven, J.R.F.W., Pierik, H.J., van der Vegt, M., Bouma, T.J., Kleinhans, M.G.	Model of 36 estuaries across the world.	Used simulation models to calculate hydrodynamic response to sea-level rise in estuaries ranging in size from .1 to 1000 kilometers squared. Three scenarios were used. 1: increase in SLR of 1m over 100 years. Scenario 2: changing tidal amplitude at the estuary mouth between -.25m and .5m. Scenario 3: changing estuary width.	One time data collection	Impacts of sea-level rise vary between small, shallow and damping estuaries versus large, deep, and amplifying estuaries. Size was the strongest indicator of sensitivity. Large, amplified estuaries are less likely to be further amplified by an increase in SLR. tidal amplification impacts establishing salt marshes through inundation - widening of the estuary mouth increases the tidal prism moving salt marshes into the intertidal zone and creating more intertidal area. It also creates greater risk of flooding at high tides and loss of navigability during low tides. Decrease in adequate sediment supply in congruence with SLR is created in situations of lower tidal amplitude, but higher amplitude provides sufficient sediment. Small estuaries are less impacted by tidal amplitude. Managed realignment is appropriate as a management technique for large estuaries to counteract sediment starvation.		Sediment fluxes	
75	Li, N., Wang, Z., Feng, Y., Lingqian, X.	Yellow Sea Coastline in East China	Study of habitat availability and long-term reclamation efforts impacts to population size of endangered and culturally important Red-crowned crane Grus Japonesis. Use of GPS data to determine land use pattern change. Field data to determine population changes, and historical field data to compare land use changes.	Historical data taken from 1975, 1991, 2000. Field data taken from 2006, 2010, 2013	Reclaimed coastal areas increased since 1975, with a mild decrease post 2000. The wintering populatio of G. japonesis has increased substantially in congruence with increased reclamation. Areas that are important to the bird include fish ponds, bare tidal flats, and s. alterniflora. Areas negatively correlated with population are residential zones and p. australis.	Mudflats	Animal Response / Survival	Land reclamation

75	Li, N., Wang, Z., Feng, Y., Lingqian, X.	Yellow Sea Coastline in East China	Study of habitat availability and long-term reclamation efforts impacts to population size of endangered and culturally important Red-crowned crane Grus Japonesis. Use of GPS data to determine land use pattern change. Field data to determine population changes, and historical field data to compare land use changes.	Historical data taken from 1975, 1991, 2000. Field data taken from 2006, 2010, 2013	Reclaimed coastal areas increased since 1975, with a mild decrease post 2000. The wintering populatioı of G. japonesis has increased substantially in congruence with increased reclamation. Areas that are important to the bird include fish ponds, bare tidal flats, and s. alterniflora. Areas negatively correlated with population are residential zones and p. australis.	Salt Marsh		
75	Li, N., Wang, Z., Feng, Y., Lingqian, X.	Yellow Sea Coastline in East China	Study of habitat availability and long-term reclamation efforts impacts to population size of endangered and culturally important Red-crowned crane Grus Japonesis. Use of GPS data to determine land use pattern change. Field data to determine population changes, and historical field data to compare land use changes.	Historical data taken from 1975, 1991, 2000. Field data taken from 2006, 2010, 2013	Reclaimed coastal areas increased since 1975, with a mild decrease post 2000. The wintering populatioı of G. japonesis has increased substantially in congruence with increased reclamation. Areas that are important to the bird include fish ponds, bare tidal flats, and s. alterniflora. Areas negatively correlated with population are residential zones and p. australis.	Birds		Invasive Species
76	Lincoln, A.E., Shaffer, J.A., Quinn, T.P.	Elwha River Estuary, Washington, USA, and Salt Creek Estuary, Washington, USA.	Study of estuary use by bull trout and how it is impacted by an upstream dam. Bull trout are facultatively anadromous species whose populations have been isolated in freshwater due to twc dams that have not allowed fish passage for 100 years. The removal of the dams provided an opportunity to study use of estuary by bull trout. Study included seined collection and identification at both estuaries.	Monthly, March 2007 to November, 2017. Included times before and after dam removal.	No bull trout were found in the Salt Creek Estuary. 69 were encountered from 411 seines in the Elwha River Estuary over 10 years. Catches increased in conjunction with dam removal in 2011, and increased even more dramatically after the removal of another dam along the same river in 2014. Catches returned to low levels in 2016-2017. Results suggest estuary use year round and after the first year of life.	Fish	Habitat Distribution	Upstream modification
77	Liu, Z.C., de Lange, W.P., Bryan, K.R.	Tairua Estuary, New Zealand	Use of modelling software to determine the impact of Sea Level Rise and predicted sediment accretion on the Tairua Estuary. Four potential models were included using 0, 0.5, 0.8, and 1.2 meters in sea level rise. Model inputs were informed by field studies of existing water elevation, current velocities, wave height and period.	Field sampling was collected from July 27 to Sept 4, 2010 and June 8 to July 11, 2011. Modeling was a one time data collection	General increasing trend in tidal range associated with SLR. Estuary is predicted to move from being ebl dominated with fluvial sediment inputs to flood dominated with marine sediment inputs. A sediment deficit is predicted to occur due to poor marine supply. Sediment movement is also predicted to increase coastal erosion.	Salt Marsh	Sediment fluxes	Sea-level rise
77	Liu, Z.C., de Lange, W.P., Bryan, K.R.	Tairua Estuary, New Zealand	Use of modelling software to determine the impact of Sea Level Rise and predicted sediment accretion on the Tairua Estuary. Four potential models were included using 0, 0.5, 0.8, and 1.2 meters in sea level rise. Model inputs were informed by field studies of existing water elevation, current velocities, wave height and period.	Field sampling was collected from July 27 to Sept 4, 2010 and June 8 to July 11, 2011. Modeling was a one time data collection	General increasing trend in tidal range associated with SLR. Estuary is predicted to move from being ebl dominated with fluvial sediment inputs to flood dominated with marine sediment inputs. A sediment deficit is predicted to occur due to poor marine supply. Sediment movement is also predicted to increase coastal erosion.	Mudflats	Sediment fluxes	Sediment fluxes
78	Lynum, C.A., Bulseco, A.N., Dunphy, C.M., Osborne, S.M., Vineis, J.H., Bowen, J.L.	Four marshes in Pleasant Bay estuarine complex, Cape Cod, MA, USA, three reference and one restored.	Study of soil microbial communities within oligohaline marshes (S. alterniflora = typical, Typha = invasive, P. australis = invasive) to determine the trajectory of restoration efforts within a restored salt marsh in comparison to three established reference marshes. Restored marsh previously had tidal flow restricted. Microbial community was studied before and after tidal flow was restored to the area. Three references were chosen to include a variety of possible trajectories of recovery.	Pre-restoration: June, August, October, 2015; Post-restoration: June, July, August, October, 2016-2017.	Sediment and pore water characteristics in invasive regions became more similar to all reference marshes over the course of the study but were already very similar to reference marshes in the S. alterniflora section. Microbial communities in all three study areas within the marsh changed quickly and dramatically after the re-introduction of tidal flow in the trajectory of the reference marshes. Microbial prokaryotic and fungal communities provide early detection of restoration effectiveness.	Salt Marsh	Restoration / Recovery	Modification - General
78	Lynum, C.A., Bulseco, A.N., Dunphy, C.M., Osborne, S.M., Vineis, J.H., Bowen, J.L.	Four marshes in Pleasant Bay estuarine complex, Cape Cod, MA, USA, three reference and one restored.	Study of soil microbial communities within oligohaline marshes (S. alterniflora = typical, Typha = invasive, P. australis = invasive) to determine the trajectory of restoration efforts within a restored salt marsh in comparison to three established reference marshes. Restored marsh previously had tidal flow restricted. Microbial community was studied before and after tidal flow was restored to the area. Three references were chosen to include a variety of possible trajectories of recovery.	Pre-restoration: June, August, October, 2015; Post-restoration: June, July, August, October, 2016-2017.	Sediment and pore water characteristics in invasive regions became more similar to all reference marshes over the course of the study but were already very similar to reference marshes in the S. alterniflora section. Microbial communities in all three study areas within the marsh changed quickly and dramatically after the re-introduction of tidal flow in the trajectory of the reference marshes. Microbial prokaryotic and fungal communities provide early detection of restoration effectiveness.	Microbiome	Microbial response / survival	
78	Lynum, C.A., Bulseco, A.N., Dunphy, C.M., Osborne, S.M., Vineis, J.H., Bowen, J.L.	Four marshes in Pleasant Bay estuarine complex, Cape Cod, MA, USA, three reference and one restored.	Study of soil microbial communities within oligohaline marshes (S. alterniflora = typical, Typha = invasive, P. australis = invasive) to determine the trajectory of restoration efforts within a restored salt marsh in comparison to three established reference marshes. Restored marsh previously had tidal flow restricted. Microbial community was studied before and after tidal flow was restored to the area. Three references were chosen to include a variety of possible trajectories of recovery.	Pre-restoration: June, August, October, 2015; Post-restoration: June, July, August, October, 2016-2017.	Sediment and pore water characteristics in invasive regions became more similar to all reference marshes over the course of the study but were already very similar to reference marshes in the S. alterniflora section. Microbial communities in all three study areas within the marsh changed quickly and dramatically after the re-introduction of tidal flow in the trajectory of the reference marshes. Microbial prokaryotic and fungal communities provide early detection of restoration effectiveness.	Microbiome		
79	MacKenzie, R.A., Dionne, M., Miller, J., Haas, M., Morgan, P.A.	Nine fringing marsh ecosystems in Casco Bay, ME, USA	Study measures differences in benthic infaunal invertebrate structure between invasive Typha sp. & P. australis communities and naturally occurring S. alterniflora (low marsh) & S. patens (high marsh) communities. Core samples were collected and examined and benthic community assemblages were recorded.	June, July, and August, 2002 & 2003. Samples taken at slack tide, twice over two days per sample.	Invertebrate densities were higher in low-marsh zones (S. alterniflora). There was not a significant difference in invertebrate density between high marsh S. patens and P. australis sites. Oligochaetes were the most abundant type of invertebrate at all sites. Biomass was greater at all low marsh sites than high marsh and P. australis sites. Organic content was higher in high marsh and P. Australis areas than low marsh. Pore water salinity was lower in high marsh and P. Australis areas than low marsh. Plant diversity was higher in high marsh areas than P. Australis areas. Invertebrate diversity across all areas did not differ significantly.	Food Web		

79	MacKenzie, R.A., Dionne, M., Miller, J., Haas, M., Morgan, P.A.	Nine fringing marsh ecosystems in Casco Bay, ME, USA	Study measures differences in benthic infaunal invertebrate structure between invasive Typha sp. & P. australis communities and naturally occurring S. alterniflora (low marsh) & S. patens (high marsh) communities. Core samples were collected and examined and benthic community assemblages were recorded.	June, July, and August, 2002 & 2003. Samples taken at slack tide, twice over two days per sample.	Invertebrate densities were higher in low-marsh zones (S. alterniflora). There was not a significant difference in invertebrate density between high marsh S. patens and P. australis sites. Oligochaetes were the most abundant type of invertebrate at all sites. Biomass was greater at all low marsh sites than high marsh and P. australis sites. Organic content was higher in high marsh and P. Australis areas than low marsh. Pore water salinity was lower in high marsh and P. Australis areas than low marsh. Plant diversity was higher in high marsh areas than P. Australis areas. Invertebrate diversity across all areas did not differ significantly.	Salt Marsh	Species Composition	Invasive Species
79	MacKenzie, R.A., Dionne, M., Miller, J., Haas, M., Morgan, P.A.	Nine fringing marsh ecosystems in Casco Bay, ME, USA	Study measures differences in benthic infaunal invertebrate structure between invasive Typha sp. & P. australis communities and naturally occurring S. alterniflora (low marsh) & S. patens (high marsh) communities. Core samples were collected and examined and benthic community assemblages were recorded.	June, July, and August, 2002 & 2003. Samples taken at slack tide, twice over two days per sample.	Invertebrate densities were higher in low-marsh zones (S. alterniflora). There was not a significant difference in invertebrate density between high marsh S. patens and P. australis sites. Oligochaetes were the most abundant type of invertebrate at all sites. Biomass was greater at all low marsh sites than high marsh and P. australis sites. Organic content was higher in high marsh and P. Australis areas than low marsh. Pore water salinity was lower in high marsh and P. Australis areas than low marsh. Plant diversity was higher in high marsh areas than P. Australis areas. Invertebrate diversity across all areas did not differ significantly.	Invertebrates	Plant Diversity	
79	MacKenzie, R.A., Dionne, M., Miller, J., Haas, M., Morgan, P.A.	Nine fringing marsh ecosystems in Casco Bay, ME, USA	Study measures differences in benthic infaunal invertebrate structure between invasive Typha sp. & P. australis communities and naturally occurring S. alterniflora (low marsh) & S. patens (high marsh) communities. Core samples were collected and examined and benthic community assemblages were recorded.	June, July, and August, 2002 & 2003. Samples taken at slack tide, twice over two days per sample.	Invertebrate densities were higher in low-marsh zones (S. alterniflora). There was not a significant difference in invertebrate density between high marsh S. patens and P. australis sites. Oligochaetes were the most abundant type of invertebrate at all sites. Biomass was greater at all low marsh sites than high marsh and P. australis sites. Organic content was higher in high marsh and P. Australis areas than low marsh. Pore water salinity was lower in high marsh and P. Australis areas than low marsh. Plant diversity was higher in high marsh areas than P. Australis areas. Invertebrate diversity across all areas did not differ significantly.		Biodiversity	
80	Magni, P., Como, S., Montani, S., Tsutsumi, H.	Shinkawa-Kasugakawa Estuary, Seto Inland Sea, Japan	Study of bivalve-mediated nutrient fluxes in the intertidal sand and mudflats. Specifically, macrobenthic assemblages, pore-water nutrients (NH4+, PO4-3-, SiO2, and NO3- + NO2-), sedimentary acid-volatile sulfide, and benthic chlorophyll-a. Association of chemicistry changes with bivalves Ruditapes philippinarumand Arcuatula senhousia was examined.	Six consecutive seasons from summer, 1994 to autumn, 1995	There was significant seasonal variation in nutrient fluxes due to bivalve activity. Fluxes of NH4+, PO4-3 and SiO2 due to R. philippinarum were highest in summer 94. Fluxes of NH4+, PO4-3- and SiO2 due to A senhousia were highest in summer 94 and 95. Pore water nutrient concentrations followed a similar pattern. Authors attribute this to changing standing stocks within the estuary. Results indicate seasonal patterns in nutrient recycling related to bivalve abundance and activity levels being highest in summer. Nutrient recycling is important for primary production.	Sand Flats	Water Quality	Baseline assessment
80	Magni, P., Como, S., Montani, S., Tsutsumi, H.	Shinkawa-Kasugakawa Estuary, Seto Inland Sea, Japan	Study of bivalve-mediated nutrient fluxes in the intertidal sand and mudflats. Specifically, macrobenthic assemblages, pore-water nutrients (NH4+, PO4-3-, SiO2, and NO3- + NO2-), sedimentary acid-volatile sulfide, and benthic chlorophyll-a. Association of chemicistry changes with bivalves Ruditapes philippinarumand Arcuatula senhousia was examined.	Six consecutive seasons from summer, 1994 to autumn, 1995	There was significant seasonal variation in nutrient fluxes due to bivalve activity. Fluxes of NH4+, PO4-3 and SiO2 due to R. philippinarum were highest in summer 94. Fluxes of NH4+, PO4-3- and SiO2 due to A senhousia were highest in summer 94 and 95. Pore water nutrient concentrations followed a similar pattern. Authors attribute this to changing standing stocks within the estuary. Results indicate seasonal patterns in nutrient recycling related to bivalve abundance and activity levels being highest in summer. Nutrient recycling is important for primary production.	Mudflats		
80	Magni, P., Como, S., Montani, S., Tsutsumi, H.	Shinkawa-Kasugakawa Estuary, Seto Inland Sea, Japan	Study of bivalve-mediated nutrient fluxes in the intertidal sand and mudflats. Specifically, macrobenthic assemblages, pore-water nutrients (NH4+, PO4-3-, SiO2, and NO3- + NO2-), sedimentary acid-volatile sulfide, and benthic chlorophyll-a. Association of chemicistry changes with bivalves Ruditapes philippinarum and Arcuatula senhousia was examined.	Six consecutive seasons from summer, 1994 to autumn, 1995	There was significant seasonal variation in nutrient fluxes due to bivalve activity. Fluxes of NH4+, PO4-3 and SiO2 due to R. philippinarum were highest in summer 94. Fluxes of NH4+, PO4-3- and SiO2 due to A senhousia were highest in summer 94 and 95. Pore water nutrient concentrations followed a similar pattern. Authors attribute this to changing standing stocks within the estuary. Results indicate seasonal patterns in nutrient recycling related to bivalve abundance and activity levels being highest in summer. Nutrient recycling is important for primary production.	Bivalves		
81	Marques, S.C., Pardal, M.A., Primo, A.L., Martinho, F., Falcao, J., Azeiteiro, U., Molinero, J.C.	Mondego Estuary, Portugal	zooplankton communities were collected and assessed over 10 years in search of changes to assemblages as a result of changing sea-surface temperatures and the north-atlantic oscillation.	Monthly from January, 2003 to December, 2012 at high tide.	Changes in hydrological conitions and changes in the north atlantic oscillations were prominent with significant monthly variation. Variance was most significant around 2008. Zooplankton assemblages and local hydrological conditions appear to be strongly influenced by the changes in the north atlantic oscillations.	Water	Species Composition	Water Temperature increase
81	Marques, S.C., Pardal, M.A., Primo, A.L., Martinho, F., Falcao, J., Azeiteiro, U., Molinero, J.C.	Mondego Estuary, Portugal	zooplankton communities were collected and assessed over 10 years in search of changes to assemblages as a result of changing sea-surface temperatures and the north-atlantic oscillation.	Monthly from January, 2003 to December, 2012 at high tide.	Changes in hydrological conitions and changes in the north atlantic oscillations were prominent with significant monthly variation. Variance was most significant around 2008. Zooplankton assemblages and local hydrological conditions appear to be strongly influenced by the changes in the north atlantic oscillations.	Zooplankton		
82	Martin, D.L., Chiari, Y., Boone, E., Sherman, T.D., Ross, C., Wyllie-Echeverria, S., Gaydos, J.K., Boettcher, A.A.	Global	Labyrinthula is the protist responsible for seagrass wasting desease. Phylogenetic analysis of protist Labyrinthula was conducted from up to 16 types of seagrass hosts from around the world. Tissue samples were collected and Labyrinthula was extracted and its DNA was studied for cladogenesis and pathogenicity.	No timeline was provided.	Pathogenicity was high throughout all samples. Isolates showed differing abilities to cross-infect across different species from different regions of the globe. Regional and climactic differences appear to be as influential if not more than diversity in host species in influencing the host capacity for Labyrintula strains.	Seagrass	Microbial response / survival	Invasive Species
83	McFarland, K., Hare, M.P.	Hudson/Raritan Estuary near Tarrytown, NY (Near NYC)	Assessment of oyster performance across the estuary-salinity gradient to evaluate habitat suitability for restoring oyster reefs to the NYC area. Seven sites were selected for caged oyster outplants across the salinity gradient. Oysters had been previously spawned in a hatchery from a mid-salinity wild catch.	Deployments were made Aug 25, 2015. Growth and survivability were measured until October 2017.	Temperature was the only variable significantly associated with survival. Sites closest to the river had high mortality rates over winter, probably due to cages being exposed to winter weather in open air at low tide for extended periods. Sites closest to the open ocean had high mortality rates over the summer, probably due to exposure to predators. Survival was generally highest closest to the Jamaica Bay site - a sheltered estuary near the ocean interface. Growth rates were sustained from June through August, and were relatively dormant throughout the winter. Growth rates were highest around Jamaica Bay and similar to wild populations.	Rocky Reefs	Restoration / Recovery	Water Temperature increase
83	McFarland, K., Hare, M.P.	Hudson/Raritan Estuary near Tarrytown, NY (Near NYC)	Assessment of oyster performance across the estuary-salinity gradient to evaluate habitat suitability for restoring oyster reefs to the NYC area. Seven sites were selected for caged oyster outplants across the salinity gradient. Oysters had been previously spawned in a hatchery from a mid-salinity wild catch.	Deployments were made Aug 25, 2015. Growth and survivability were measured until October 2017.	Temperature was the only variable significantly associated with survival. Sites closest to the river had high mortality rates over winter, probably due to cages being exposed to winter weather in open air at low tide for extended periods. Sites closest to the open ocean had high mortality rates over the summer, probably due to exposure to predators. Survival was generally highest closest to the Jamaica Bay site - a sheltered estuary near the ocean interface. Growth rates were sustained from June through August, and were relatively dormant throughout the winter. Growth rates were highest around Jamaica Bay and similar to wild populations.	Bivalves	Water Quality	

83	McFarland, K., Hare, M.P.	Hudson/Raritan Estuary near Tarrytown, NY (Near NYC)	Assessment of oyster performance across the estuary-salinity gradient to evaluate habitat suitability for restoring oyster reefs to the NYC area. Seven sites were selected for caged oyster outplants across the salinity gradient. Oysters had been previously spawned in a hatchery from a mid-salinity wild catch.	Deployments were made Aug 25, 2015. Growth and survivability were measured until October 2017.	Temperature was the only variable significantly associated with survival. Sites closest to the river had high mortality rates over winter, probably due to cages being exposed to winter weather in open air at low tide for extended periods. Sites closest to the open ocean had high mortality rates over the summer, probably due to exposure to predators. Survival was generally highest closest to the Jamaica Bay site - a sheltered estuary near the ocean interface. Growth rates were sustained from June through August, and were relatively dormant throughout the winter. Growth rates were highest around Jamaica Bay and similar to wild populations.		Animal Response / Survival	
84	McKew, B.A., Taylor, J.D., McGenity, T.J., Underwood, G.J.C.	Upper Colne Point saltmarsh in southwest UK.	Study of microbial responses to dessication and rewetting in salt marshes by examining 78 core samples from a typical back-barrier salt marsh, a selection of which were placed under a period of dessication (23 days). A control sample had regular tidal flow simulated. Dessicated sediments were rewetted through a regular tidal cycle for four days. Cores were analyzed for pore-water salinity, water activity, water content, bacterial activity, MPB biomass (fluorescence), and clorophyll a.	28 day lab experiment.	Pore water salinity increased during dessication while water activity and water content decreased but all values came close to original values with the four day tidal cycle after dessication. Values remained stable in the tidally wetted sediments. MPB biomass decreased during dessication but spiked back up after regular wetting. Chlorophyll a levels remained lower in the dessicated sediment, even after rewetting. Bacterial activity decreased during dessication but spiked up to normal levels quickly post re wetting.	Salt Marsh	Microbial response / survival	Drought
84	McKew, B.A., Taylor, J.D., McGenity, T.J., Underwood, G.J.C.	Upper Colne Point saltmarsh in southwest UK.	Study of microbial responses to dessication and rewetting in salt marshes by examining 78 core samples from a typical back-barrier salt marsh, a selection of which were placed under a period of dessication (23 days). A control sample had regular tidal flow simulated. Dessicated sediments were rewetted through a regular tidal cycle for four days. Cores were analyzed for pore-water salinity, water activity, water content, bacterial activity, MPB biomass (fluorescence), and clorophyll a.	28 day lab experiment.	Pore water salinity increased during dessication while water activity and water content decreased but all values came close to original values with the four day tidal cycle after dessication. Values remained stable in the tidally wetted sediments. MPB biomass decreased during dessication but spiked back up after regular wetting. Chlorophyll a levels remained lower in the dessicated sediment, even after rewetting. Bacterial activity decreased during dessication but spiked up to normal levels quickly post re wetting.	Microbiome	Water Quality	
85	Melo, W., Pinho, J., Iglesias, I., Bio, A., Avilez-Valente, P., Vieira, J., Bastos, L., Veloso-Gomes, F.	Minho Estuary, Portugal	Use of modelling tools to assess changes in hydrodynamic and morphodynamic impacts of sea-level rise to the Minho River Estuary. Assessed potential changes due to changes in tides, storm surge, wave action, and river discharge.	One time data collection.	Predicted SLR will reduce riverine flow velocity and subsequent sediment transport but increase tidal inundation levels. Sediment transport to the estuarine platform will then likely be significant during flood events, rather than regular river discharge. Different coastal regions along the estuarine gradient are at higher risk than others of coastal inundation.	Morphology	Currents / Discharge / Hydrology	Sea-level rise
85	Melo, W., Pinho, J., Iglesias, I., Bio, A., Avilez-Valente, P., Vieira, J., Bastos, L., Veloso-Gomes, F.	Minho Estuary, Portugal	Use of modelling tools to assess changes in hydrodynamic and morphodynamic impacts of sea-level rise to the Minho River Estuary. Assessed potential changes due to changes in tides, storm surge, wave action, and river discharge.	One time data collection.	Predicted SLR will reduce riverine flow velocity and subsequent sediment transport but increase tidal inundation levels. Sediment transport to the estuarine platform will then likely be significant during flood events, rather than regular river discharge. Different coastal regions along the estuarine gradient are at higher risk than others of coastal inundation.	Water	Sediment fluxes	
86	Meyer, D.L., Posey, M.H.	Bogue Sound, Back Sound, and Core Sound; mid-coastal estuaries along North Carolina, USA	Three small island marshes (400-1000m2) and three large island marshes (3000-10000 m2) were paired with expansive fringe marshes with interconnected meandering channels. At al selected sample sites, stem densities were measured, sedimentation was analyzed, marsh nekton including fish, crab, and shrimp, and finfish were collected and analyzed. Results were assessed against influence of marsh size, landscape, and other potential factors on nekton and finfish	June, November, and March starting June 2002 ending March 2004.	Density of nekton was highest at extensive fringe marshes than the other two habitat types. Finfish tended to prefer small island marshes over large marshes and fringe marshes. Variety of marsh sub-habitats within extensive fringe marshes are thought to contribute to higher density and species richness of nekton in extensive fringe marshes. Lower area-perimiter ratios were important for finfish species. Species richness and density was higher in small island marshes than large or extensive fringe marshes.	Salt Marsh	Species Composition	Baseline assessment
86	Meyer, D.L., Posey, M.H.	Bogue Sound, Back Sound, and Core Sound; mid-coastal estuaries along North Carolina, USA	Three small island marshes (400-1000m2) and three large island marshes (3000-10000 m2) were paired with expansive fringe marshes with interconnected meandering channels. At al selected sample sites, stem densities were measured, sedimentation was analyzed, marsh nekton including fish, crab, and shrimp, and finfish were collected and analyzed. Results were assessed against influence of marsh size, landscape, and other potential factors on nekton and finfish	June, November, and March starting June 2002 ending March 2004.	Density of nekton was highest at extensive fringe marshes than the other two habitat types. Finfish tended to prefer small island marshes over large marshes and fringe marshes. Variety of marsh sub-habitats within extensive fringe marshes are thought to contribute to higher density and species richness of nekton in extensive fringe marshes. Lower area-perimiter ratios were important for finfish species. Species richness and density was higher in small island marshes than large or extensive fringe marshes.	Fish	Biodiversity	
87	Mittermayr, A., Fox, S.E., Sommer, U.	One seagrass bed within the Kiel Fjord Ecosystem, Baltic Sea	Use of isotopic analysis to determine food web characteristics within a Z. marina seagrass bed. delta13C, delta15N, and delta34S were studied simultaneously to capture carbon source, trophic level, and sulfur enrichment. Samples of phytoplankton, zooplankton, Z. marina, attached epiphytic algae, macrozoobenthic organisms, and pelagic macroorganisms were collected within the same Z. marina patch. Samples were taken to a lab for isotope analysis.	Samples were collected biweekly from March through September, 2011.	Variation of stable isotopes was stronger within species than between species. Some portions of the omnivore samples were strictly herbivorous and carnivorous, lending to dietary plasticity which allows for resilience during changing biotic conditions. There was strong temporal variation of stable isotopes within Seston and Z. marina, suggesting impacts of increased water temperatures in summer. The most abundant carbon source in the system was Seston, followed by epiphytic algae attached to Z. marina. The seagrass itself appeared to show little or indistinguishable importance.	Food Web	Species Composition	Diversity loss
87	Mittermayr, A., Fox, S.E., Sommer, U.	One seagrass bed within the Kiel Fjord Ecosystem, Baltic Sea	Use of isotopic analysis to determine food web characteristics within a Z. marina seagrass bed. delta13C, delta15N, and delta34S were studied simultaneously to capture carbon source, trophic level, and sulfur enrichment. Samples of phytoplankton, zooplankton, Z. marina, attached epiphytic algae, macrozoobenthic organisms, and pelagic macroorganisms were collected within the same Z. marina patch. Samples were taken to a lab for isotope analysis.	Samples were collected biweekly from March through September, 2011.	Variation of stable isotopes was stronger within species than between species. Some portions of the omnivore samples were strictly herbivorous and carnivorous, lending to dietary plasticity which allows for resilience during changing biotic conditions. There was strong temporal variation of stable isotopes within Seston and Z. marina, suggesting impacts of increased water temperatures in summer. The most abundant carbon source in the system was Seston, followed by epiphytic algae attached to Z. marina. The seagrass itself appeared to show little or indistinguishable importance.	Seagrass		

88	Oosterlee, L., Cox, T.J.S., Vandenbruwaene, W., Maris, T., Temmerman, S., Meire, P.	Lippenbroek, 8ha within the Belgian section of the Scheldt River estuary	Measurement of elevation range, accretion rates, channel erosion, and hydrological characteristics within a restored tidal marsh following a controlled reduced tidal (CRT) regime to gradually restore it from previous embankment due to former agricultural uses. Results were compared against a nearby natural marsh. Changes in sediment accretion would have been from marine sources.	Samples were collected over 9 years, starting in March 2006. Elevation changes were measured every 2 months. Vertical accretion was measured annually during the winter. Elevation change over the total area was measured at 3, 4, 6, and 9 year markers. Channel erosion and morphology was measured annually. Water levels were measured every 5 minutes.	Elevation over 9 years increased and became flatter. Within site variation of rates of elevation change was observed, the range of which decreased over time. Elevation change rates for mid and high elevations were similar to those of the natural reference site. 17 500 m3 of sediment acreted over 9 years over a surface area of 7.8ha. Creek erosion was relatively small over the study period. Former agricultural sediment was compact and low in moisture content. Moisture and organic content decreased with depth in the reclaimed marsh, but was stable at depth in the natural marsh. Surficial clay content at both sites was similiar. Sand contents were low (2-4%) except at the site closest to the tidal discharge (20%)	Salt Marsh	Elevation	Land reclamation
88	Oosterlee, L., Cox, T.J.S., Vandenbruwaene, W., Maris, T., Temmerman, S., Meire, P.	Lippenbroek, 8ha within the Belgian section of the Scheldt River estuary	Measurement of elevation range, accretion rates, channel erosion, and hydrological characteristics within a restored tidal marsh following a controlled reduced tidal (CRT) regime to gradually restore it from previous embankment due to former agricultural uses. Results were compared against a nearby natural marsh. Changes in sediment accretion would have been from marine sources.	Samples were collected over 9 years, starting in March 2006. Elevation changes were measured every 2 months. Vertical accretion was measured annually during the winter. Elevation change over the total area was measured at 3, 4, 6, and 9 year markers. Channel erosion and morphology was measured annually. Water levels were measured every 5 minutes.	Elevation over 9 years increased and became flatter. Within site variation of rates of elevation change was observed, the range of which decreased over time. Elevation change rates for mid and high elevations were similar to those of the natural reference site. 17 500 m3 of sediment acreted over 9 years over a surface area of 7.8ha. Creek erosion was relatively small over the study period. Former agricultural sediment was compact and low in moisture content. Moisture and organic content decreased with depth in the reclaimed marsh, but was stable at depth in the natural marsh. Surficial clay content at both sites was similiar. Sand contents were low (2-4%) except at the site closest to the tidal discharge (20%)	Morphology	Sediment fluxes	
89	Osland, M.J., Grace, J.B., Guntenspergen, G.R., Thorne, K.M., Carr, J.A., Feher, L.C.	Three coastlines of the conterminus US.	Use of literature-review research to identify biogeographic coastal regions as defined by the dominant foundational coastal wetland plant varieties. Temperature and aridity was overlaid across the biogeographic regions to determine climactic associations with foundational plant species.	Historical temperature data was taken from 1981 to 2010.	Existing foundational plant species were mostly grass, sedge, and rush families across the pacific northwest and the eastern seaboard, including the southern states along the gulf of Mexico (with the exception of Florida). S. alterniflora, S. patens, D. spicata, and J. roemerianus dominated in these regions, characterized by temperate humidity. Along California and the south Texas coast where the climate is more arid and semi-arid, succulents dominated. Most coastal research focuses on a small number of foundational species, mostly Spartina alterniflora. Research suggests that areas of hypersaline and arid conditions are likely to produce more succulent-dominanted wetlands as demand for freshwater grows and climate change induces more arid zones and higher temperatures. Overlap of temperate and subtropical parts of California might provide hospitable habitat for mangroves in the future.	Salt Marsh	Biodiversity	Baseline assessment
90	Osma, N., Latorre-Melin, L., Jacob, B., Contreras, P., von Dassow, P., Vargas, C.	Valdivia River Estuary and Concepcion coastal upwelling area, Arauco Gulf, Chile	Review of the carbonate chemistry patterns over the course of a season in an estuarine system subject to coastal upwelling versus a system that is not subject to coastal upwelling (concepcion). Riverine flow information was collected. Stratification of temp, salinity, and oxygen were recorded. Levels of chlorophyll a, nutrients, DIC, pH and phytoplankton abundance was collected at dpths of 2, 10, 25, and 50m in Concepcion and 1, 3, and 5m in Valdivia. Primary production and resperation were taken at both locations. Responses of phytoplankton to different pCO2 levels were assessed to determine impacts of acidification on phytoplankton assemblages.	Two sampling events in Valdivia: Aug 2014 and Jan 2015. Two sampling events in Concepcion: Sept 2015 and Jan 2016	More acidic waters were observed during the summer season at both locations due to the reduced impact of freshwater flow. However, more corrosive aragonite conditions were observed during the winter associated with freshwater inputs. Largest primary production and clorophyll a levels were recorded during summer season, and were higher at concepcion than valdivia. Inner estuarine areas showed the larges primary productivity versus sites closer to freshwater and marine inputs. Phytoplankton diversity was highest in the winter, with diatoms dominating throughout the year. Changes in temperature and nutrient concentration explained changes in phytoplankton community structures rather than carbonate chemistry. Phytoplankton abundance and diversity from valdivia increased when exposed to higher levels of pCO2 and those from concepcion decreased.	Water	Water Quality	Ocean Acidification
90	Osma, N., Latorre-Melin, L., Jacob, B., Contreras, P., von Dassow, P., Vargas, C.	Valdivia River Estuary and Concepcion coastal upwelling area, Arauco Gulf, Chile	Review of the carbonate chemistry patterns over the course of a season in an estuarine system subject to coastal upwelling versus a system that is not subject to coastal upwelling. Riverine flow information was collected. Stratification of temp, salinity, and oxygen were recorded. Levels of chlorophyll a, nutrients, DIC, pH and phytoplankton abundance was collected at dpths of 2, 10, 25, and 50m in Concepcion and 1, 3, and 5m in Valdivia. Primary production and resperation were taken at both locations. Responses of phytoplankton to different pCO2 levels were assessed to determine impacts of acidification on phytoplankton assemblages.	Two sampling events in Valdivia: Aug 2014 and Jan 2015. Two sampling events in Concepcion: Sept 2015 and Jan 2016	More acidic waters were observed during the summer season at both locations due to the reduced impact of freshwater flow. However, more corrosive aragonite conditions were observed during the winter associated with freshwater inputs. Largest primary production and clorophyll a levels were recorded during summer season, and were higher at concepcion than valdivia. Inner estuarine areas showed the larges primary productivity versus sites closer to freshwater and marine inputs. Phytoplankton diversity was highest in the winter, with diatoms dominating throughout the year. Changes in temperature and nutrient concentration explained changes in phytoplankton community structures rather than carbonate chemistry. Phytoplankton abundance and diversity from valdivia increased when exposed to higher levels of pCO2 and those from concepcion decreased.	Phytoplankton	Productivity	
90	Osma, N., Latorre-Melin, L., Jacob, B., Contreras, P., von Dassow, P., Vargas, C.	Valdivia River Estuary and Concepcion coastal upwelling area, Arauco Gulf, Chile	Review of the carbonate chemistry patterns over the course of a season in an estuarine system subject to coastal upwelling versus a system that is not subject to coastal upwelling. Riverine flow information was collected. Stratification of temp, salinity, and oxygen were recorded. Levels of chlorophyll a, nutrients, DIC, pH and phytoplankton abundance was collected at dpths of 2, 10, 25, and 50m in Concepcion and 1, 3, and 5m in Valdivia. Primary production and resperation were taken at both locations. Responses of phytoplankton to different pCO2 levels were assessed to determine impacts of acidification on phytoplankton assemblages.	Two sampling events in Valdivia: Aug 2014 and Jan 2015. Two sampling events in Concepcion: Sept 2015 and Jan 2016	More acidic waters were observed during the summer season at both locations due to the reduced impact of freshwater flow. However, more corrosive aragonite conditions were observed during the winter associated with freshwater inputs. Largest primary production and clorophyll a levels were recorded during summer season, and were higher at concepcion than valdivia. Inner estuarine areas showed the larges primary productivity versus sites closer to freshwater and marine inputs. Phytoplankton diversity was highest in the winter, with diatoms dominating throughout the year. Changes in temperature and nutrient concentration explained changes in phytoplankton community structures rather than carbonate chemistry. Phytoplankton abundance and diversity from valdivia increased when exposed to higher levels of pCO2 and those from concepcion decreased.		Biodiversity	

91	Palinkas, C.M., Testa, J.M., Cornwell, J.C., Li,M., Sanford, L.P.	Components upstream and downstream of the Conowinga dam along the Susquehanna River into Chesapeake Bay	An exploration of sediment transport characteristics between the upstream and downstream side of the dam closest to the estuary to determine the dam's influence on sediment transport and how that interacts with flooding events.	Historical data was collected from Jan 1978 to Dec 2017 (river discharge, suspended particulates). Field samples were collected on particle settling velocity in 2015 and 2016. Sedimentology (core) samples were collected in Aug 2015 and Apr 2016. Sediment water fluxes were sampled 2015-2016.	During regular river flow with the dam operational, sediment supply, including N and P has declined since 1978. Sediment deposits are correlated with spring freshet from April to June. Upstream deposits had coarser sediment than downstream, which was finer. Flooding events had the effect of redistributing sediment through erosion from temporary stores. Suspension of sediment prevents it from settling until the energy from flow is absorbed. For this reason, heavy storm events often do not lead to high sediment accumulation.	Mudflats	Sediment fluxes	Upstream modification
91	Palinkas, C.M., Testa, J.M., Cornwell, J.C., Li,M., Sanford, L.P.	Components upstream and downstream of the Conowinga dam along the Susquehanna River into Chesapeake Bay	An exploration of sediment transport characteristics between the upstream and downstream side of the dam closest to the estuary to determine the dam's influence on sediment transport and how that interacts with flooding events.	Historical data was collected from Jan 1978 to Dec 2017 (river discharge, suspended particulates). Field samples were collected on particle settling velocity in 2015 and 2016. Sedimentology (core) samples were collected in Aug 2015 and Apr 2016. Sediment water fluxes were sampled 2015-2016.	During regular river flow with the dam operational, sediment supply, including N and P has declined since 1978. Sediment deposits are correlated with spring freshet from April to June. Upstream deposits had coarser sediment than downstream, which was finer. Flooding events had the effect of redistributing sediment through erosion from temporary stores. Suspension of sediment prevents it from settling until the energy from flow is absorbed. For this reason, heavy storm events often do not lead to high sediment accumulation.	Morphology	Currents / Discharge / Hydrology	
92	Pelletier, M.C., Ebersole, J., Mulvaney, K., Rashleigh, B., Gutierrez, M.N., Chintala, M., Kuhn, A., Molina, M., Bagley, M., Lane, C.	Not location specific. Lit-review type data collection	Literature search to determine conceptual factors of resilience in aquatic ecosystems. Authors were searching for tools of recognition and prevention of regime shifts.	One time data collection.	"Resilience is maintained or enhanced by connectivity, habitat heterogeneity, functional redundancy and diversity." Connectivity provides opportunity for nutrient exchange and consistent points of refuge for migratory species. habitat heterogeneity provides multiple disturbance responses and life history support for migratory species. In estuaries, the heterogeneity within the water column [thermoclines, haloclines] contributes to habitat heterogeneity. Nutrient inputs that decrease resilience in estuaries ar mainly from excess nitrogen, which transforms the ecosystem from one where seagrass and macrophytes can grow into one that is dominated by algal mats and phytoplankton blooms. Contaminant impacts have fewer and less pervasive impacts than overenrichment. Dams have caused decreased behavioural and life historical diversity in salmon populations in the US Pacific Northwest. Restoration efforts in general tend to show a lag in recovery response time.	Whole Estuary	Resilience	
93	Pereira, A.M., Range, P., Campoy, A., Oliveira, A.P., Joaquim, S., Matias, D., Chicharo, L., Gaspar, M.B.	Lab-based study in Portugal	Larvae of the bivalve wedge shell clam Donax trunclus were studied under two scenarios of ocean acidification to determin impacts of acidification on shell formation.	Experiment was terminated after 9 days due to high mortality rates	Hatching rate success was highest in the control group. Highest acidity group did not develop at the same rate as low acidity and control, with many individuals not even making it to the next developmental stage. Many of those individuals that made it through the development process developed abnormally in the acidic treatments. Total number of individuals still alive were dramatically lower after nine days in all treatments, but most significantly the treatment with lower levels of pH.	Rocky Reefs	Animal Response / Survival	Ocean Acidification
93	Pereira, A.M., Range, P., Campoy, A., Oliveira, A.P., Joaquim, S., Matias, D., Chicharo, L., Gaspar, M.B.	Lab-based study in Portugal	Larvae of the bivalve wedge shell clam Donax trunclus were studied under two scenarios of ocean acidification to determin impacts of acidification on shell formation.	Experiment was terminated after 9 days due to high mortality rates	Hatching rate success was highest in the control group. Highest acidity group did not develop at the same rate as low acidity and control, with many individuals not even making it to the next developmental stage. Many of those individuals that made it through the development process developed abnormally in the acidic treatments. Total number of individuals still alive were dramatically lower after nine days in all treatments, but most significantly the treatment with lower levels of pH.	Bivalves		
94	Pettengill, T.M., Crotty, S.M., Angelini, C., Bertness, M.D.	22 Sites across Cape Cod, MA and Narragansett Bay, RI.	Study of grazing impact to salt marshes of crab species Sesarma reticulatum whose density increased as a result of local predator depletion. Analyzed the spatial features of marsh die-off to identify predictable patterns. Studied control factors of substrate hardness, tidal creek flow regime, and Sesarma densities.	Sites were analyzed over twelve years.	Healthy marshes and sites with soft soils are naturally resistent to die-off due to herbivory from Sesarma sp. as they do not provide favourable conditions for the crab to burrow. Sites that are already dying off are vulnerable to continued degradation from crab grazers along the margins of peat-like soil where the harder structure allows room for burrowing behaviour. Sites that were in recovery phase showed stronger resistance to over-grazing than sites that marsh species had mostly died off from. However, sites with soft mud sediment remained relatively free of crab presence and impact.	Salt Marsh	Habitat Distribution	Diversity loss
94	Pettengill, T.M., Crotty, S.M., Angelini, C., Bertness, M.D.	22 Sites across Cape Cod, MA and Narragansett Bay, RI.	Study of grazing impact to salt marshes of crab species Sesarma reticulatum whose density increased as a result of local predator depletion. Analyzed the spatial features of marsh die-off to identify predictable patterns. Studied control factors of substrate hardness, tidal creek flow regime, and Sesarma densities.	Sites were analyzed over twelve years.	Healthy marshes and sites with soft soils are naturally resistent to die-off due to herbivory from Sesarma sp. as they do not provide favourable conditions for the crab to burrow. Sites that are already dying off are vulnerable to continued degradation from crab grazers along the margins of peat-like soil where the harder structure allows room for burrowing behaviour. Sites that were in recovery phase showed stronger resistance to over-grazing than sites that marsh species had mostly died off from. However, sites with soft mud sediment remained relatively free of crab presence and impact.	Crustaceans		
95	Plaisted, H.K., Novak, A.B., Weigel, S., Klein, A.S., Short, F.T.	Outdoor mesocosm lab in Durham, New Hampshire. Eelgrass samples were collected from ten separate locations across Rhode Island, New Hampshire, Massachusetts, Connecticut, and New York	To determine the relevance of genetic diversity on survivability in different eutrophic conditions, eelgrass (Zostera Marina) species samples were collected from genetically distinct populations and tested in an outdoor lab setting against different levels of light deprivation and sedimentation/organic matter inputs. Allelic richness was identified for each of the populations to determine genetic diversity within populations. Survivability and productivity were measured.	3 Months over the summer in 2011	Eelgrass survival was consistently lower in all treatments with higher levels of organic matter and reduced light. High organic matter treatments lowered levels of production. Reduced light decreased the number of shoots, and number of leaves per shoot, which was not impacted by organic matter. Organic matter decreased the shoot, root, and leaf size and density. Overall survivability and productivity under eutrophic conditions was correlated with genetic diversity. Observed heterozygosity accounted for 37-51% of variance in resilience to eutrophic factors.	Seagrass	Plant Density	Eutrophication
95	Plaisted, H.K., Novak, A.B., Weigel, S., Klein, A.S., Short, F.T.	Outdoor mesocosm lab in Durham, New Hampshire. Eelgrass samples were collected from ten separate locations across Rhode Island, New Hampshire, Massachusetts, Connecticut, and New York	To determine the relevance of genetic diversity on survivability in different eutrophic conditions, eelgrass (Zostera Marina) species samples were collected from genetically distinct populations and tested in an outdoor lab setting against different levels of light deprivation and sedimentation/organic matter inputs. Allelic richness was identified for each of the populations to determine genetic diversity within populations. Survivability and productivity were measured.	3 Months over the summer in 2011	Eelgrass survival was consistently lower in all treatments with higher levels of organic matter and reduced light. High organic matter treatments lowered levels of production. Reduced light decreased the number of shoots, and number of leaves per shoot, which was not impacted by organic matter. Organic matter decreased the shoot, root, and leaf size and density. Overall survivability and productivity under eutrophic conditions was correlated with genetic diversity. Observed heterozygosity accounted for 37-51% of variance in resilience to eutrophic factors.			Diversity Loss

96	Prahalad, V.N.	Salt Marshes throughout northern Tasmania along the Boulanger Bay-Robbins Passage	Aerial photo interpretation and ground and aerial survey was used to determine human impacts. Imagery was used to determine saltmarsh degradation from ditching, levees.	25 photos represented sixtime periods over 55 years from 1951-2006	16% of salt marshes have been lost to human impacts (219 ha) since 1952. Another 67% (752 ha) of what is remaining as of 2006 are currently being impacted by human disturbance. Levees have had the largest impact, followed by ditch construction and removal of buffer zones.	Salt Marsh	Habitat Distribution	Hardened coastal defences
96	Prahalad, V.N.	Salt Marshes throughout northern Tasmania along the Boulanger Bay-Robbins Passage	Aerial photo interpretation and ground and aerial survey was used to determine human impacts. Imagery was used to determine saltmarsh degradation from ditching, levees.	25 photos represented sixtime periods over 55 years from 1951-2006	16% of salt marshes have been lost to human impacts (219 ha) since 1952. Another 67% (752 ha) of what is remaining as of 2006 are currently being impacted by human disturbance. Levees have had the largest impact, followed by ditch construction and removal of buffer zones.		Habitat Connectivity	Land reclamation
96	Prahalad, V.N.	Salt Marshes throughout northern Tasmania along the Boulanger Bay-Robbins Passage	Aerial photo interpretation and ground and aerial survey was used to determine human impacts. Imagery was used to determine saltmarsh degradation from ditching, levees.	25 photos represented sixtime periods over 55 years from 1951-2006	16% of salt marshes have been lost to human impacts (219 ha) since 1952. Another 67% (752 ha) of what is remaining as of 2006 are currently being impacted by human disturbance. Levees have had the largest impact, followed by ditch construction and removal of buffer zones.			Channelization
97	Prosser, D.J., Nagel, J.L., Howlin, S., Marban, P.R., Day, D.D., Erwin, R.M.	21 sub-estuaries within Chesapeake Bay	Shorebird abundance used as indicator of estuary integrity. Use of ArcGIS sattelite imagery was used to delineate subestuaries by land-use and shorebird habitat types. Boat surveys included waterfowl, shorebirds, marsh birds, seabirds, wading birds, selected raptors and perching birds associated with water. Sub-estuaries were scored against an Index of Waterbird Community Integrity (IWCI) to quantify sensitivity of waterbird communities to human disturbance.	Field studies completed in late summer (southward migration) and late fall (overwintering population) over five years, but only one year of data per sub-estuary.	64 waterbird species were identified, 44 in late summer and 51 in late fall. Mean species richness was 18.9+/-.75 in late summer and 20.9+/-1.05. Lower IWCI scorings were strongly associated with hardened shorelines and bulkheads as lower abundances of disturbance sensitive species were identified in those impacted sub-estuaries. This can be explained by reduced vegetation/habitat availability for foraging, nesting, roosting, and prey abundance. Armoured sandy beaches also had reduced abundance and diversity of shorebirds due to loss of shallow foraging zones. Lower IWCI score were also associated with Phragmites-dominated marshes, showing reduced habitat quality and function where invasives have taken over. Natural/undeveloped shorelines supported higher IWCI scorings, even when the watershed was highly developed.	Birds	Animal Response / Survival	Hardened coastal defences
97	Prosser, D.J., Nagel, J.L., Howlin, S., Marban, P.R., Day, D.D., Erwin, R.M.	21 sub-estuaries within Chesapeake Bay	Shorebird abundance used as indicator of estuary integrity. Use of ArcGIS sattelite imagery was used to delineate subestuaries by land-use and shorebird habitat types. Boat surveys included waterfowl, shorebirds, marsh birds, seabirds, wading birds, selected raptors and perching birds associated with water. Sub-estuaries were scored against an Index of Waterbird Community Integrity (IWCI) to quantify sensitivity of waterbird communities to human disturbance.	Field studies completed in late summer (southward migration) and late fall (overwintering population) over five years, but only one year of data per sub-estuary.	64 waterbird species were identified, 44 in late summer and 51 in late fall. Mean species richness was 18.9+/-.75 in late summer and 20.9+/-1.05. Lower IWCI scorings were strongly associated with hardened shorelines and bulkheads as lower abundances of disturbance sensitive species were identified in those impacted sub-estuaries. This can be explained by reduced vegetation/habitat availability for foraging, nesting, roosting, and prey abundance. Armoured sandy beaches also had reduced abundance and diversity of shorebirds due to loss of shallow foraging zones. Lower IWCI score were also associated with Phragmites-dominated marshes, showing reduced habitat quality and function where invasives have taken over. Natural/undeveloped shorelines supported higher IWCI scorings, even when the watershed was highly developed.			
98	Raposa, K.B., Lerberg, S., Cornu, C., Fear, J., Garfield, N., Peter, C., Weber, R.L.J., Moore, G., Burdick, D., Dionne, M.	Coggeshall and Nagg salt marshes within Narragansett Bay National Estuarine Research Reserve, Prudence Island, Rhode Island.	Study of changes to vegetation and spatial profile of both salt marshes in relation to sea-level rise. Measured community composition, percent vegetation cover, marsh platform elevation, water levels, habitats.	Late August-Early Sept Nine years between 2000 and 2013 at Coggeshall Marsh and Annually from 2008 to 2013 at Nag Marsh.	Salt marsh vegetation community in Coggeshall marsh changed significantly over time due to a decrease in Spartina patens and an increase in Spartina alterniflora. Nag marsh showed a similar trend but changes were not statistically significant. Juncas gerardii increased in Coggeshall, and Iva frutescens decreased in Nag. Areas of vegetation die-back increased in both marshes in direct relation to increases in mean high-water. Spartina alterniflora showed more natural recovery/resilience to die-back than Spartina patens. S. patens resilience was higher in the marsh locations with higher elevation and less tidal inundation.	Salt Marsh	Habitat Distribution	Sea-level rise
98	Raposa, K.B., Lerberg, S., Cornu, C., Fear, J., Garfield, N., Peter, C., Weber, R.L.J., Moore, G., Burdick, D., Dionne, M.	Coggeshall and Nagg salt marshes within Narragansett Bay National Estuarine Research Reserve, Prudence Island, Rhode Island.	Study of changes to vegetation and spatial profile of both salt marshes in relation to sea-level rise. Measured community composition, percent vegetation cover, marsh platform elevation, water levels, habitats.	Late August-Early Sept Nine years between 2000 and 2013 at Coggeshall Marsh and Annually from 2008 to 2013 at Nag Marsh.	Salt marsh vegetation community in Coggeshall marsh changed significantly over time due to a decrease in Spartina patens and an increase in Spartina alterniflora. Nag marsh showed a similar trend but changes were not statistically significant. Juncas gerardii increased in Coggeshall, and Iva frutescens decreased in Nag. Areas of vegetation die-back increased in both marshes in direct relation to increases in mean high-water. Spartina alterniflora showed more natural recovery/resilience to die-back than Spartina patens. S. patens resilience was higher in the marsh locations with higher elevation and less tidal inundation.		Habitat Connectivity	
98	Raposa, K.B., Weber, R.L.J., Ekberg, M.C., Ferguson, W.	17 tidal restoration wetlands against 5 reference wetlands within estuaries in Maine, Rhode Island, Virginia, North Carolina, and Oregon	Use of restoration performance index (RPI) to determine the level of progress of estuary restoration projects in marshes, compare restoration performance of different types of restoration, and identify environmental parameters driving restoration performance. Field sampling included vegetation data from low marsh, high marsh, and transition to land in all estuaries. Other parameters included tidal inundation levels, pore water salinity, and soil characteristics.	July through September 2008 to 2010	Low RPI vegetation scores for restored wetlands were generally due to differences in percent cover of dominant species. Percent cover of invasives was also a factor but not included in the analysis. Species richness was similar between restored and reference wetlands. Restoration project types did not show any significant differences in RPI performance. Percent cover on eastern marshes of S. alterniflora, S. patens, D. spicata and bare patches were more prevalent on reference marshes and P. australis communities were more prevalent on restored marshes. Western reference marshes had more Phalaris arundinaea, and restored included more Agristis stolonifera, Carex lyngbyei, Triglochin maritinum, and Deschampsia caespitosa. Higher RPI scores were linked to higher groundwater depth and less linked to wetland surface elevation. No significant links were made to soil parameters and pore water salinity was only an explanatory factor in some of the estuaries.	Salt Marsh	Restoration / Recovery	Restoration assessment
99	Raw, J.L., Riddin, T., Wasserman, J., Lehman, T.W.K., Bornman, T.G., Adams, J.B.	Six sites within the Knysna Estuary, South Africa	Existing salt-marsh conditions and coastal development were recorded using desktop survey software (ArcMap, Google Earth, Avenza). Sea level rise was calculated and overlaid for time periods between 1960 and 2017. Surface elevation and relative sea-level rise were measured in the field. Sediment cores were taken to test for moisture content and organic content. Coastal squeeze (sea-level rise meeting coastal communities thus preventing transitional habitat (marsh) development) was measured using SLAMM model (Sea-level affecting marshes model).	Current desktop data, tidal data from 1960 to 2017. Surface elevation was measured annually from 2009 to 2011 and again in 2018.	A few of the sites were found to be gaining surface elevation at a rate faster than relative sea-level rise while other sites were showing a deficit. Sediment organic content was highest in surface layers. SLAMM model outputs showed protecting land from SLR caused coastal squeeze, reducing and eliminating salt marshes in all instances. Marsh area is predicted to be reduced by 40.2% by 2100, unless developed areas converted to salt marshes, which would increase the area by 57.5%. Seagrass habitat is predicted to increase along with tidal flat area.	Salt Marsh	Habitat Distribution	Sea-level rise
99	Raw, J.L., Riddin, T., Wasserman, J., Lehman, T.W.K., Bornman, T.G., Adams, J.B.	Six sites within the Knysna Estuary, South Africa	Existing salt-marsh conditions and coastal development were recorded using desktop survey software (ArcMap, Google Earth, Avenza). Sea level rise was calculated and overlaid for time periods between 1960 and 2017. Surface elevation and relative sea-level rise were measured in the field. Sediment cores were taken to test for moisture content and organic content. Coastal squeeze (sea-level rise meeting coastal communities thus preventing transitional habitat (marsh) development) was measured using SLAMM model (Sea-level affecting marshes model).	Current desktop data, tidal data from 1960 to 2017. Surface elevation was measured annually from 2009 to 2011 and again in 2018.	A few of the sites were found to be gaining surface elevation at a rate faster than relative sea-level rise while other sites were showing a deficit. Sediment organic content was highest in surface layers. SLAMM model outputs showed protecting land from SLR caused coastal squeeze, reducing and eliminating salt marshes in all instances. Marsh area is predicted to be reduced by 40.2% by 2100, unless developed areas converted to salt marshes, which would increase the area by 57.5%. Seagrass habitat is predicted to increase along with tidal flat area.		Habitat Connectivity	Land reclamation

100	Rogers, K., Woodroffe, C.D.	102 estuaries along the south coast of New South Wales, Australia	Use of ArcGIS to categorize accepted indicators of exposure, sensitivity, and adaptive capacity of land forms to storms and climate change. Coastal and fluvial inundation and erosion were modelled against estuary catchment areas.	One time data collection	Estuaries showing the most vulnerability are those with large catchment areas (areas exceeding 100 000ha have approx 2000ha vulnerable area), broad estuarine valleys (larger floodplain areas), mature stages of infill (more sedimentation = more vulnerable mudflats), or entrances orientated towards the prevailing wave direction. Area below 15m elevation indicates total area of vulnerability within a catchment. Land use was an important driver as grazing land was most vulnerable to fluvial flooding and erosion. Urban areas on estuarine plains had high vulnerability scores.	Morphology	Currents / Discharge / Hydrology	Baseline assessment
101	Rozencranz, J.A., Thorne, K.M., Buffington, K.J., Takekawa, J.Y., Hechinger, R.F., Stewart, T.E., Ambrose, R.F., MacDonald, G.M., Holmgren, M.A., Crooks, J.A., Patton, R.T., Lafferty, K.D.	Six tidal salt marshes in southern California	Assessment of vulnerability of Belding's savannah sparrows (BSSP - a bird that relies on high salt marshes for habitat) to sea level rise by mapping and modelling anticipated changes to salt marsh habitat. Digital elevation models and lidar techniques were used for modelling. Transect surveys were completed at two salt marsh sites. Breeding periods were measured including egg laying, incubation, nestling, postnestling, and parental care	One transect study was completed twice monthly from Jan 2012 to March 2013. The other was one day in Feb, 2018.	Under a low rate of SLR model, the predicted distribution of BSSP is shown to shift extensively. Differen estuaries are predicted to respond differently, but breeding habitat is generally expected to decrease at all sites. One of the sites is expected to remain stable at 99% foraging habitat and 100% breeding habitat left in 2110. Breeding habitat is expected to decrease dramatically at all other sites, while foraging habitat is generally more variable but clearly shows a decreasing trend at all other sites. Under a high rate of SLR model, complete submergence of foragign and breeding habitat is expected at all six sites	Salt Marsh	Animal Response / Survival	Sea-level rise
101	Rozencranz, J.A., Thorne, K.M., Buffington, K.J., Takekawa, J.Y., Hechinger, R.F., Stewart, T.E., Ambrose, R.F., MacDonald, G.M., Holmgren, M.A., Crooks, J.A., Patton, R.T., Lafferty, K.D.	Six tidal salt marshes in southern California	Assessment of vulnerability of Belding's savannah sparrows (BSSP - a bird that relies on high salt marshes for habitat) to sea level rise by mapping and modelling anticipated changes to salt marsh habitat. Digital elevation models and lidar techniques were used for modelling. Transect surveys were completed at two salt marsh sites. Breeding periods were measured including egg laying, incubation, nestling, postnestling, and parental care	One transect study was completed twice monthly from Jan 2012 to March 2013. The other was one day in Feb, 2018.	Under a low rate of SLR model, the predicted distribution of BSSP is shown to shift extensively. Differen estuaries are predicted to respond differently, but breeding habitat is generally expected to decrease at all sites. One of the sites is expected to remain stable at 99% foraging habitat and 100% breeding habitat left in 2110. Breeding habitat is expected to decrease dramatically at all other sites, while foraging habitat is generally more variable but clearly shows a decreasing trend at all other sites. Under a high rate of SLR model, complete submergence of foreign and breeding habitat is expected at all six sites	Birds		
102	Scapin, L., Zucchetta, M., Sfriso, A., Franzoi, P.	Over 50 sampling sites within the Venice Lagoon, Italy.	Comparison of analysis through modelling of site scale and patch mosaic scales to determine influences on fish assemblages in seagrass meadows. Extensive surveys were completed to determine fish assemblages on site. Abiotic variables tested included temp, dissolved oxygen, sediment grain size and turbidity. Other biotic factors included percent seagrass cover, tall meadows vs. mixed and short meadows. Mosaics were established by classifying nine habitat types within the estuary and studied as they related to seagrass. Sampling sites were modelled at 50, 100, 300, 500, and 800 meter scales to identify patterns.	Nine years of fish surveys from 2002 to 2015 in either spring, summer, or autumn	All scales had relevant explanations for variability of fish biomass density, while species richness was more defined at the site scale. Temperature was negatively correlated with all biotic factors. Results indicate that both landscape and site scales are important in determining fish use of estuarine habitat.	Fish	Habitat Distribution	Water temperature increase
102	Scapin, L., Zucchetta, M., Sfriso, A., Franzoi, P.	Over 50 sampling sites within the Venice Lagoon, Italy.	Comparison of analysis through modelling of site scale and patch mosaic scales to determine influences on fish assemblages in seagrass meadows. Extensive surveys were completed to determine fish assemblages on site. Abiotic variables tested included temp, dissolved oxygen, sediment grain size and turbidity. Other biotic factors included percent seagrass cover, tall meadows vs. mixed and short meadows. Mosaics were established by classifying nine habitat types within the estuary and studied as they related to seagrass. Sampling sites were modelled at 50, 100, 300, 500, and 800 meter scales to identify patterns.	Nine years of fish surveys from 2002 to 2015 in either spring, summer, or autumn	All scales had relevant explanations for variability of fish biomass density, while species richness was more defined at the site scale. Temperature was negatively correlated with all biotic factors. Results indicate that both landscape and site scales are important in determining fish use of estuarine habitat.	Seagrass	Habitat Connectivity	
102	Scapin, L., Zucchetta, M., Sfriso, A., Franzoi, P.	Over 50 sampling sites within the Venice Lagoon, Italy.	Comparison of analysis through modelling of site scale and patch mosaic scales to determine influences on fish assemblages in seagrass meadows. Extensive surveys were completed to determine fish assemblages on site. Abiotic variables tested included temp, dissolved oxygen, sediment grain size and turbidity. Other biotic factors included percent seagrass cover, tall meadows vs. mixed and short meadows. Mosaics were established by classifying nine habitat types within the estuary and studied as they related to seagrass. Sampling sites were modelled at 50, 100, 300, 500, and 800 meter scales to identify patterns.	Nine years of fish surveys from 2002 to 2015 in either spring, summer, or autumn	All scales had relevant explanations for variability of fish biomass density, while species richness was more defined at the site scale. Temperature was negatively correlated with all biotic factors. Results indicate that both landscape and site scales are important in determining fish use of estuarine habitat.		Water Quality	
103	Schaffner, L.C.	Two main disposal cells (B and C) within Lower Chesapeake Bay, Wolf Trap dredge disposal site, had sediments disposed from 1987 to 1989. A non-dredged reference site in the estuary was used for	Study of community-level responses of soft-sediment macrobenthos to dredged sediments. Benthic samples were collected using a corer. Samples were examined for sediment grain size, total organic carbon, organism biomass, weight, and species.	Cell B was sampled quarterly for a year, starting in Fall 1987 and then two successive springs (1988, 1989). Cell C was sampled quarterly for a year starting in Spring 1989, and then two successive springs (1990, 1991)	Disturbance severity was a driving indicator of the rates of recovery of soft-sediment macrobenthos. It took approximately 1.5 years for species richness, abundance, biomass, and community composition tc mimic the reference site. Resilience was high across macrobenthic communities due to burrowing activity through rapidly deposited sediment. Shallow sedimentation events showed stronger success in re-colonization. Some species showed strong/dense recruitment events in colonizing the new sediment Salinity was a key factor controlling patterns of species richness.	Food Web	Species Composition	Dredging
103	Schaffner, L.C.	Two main disposal cells (B and C) within Lower Chesapeake Bay, Wolf Trap dredge disposal site, had sediments disposed from 1987 to 1989. A non-dredged reference site in the estuary was used for	Study of community-level responses of soft-sediment macrobenthos to dredged sediments. Benthic samples were collected using a corer. Samples were examined for sediment grain size, total organic carbon, organism biomass, weight, and species.	Cell B was sampled quarterly for a year, starting in Fall 1987 and then two successive springs (1988, 1989). Cell C was sampled quarterly for a year starting in Spring 1989, and then two successive springs (1990, 1991)	Disturbance severity was a driving indicator of the rates of recovery of soft-sediment macrobenthos. It took approximately 1.5 years for species richness, abundance, biomass, and community composition tc mimic the reference site. Resilience was high across macrobenthic communities due to burrowing activity through rapidly deposited sediment. Shallow sedimentation events showed stronger success in re-colonization. Some species showed strong/dense recruitment events in colonizing the new sediment Salinity was a key factor controlling patterns of species richness.	Mudflats		

103	Schaffner, L.C.	Two main disposal cells (B and C) within Lower Chesapeake Bay, Wolf Trap dredge disposal site, had sediments disposed from 1987 to 1989. A non-dredged reference site in the estuary was used for	Study of community-level responses of soft-sediment macrobenthos to dredged sediments. Benthic samples were collected using a corer. Samples were examined for sediment grain size, total organic carbon, organism biomass, weight, and species.	Cell B was sampled quarterly for a year, starting in Fall 1987 and then two successive springs (1988, 1989). Cell C was sampled quarterly for a year starting in Spring 1989, and then two successive springs (1990, 1991)	Disturbance severity was a driving indicator of the rates of recovery of soft-sediment macrobenthos. It took approximately 1.5 years for species richness, abundance, biomass, and community composition to mimic the reference site. Resilience was high across macrobenthic communities due to burrowing activity through rapidly deposited sediment. Shallow sedimentation events showed stronger success in re-colonization. Some species showed strong/dense recruitment events in colonizing the new sediment. Salinity was a key factor controlling patterns of species richness.	Invertebrates	Animal Response / Survival	
104	Schallenberg, M., Burns, C.W.	Two tidally influenced coastal lakes along a lake/wetland complex: Lake Waipori and Lake Waihola in New Zealand's south island. Eight sampling sites were included.	Study aimed to determine spatial and temporal water-quality characteristics influenced by meteorological and hydrological patterns. Additional goal was to assess the impact of water quality gradients on plankton community structure. Water quality data was collected, as well as meteorogical, hydroloigcal, physico-chemical, and planktonic variables.	Data collected every two weeks Sept 1, 1997 to Sept 10, 1998.	Water quality data was highly variable throughout the study period. Seasonality contributed strongly to temperature changes throughout and changes in conductivity in Lake Waihola. Suspended particulate matter was strongly influenced by wind patterns in the lakes and influenced by rainfall patterns in the river. Phytoplankton across all sites were highly influenced by other sites. Salinity was impacted by residence time, and was associated with chloride concentration, total nitrogen, chlorophyll a, suspended particulate matter, turbidity, pH, and total phosphorus. Hydrological and meteorological variables explained 62% of the variation in water quality variables. Influencers were wind, river discharge, and rainfall. Nutrients and phytoplankton are also impacted by groundwater inflows.	Water	Water Quality	Baseline assessment
104	Schallenberg, M., Burns, C.W.	Two tidally influenced coastal lakes along a lake/wetland complex: Lake Waipori and Lake Waihola in New Zealand's south island. Eight sampling sites were included.	Study aimed to determine spatial and temporal water-quality characteristics influenced by meteorological and hydrological patterns. Additional goal was to assess the impact of water quality gradients on plankton community structure. Water quality data was collected, as well as meteorogical, hydroloigcal, physico-chemical, and planktonic variables.	Data collected every two weeks Sept 1, 1997 to Sept 10, 1998.	Water quality data was highly variable throughout the study period. Seasonality contributed strongly to temperature changes throughout and changes in conductivity in Lake Waihola. Suspended particulate matter was strongly influenced by wind patterns in the lakes and influenced by rainfall patterns in the river. Phytoplankton across all sites were highly influenced by other sites. Salinity was impacted by residence time, and was associated with chloride concentration, total nitrogen, chlorophyll a, suspended particulate matter, turbidity, pH, and total phosphorus. Hydrological and meteorological variables explained 62% of the variation in water quality variables. Influencers were wind, river discharge, and rainfall. Nutrients and phytoplankton are also impacted by groundwater inflows.	Phytoplankton	Currents / Discharge / Hydrology	
105	Schuerch, M., Dolch, T., Bisgwa, J., Vafeidis, A.T.	Mature section of oldsumer foreland salt marsh on the northwest side of Foehr Island, North Sea (Germany)	Sediment cores were sampled and compared against historical aerial photographs to determine events that may have impacted sediment layers on the salt marsh. Pressure sensors were used to record water levels during higher than normal tidal inundation event. Suspended sediment concentrations (SSC) were measured to determine the source of sedimentation. Inundation patterns were modeled using LiDAR. Cores were assessed for grain size, carbon content, and bulk density. Sediment samples were dated using radioisotopes. Historical storm events were compared against results.	Photographs were from six years: 1937, 1958, 1988, 1995, 2003, and 2010. Inundation event was Mar15, 2014. Cores were collected Jan 22, 2009.	The salt marsh was established behind an already existing sand-spit shelter. Agricultural activity included draining the main water exchange of the marsh. When the main water exchange of the northern creek was blocked off, a new water exchange creek naturally established itself and sedimentation increased in the mature sections of the marsh. The marsh and the sand spit slowly grew in tandem with each other. Tidal flows during storm events enter through an overwash breach in the sand spit allowing sediment to move towards the marsh. More sediment is brought in through the breach than the regular tidal creeks. The marsh grew slowly in earlier years and accelerated growth in more recent decades. A set of sandy sediment deposition events caused a large influx in the 1980s and early 90s throughout the core samples. This is associated with the rapid recent saltmarsh growth.		Sediment fluxes	Land reclamation
105	Schuerch, M., Dolch, T., Bisgwa, J., Vafeidis, A.T.	Mature section of oldsumer foreland salt marsh on the northwest side of Foehr Island, North Sea (Germany)	Sediment cores were sampled and compared against historical aerial photographs to determine events that may have impacted sediment layers on the salt marsh. Pressure sensors were used to record water levels during higher than normal tidal inundation event. Suspended sediment concentrations (SSC) were measured to determine the source of sedimentation. Inundation patterns were modeled using LiDAR. Cores were assessed for grain size, carbon content, and bulk density. Sediment samples were dated using radioisotopes. Historical storm events were compared against results.	Photographs were from six years: 1937, 1958, 1988, 1995, 2003, and 2010. Inundation event was Mar15, 2014. Cores were collected Jan 22, 2009.	The salt marsh was established behind an already existing sand-spit shelter. Agricultural activity included draining the main water exchange of the marsh. When the main water exchange of the northern creek was blocked off, a new water exchange creek naturally established itself and sedimentation increased in the mature sections of the marsh. The marsh and the sand spit slowly grew in tandem with each other. Tidal flows during storm events enter through an overwash breach in the sand spit allowing sediment to move towards the marsh. More sediment is brought in through the breach than the regular tidal creeks. The marsh grew slowly in earlier years and accelerated growth in more recent decades. A set of sandy sediment deposition events caused a large influx in the 1980s and early 90s throughout the core samples. This is associated with the rapid recent saltmarsh growth.		Sediment fluxes	Increased currents
105	Schuerch, M., Dolch, T., Bisgwa, J., Vafeidis, A.T.	Mature section of oldsumer foreland salt marsh on the northwest side of Foehr Island, North Sea (Germany)	Sediment cores were sampled and compared against historical aerial photographs to determine events that may have impacted sediment layers on the salt marsh. Pressure sensors were used to record water levels during higher than normal tidal inundation event. Suspended sediment concentrations (SSC) were measured to determine the source of sedimentation. Inundation patterns were modeled using LiDAR. Cores were assessed for grain size, carbon content, and bulk density. Sediment samples were dated using radioisotopes. Historical storm events were compared against results.	Photographs were from six years: 1937, 1958, 1988, 1995, 2003, and 2010. Inundation event was Mar15, 2014. Cores were collected Jan 22, 2009.	The salt marsh was established behind an already existing sand-spit shelter. Agricultural activity included draining the main water exchange of the marsh. When the main water exchange of the northern creek was blocked off, a new water exchange creek naturally established itself and sedimentation increased in the mature sections of the marsh. The marsh and the sand spit slowly grew in tandem with each other. Tidal flows during storm events enter through an overwash breach in the sand spit allowing sediment to move towards the marsh. More sediment is brought in through the breach than the regular tidal creeks. The marsh grew slowly in earlier years and accelerated growth in more recent decades. A set of sandy sediment deposition events caused a large influx in the 1980s and early 90s throughout the core samples. This is associated with the rapid recent saltmarsh growth.		Elevation	
106	Schutte, C.A., Marton, J.M., Bernhard, A.E., Giblin, A.E., Roberts, B.J.	Salt marshes within Terrebonne Bay, south coast Louisiana, USA	Investigation of the influence of oil contamination on nitrogen cycling related to the prevention of eutrophication and hypoxia in salt marshes. Samples were collected along a transect from the marsh edge towards its interior. Elevation = 10-12cm. Comparison of sites that were in contact with deepwater horizon oil spill to those that were not. Core samples were taken at each site for measurement of chemical/physical properties and denitrification potential. Nitrogen concentrations were measured from nearby water. Soil was further measured for water content, DIN, DIP, organic carbon and organic nitrogen	Every other month from March 2013 to April 2014.	Higher elevations of 10-12cm at the center of one marsh was characterized by more peaty soils and associated with the highest denitrification potentials. The unoiled site showed positive correlations between elevation, nitrification potential, microbial abundances, soil Eh, soil organic carbon, and extractable nitrate and ammonium. This was not the case at sites of lower elevation and those impacted by the oil spill. There was not a significant difference in nitrification potential between the oiled and unoiled site. There was no significant difference in microbial functional gene abundance between unoiled and oiled site.	Salt Marsh	Water Quality	Pollution

106	Schutte, C.A., Marton, J.M., Bernhard, A.E., Giblin, A.E., Roberts, B.J.	Salt marshes within Terrebonne Bay, south coast Louisiana, USA	Investigation of the influence of oil contamination on nitrogen cycling related to the prevention of eutrophication and hypoxia in salt marshes. Samples were collected along a transect from the marsh edge towards its interior. Elevation = 10-12cm. Comparison of sites that were in contact with deepwater horizon oil spill to those that were not. Core samples were taken at each site for measurement of chemical/physical properties and denitrification potential. Nitrogen concentrations were measured from nearby water. Soil was further measured for water content, DIN, DIP, organic carbon and organic nitrogen	Every other month from March 2013 to April 2014.	Higher elevations of 10-12cm at the center of one marsh was characterized by more peaty soils and associated with the highest denitrification potentials. The unoiled site showed positive correlations between elevation, nitrification potential, microbial abundances, soil Eh, soil organic carbon, and extractable nitrate and ammonium. This was not the case at sites of lower elevation and those impacted by the oil spill. There was not a significant difference in nitrification potential between the oiled and unoiled site. There was no significant difference in microbial functional gene abundance between unoiled and oiled site.		Elevation	Eutrophication
107	Seitz, R.D., Wennhage, H., Bergstrom, U., Lipcius, R.N., Ysebaert, T.	Fish and fish habitat throughout Europe	Literature review on the ecological value of coastal habitats for 59 exploited fish species. European commercially important fish species were combined with habitat type for each literature search to define importance of habitat in fish stocks. Habitats of seagrass, intertidal soft bottom, subtidal soft bottom, kelp, shallow open water, salt marsh, mussel beds, macroalgae, and rocky shore were assigned based on feeding, spawning, nursery, and migration.	One time data collection	44% of commercially important fish use coastal habitats. For Plaice (flounder), soft, shallow sediment substratum is important for nursery ground. There is a positive relationship between nursery size and population abundance. Young cod require complex habitat types (habitat heterogeneity), including seagrass, kelp, rocky shores, and gravel bottoms with attached fauna. Brown shrimp prefer shallow coastal areas in sand or muddy sand habitats, and migrate in and out of estuaries. They support the development of habitat structures through cascade effects as predators in shallow, soft bottom communities. The degree to which the habitats limit population growth (as opposed to overfishing) was difficult to discern from the literature.	Fish	Habitat Distribution	Baseline assessment
107	Seitz, R.D., Wennhage, H., Bergstrom, U., Lipcius, R.N., Ysebaert, T.	Fish and fish habitat throughout Europe	Literature review on the ecological value of coastal habitats for 59 exploited fish species. European commercially important fish species were combined with habitat type for each literature search to define importance of habitat in fish stocks. Habitats of seagrass, intertidal soft bottom, subtidal soft bottom, kelp, shallow open water, salt marsh, mussel beds, macroalgae, and rocky shore were assigned based on feeding, spawning, nursery, and migration.	One time data collection	44% of commercially important fish use coastal habitats. For Plaice (flounder), soft, shallow sediment substratum is important for nursery ground. There is a positive relationship between nursery size and population abundance. Young cod require complex habitat types (habitat heterogeneity), including seagrass, kelp, rocky shores, and gravel bottoms with attached fauna. Brown shrimp prefer shallow coastal areas in sand or muddy sand habitats, and migrate in and out of estuaries. They support the development of habitat structures through cascade effects as predators in shallow, soft bottom communities. The degree to which the habitats limit population growth (as opposed to overfishing) was difficult to discern from the literature.			
108	Spencer, K.L., Cundy, A.B., Davies-Hearn, S., Hughes, R., Turner, S., MacLeod, C.L.	Orplands Farm managed realignment site in Blackwater Estuary, Essex, United Kingdom. Prior to breach, area was drained for agricultural purposes.	A study of the impacts of managed realignment on sedimentation, including differences in sediment between pre-breach and post-breach physicochemical characteristics. Also aimed to understand impacts of sedimentation on vegetation colonisation and its relationship with sea-level rise. Core sampling was used up to depth of 40 cm along transects that fanned out from the breach location. Study included redox potential, pH, moisture content, organic matter content, and radioactivity. A vegetation survey was completed along both transects.	Monitoring work was done 8 years after managed realignment in 1995. Cores were taken in the summer of 2003 over two days at low tide.	Organic content, moisture content, and redox potential decreased at depth. Moisture content and organic content was higher at the control site but increased in the upper layers of the test site. Grain size showed an increase in the top 8cm. An increase in Na towards the top suggests tidal inundation and evaporation patterns. There are no visible changes in sediment characteristics or texture related to the breach event. A relict landform is apparent from physicochemical factors at 6-8cm depth that prevents water and nutrient transfers between sedimentary layers that could be important for the ability of macrophyte root systems to colonize the soil. It is therefore estimated that 6-8 cm of sediment accumulated since the breach. Area nearest to the breach location is colonized by opportunistic algae and cyanobacteria. Other areas have shown success in establishment of pioneer and low-marsh communities, although density is lower than other MR sites. This is attributed to poor drainage caused by the relict landform. Elevation is most important factor determining species composition.	Salt Marsh	Sediment fluxes	Shoreline realignment
108	Spencer, K.L., Cundy, A.B., Davies-Hearn, S., Hughes, R., Turner, S., MacLeod, C.L.	Orplands Farm managed realignment site in Blackwater Estuary, Essex, United Kingdom. Prior to breach, area was drained for agricultural purposes.	A study of the impacts of managed realignment on sedimentation, including differences in sediment between pre-breach and post-breach physicochemical characteristics. Also aimed to understand impacts of sedimentation on vegetation colonisation and its relationship with sea-level rise. Core sampling was used up to depth of 40 cm along transects that fanned out from the breach location. Study included redox potential, pH, moisture content, organic matter content, and radioactivity. A vegetation survey was completed along both transects.	Monitoring work was done 8 years after managed realignment in 1995. Cores were taken in the summer of 2003 over two days at low tide.	Organic content, moisture content, and redox potential decreased at depth. Moisture content and organic content was higher at the control site but increased in the upper layers of the test site. Grain size showed an increase in the top 8cm. An increase in Na towards the top suggests tidal inundation and evaporation patterns. There are no visible changes in sediment characteristics or texture related to the breach event. A relict landform is apparent from physicochemical factors at 6-8cm depth that prevents water and nutrient transfers between sedimentary layers that could be important for the ability of macrophyte root systems to colonize the soil. It is therefore estimated that 6-8 cm of sediment accumulated since the breach. Area nearest to the breach location is colonized by opportunistic algae and cyanobacteria. Other areas have shown success in establishment of pioneer and low-marsh communities, although density is lower than other MR sites. This is attributed to poor drainage caused by the relict landform. Elevation is most important factor determining species composition.		Habitat Distribution	
109	Stapp, L.S., Thomsen, J., Schade, H., Bock, C., Melzner, F., Portner, H.O., Lannig, G.	Lab studies with samples collected from Kiel Ford, Baltic Sea, with highly variable PCO2 conditions due to upwelling patterns.	Tested multiple generations of bivalve for adaptation potential under different levels of ocean acidification. Measurement of Mytilus edulis (Baltic blue mussel). Animals were collected, kept in a flow-through aquaria lab environment, and bred. Embryos were exposed to 3 PCO2 levels, one control, one intermediate increase, one high. Larvae settled after 21 days, then acclimated over 12 months, before another round of induced spawning. Post spawn, adults were selected and physiologically tested. pH, DIC, temp, and salinity were measured throughout. Clearance/filtration of feed (Rhodomonas), metabolic rates, ionic buffer composition, tissue oxygen consumption, and protein biosyntheses were measured.	Life cycle of a second generation of mussels exposed to different OA conditions over 1 year. Mature individuals collected and spawned in June 2012.	F1 larval survival was lower under high PCO2 but not significantly different between control and intermediate levels. F1 families were then divided to those that were tolerant under high PCO2 and those that were not. Clearance/filtration rates were impacted under high PCO2 but not significantly by control and intermediate PCO2 levels. Under control conditions, oxygen metabolism was increased for those families that were sensitive to OA compared to tolerant. Tissue oxygen consumption rates of sensitive families were lower than control, but rates for tolerant families were higher than control. Factorial metabolic scope was greatly reduced in tolerant families under the highest acidification level. Routine metabolic rates were increased in intermediate conditions for tolerant families. Results indicate high PCO2 levels will favor mussel families with efficient metabolisms	Rocky Reefs	Animal Response / Survival	Ocean Acidification

109	Stapp, L.S., Thomsen, J., Schade, H., Bock, C., Melzner, F., Portner, H.O., Lannig, G.	Lab studies with samples collected from Kiel Ford, Baltic Sea, with highly variable PCO2 conditions due to upwelling patterns.	Tested multiple generations of bivalve for adaptation potential under different levels of ocean acidification. Measurement of Mytilus edulis (Baltic blue mussel). Animals were collected, kept in a flow-through aquaria lab environment, and bred. Embryos were exposed to 3 PCO2 levels, one control, one intermediate increase, one high. Larvae settled after 21 days, then acclimated over 12 months, before another round of induced spawning. Post spawn, adults were selected and physiologically tested. pH, DIC, temp, and salinity were measured throughout. Clearance/filtration of feed (Rhodomonas), metabolic rates, ionic buffer composition, tissue oxygen consumption, and protein biosyntheses were measured.	Life cycle of a second generation of mussels exposed to different OA conditions over 1 year. Mature individuals collected and spawned in June 2012.	F1 larval survival was lower under high PCO2 but not significantly different between control and intermediate levels. F1 families were then divided to those that were tolerant under high PCO2 and those that were not. Clearance/filtration rates were impacted under high PCO2 but not significantly by control and intermediate PCO2 levels. Under control conditions, oxygen metabolism was increased for those families that were sensitive to OA compared to tolerant. Tissue oxygen consumption rates of sensitive families were lower than control, but rates for tolerant families were higher than control. Factorial metabolic scope was greatly reduced in tolerant families under the highest acidification level. Routine metabolic rates were increased in intermediate conditions for tolerant families. Results indicate high PCO2 levels will favor mussel families with efficient metabolisms	Bivalves		
110	Staszak, L.A., Armitage, A.R.	12 Restored and 6 reference sampling sites around Galveston Bay, Texas.	Application of rapid assessment methods (RAMs) to determine ecosystem integrity in restored marshes. Assessment included landscape/site characteristics (barriers preventing landward migration, artificial structures), hydrological modifications (berms, channels), wildlife habitat (% cover of each plant species, plant diversity, invasives, epifaunal densities), belowground characteristics (soil stability, root volume, pH, conductivity). Differences were calculated between reference, restored sites <10 yo, and restored sites >10yo.	Not identified in text.	Ecosystem index scored restored sites lower than reference sites (75.4 vs 81.1/100), mostly due to below-ground characteristics and epifaunal densities. Differences between young and old restored sites differed based on vegetation diversity, pore water salinity, and soil stability. Older sites also had higher root densities.	Salt Marsh	Restoration / Recovery	Restoration assessment
111	Stein, E.D., Doughty, C.L., Lowe, J., Cooper, M., Sloane, E.B., Bram, D.L.	Entire Southern California coastline (420km from Mexico border north) consisting of 105 wetlands	Use of historical ecological analysis vs contemporary mapping, wetland archetype categorization, SLR predictions, and review of potential management scenarios to develop recommendations for wetland restoration. Historical topographic imagery was overlaid onto contemporary mapping datasets in ArcGIS. Archetypes were assigned based on catchment properties, wetland dimensions, proportion of subtidal vs. intertidal area, inlet dimensions and condition, and wetland volume/capacity. SLR modelling used elevation / predicted accretion vs. predicted water levels and mouth dynamics index.	Historical imagery from 1850s to 1890s	75% of historical estuarine area was dominated by vegetated wetlands and subtidal water. Remaining 25% was intertidal flats, open water, and salt flats. Over half of historical estuarine area was concentrated in two main estuaries, Mission Bay and San Diego Bay. Majority of coastal systems were small and very small coastal wetlands. There has been an overall loss of approx 48% of historical estuarine habitats, with 75% loss of estuarine vegetated habitats in favor of subtidal water with greatest shifts occurring in urban areas of Los Angeles and San Diego. Approx 43% of estuarine habitat has been converted to non-estuarine features (agri, urban, open space). SLR predictions suggest loss of additional 70% of wetlands by 2100 (1.7m SLR). Declines are expected to differ depending on estuary profile and existing damage. Active expansion of existing wetlands as well as managed realignment to allow wetlands into developed areas are recommended mitigation tools. Other options include increasing annual sedimentation rates, but one-time subtidal sediment deposition would not be as effective. Managing tidal mouth dynamics is another option but would not be effective for the amount of input required.	Salt Marsh	Habitat Distribution	Land reclamation
111	Stein, E.D., Doughty, C.L., Lowe, J., Cooper, M., Sloane, E.B., Bram, D.L.	Entire Southern California coastline (420km from Mexico border north) consisting of 105 wetlands	Use of historical ecological analysis vs contemporary mapping, wetland archetype categorization, SLR predictions, and review of potential management scenarios to develop recommendations for wetland restoration. Historical topographic imagery was overlaid onto contemporary mapping datasets in ArcGIS. Archetypes were assigned based on catchment properties, wetland dimensions, proportion of subtidal vs. intertidal area, inlet dimensions and condition, and wetland volume/capacity. SLR modelling used elevation / predicted accretion vs. predicted water levels and mouth dynamics index.	Historical imagery from 1850s to 1890s	75% of historical estuarine area was dominated by vegetated wetlands and subtidal water. Remaining 25% was intertidal flats, open water, and salt flats. Over half of historical estuarine area was concentrated in two main estuaries, Mission Bay and San Diego Bay. Majority of coastal systems were small and very small coastal wetlands. There has been an overall loss of approx 48% of historical estuarine habitats, with 75% loss of estuarine vegetated habitats in favor of subtidal water with greatest shifts occurring in urban areas of Los Angeles and San Diego. Approx 43% of estuarine habitat has been converted to non-estuarine features (agri, urgan, open space). SLR predictions suggest loss of additional 70% of wetlands by 2100 (1.7m SLR). Declines are expected to differ depending on estuary profile and existing damage. Active expansion of existing wetlands as well as managed realignment to allow wetlands into developed areas are recommended mitigation tools. Other options include increasing annual sedimentation rates, but one-time subtidal sediment deposition would not be as effective. Managing tidal mouth dynamics is another option but would not be effective for the amount of input required.			Sea-level rise
112	Taylor, L., Curson, D., Verutes, G.M., Wilsey, C.	Salt marsh sites throughout Chesapeake Bay and Delaware Bay, across New Jersey, Delaware, Maryland, and Virginia	Use of spatial analysis to assess the interior erosion of high tidal marsh zones from waterlogging, and identify potential areas of for restoration to support re-vegetation through artificial drainage channels that connect to the tidal creek network. Spatial analysis first identified high marshes water-logged or vulnerable to water-logging, then identified sites with elevation capital to allow for artificial drainage, then identified each site's current drainage ability. All layers were then overlaid in GIS	Not specified	Largest areas of high marsh waterlogging occur along the eastern shores of middle Chesapeake Bay in Dorchester County, Maryland, and along the Atlantic Coast of New Jersey, in Cape May, Atlantic, and Cumberland counties. New Jersey has the largest extent of waterlogged high marsh. Within the sites, 239 were selected for potential restoration because they had enough elevation capital and were isolated from the existing tidal creek network. Most sites were located along the east shore of Chesapeake Bay.	Salt Marsh	Habitat Distribution	
112	Taylor, L., Curson, D., Verutes, G.M., Wilsey, C.	Salt marsh sites throughout Chesapeake Bay and Delaware Bay, across New Jersey, Delaware, Maryland, and Virginia	Use of spatial analysis to assess the interior erosion of high tidal marsh zones from waterlogging, and identify potential areas of for restoration to support re-vegetation through artificial drainage channels that connect to the tidal creek network. Spatial analysis first identified high marshes water-logged or vulnerable to water-logging, then identified sites with elevation capital to allow for artificial drainage, then identified each site's current drainage ability. All layers were then overlaid in GIS	Not specified	Largest areas of high marsh waterlogging occur along the eastern shores of middle Chesapeake Bay in Dorchester County, Maryland, and along the Atlantic Coast of New Jersey, in Cape May, Atlantic, and Cumberland counties. New Jersey has the largest extent of waterlogged high marsh. Within the sites, 239 were selected for potential restoration because they had enough elevation capital and were isolated from the existing tidal creek network. Most sites were located along the east shore of Chesapeake Bay.		Sediment fluxes	

112	Taylor, L., Curson, D., Verutes, G.M., Wilsey, C.	Salt marsh sites throughout Chesapeake Bay and Delaware Bay, across New Jersey, Delaware, Maryland, and Virginia	Use of spatial analysis to assess the interior erosion of high tidal marsh zones from waterlogging, and identify potential areas of for restoration to support re-vegetation through artificial drainage channels that connect to the tidal creek network. Spatial analysis first identified high marshes water-logged or vulnerable to water-logging, then identified sites with elevation capital to allow for artificial drainage, then identified each site's current drainage ability. All layers were then overlaid in GIS	Not specified	Largest areas of high marsh waterlogging occur along the eastern shores of middle Chesapeake Bay in Dorchester County, Maryland, and along the Atlantic Coast of New Jersey, in Cape May, Atlantic, and Cumberland counties. New Jersey has the largest extent of waterlogged high marsh. Within the sites, 239 were selected for potential restoration because they had enough elevation capital and were isolated from the existing tidal creek network. Most sites were located along the east shore of Chesapeake Bay.		Restoration / Recovery	
113	Trevathan-Tackett, S.M., Allnutt, T.R., Sherman, C.D.H., Richardson, M.F., Crowley, T.M., Macreadie, P.I.	Six estuaries along the Western section of the southern Victoria coastline in Australia	Estuary conditions were categorized based on hydrology, land use, water quality, aquatic life, and degree of modification. Measurements for salinity and temp were taken. Seagrass samples were taken and filtered to capture bacterial and fungal epiphytes and endophytes. DNA extraction was completed on microbes, which were then analyzed to characterize the microbiomes at each estuary seagrass bed.	One time data collection, July 6-8, 2016	Bacterial alpha diversity was higher towards the more marine zones, mirroring other typical estuarine species. Beta diversity of bacteria was not significantly impacted by degree of modification, but was highly variable across other site characteristics, most notably driven by salinity. Beta diversity of fungal communities were generally statistically different across site characteristics as well. However, core fungal species were generally independent of the site. Functional redundancy of both provided by diversity in seagrass microbiome is important to support nutrient digestion in seagrass beds. Results show degree of estuarine modification is not the main pressure faced by seagrass.	Seagrass	Microbial response / survival	Modification - General
113	Trevathan-Tackett, S.M., Allnutt, T.R., Sherman, C.D.H., Richardson, M.F., Crowley, T.M., Macreadie, P.I.	Six estuaries along the Western section of the southern Victoria coastline in Australia	Estuary conditions were categorized based on hydrology, land use, water quality, aquatic life, and degree of modification. Measurements for salinity and temp were taken. Seagrass samples were taken and filtered to capture bacterial and fungal epiphytes and endophytes. DNA extraction was completed on microbes, which were then analyzed to characterize the microbiomes at each estuary seagrass bed.	One time data collection, July 6-8, 2016	Bacterial alpha diversity was higher towards the more marine zones, mirroring other typical estuarine species. Beta diversity of bacteria was not significantly impacted by degree of modification, but was highly variable across other site characteristics, most notably driven by salinity. Beta diversity of fungal communities were generally statistically different across site characteristics as well. However, core fungal species were generally independent of the site. Functional redundancy of both provided by diversity in seagrass microbiome is important to support nutrient digestion in seagrass beds. Results show degree of estuarine modification is not the main pressure faced by seagrass.	Microbiome	Biodiversity	
113	Trevathan-Tackett, S.M., Allnutt, T.R., Sherman, C.D.H., Richardson, M.F., Crowley, T.M., Macreadie, P.I.	Six estuaries along the Western section of the southern Victoria coastline in Australia	Estuary conditions were categorized based on hydrology, land use, water quality, aquatic life, and degree of modification. Measurements for salinity and temp were taken. Seagrass samples were taken and filtered to capture bacterial and fungal epiphytes and endophytes. DNA extraction was completed on microbes, which were then analyzed to characterize the microbiomes at each estuary seagrass bed.	One time data collection, July 6-8, 2016	Bacterial alpha diversity was higher towards the more marine zones, mirroring other typical estuarine species. Beta diversity of bacteria was not significantly impacted by degree of modification, but was highly variable across other site characteristics, most notably driven by salinity. Beta diversity of fungal communities were generally statistically different across site characteristics as well. However, core fungal species were generally independent of the site. Functional redundancy of both provided by diversity in seagrass microbiome is important to support nutrient digestion in seagrass beds. Results show degree of estuarine modification is not the main pressure faced by seagrass.	Microbiome		
114	Vasconcelos, R.P., Batista, M.I., Henriques, S.	Global review	Review of fish assemblages as proxy for biodiversity in estuaries and its relationship to environmental features, human pressures and/or levels of protection. Fish assemblages were first characterized, identified for vulnerability and resilience traits, and ecosystem features were categorized for estuaries worldwide. Intensity of human activity and levels of protection were estimated for each estuary.	Not specified	Estuarine fish species generally have medium to high levels of resilience. There is a negative relationship between abundance and biomass per individual. There is a positive relationship between resilient traits of fish assemblages and levels of environmental protection of estuaries. Results suggest that estuarine fish assemblages are more sensitive to anthropogenic pressures in regions of high latitudes (especially Europe), and estuaries with high connectivity to the marine system (open with wide tidal amplitude). Proportion of resilient fish species in estuaries decreases in Europe. Fish body size tends to be larger at higher latitudes	Fish	Biodiversity	Diversity loss
114	Vasconcelos, R.P., Batista, M.I., Henriques, S.	Global review	Review of fish assemblages as proxy for biodiversity in estuaries and its relationship to environmental features, human pressures and/or levels of protection. Fish assemblages were first characterized, identified for vulnerability and resilience traits, and ecosystem features were categorized for estuaries worldwide. Intensity of human activity and levels of protection were estimated for each estuary.	Not specified	Estuarine fish species generally have medium to high levels of resilience. There is a negative relationship between abundance and biomass per individual. There is a positive relationship between resilient traits of fish assemblages and levels of environmental protection of estuaries. Results suggest that estuarine fish assemblages are more sensitive to anthropogenic pressures in regions of high latitudes (especially Europe), and estuaries with high connectivity to the marine system (open with wide tidal amplitude). Proportion of resilient fish species in estuaries decreases in Europe. Fish body size tends to be larger at higher latitudes		Habitat Distribution	Modification - General
115	Verdelhos, T., Cardoso, P.G., Dolbeth, M., Pardal, M.A.	One seagrass bed and one sand flat within the Mondego Estuary Intertidal Area	Investigation of Scrobicularia plana (commercially important estuarine bivalve) responses to extreme weather events after recovering from eutrophication in congruence with restoration work. Investigation also evaluation of long-term effectiveness of active ecosystem management and a comparison of responses between the seagrass and the sandflat settings. Collections took place from both habitat types, seagrass habitat had higher organic content and water flow velocity from the sandflat. Information collected included length x weight and secondary production.	Samples were taken monthly for 6 years, from Jan 1999 to Dec 2005.	Several extreme weather events occurred during the sampling, including heavy rains with a 1:100 flood, extremely dry and very dry temperatures, and extreme heat waves. Salinity levels and water temperatures adjusted accordingly with the climate, and seagrass recovery was negatively impacted by each event. S. plana populations were dominated by juveniles, with recruitment being higher in the sandflat area. Biomass decreased after extreme weather events. The population was more structured and stable in the seagrass bed, including evenness between cohorts. In the sandflat area, there was less even representation between cohorts, with older individuals no longer represented after weather events. Sandflat generally had younger cohorts and higher abundance where seagrass had larger, older individuals, with lower abundance. Individuals in the seagrass bed had better recovery after extreme events.	Seagrass	Animal Response / Survival	Eutrophication
115	Verdelhos, T., Cardoso, P.G., Dolbeth, M., Pardal, M.A.	One seagrass bed and one sand flat within the Mondego Estuary Intertidal Area	Investigation of Scrobicularia plana (commercially important estuarine bivalve) responses to extreme weather events after recovering from eutrophication in congruence with restoration work. Investigation also evaluation of long-term effectiveness of active ecosystem management and a comparison of responses between the seagrass and the sandflat settings. Collections took place from both habitat types, seagrass habitat had higher organic content and water flow velocity from the sandflat. Information collected included length x weight and secondary production.	Samples were taken monthly for 6 years, from Jan 1999 to Dec 2005.	Several extreme weather events occurred during the sampling, including heavy rains with a 1:100 flood, extremely dry and very dry temperatures, and extreme heat waves. Salinity levels and water temperatures adjusted accordingly with the climate, and seagrass recovery was negatively impacted by each event. S. plana populations were dominated by juveniles, with recruitment being higher in the sandflat area. Biomass decreased after extreme weather events. The population was more structured and stable in the seagrass bed, including evenness between cohorts. In the sandflat area, there was less even representation between cohorts, with older individuals no longer represented after weather events. Sandflat generally had younger cohorts and higher abundance where seagrass had larger, older individuals, with lower abundance. Individuals in the seagrass bed had better recovery after extreme events.	Sand Flats		Freshwater flows / precipitation

115	Verdelhos, T., Cardoso, P.G., Dolbeth, M., Pardal, M.A.	One seagrass bed and one sand flat within the Mondego Estuary Intertidal Area	Investigation of Scrobicularia plana (commercially important estuarine bivalve) responses to extreme weather events after recovering from eutrophication in congruence with restoration work. Investigation also evaluation of long-term effectiveness of active ecosystem management and a comparison of responses between the seagrass and the sandflat settings. Collections took place from both habitat types, seagrass habitat had higher organic content and water flow velocity from the sandflat. Information collected included length x weight and secondary production.	Samples were taken monthly for 6 years, from Jan 1999 to Dec 2005.	Several extreme weather events occurred during the sampling, including heavy rains with a 1:100 flood extremely dry and very dry temperatures, and extreme heat waves. Salinity levels and water temperatures adjusted accordingly with the climate, and seagrass recovery was negatively impacted by each event. S. plana populations were dominated by juveniles, with recruitment being higher in the sandflat area. Biomass decreased after extreme weather events. The population was more structured and stable in the seagrass bed, including evenness between cohorts. In the sandflat area, there was less even representation between cohorts, with older individuals no longer represented after weather events. Sandflat generally had younger cohorts and higher abundance where seagrass had larger, older individuals, with lower abundance. Individuals in the seagrass bed had better recovery after extreme events.	Bivalves		Drought
116	Wang, F., Yan, J., Ma, X., Qiu, D., Xie, T., Cui, B.	Four sites within the Yellow River Delta, China, within Dongying City, Shandong Province, China.	To better understand endemic salt marsh responses to different levels of tidal inundation for the species Sueda salsa - a marsh grass endemic to China, plant traits and edaphic conditions were measured. Recorded elements included the tidal regime at four locations along the tidal spectrum, soil properties from core samples (C-N-P content, soil-water content, pH, salinity), abundance of s. salsa at plots along transect, plant height, plant C-N-P content, and sum of biomass.	Sept 22 to Nov 22, 2017. Tidal data was measured every 10 minutes. All other samples were one-time data collection.	Sites were labelled from A to D, with A facing the open ocean with highest levels of inundation and D closest to shore facing the lowest tidal inundation. Shoot density didn't show a pattern related to tidal inundation levels. Plant height was highest at site A and lowest at site D, favouring higher inundation levels. However, site D had highest levels of biomass, both above ground and below ground. Salinity, water content, pH, total nitrogen, and total phosphorus were not significantly different between sites. However, total organic content was different between sites, generally highest at site D. There is a linear positive relation between soil organic carbon and plant biomass	Salt Marsh	Plant Density	Sea-level rise
116	Wang, F., Yan, J., Ma, X., Qiu, D., Xie, T., Cui, B.	Four sites within the Yellow River Delta, China, within Dongying City, Shandong Province, China.	To better understand endemic salt marsh responses to different levels of tidal inundation for the species Sueda salsa - a marsh grass endemic to China, plant traits and edaphic conditions were measured. Recorded elements included the tidal regime at four locations along the tidal spectrum, soil properties from core samples (C-N-P content, soil-water content, pH, salinity), abundance of s. salsa at plots along transect, plant height, plant C-N-P content, and sum of biomass.	Sept 22 to Nov 22, 2017. Tidal data was measured every 10 minutes. All other samples were one-time data collection.	Sites were labelled from A to D, with A facing the open ocean with highest levels of inundation and D closest to shore facing the lowest tidal inundation. Shoot density didn't show a pattern related to tidal inundation levels. Plant height was highest at site A and lowest at site D, favouring higher inundation levels. However, site D had highest levels of biomass, both above ground and below ground. Salinity, water content, pH, total nitrogen, and total phosphorus were not significantly different between sites. However, total organic content was different between sites, generally highest at site D. There is a linear positive relation between soil organic carbon and plant biomass		Plant Diversity	
117	Windham, R., Nunnally, A.P., Quigg, A.	Galveston Bay, Texas	Rangia cuneata clams (atlantic rangia clams) were studied for suitability as estuarine bioindicators of environmental demands on freshwater and sediment flow, since they thrive in brackish waters. One measured variable included total daily mean discharge from 1983 to 2014. This was compared against R. cuneata populations records (abundance and distribution) from 1983 to 2014. Other parameters included temperature, dissolved oxygen, and salinity. From 2010 to 2014, individuals were sampled and measured for weight, size, sex, and health (based on weight proxy equation).	1983 to 2014	Clam abundance has been steadily decreasing since the 1980s based on catch per unit effort. Decreased abundance is associated with increased variability in freshwater flows, and annual distance from mean flow values. Health was lowest in the fall and highest in the summer. Sex ratios showed that males were more prevalent than females. Biomass generally decreased over time.	Mudflats	Animal Response / Survival	Freshwater flows / precipitation
117	Windham, R., Nunnally, A.P., Quigg, A.	Galveston Bay, Texas	Rangia cuneata clams (atlantic rangia clams) were studied for suitability as estuarine bioindicators of environmental demands on freshwater and sediment flow, since they thrive in brackish waters. One measured variable included total daily mean discharge from 1983 to 2014. This was compared against R. cuneata populations records (abundance and distribution) from 1983 to 2014. Other parameters included temperature, dissolved oxygen, and salinity. From 2010 to 2014, individuals were sampled and measured for weight, size, sex, and health (based on weight proxy equation).	1983 to 2014	Clam abundance has been steadily decreasing since the 1980s based on catch per unit effort. Decreased abundance is associated with increased variability in freshwater flows, and annual distance from mean flow values. Health was lowest in the fall and highest in the summer. Sex ratios showed that males were more prevalent than females. Biomass generally decreased over time.	Bivalves		
117	Windham, R., Nunnally, A.P., Quigg, A.	Galveston Bay, Texas	Rangia cuneata clams (atlantic rangia clams) were studied for suitability as estuarine bioindicators of environmental demands on freshwater and sediment flow, since they thrive in brackish waters. One measured variable included total daily mean discharge from 1983 to 2014. This was compared against R. cuneata populations records (abundance and distribution) from 1983 to 2014. Other parameters included temperature, dissolved oxygen, and salinity. From 2010 to 2014, individuals were sampled and measured for weight, size, sex, and health (based on weight proxy equation).	1983 to 2014	Clam abundance has been steadily decreasing since the 1980s based on catch per unit effort. Decreased abundance is associated with increased variability in freshwater flows, and annual distance from mean flow values. Health was lowest in the fall and highest in the summer. Sex ratios showed that males were more prevalent than females. Biomass generally decreased over time.	Sand Flats		
118	Wong, M.C., Griffiths, G., Vercaemer, B.	Port l'Hebert Bay, south shore, Nova Scotia	To test responses of Zostera marina to reduced light availability, different levels of shading were applied to a 2km2 seagrass bed. 0%, 34%, and 64% light reduction to the benthic zone were applied in situ to experimental sections using greenhouse shade cloth. Measured variables before and after each experimental period included shoot density, water temperature, number of leaves per shoot, total clorophyll (a and b) concentration, phenolic acid concentration, and water soluble carbohydrates.	Two nine week experiments. One was done in spring/ early summer. Another was done in late summer/fall. May 18-July 20 and Aug 29-Nov1, 2017. 6-week recovery and 2 year monitoring after.	Spring experiment: shoot density was lowered in the highest shade level after 6 weeks. A high temperature event reduced shoot density in all plots. After6 weeks recovery, shoot density recovered quickly in the unshaded plot but not in either of the shaded plots. This trend continued after two overwintering periods (up to week 99). Sheath length increased significantly in highest shade plot Fall experiment: shoot density declined in both shaded plots significantly during the second round of shading, and maintained much lower density levels throughout and after 6 weeks recovery. Recovery was witnessed after 2 years but remained significantly lower in the highest shade plot.	Seagrass	Light access / Attenuation	Turbidity

118	Wong, M.C., Griffiths, G., Vercaemer, B.	Port l'Hebert Bay, south shore, Nova Scotia	To test responses of Zostera marina to reduced light availability, different levels of shading were applied to a 2km2 seagrass bed. 0%, 34%, and 64% light reduction to the benthic zone were applied in situ to experimental sections using greenhouse shade cloth. Measured variables before and after each experimental period included shoot density, water temperature, number of leaves per shoot, total clorophyll (a and b) concentration, phenolic acid concentration, and water soluble carbohydrates.	Two nine week experiments. One was done in spring/ early summer. Another was done in late summer/fall. May 18-July 20 and Aug 29-Nov1, 2017. 6-week recovery and 2 year monitoring after.	Spring experiment: shoot density was lowered in the highest shade level after 6 weeks. A high temperature event reduced shoot density in all plots. After6 weeks recovery, shoot density recovered quickly in the unshaded plot but not in either of the shaded plots. This trend continued after two overwintering periods (up to week 99). Sheath length increased significantly in highest shade plot Fall experiment: shoot density declined in both shaded plots significantly during the second round of shading, and maintained much lower density levels throughout and after 6 weeks recovery. Recovery was witnessed after 2 years but remained significantly lower in the highest shade plot.	Water		
119	Woo, I., Davis, M.J., Ellings, C.S., Hodgson, S., Takekawa, J.Y., Nakai, G., de la Cruz, S.E.W.	14 sampling stations within Nisqually River Delta, Puget Sound, Washington	Purpose of study was to understand the effects of a patch habitat mosaic on foraging opportunities for juvenile chinook salmon. Chinook juveniles and prey species were sampled from five different habitat types: freshwater tidal forest, transitional emergent marsh, emergent salt marsh, intertidal mudflat, and eelgrass. Prey was collected using traps, nets, and cores to capture terrestrial, aquatic, and benthic zones. Epifaunal prey in zostera beds was collected from Z. marina blades. Chinook samples were collected from seining events, stomach contents were assessed. Other variables collected included temp, salinity, and dissolved oxygen.	Prey sampling occurred biweekly from March through July, 2014 and 2015. Beach seines for chinook were from 2010 to 2015. Frequency undefined.	Prey resources were found to be predicted by year, month, and habitat type. Within habitat types, seasonal differences were strong predictors. Transitional emergent salt marshes from May to June had the largest terrestrial prey biomass. Terrestrial insect drift was strongest in tidal forest area, but weak ir delta mudflat and eelgrass. Aquatic prey was most prevalent at emergent salt marshes, but weak in tidal forest and transitional emergent salt marshes. Epifaunal prey was highest in the summer at the eelgrass site. Insect taxa tended to decrease along the fresh-saltwater gradient. Community overlap wa strongest between delta mudflat and eelgrass. Mysids were very prevalent in May-June in aquatic samples. Estuary-wide prey samples were relatively diverse. Highest densities of hatchery juvenile salmon were observed in both saltmarsh habitat types and delta mudflats, but habitat distributions for non-hatchery fish were relatively evenly-distributed. Habitat type was primary predictor of diet.	Fish	Habitat Distribution	Baseline assessment
119	Woo, I., Davis, M.J., Ellings, C.S., Hodgson, S., Takekawa, J.Y., Nakai, G., de la Cruz, S.E.W.	14 sampling stations within Nisqually River Delta, Puget Sound, Washington	Purpose of study was to understand the effects of a patch habitat mosaic on foraging opportunities for juvenile chinook salmon. Chinook juveniles and prey species were sampled from five different habitat types: freshwater tidal forest, transitional emergent marsh, emergent salt marsh, intertidal mudflat, and eelgrass. Prey was collected using traps, nets, and cores to capture terrestrial, aquatic, and benthic zones. Epifaunal prey in zostera beds was collected from Z. marina blades. Chinook samples were collected from seining events, stomach contents were assessed. Other variables collected included temp, salinity, and dissolved oxygen.	Prey sampling occurred biweekly from March through July, 2014 and 2015. Beach seines for chinook were from 2010 to 2015. Frequency undefined.	Prey resources were found to be predicted by year, month, and habitat type. Within habitat types, seasonal differences were strong predictors. Transitional emergent salt marshes from May to June had the largest terrestrial prey biomass. Terrestrial insect drift was strongest in tidal forest area, but weak ir delta mudflat and eelgrass. Aquatic prey was most prevalent at emergent salt marshes, but weak in tidal forest and transitional emergent salt marshes. Epifaunal prey was highest in the summer at the eelgrass site. Insect taxa tended to decrease along the fresh-saltwater gradient. Community overlap wa strongest between delta mudflat and eelgrass. Mysids were very prevalent in May-June in aquatic samples. Estuary-wide prey samples were relatively diverse. Highest densities of hatchery juvenile salmon were observed in both saltmarsh habitat types and delta mudflats, but habitat distributions for non-hatchery fish were relatively evenly-distributed. Habitat type was primary predictor of diet.	Food Web	Species Composition	
119	Woo, I., Davis, M.J., Ellings, C.S., Hodgson, S., Takekawa, J.Y., Nakai, G., de la Cruz, S.E.W.	14 sampling stations within Nisqually River Delta, Puget Sound, Washington	Purpose of study was to understand the effects of a patch habitat mosaic on foraging opportunities for juvenile chinook salmon. Chinook juveniles and prey species were sampled from five different habitat types: freshwater tidal forest, transitional emergent marsh, emergent salt marsh, intertidal mudflat, and eelgrass. Prey was collected using traps, nets, and cores to capture terrestrial, aquatic, and benthic zones. Epifaunal prey in zostera beds was collected from Z. marina blades. Chinook samples were collected from seining events, stomach contents were assessed. Other variables collected included temp, salinity, and dissolved oxygen.	Prey sampling occurred biweekly from March through July, 2014 and 2015. Beach seines for chinook were from 2010 to 2015. Frequency undefined.	Prey resources were found to be predicted by year, month, and habitat type. Within habitat types, seasonal differences were strong predictors. Transitional emergent salt marshes from May to June had the largest terrestrial prey biomass. Terrestrial insect drift was strongest in tidal forest area, but weak ir delta mudflat and eelgrass. Aquatic prey was most prevalent at emergent salt marshes, but weak in tidal forest and transitional emergent salt marshes. Epifaunal prey was highest in the summer at the eelgrass site. Insect taxa tended to decrease along the fresh-saltwater gradient. Community overlap wa strongest between delta mudflat and eelgrass. Mysids were very prevalent in May-June in aquatic samples. Estuary-wide prey samples were relatively diverse. Highest densities of hatchery juvenile salmon were observed in both saltmarsh habitat types and delta mudflats, but habitat distributions for non-hatchery fish were relatively evenly-distributed. Habitat type was primary predictor of diet.			
120	Xie, Z., Liu, J., Zhu, G., Shao, Q, Xu, X.	Tianjin Beidagang Wetland Natural Reserve - protected intertidal wetlands in warm-temperate section of China	Geographic analysis of changes over time in land use and land cover in an urban-industrial (oil resource) setting, and its impacts on spatial changes in a protected intertidal wetland. Historical images were overlaid and compared against water quality data, time-series socioeconomic data, and historical information about land-use change. GIS analysis was completed. Livestock production on marshes and mudflats has also increased.	Images from Sept, 1988, Aug, 1999, and Sept, 2008.	Land use has shifted since the eighties from cultivated land to settlements. Area of settlements, saltwater bodies, and unused land increased, while cultivated land decreased by 38.71% and traffic increased by 48.11%. Coastal wetlands were impacted by oil-field development and production. Environmental quality has been disrupted by heavy metals, water, and oil leakage/pollution. Pollutant concentration includes chemical oxygen demand and suspended substances. Coastal wetland biomass has sharply decreased. Mollusc populations were more than 3 times higher in 1983 (599.4ind/m2) than 2003 (190.11ind/m2). Hydrocarbon content and faecal coliform in shellfish was way above health standards. Water quality improved in 2007 after protection measures were put in place.	Salt Marsh	Water Quality	Land reclamation
120	Xie, Z., Liu, J., Zhu, G., Shao, Q, Xu, X.	Tianjin Beidagang Wetland Natural Reserve - protected intertidal wetlands in warm-temperate section of China	Geographic analysis of changes over time in land use and land cover in an urban-industrial (oil resource) setting, and its impacts on spatial changes in a protected intertidal wetland. Historical images were overlaid and compared against water quality data, time-series socioeconomic data, and historical information about land-use change. GIS analysis was completed. Livestock production on marshes and mudflats has also increased.	Images from Sept, 1988, Aug, 1999, and Sept, 2008.	Land use has shifted since the eighties from cultivated land to settlements. Area of settlements, saltwater bodies, and unused land increased, while cultivated land decreased by 38.71% and traffic increased by 48.11%. Coastal wetlands were impacted by oil-field development and production. Environmental quality has been disrupted by heavy metals, water, and oil leakage/pollution. Pollutant concentration includes chemical oxygen demand and suspended substances. Coastal wetland biomass has sharply decreased. Mollusc populations were more than 3 times higher in 1983 (599.4ind/m2) than 2003 (190.11ind/m2). Hydrocarbon content and faecal coliform in shellfish was way above health standards. Water quality improved in 2007 after protection measures were put in place.		Habitat Distribution	
121	Zabarte-Maeztu, I., Matheson, F., Manley-Harris, M., Davies-Colley, R.J., Oliver, M., Hawes, I.	15 seagrass sampling sites within Pauatahanui Inlet, New Zealand,	Research was set in an estuary that has seen significant decline in seagrass meadows. To research potential causes of seagrass decline and failure to recover, light climate and substrate characteristics were measured. Sites were chosen based on known historical seagrass cover, existing cover, and locations o potential seagrass. Variables included seagrass percent cover, core analysis, porewater nutrient and H2S content, redox potential, photosynthetically active radiation (PAR), temperature, and water level/tidal exposure.	seagrass and core samples were collected 23-31 Aug (winter), 2018 and 8-15 Feb, 2019 (summer). Tidal exposure was measured 23-Aug to 3-Oct, 2018 (winter) and 8-Feb to 21 Mar, 2019.	Historical sites tended to be closer to the river mouth, whereas other sites tended to be closer to the estuary mouth.Substrate mud content and coarse sand was higher in historical seagrass beds versus existing and potential seagrass sites. Substrate bulk density was higher at historical sites versus the others. Highest organic matter content in winter was historical sites and in summer was existing sites. This suggests organic content was transferred to the historic sites in the winter from the river, and was created in the summer at seagrass beds. Redox was more negative at historic sites during the winter, but same across sites in the summer. PAR was highest for all sites at low tide when the water is less sediment ridden and the water level is lower. HS sites had high sedimentation. Max seagrass cover occurred where substrate mud content was 13-23% and 1.3-3% organic content.	Seagrass	Habitat Distribution	Sediment fluxes

121	Zabarte-Maeztu, I., Matheson, F., Manley-Harris, M., Davies-Colley, R.J., Oliver, M., Hawes, I.	15 seagrass sampling sites within Pauatahanui Inlet, New Zealand,	Research was set in an estuary that has seen significant decline in seagrass meadows. To research potential causes of seagrass decline and failure to recover, light climate and substrate characteristics were measured. Sites were chosen based on known historical seagrass cover, existing cover, and locations o potential seagrass. Variables included seagrass percent cover, core analysis, porewater nutrient and H2S content, redox potential, photosynthetically active radiation (PAR), temperature, and water level/tidal exposure.	seagrass and core samples were collected 23-31 Aug (winter), 2018 and 8-15 Feb, 2019 (summer). Tidal exposure was measured 23-Aug to 3-Oct, 2018 (winter) and 8-Feb to 21 Mar, 2019.	Historical sites tended to be closer to the river mouth, whereas other sites tended to be closer to the estuary mouth.Substrate mud content and coarse sand was higher in historical seagrass beds versus existing and potential seagrass sites. Substrate bulk density was higher at historical sites versus the others. Highest organic matter content in winter was historical sites and in summer was existing sites. This suggests organic content was transferred to the historic sites in the winter from the river, and was created in the summer at seagrass beds. Redox was more negative at historic sites during the winter, but same across sites in the summer. PAR was highest for all sites at low tide when the water is less sediment ridden and the water level is lower. HS sites had high sedimentation. Max seagrass cover occurred where substrate mud content was 13-23% and 1.3-3% organic content.		Plant Density	
121	Zabarte-Maeztu, I., Matheson, F., Manley-Harris, M., Davies-Colley, R.J., Oliver, M., Hawes, I.	15 seagrass sampling sites within Pauatahanui Inlet, New Zealand,	Research was set in an estuary that has seen significant decline in seagrass meadows. To research potential causes of seagrass decline and failure to recover, light climate and substrate characteristics were measured. Sites were chosen based on known historical seagrass cover, existing cover, and locations o potential seagrass. Variables included seagrass percent cover, core analysis, porewater nutrient and H2S content, redox potential, photosynthetically active radiation (PAR), temperature, and water level/tidal exposure.	seagrass and core samples were collected 23-31 Aug (winter), 2018 and 8-15 Feb, 2019 (summer). Tidal exposure was measured 23-Aug to 3-Oct, 2018 (winter) and 8-Feb to 21 Mar, 2019.	Historical sites tended to be closer to the river mouth, whereas other sites tended to be closer to the estuary mouth.Substrate mud content and coarse sand was higher in historical seagrass beds versus existing and potential seagrass sites. Substrate bulk density was higher at historical sites versus the others. Highest organic matter content in winter was historical sites and in summer was existing sites. This suggests organic content was transferred to the historic sites in the winter from the river, and was created in the summer at seagrass beds. Redox was more negative at historic sites during the winter, but same across sites in the summer. PAR was highest for all sites at low tide when the water is less sediment ridden and the water level is lower. HS sites had high sedimentation. Max seagrass cover occurred where substrate mud content was 13-23% and 1.3-3% organic content.		Water Quality	
121	Zabarte-Maeztu, I., Matheson, F., Manley-Harris, M., Davies-Colley, R.J., Oliver, M., Hawes, I.	15 seagrass sampling sites within Pauatahanui Inlet, New Zealand,	Research was set in an estuary that has seen significant decline in seagrass meadows. To research potential causes of seagrass decline and failure to recover, light climate and substrate characteristics were measured. Sites were chosen based on known historical seagrass cover, existing cover, and locations o potential seagrass. Variables included seagrass percent cover, core analysis, porewater nutrient and H2S content, redox potential, photosynthetically active radiation (PAR), temperature, and water level/tidal exposure.	seagrass and core samples were collected 23-31 Aug (winter), 2018 and 8-15 Feb, 2019 (summer). Tidal exposure was measured 23-Aug to 3-Oct, 2018 (winter) and 8-Feb to 21 Mar, 2019.	Historical sites tended to be closer to the river mouth, whereas other sites tended to be closer to the estuary mouth.Substrate mud content and coarse sand was higher in historical seagrass beds versus existing and potential seagrass sites. Substrate bulk density was higher at historical sites versus the others. Highest organic matter content in winter was historical sites and in summer was existing sites. This suggests organic content was transferred to the historic sites in the winter from the river, and was created in the summer at seagrass beds. Redox was more negative at historic sites during the winter, but same across sites in the summer. PAR was highest for all sites at low tide when the water is less sediment ridden and the water level is lower. HS sites had high sedimentation. Max seagrass cover occurred where substrate mud content was 13-23% and 1.3-3% organic content.		Light Access / Attenuation	
122	Zeldis, J.R., Depree, C., Gongol, C., South, P.M., Marriner, A., Schiel, D.R.	9 sampling sites within the Avon Heathcote estuary, adjacent to Christchurch, New Zealand	Study tested the effectiveness and the rate at which the Avon-Heathcote Estuary (AHE) recovered from the impacts of harbouring wastewater from a shoreline treatment plant after the pollutants were diverted to an offshore outfall location. Sampled indicators included water column nutrients, sediment properties (%OM, %N, %C, delta15N isotope, and porosity), sediment porewater nutrients, benthic microalgal biomass, macrofaunal abundance, and sediment fluxes of oxygen, dissolved nutrients, and denitrification.	winter and summer samples were collected over 6 years (frequency undefined), starting in March 2010 immediately after a wastewater outfall diversion. Sampling continued after sewage line breached into the estuary due to the earthquake in 2011.	Inner estuary sites showed highest levels of ammonium, and dissolved reactive phosphorus and lowest values towards the estuary mouth. Nitrate was highest at river mouth sites. Ammonium levels decreased significantly after a few months of the wastewater diversion, but then increased again after the 2011 earthquake. Total DIN concentrations were reduced but not dramatically because of nitrate discharge from rivers. Sediment %OM, %N, %C were all strongly associated with mud-type sediment. Sediment nitrogen (ammonium) near the treatment plant location was the only factor that changed significantly between pre-diversion and post-diversion. Benthic microalgal (BMA) biomass decreased immediately and significantly after the diversion but increased after the earthquake, and then retreatec again. Consistent with BMA, deposit-feeding polychaetes from sediment cores significantly reduced in abundance after the diversion, where median densities of Capitellidae and Aonides trifida reduced fron 3700 to 800 in 1 year at some sites, and A. trifida at another site was reduced from 8000 to 3200 in 2 years. Consistent with BMA, NPP was high close to the wastewater treatment site pre-diversion, and was reduced post-diversion. The discharge site then became net-heterotrophic.	Water	Water Quality	Pollution
122	Zeldis, J.R., Depree, C., Gongol, C., South, P.M., Marriner, A., Schiel, D.R.	9 sampling sites within the Avon Heathcote estuary, adjacent to Christchurch, New Zealand	Study tested the effectiveness and the rate at which the Avon-Heathcote Estuary (AHE) recovered from the impacts of harbouring wastewater from a shoreline treatment plant after the pollutants were diverted to an offshore outfall location. Sampled indicators included water column nutrients, sediment properties (%OM, %N, %C, delta15N isotope, and porosity), sediment porewater nutrients, benthic microalgal biomass, macrofaunal abundance, and sediment fluxes of oxygen, dissolved nutrients, and denitrification.	winter and summer samples were collected over 6 years (frequency undefined), starting in March 2010 immediately after a wastewater outfall diversion. Sampling continued after sewage line breached into the estuary due to the earthquake in 2011.	Inner estuary sites showed highest levels of ammonium, and dissolved reactive phosphorus and lowest values towards the estuary mouth. Nitrate was highest at river mouth sites. Ammonium levels decreased significantly after a few months of the wastewater diversion, but then increased again after the 2011 earthquake. Total DIN concentrations were reduced but not dramatically because of nitrate discharge from rivers. Sediment %OM, %N, %C were all strongly associated with mud-type sediment. Sediment nitrogen (ammonium) near the treatment plant location was the only factor that changed significantly between pre-diversion and post-diversion. Benthic microalgal (BMA) biomass decreased immediately and significantly after the diversion but increased after the earthquake, and then retreatec again. Consistent with BMA, deposit-feeding polychaetes from sediment cores significantly reduced in abundance after the diversion, where median densities of Capitellidae and Aonides trifida reduced fron 3700 to 800 in 1 year at some sites, and A. trifida at another site was reduced from 8000 to 3200 in 2 years. Consistent with BMA, NPP was high close to the wastewater treatment site pre-diversion, and was reduced post-diversion. The discharge site then became net-heterotrophic.	Mudflats	Species Composition	Eutrophication
122	Zeldis, J.R., Depree, C., Gongol, C., South, P.M., Marriner, A., Schiel, D.R.	9 sampling sites within the Avon Heathcote estuary, adjacent to Christchurch, New Zealand	Study tested the effectiveness and the rate at which the Avon-Heathcote Estuary (AHE) recovered from the impacts of harbouring wastewater from a shoreline treatment plant after the pollutants were diverted to an offshore outfall location. Sampled indicators included water column nutrients, sediment properties (%OM, %N, %C, delta15N isotope, and porosity), sediment porewater nutrients, benthic microalgal biomass, macrofaunal abundance, and sediment fluxes of oxygen, dissolved nutrients, and denitrification.	winter and summer samples were collected over 6 years (frequency undefined), starting in March 2010 immediately after a wastewater outfall diversion. Sampling continued after sewage line breached into the estuary due to the earthquake in 2011.	Inner estuary sites showed highest levels of ammonium, and dissolved reactive phosphorus and lowest values towards the estuary mouth. Nitrate was highest at river mouth sites. Ammonium levels decreased significantly after a few months of the wastewater diversion, but then increased again after the 2011 earthquake. Total DIN concentrations were reduced but not dramatically because of nitrate discharge from rivers. Sediment %OM, %N, %C were all strongly associated with mud-type sediment. Sediment nitrogen (ammonium) near the treatment plant location was the only factor that changed significantly between pre-diversion and post-diversion. Benthic microalgal (BMA) biomass decreased immediately and significantly after the diversion but increased after the earthquake, and then retreatec again. Consistent with BMA, deposit-feeding polychaetes from sediment cores significantly reduced in abundance after the diversion, where median densities of Capitellidae and Aonides trifida reduced fron 3700 to 800 in 1 year at some sites, and A. trifida at another site was reduced from 8000 to 3200 in 2 years. Consistent with BMA, NPP was high close to the wastewater treatment site pre-diversion, and was reduced post-diversion. The discharge site then became net-heterotrophic.	Invertebrates		

123	Zhu, L., Chen, Q., Wang, H., Capurso, W., Niemoczynski, L., Hu, K., Snedden, G.	Six stations in Gandy's Beach, New Jersey, in upper Delaware Bay	Study quantified the wave attentuation properties of constructed oyster reefs (CORs) as a shoreline/marsh edge erosion protection mechanism for management. CORs were made of concrete blocks in 2016, and emerge during low tide but remain submerged between mid and high tide. 2 buoy stations were used to collect tidal data, six pressure transducers were used to collect data estimating wave spectra. For winter storms occurred during data collection period.	Sensor data was collected every 30 mins from Jan 31 to Apr 2, 2018	Submerged CORs provide partial attentuation of wave energy. Spectral analysis revealed that there is an energy transfer from primary waves to high harmonics (breaking up the wave into multiple energy forms, energy is spread out and less intense in these situations) after the waves transfer over the CORs. Intense swell energy from the atlantic ocean was not dampened by the CORs, even at low tide when they were emergent.	Rocky Reefs	Currents / Discharge / Hydrology	Increased Currents
123	Zhu, L., Chen, Q., Wang, H., Capurso, W., Niemoczynski, L., Hu, K., Snedden, G.	Six stations in Gandy's Beach, New Jersey, in upper Delaware Bay	Study quantified the wave attentuation properties of constructed oyster reefs (CORs) as a shoreline/marsh edge erosion protection mechanism for management. CORs were made of concrete blocks in 2016, and emerge during low tide but remain submerged between mid and high tide. 2 buoy stations were used to collect tidal data, six pressure transducers were used to collect data estimating wave spectra. For winter storms occurred during data collection period.	Sensor data was collected every 30 mins from Jan 31 to Apr 2, 2018	Submerged CORs provide partial attentuation of wave energy. Spectral analysis revealed that there is an energy transfer from primary waves to high harmonics (breaking up the wave into multiple energy forms, energy is spread out and less intense in these situations) after the waves transfer over the CORs. Intense swell energy from the atlantic ocean was not dampened by the CORs, even at low tide when they were emergent.	Bivalves		
124	Zou, Y., Tang, C., Niu, J., Wang, T., Zie, Y., Guo, H.	Chongming Dongtan wetlands within Yangtze River Estuary, Shanghai, China	Understanding the relationship between wetland habitats and migrating waterbird population through the nature reserve. In the study area, Spartina spp invasive. Scirpus mariqueter (bullrush) and Phragmites australis (common reed) are both native.	Waterbird survey data was collected from 2006 to 2012. Surveys lasted 4-5 days, including before and after neap tide, started 1h after sunrise and lasted 4-5 hours each day.	Prevalence of anatidae (ducks, geese, and swans) was positively linked to Scirpus mariqueter, but negatively linked to Phragmites Australis. Anatidae was negatively linked to reductions in aquaculture (finfish and crab) area. Characriidae (plovers) and Laridae were positively linked to deep water habitats but negatively linked to Spartina alterniflora habitat. Plover density was linked to Scirpus habitat.	Salt Marsh	Animal Response / Survival	Invasive Species
124	Zou, Y., Tang, C., Niu, J., Wang, T., Zie, Y., Guo, H.	Chongming Dongtan wetlands within Yangtze River Estuary, Shanghai, China	Understanding the relationship between wetland habitats and migrating waterbird population through the nature reserve. In the study area, Spartina spp invasive. Scirpus mariqueter (bullrush) and Phragmites australis (common reed) are both native.	Waterbird survey data was collected from 2006 to 2012. Surveys lasted 4-5 days, including before and after neap tide, started 1h after sunrise and lasted 4-5 hours each day.	Prevalence of anatidae (ducks, geese, and swans) was positively linked to Scirpus mariqueter, but negatively linked to Phragmites Australis. Anatidae was negatively linked to reductions in aquaculture (finfish and crab) area. Characriidae (plovers) and Laridae were positively linked to deep water habitats but negatively linked to Spartina alterniflora habitat. Plover density was linked to Scirpus habitat.	Birds		