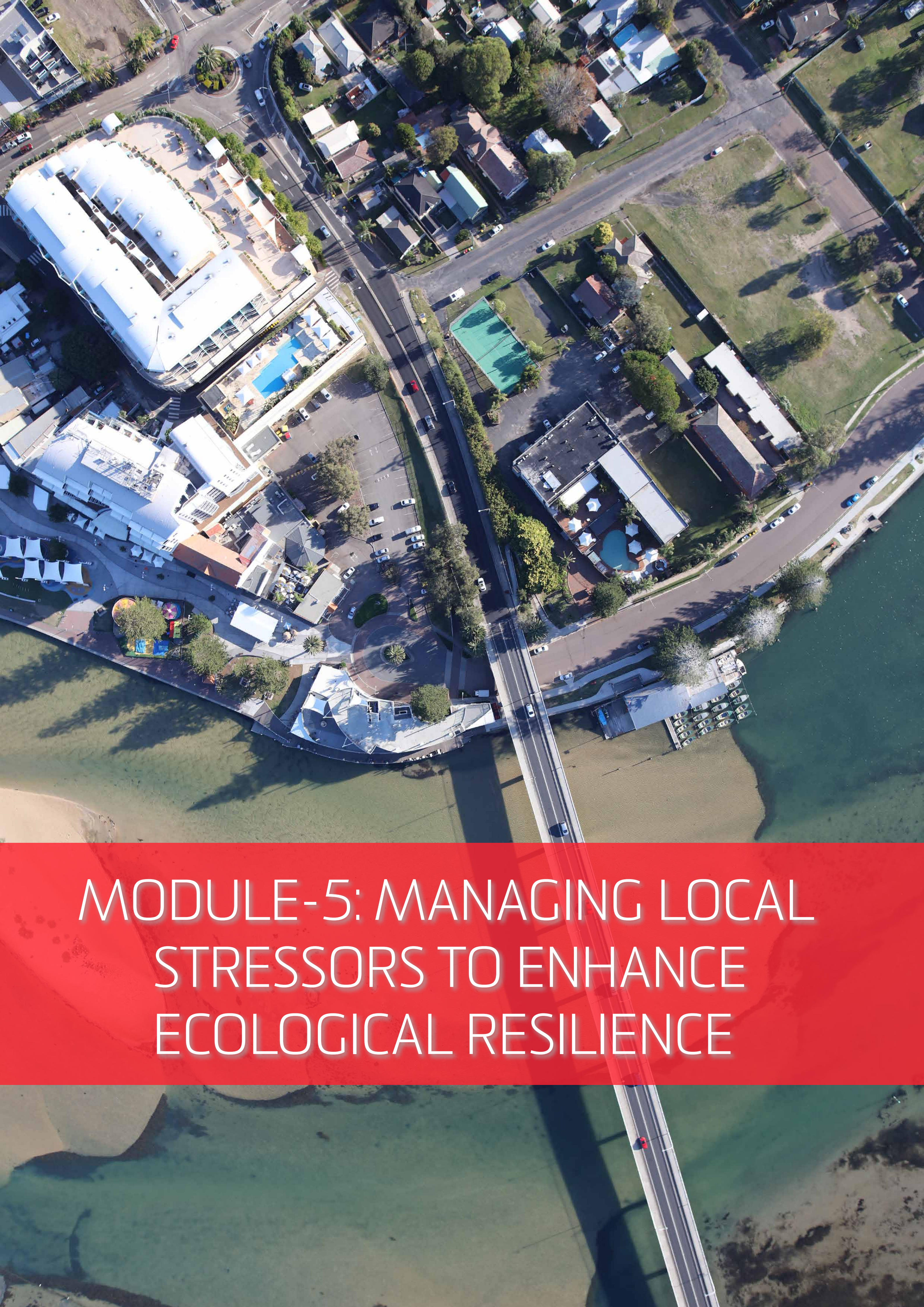

MODULE-5: MANAGING LOCAL STRESSORS TO ENHANCE ECOLOGICAL RESILIENCE

"Ensuring the persistence of estuarine habitats, dependent communities and ecological processes requires simultaneous management of both local and global stressors."[2]

Bobbin Head Marinea, Cowan Creek, NSW; photo: Chris Drummond, WRL, UNSW

MODULE OUTLINE

Preface

This guide is the result of five years of research and close collaboration between project partners. The guidelines and information reproduced in this guide have been agreed by the project partners based on their extensive knowledge and experience in the field of estuaries and climate change with advice from the scientific community. The guide has been published as a series of modules. Each module is a stand-alone document addressing an important aspect of climate change risks in estuaries. The following modules are available in the series (titles are abbreviated here):

1. Introduction
2. Changes in climate
3. Physical responses
4. Ecological responses
5. **Managing local stressors (this module)**
6. Application of the framework
7. Review of ecological thresholds
8. Knowledge gaps and research needs

Summary of Module-5

Modules 1-4 illustrated how the physico-chemical environment of estuaries will likely respond to changes in the global climate system (climate stressors) and how this might affect estuary ecosystems. The local stressors to which an estuarine ecosystem is exposed can influence the way in which it responds to these climate change stressors. Understanding how local stressors, resulting from coastal development and human uses of the coastal zone, and climate change stressors interact is useful for identifying appropriate local management actions to minimise impacts of climate change on ecosystems.

Questions addressed by Module-5

1. What are the local stressors operating within NSW estuaries that act synergistically with climate stressors?
2. When and where are negative interactions between local and climate stressors greatest along the NSW coast?
3. How might local stressors be managed to enhance the resilience of NSW estuarine ecosystems to climate stressors?

Cover photo

Drone view of a bridge crossing the Tuggerah Lake estuary entrance channel, The Entrance, NSW; Photo: Chris Drummond, WRL, UNSW

Authors

Melanie Bishop, Valentin Heimhuber, William Glamore

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Peer review

Module-5 has been peer-reviewed by Dr. Katherine Dafforn (Marine Research Centre, Macquarie University) and Dr. Ana Bugnot (Sydney Institute of Marine Science).

Tip for readers:

The modules in this series are designed to be read as double page booklets. To benefit from the double page sized figures and illustrations, it is recommended to read the modules in double page view, which is possible with most pdf readers. The first page is the booklet cover and should be in single page view.

1 Introduction

1.1 Pressures and stressors affecting estuaries

Over 80% of the population of NSW lives in coastal areas,[1] with estuaries often the focal points of urban development and industrial and agricultural activities. Human population growth in the coastal zone negatively affects estuaries by modifying shorelines, destroying habitats, introducing contaminants, altering freshwater flows and depleting resources, such as fisheries and sand. These **pressures** on estuaries result in changes to the physico-chemical environment, with those altered conditions that cause **stress** to organisms and ecosystems termed **stressors**.[2]

The local pressures to which an estuarine ecosystem is exposed can influence the way in which it responds to global climate change pressures such as increases in ocean temperature, sea level rise or oceanic acidification. As illustrated in Figure 1, both local and global pressures typically impact ecosystem health indirectly by causing changes in the physico-chemical environment of organisms (i.e. stressors). However, some local pressures such as fishing or land reclamation can also affect ecosystem health directly.

> The local pressures to which an estuarine ecosystem is exposed can influence the way in which it responds to global climate change pressures such as increases in ocean temperature, sea level rise or oceanic acidification.

Module-3 illustrated how projected changes in climate presssures can be translated into physico-chemical stressors to estuaries using a variety of modelling techniques. Quantifying the impacts of local pressures, on the other hand, typically requires detailed field investigations in addition to modeling and already available datasets are discussed in Section 3 of this module.

Global climate change and local pressures often interact synergistically to influence species, and the ecosystems of which they are a part, more strongly than would be anticipated based on the addition of their isolated effects.[4] The nature of the interactions between global and local pressures can be broadly categorized as follows:

Additive effects

Additive effects occur where the net effect of multiple pressures is equal to the sum of their effects in isolation.

Synergistic interactions

Synergistic interactions occur where the combined effect of two pressures is greater than the additive expectation

Antagonistic interactions

Antagonistic interactions occur where the combined effect is less than the additive expectation.

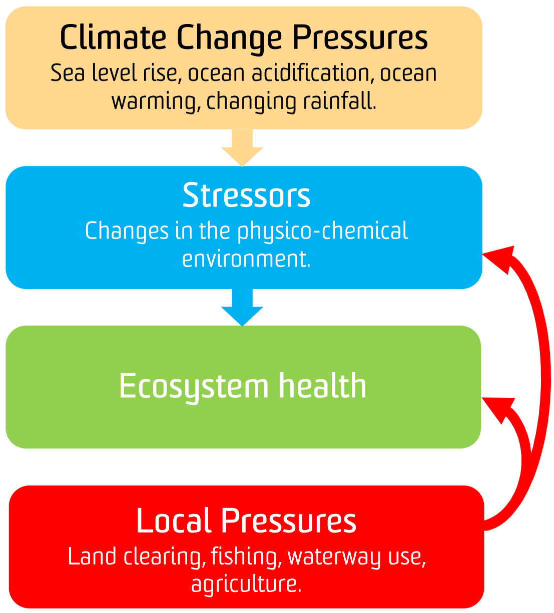

Figure 1: Conceptual diagram illustrating how local and global climate change pressures impact estuarine health through changes in the physico-chemical environment (i.e. stressors) of ecosystems.

1.2 Managing local and climate change pressures

Understanding how local and climate change pressures interact to cause stress to estuarine ecosystems is useful for identifying appropriate local management actions to minimise impacts of climate change on ecosystems. Similarly, ensuring the persistence of estuarine habitats, dependent communities and ecological processes requires simultaneous management of both local and climate change stressors.[5] A framework for assessing and managing local pressures to NSW estuaries under consideration of climate change impacts is provided in Office of Environment and Heritage (2015).[2]

"In providing estuaries with the best chance to adapt to climate change the goal should be to reduce the threats associated with current pressures and stressors so as to increase resilience."[2]

Some examples of common threats to NSW estuaries, that are explored in more detail in the next section of this module, are provided in Table 1. For each major threat (e.g. eutrophication, changed flow conditions), the table provides examples of the underlying pressures and corresponding stressors. For instance, the threat of 'loss of intertidal habitat' is caused by local pressures, such as land reclamation and, in some circumstances, also by global pressures such as sea level rise.[6] The resulting removal and disturbance of habitat represents a stressor, which can result in reduction of biodiversity, changes in food webs and reductions in fisheries productions.

> "While climate change may increase the risk associated with existing threats (such as eutrophication and loss of habitat), many best management practices to reduce the impacts of these threats may also be applied as part of adaptation strategies for climate change."[2]

Management strategies that reduce global pressures are slow and complex to put in place due to the required collaboration among countries or regional management bodies. Local management strategies, by contrast, are often quicker and easier to enact and may act on impacts of global pressures indirectly, by reducing the impacts of local pressures. Whether a reduction in a local pressure reduces or exacerbates impacts of climate change will, however, depend on how they interact. Reduction of local stressors will be of greatest benefit where they interact synergistically with global stressors. Reducing local stressors may give only small benefits, or could even worsen global stressor impacts, if the two act antagonistically.

In the following sections we identify some local pressures operating within NSW estuaries that act synergistically with climate pressures. We identify how management strategies aimed at reducing or removing these pressures may enhance the resilience of estuarine ecosystems to climate pressures. The examples we provide are not exhaustive and have been chosen based on the relatively high threat they represent to NSW estuaries, and the availability of scientific evidence to support their synergistic interaction. It is, however, likely that there are a plethora of other synergistic interactions between local and climate pressures that represent a threat to NSW estuaries. For example, rising temperatures may accelerate the rate of degredation of macro-plastics into microplastics – the latter of which may be more readily uptaken by filter-feeding organisms. In evaluating which local pressures to target for management aimed at building climate resilience, the full suite of possible synergistic interactions should be considered.

Table 1: Some common threats, local and climate change pressures and corresponding stressors affecting estuaries. The colour coding is based on the conceptual diagram of impacts shown in Figure 1, where red = pressures, blue = stressors, green = ecosystem health. This table was adapted from NSW Office of Environment and Heritage (2015)[2]

Threat	Pressures (examples)	Stressors (examples)	Potential impacts
Intertidal habitat loss	Wetland filling & foreshore reclamation Shoreline armouring Foreshore construction Sea level rise	Habitat removal or disturbance	Reduction in biodiversity Changes to food webs Reduction in fishery production Increases in threatened species & endangered ecological communities Shifts in trophic structure Reduced resilience of aquatic habitats
Eutrophi-cation	Land clearance Land management practices Point source pollution, such as sewage treatment plants Non-point source pollution, such as runoff from urban & agricultural environments	Increased nutrient loads	Algal blooms Fish kills Unpleasant odours Reduction in recreational amenity Reduction in habitat & biodiversity Reduction in fishery & aquaculture production
Changed flow con-ditions	Extraction & river regulation In stream barriers Land clearance Land drainage & floodgates Altered entrance conditions (ICOLL entrance intervention, entrance training works) Climate change	Changed hydrodynamics Changed tidal limits & salinity zones Changed sediment supply Black water events	Change in vegetation community structure Reduction in fishery & aquaculture production Altered salinity regimes & sediment patterns Changes in groundwater dependent ecosystems
Metal pollution	Point source pollution, such as industrial discharges Non-point source pollution, such as runoff from urban environments Atmospheric deposition Anti-fouling paints	Increased metal concentrations	Toxicity Reduction in biodiversity Fish kills Reduction in recreational amenity Reduction in fishery & aquaculture production
Overharv est of fisheries	Recreational fishing Commercial fishing	Reduction in predators Reduction in herbivores	Reduction in biodiversity Changes to food webs Reduction in fishery production Increases in threatened species & endangered ecological communities Shifts in trophic structure Reduced resilience of aquatic habitats

In providing estuaries with the best chance to adapt to climate change the goal should be to reduce the threats associated with current pressures and stressors so as to increase resilience.[2]

Engineered intertidal flats in Port Bottany, Sydney, NSW; photo: Chris Drummond, WRL, UNSW

2 Examples of synergies and management strategies

2.1 Shoreline defence

Along urbanised sections of the NSW coastline as much as 50% of the shoreline is armoured by shoreline protection structures such as seawalls and revetments. Although intended to stabilise reclaimed land and protect coastal property and infrastructure from rising sea-levels and storm surge, such 'defence' structures can, to the contrary, exacerbate impacts of sea-level rise by causing coastal squeeze. Coastal squeeze occurs where intertidal and shallow subtidal habitats are squeezed between rising sea levels on the seaward side and defence structures on the landward side.[7] Saltmarsh, mangrove forests, intertidal seagrass beds and intertidal sand and mudflats are particularly susceptible to loss from coastal squeeze due to their intertidal distribution. Because saltmarsh, mangroves and seagrass beds play an important natural role in stabilising sediments and dissipating wave energy, the loss of these habitats can serve to enhance the susceptibility of the shoreline to erosion and inundation.

One alternative to hard defence structures is to instead protect shorelines via 'soft-engineering' approaches such as sand or mudflat nourishment and/or establishment of 'living shorelines' that utilise coastal vegetation (i.e. mangroves, saltmarsh) or bivalve (i.e. oyster) reefs to reduce wave energy and trap sediments. These approaches can serve to conserve or even extend areas of estuarine habitat through habitat rehabilitation and/or restoration. In addition to providing shoreline protection, soft-engineering approaches typically deliver a multitude of co-benefits that may include sequestration of carbon, provision of food and habitat for commercially and recreationally important fisheries and/or improvement of water quality through biological filter-feeding and/or pollutant trapping. Soft engineering projects may, however, require substantial ongoing maintenance and may not be suitable for high-energy or highly polluted environments. For example, the ongoing erosion of shorelines may necessitate that sand/mud nourishment be repeated every 3-5 years to maintain ongoing shoreline protection. Restoration of oyster reefs for shoreline stabilisation may not be possible in environments where high rates of sedimentation inhibit filter feeding, where a legacy of tributyltin inhibits oyster reproduction, or where poor water quality leads to frequent oyster disease outbreaks.

> Along urbanised sections of the NSW coastline as much as 50% of the shoreline is armoured by shoreline protection structures such as seawalls and revetments.

A second alternative is retreat, whereby the shoreline is not defended, rising sea-levels are allowed to inundate the land and estuarine habitats can naturally migrate inland. Under a scenario of retreat, existing coastal defence structures are abandoned or removed, settlements and infrastructure are relocated as they are progressively threatened, and new developments are prevented in vulnerable areas. Modelling of future scenarios for Moreton Bay Queensland – an estuary which shares many habitat types with NSW estuaries – confirms large differences in impacts of sea level rise on estuarine habitats under scenarios of retreat and coastal defence.[8] Whereas under a strategy of defending all potentially inundated areas using levees, all coastal ecosystems experience habitat loss, by as much as 71 km^2 for mangroves, a strategy of retreat enables an overall expansion of coastal ecosystems by 19 km^2 (17%) by 2100. Nevertheless, the cost of building defences is substantially less (AU$1.28–3.21 billion) than that of purchasing land for conservation under a scenario of coastal retreat (AU$11.27 billion), although there are hidden costs of defence associated with loss of ecosystem services provided by declining ecosystems.[8]

2.2 Nutrient enrichment

Anthropogenic nutrient enrichment is widely considered to be amongst the greatest stressors to estuarine ecosystems, globally. Agriculture, wastewater discharge, urban runoff, and consumption of fossil fuels (atmospheric deposition), can increase nutrient inputs to estuaries to many times their natural background levels. With increasing nutrient enrichment a progression of symptoms can be seen, starting with observations of high concentrations of chlorophyll a and/or macroalgal blooms, smothering of submerged aquatic vegetation, such as seagrass, with fast growing algae, a shift from benthic to pelagic dominated productivity, low dissolved oxygen and occurrences of nuisance or harmful algal blooms.

> Anthropogenic nutrient enrichment is widely considered to be amongst the greatest stressors to estuarine ecosystems, globally.

The susceptibility of estuaries to these impacts of nutrient enrichment varies as a function of their geomorphology and climatic setting. High ratios of nutrient loading per unit area of estuary, long residence times of water in estuarine systems, and water column stratification all tend to exacerbate nutrient impacts.[9] By contrast, high flushing rates, vertical mixing and a high natural capacity of the ecological system to take-up and sequester nutrients can diminish impacts.[9] In modifying these factors, climate change stressors are expected to act synergistically with nutrient enrichment to exacerbate impacts.

For example, several aspects of climate change are expected to enhance the incidence and severity of harmful algal blooms: longer periods of warm temperatures, increased intensity of vertical stratification, increased salinisation, and increased intensity of storms and drought frequency and duration.[10] Storms can increase nutrient transport from the land into estuaries, while droughts increase residence times, retention of nutrients in estuaries and, hence, algal blooms. Harmful algal blooms can dramatically alter ecosystem biodiversity, and influence recreation, fisheries and a host of other ecosystem services.

Similarly, hypoxia, a widespread and increasing environmental problem caused by a combination of anthropogenic nutrient enrichment and physical characteristics of systems, is being exacerbated by climate change. This is not only because climate change is expected to lead to the physical conditions, such as stratification of water, and enhanced residence time, that lead to development of hypoxic conditions, but also because as temperatures increase, so too do metabolic rates of aquatic organisms and, hence, their oxygen requirements. The oxygen concentrations required for fish to meet baseline metabolic requirements increase with temperature.

Warming and nutrient inputs may worsen declines of seagrass by simultaneously increasing growth of phytoplankton and epiphytes. Similarly, the simultaneous enrichment of nutrient and CO_2 pollution is anticipated to enable a synergistic increase in the spatial cover and biomass of turfing algae that displaces kelp.[11]

Nutrient inputs to estuaries may be locally managed through a variety of strategies including land-use planning, waste-water treatment, and water-sensitive urban design. Office of Environment and Heritage (OEH) scientists have developed the The Coastal Eutrophication Risk Assessment Tool (CERAT) to allow managers to better understand and predict how land-based activities such as urban development, deforestation and agriculture will influence nutrient and sediment exports to estuaries, and resultant impacts on water quality, algal blooms and seagrass.The tool is available at:

http://www.ozcoasts.gov.au/nrm_rpt/cerat/index.jsp

CERAT consists of:

- a water quality database
- contextual spatial information for the catchment or estuary
- a coupled series of catchment and estuary models for the main (184) estuaries in NSW.

The models, which are suitable for use by non-experts, can be used to identify ways in which nutrient impacts to NSW estuaries may be locally managed, to minimise synergistic interactions with climate stressors.

2.3 Flow modification

Urbanisation of catchments has led to major changes in hydrology. Water-retaining vegetation has been replaced with impermeable surfaces such as buildings and roads. Over 80% of the Sydney Harbour catchment is now covered by concrete and in urbanised catchments as much as 80% of stormwater now runs through an underground network of drains. Urban stormwater systems concentrate runoff delivery into discrete pulses, of increased volume, as compared to those of unmodified natural systems.[12] This can result in changes in the salinity regime of estuaries, and can enhance delivery of pollutants, such as nitrogen, phosphorous, polycyclic aromatic hydrocarbons and metals to their waters.[12] More than two-thirds of pollutants entering Sydney Harbour do so via stormwater drains. Large runoff events can also cause scouring, sediment resuspension and subsequent redeposition.[13]

> Over 80% of the Sydney Harbour catchment is now covered by concrete and in urbanised catchments as much as 80% of stormwater now runs through an underground network of drains.

Direct and indirect effects of changes in runoff can have large impacts on estuarine ecosystems. Stenohaline organisms, with narrow salinity tolerances, can be negatively impacted by changes to salinity, especially where these are system wide and of protracted duration.[14] Freshwater pulses may also trigger spawning events of some organisms at suboptimal times of year. Sessile organisms, that cannot migrate to avoid unfavourable environmental conditions, will be particular susceptible to changes in salinity, as well as input of pollutants. Sediment resuspension can negatively impact aquatic primary producers by reducing water clarity, and redeposition can smoother species such as seagrasses.

The projected combination of increased extreme rainfall intensities and more frequent and pronounced dry spells under climate change is likely to exacerbate these effects of urbanisation on catchment hydrology.[15] In addition, a shift in the seasonality of rainfall is projected for NSW (see Module-2) and the resulting shifts in the flow regimes of coastal rivers (i.e. increases in summer flows and decreases in winter flows) may have profound impacts on estuaries.

Water sensitive urban design (WSUD) can assist in minimising negative synergistic effects of urbanisation and climate change on runoff, by improving the quality of stormwater runoff, reducing the volume of runoff and peak flows and integrating stormwater management into the landscape. This may be achieved by detaining stormwater using vegetation, constructed wetlands, ponds, and other bioretention devices, capturing rainwater using water tanks and/or increasing the permeability of surfaces, for example by utilising porous paving.

In New South Wales, the State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004 (NSW) is the primary piece of policy mandating adoption of WSUD. BASIX is an online program that allows users to model the effect of WSUD elements, such as use of rainwater tanks, stormwater tanks and greywater recycling, for residential development by entering data such as location, size, and building materials. The program outputs scores against water and energy use reduction targets.

2.4 Metal pollution

The legacy of past industry has resulted in locally high concentrations of heavy metals, including mercury, lead and copper, in New South Wales estuaries. Heavy metal hot-spots include Lake Macquarie, Sydney Harbour and the Hunter River.[9] When metals enter a waterway, they readily associate with sediment particles and accumulate in the sediment layer. They can also dissociate from sediment particles, and enter the porewater and overlying water as free metal ion solutes. Controls on industrial discharges and on the types of antifouling paints used have reduced levels of some heavy metals (e.g. tributyltin) in many areas. Problems remain in areas requiring maintenance dredging or where sediments may be disturbed and resuspended into the water column.

Estuarine plants and animals may be exposed to both dissolved and sediment-bound metals. They uptake

Along urbanised sections of the NSW coastline as much as 50% of the shoreline is armoured by shoreline protection structures such as seawalls and revetments.

Protected shoreline along the Narrabean Lagoon, Sydney, NSW; photo: Chris Drummond, WRL, UNSW dissolved metals from the porewater through diffusion across cell membranes and from the sediment through ingestion of sediment particles and associated food. Depending on the type and level of metal contamination and traits of the exposed organism, effects may be lethal, or non-lethal, affecting behaviour, growth and/or reproduction.

> Three to 12-fold increases in uptake of metals by aquatic animals are typically seen with every 10°C of environmental temperature increase.[13]

Temperature can affect the response of aquatic invertebrates to trace metals[16], elevating mortality rates in 80% of cases. This is, in part, explained by increased rates of metal uptake and accumulation by animals at higher temperatures.[16,17] Three to 12-fold increases in uptake are typically seen with every 10°C of environmental temperature increase.[17] Additionally, interactions between environmental temperature and metal pollution negatively affect physiological tolerance to both stressors. Both elevated temperature and toxic metal stress negatively impact maintenance costs, mitochondrial efficiency and oxygen uptake and delivery to the tissues, with exposure to one of these stressors sensitizing an organism to the other.

Minimising exposure of estuarine plants and animals to metal contamination is therefore critical for maximising their capacity to tolerate and adapt to climate warming. Remediation of highly metal-contaminated sites, avoidance of dredging and sediment resuspending activities in known contamination hot-spots and maintenance of tight controls on contemporary sources of metal pollution may each be strategies in minimising exposure of estuarine organisms to metals.

2.5 Over-harvest of fisheries

New South Wales is home to more than 1000 species of fish and tens of thousands of species of crustaceans, molluscs and beach-worms, some of which are the target of recreational and commercial fishing activities. In addition to their considerable economic and social value, these species can also be critically important in maintaining food-web structure and function either because they are important consumers (e.g. species, such as the blue groper which consume urchins, are critical for controlling urchin-grazing on kelp) or because they are habitat-forming species (e.g. oyster reefs provide food and habitat to other species). In doing so, they can be important buffers of environmental change.

Historic and, in some cases, ongoing over-harvest of ecologically important species has increased the vulnerability of associated ecological communities to climate-induced changes. For example, it is estimated that since European settlement, over 90% of New South Wales oyster reefs have been lost, largely due to historic overharvest for food and lime.[18] Intertidal oysters provide moist and shaded microhabitats between their shells that protect associated biodiversity from temperature and desiccation stress.[19,20] Loss of these protective microhabitats due to overharvest therefore places associated biodiversity at greater risk of negative effects of global warming.

> The ongoing use of ecosystem-based management of fisheries is critical to ensuring ecologically important species are maintained at sufficient density so as to continue to provide ecologically important roles.

As another example, reduction in predator numbers has allowed urchins to proliferate and expand in range along the south-east Australian coast, in response to warming and a strengthening East Australian Current.[21] The net effect has been widespread loss of kelp forests from urchin grazing.[21]

The ongoing use of ecosystem-based management of fisheries is critical to ensuring ecologically important species are maintained at sufficient density so as to continue to provide ecologically important roles. Where ecologically important species have suffered historic decline, but present-day environmental conditions are suitable for their recovery, no-take zones in some instances coupled with restoration and/or restocking, can be effective in increasing population sizes and reinstating lost ecosystem services.

2.6 Interactions involving more than two pressures

The above examples focus on synergistic interactions between pairs of local and climate pressures, but it is worth noting that in almost all instances, estuarine ecosystems will also be exposed to a multitude of additional local and climate pressures, acting either simultaneously or in succession. While in some instances these additional pressures will have little impact on the key interactions described above, in other instances they may dampen, exacerbate or change the nature of the interactions between these.

For example, in urbanised estuaries, coastal structures such as marinas and breakwaters that slow flow can increase accumulation of contaminants in sediments, exacerbating the negative effects of rising temperatures on metal uptake and toxicity. Flow modifications that result in greater nutrient inputs into estuaries under altered rainfall scenarios, may make estuaries more susceptible to algal blooms under conditions of warming. However, whether the frequency and intensity of algal blooms increases is contingent on whether sediment loads are simultaneously enhanced by the combined effects of flow modification and enhanced rainfall. This is because turbidity acts antagonistically with nutrients to influence algal blooms, due to the light requirement of algal photosynthesis.

In order to predict and manage these more complex multi-stressor effects, conceptual process models, that connect pressures to those factors that limit growth, survival and reproduction of organisms are needed. Where possible, these should be built using real data on the pressures facing an individual estuary as well as on best available data on the environmental tolerances of organisms (see Module-7).

Intertidal flat in the Brisbane Water estuary, Ettalong, Central Coast, NSW; photo: Chris Drummond, WRL, UNSW

3 Data on local stressors in NSW estuaries

The 2010 State of the Catchments[9] provides the first comprehensive assessment of the status of stress-causing pressures facing all NSW estuaries. The assessment was conducted using data collected up until early 2009 by NSW Government agencies, local councils, universities, water and power authorities and consultants. It collated data on land clearing, human population density, freshwater flows, habitat disturbance, sediment inputs, nutrient inputs, fishing, tidal flow and climate change to create a pressure index, indicative of stressor levels. This report represents the primary source of data on local pressures to NSW estuaries as well as a rating of the present state of all estuaries.

An example of the type of information available in the report is shown in Figure 2, which summarises a set of indicators for pressures by region along the NSW coastline. Although the data are now several years old, they nevertheless give an invaluable indication of the particular pressures, and hence stressors, to which individual NSW estuaries are most exposed.

Figure 2 shows that in some regions, estuaries are facing high and even very high pressures from particular indicators such as population, sediment input and nutrient input that are associated with stress to estuarine ecosystems. Within these regions, detailed estuary-specific and site-specific analysis of pressures is warranted.

The data that was used in the State of the Catchments report continues to be collected across estuaries in NSW and can be obtained from the NSW OEH upon request. In addition, up-to-date water quality data is available from NSW coastal Councils and industry programs, such as the NSW Shellfish Program, which monitors water quality in oyster growing areas. A detailed overview of available data sources for important physical and chemical variables in NSW estuaries is provided in Module-3 of this guide.

PRESSURE

5	Very low
4	Low
3	Moderate
2	High
1	Very high

	PRESSURE INDEX	INDICATOR								CONFIDENCE
		Cleared land	Population	Sediment input	Nutrient input	Freshwater flow	Disturbed habitat	Tidal flow	Fishing	
ALL NSW ESTUARIES	3.6	3.0	3.0	2.7	3.0	4.1	4.8	3.9	4.6	H
ALL NR ESTUARIES	3.5	2.8	2.8	2.2	2.7	4.1	4.9	3.5	4.6	H
ALL HCR ESTUARIES	3.3	2.7	2.6	2.4	2.7	3.9	4.9	3.7	4.2	H
ALL HNSM ESTUARIES	3.0	2.2	1.4	1.7	2.2	3.3	4.4	4.3	4.8	H
ALL SR ESTUARIES	3.9	3.3	3.4	3.2	3.4	4.3	4.7	4.0	4.7	H

Figure 2: Pressure rating of NSW estuaries by region. NR = Northern rivers, HCR = Hunter and Central Rivers, HNSM = Hawkesbury–Nepean and Sydney Metropolitan Rivers, SR = Southern Rivers Source: The State of the Catchments 2010" from Roper et al. (2011)[9]

References

1. Australian Bureau of Statistics. A 3101.0 - Australian Demographic Statistics, Sep 2018. A 31010 - Aust Demogr Stat 2019. http://www.abs.gov.au/ausstats/abs@.nsf/latestProducts/3101.0Media Release1Sep 2018 (accessed April 9, 2019).
2. Office of Environment and Heritage. NSW Coastal Management Manual Part C: Coastal Management Toolkit. A guide to managing estuary ecosystems. 2015.
3. Scheltinga DM, Moss A. A framework for assessing the health of coastal waters: a trial of the national set of estuarine , coastal and marine indicators in Queensland - Final Report. 2007.
4. Crain CM, Kroeker K, Halpern BS. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol Lett 2008;**11**(12):1304–15. https://doi.org/10.1111/j.1461-0248.2008.01253.x.
5. Halpern BS, McLeod KL, Rosenberg AA, Crowder LB. Managing for cumulative impacts in ecosystem-based management through ocean zoning. Ocean Coast Manag 2008;**51**(3):203–11. https://doi.org/10.1016/j.ocecoaman.2007.08.002.
6. Rodríguez JF, Saco PM, Sandi S, Saintilan N, Riccardi G. Potential increase in coastal wetland vulnerability to sea-level rise suggested by considering hydrodynamic attenuation effects. Nat Commun 2017;**8**(May). https://doi.org/10.1038/ncomms16094.
7. Pontee N. Defining coastal squeeze: A discussion. Ocean Coast Manag 2013;**84**:204–7. https://doi.org/10.1016/j.ocecoaman.2013.07.010.
8. Mills M, Leon JX, Saunders MI, *et al.* Reconciling Development and Conservation under Coastal Squeeze from Rising Sea Level 2016;**9**(October):361–8. https://doi.org/10.1111/conl.12213.
9. Roper T, Creese B, Scanes P, *et al.* Assessing the condition of estuaries and coastal lake ecosystems in NSW, evaluation and reporting program, Technical report series. 2011.
10. Paerl HW, Scott JT. Throwing fuel on the fire: Synergistic effects of excessive nitrogen inputs and global warming on harmful algal blooms. Environ Sci Technol 2010;**44**(20):7756–8. https://doi.org/10.1021/es102665e.
11. Falkenberg LJ, Russell BD, Connell SD. Stability of strong species interactions resist the synergistic effects of local and global pollution in kelp forests. PLoS One 2012;**7**(3). https://doi.org/10.1371/journal.pone.0033841.
12. Vaze J, Chiew FHS. Study of pollutant washoff from small impervious experimental plots. Water Resour Res 2003;**39**(6). https://doi.org/10.1029/2002WR001786.
13. Birch GF, McCready S. Catchment condition as a major control on the quality of receiving basin sediments (Sydney Harbour, Australia). Sci Total Environ 2009;**407**(8):2820–35. https://doi.org/10.1016/j.scitotenv.2008.12.051.
14. Little S, Wood PJ, Elliott M. Quantifying salinity-induced changes on estuarine benthic fauna: The potential implications of climate change. Estuar Coast Shelf Sci 2017;**198**:610–25. https://doi.org/10.1016/j.ecss.2016.07.020.
15. Evans JP, Argueso D, Olson R, Di Luca A. Bias-corrected regional climate projections of extreme rainfall in south-east Australia. Theor Appl Climatol 2017;**130**(3–4):1085–98. https://doi.org/10.1007/s00704-016-1949-9.
16. Cairns J, Heath AG, Parker BC. The effects of temperature upon the toxicity of chemicals to aquatic organisms. Hydrobiologia 1975;**47**(1):135–71. https://doi.org/10.1007/BF00036747.
17. Hutchins DA, Teyssié JL, Boisson F, Fowler SW, Fisher NS. Temperature effects on uptake and retention of contaminant radionuclides and trace metals by the brittle star Ophiothrix fragilis. Mar Environ Res 1996;**41**(4):363–78. https://doi.org/10.1016/0141-1136(95)00026-7.
18. Gillies CL, McLeod IM, Alleway HK, *et al.* Australian shellfish ecosystems: Past distribution, current status and future direction. PLoS One 2018;**13**(2). https://doi.org/10.1371/journal.pone.019091.
19. Mcafee D, Bishop MJ, Nga T, Gray Y. Structural traits dictate abiotic stress amelioration by intertidal oysters 2018;(August):2666–77. https://doi.org/10.1111/1365-2435.13210.
20. Mcafee D, Cole VJ, Bishop MJ. Latitudinal gradients in ecosystem engineering by oysters vary across habitats 2015. https://doi.org/10.1890/15-0651.
21. Ling SD, Johnson CR, Frusher SD, Ridgway KR. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci 2009;**106**(52):22341–5. https://doi.org/10.1073/pnas.0907529106.

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Drone view of a bridge crossing the Tuggerah Lake estuary entrance channel, The Entrance, NSW; Photo: Chris Drummond, WRL, UNSW