

Science of Gamay

A systematic review of current knowledge
of Botany Bay 2022



Sydney Institute of Marine Science Technical Report



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(Front cover) Aerial shot of the rock platforms at Cape Banks. The extensive rock platforms are backed by the Gamay Botany Bay National Park and the NSW Golf course. Port Botany can be seen in the background.; (back cover) A dense bed of crayweed (*Phyllospora comosa*) and red algae on Gamay's oceanic side. Images: John Turnbull www.marineexplorer.org

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Shallow estuary and mudflat with isolated mangrove trees, receiving the creek that drains urban development and Cronulla golf course, at the south-eastern margin of Woollooware Bay, adjacent to Towra Point Nature Reserve. Image: RJ Whittington, University of Sydney

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Executive summary

Botany Bay, or Gamay as it is called by First Nations people of Gamay, has a long history with humans. First Nations people have lived in the lands around Gamay for thousands of years, and more recently it has been the centre for industrial activity and development (past 200 years). This legacy of human influence means the current day Gamay is significantly different from the Gamay that First Nations people would have inhabited prior to the arrival of European settlers. The bay still hosts a composition of different habitats, some new to Gamay (e.g., hard artificial structures have created novel habitats), others highly modified (e.g., seagrass once covered much of the bay, whereas now it is limited to isolated patches on the northern and southern shorelines), and some that still exist in their original form (e.g., intertidal rocky shore at Cape Banks). Human modification of Gamay intensified in the 1970's and was comprehensively documented with a series of technical reports produced between 1978 and 1981.

Since then, the bay has, however, continued to be modified by humans and so this review seeks to provide an updated review of Gamay as it stands today. Specifically, this review collates current ecological knowledge of Gamay and its tributaries, by systematically compiling scientific peer-reviewed literature and knowledge from a wide range of stakeholders to produce a comprehensive list of published biophysical information sources. We focus on the core areas of geology, oceanography, chemistry, ecology and environmental threats to the bay. Historical literature was also included in this review as these early accounts contain some of the only records of Gamay and First Nations people of Gamay prior to British colonisation. In total, 577 different studies were included in this systematic review, including 477 journal articles, 75 reports, 13 books as well as 12 additional resources of other types. This review synthesizes this information into a succinct document accessible to stakeholders, policy makers and the general public. It is produced as a guide to the current state of knowledge of Gamay and readers are directed to references for further information.

Geological history

Gamay is part of the greater Botany Basin, originally carved out of Hawkesbury Sandstone by three ancient river systems; the Cooks River, Georges River and a third, smaller ancient river. At 9,000 yBP, sea-level rose and the combined Cooks and George paleo-rivers joined the ancient Port Hacking channel and exited to the ocean from Bate Bay.

In our review, geology was one of the scientific disciplines with the lowest number of published studies (2.9% of studies, 17 studies in total), with roughly an equal number of studies discussing the geology and geological history of Gamay as did focus on sedimentology in the bay.

Hydrology and oceanography

Since British colonisation Gamay has undergone significant development which has influenced the region's hydrology. Extensive urbanisation as well as reclamation and dredging projects have substantially altered the broader catchment and localised hydrology, including rainfall-runoff patterns, hydrodynamics and hydraulics. Many land modifications and reclamations have resulted in complex topography around the bay which generates several recirculating eddies throughout the tidal cycle. Gamay is influenced by both locally generated wind waves and remotely generated oceanic swell waves that enter the bay through the seaward entrance. Waters are generally well mixed, with low stratification. Circulation in the bay is largely barotropic due to its shallow nature and regular tidal forcing. While freshwater inflow into Gamay is typically low, during periods of rainfall, freshwater inflow occurs from two highly modified shallow rivers (the Cooks River and the Georges River). After heavy rainfall (>50 mm per day) the surface waters become stratified, with a buoyant freshwater plume 1–2 m thick overlaying saline oceanic water. This plume leaves the estuary within a few days reverting to low – flow state within a week of dry conditions.

Oceanography was the scientific discipline with the least number of published studies, comprising just 1.2% of studies, or 7 studies in total.

Soft bottom and beach habitats

Gamay contains a range of soft sediment habitats, including intertidal beaches, sandflats and mudflats as well as extensive subtidal sediment habitats. Subtidal soft sediments comprise the greatest extent of all habitat types in Gamay and have changed significantly with respect to physico-chemical characteristics as a direct and indirect result of British colonisation and associated land use changes. Gamay has a predominantly sandy subtidal benthos with the muddy areas associated with dredging near the bay's entrance, around port infrastructure and the airport runways.

Soft bottom habitats were among some of the best studied habitats in Gamay (11.1% of studies, 64 studies in total) and were commonly included in multi-habitat studies (35 studies). By comparison, beach habitats were amongst some of the most poorly studied (1.7% of studies, 10 studies in total). Gamay's extensive history of industrialisation and modification means that much of the research on soft bottom and beach habitats examines the impacts associated with habitat modification and contamination.

Seagrass habitats

Seagrass habitats in Gamay have been steadily declining at around 0.75% yr⁻¹ since the 1940s, and today only cover a little over 300 hectares. The largest historical declines in seagrass in Gamay have occurred along the northern shoreline, possibly due to historical contamination and more recently due to disruptions associated with the construction of both Port Botany and the Sydney Airport expansions.

Of all the vegetated habitats that occur in Gamay, seagrass habitats were the most poorly studied (8.3% of studies, 48 studies in total). Of those studies that do exist, most were concerned with seagrass physiology or distribution in Gamay with few considering interactions with other organisms.

Mangrove and saltmarsh habitats

Much of Gamay's coastal wetland habitat lies within the Ramsar-listed Towra Point Aquatic Reserve on the southern shore of Gamay. This extensive wetland system is Sydney's biggest and most diverse wetland system and equates to ~25% of the area of Gamay. Wetland habitats in Gamay support the aquatic ecosystem throughout the broader bay, with saltmarshes supporting the highest densities of zooplankton of all Gamay's estuarine habitats. Despite this, aerial photos show that 30% of the endangered ecological community of saltmarsh from the Towra Point wetland has been lost since the 1930s. Mangroves display the opposite trend, with mangrove cover increasing in the Bay in this time.

Subtidal rocky reefs

Much of the research on subtidal reefs in Gamay has been undertaken at Bare Island and at Cape Banks, on the bay's northern shore. Bay-wide subtidal reef in Gamay has been mapped by depth only, with the distribution and abundance of specific species within these habitats largely unknown. There is surprisingly little in the way of comprehensive assessments of subtidal rocky reef fish assemblages in Gamay, with

much of the research instead focusing on macroalgae and invertebrates. Gamay subtidal rocky reefs have, however, been a focal point of marine microbial research in Australia and have been the location for pioneering research into understanding the diversity and abundance of marine microorganisms.

Subtidal reef habitats were the second most studied habitat type (13.7% of studies, 79 studies in total) in Gamay and were most commonly studied in combination with artificial substrate habitats.

Intertidal rocky shores

Approximately 30% of the shoreline in Gamay is comprised of intertidal rocky substrata, with most located around Gamay's two headlands. This habitat generally consists of gently sloping sandstone platforms, interspaced with crevices, rock pools, cobbles and boulders. The intertidal rocky shore area around Cape Banks is a prominent site for research on key ecological processes that occur within these habitats. Excavated middens in the Gamay area suggest shellfish collected from intertidal rocky shore habitats were a significant part of the diet of First Nations people of Gamay prior to European settlement.

Rocky intertidal shore habitats were the most highly studied habitat type within Gamay. These habitats were considered in 86 single habitat studies (14.9% of studies), with an additional 10 studies that considered rocky shores amongst other habitat types. Specifically, invertebrate communities on intertidal rocky shores were overwhelmingly the most well studied taxa-habitat interaction, with the majority of this research occurring at Cape Banks.

Oyster reefs

First Nations people of Gamay have used oysters as an important food source for over 6000 years. Gamay's oyster reefs were also a valued resource to European settlers who ultimately exploited these to near extinction. Anecdotal evidence from early British settlers suggests clear evidence of shellfish farming by First Nations men of Gamay, a practice that was later adopted by British settlers when natural reefs had been depleted. Oyster production in Gamay has, however, been plagued with issues, from pollution and contamination through to disease. As a result, much of the research on oyster reefs in Gamay has been associated with the impacts from these threats, most notably this research has focused on the development of disease resistant oyster lines for aquaculture.

Open water and pelagic systems

Open water and pelagic habitats are amongst the most well studied habitats in Gamay, for both single (11.1% of studies, 64 studies in total) and multi-habitat studies (33 studies). In Gamay, planktonic processes generate a highly productive tidal discharge plume and associated front throughout the daily tidal cycle. Within the bay, these habitats support a range of fish species, whilst directly off Gamay's headlands whales, dolphins and turtles are commonly seen. Comparatively less is known about microbial communities of Gamay's open water habitats, although potentially harmful taxa with the potential to poison seafood or cause fish and invertebrate mortalities (e.g., harmful algal blooms) have been detected in the bay.

Artificial substrates

Recent estimates suggest around 40% of Gamay's shoreline now consist of hardened artificial substrate. Of the 18 studies published (3.1% of studies), most studies on artificial habitats in Gamay have focused on fish assemblages and how artificial reefs and/or breakwaters have influenced those. These studies often make comparisons to assemblages on nearby subtidal rocky reefs and have produced mixed results. Artificial reef balls have been deployed in Gamay to enhance rocky substrate and recreational fishing opportunities. The additional habitat they provide represents a ~16% increase in the area of rocky reef habitat in Gamay and supports a predominantly plankton-feeding fish assemblage. There are no published studies on fish assemblages associated with artificial substrates in either the Georges or Cooks Rivers.

Freshwater habitats

Freshwater habitats represent the most poorly studied habitats in Gamay, with only four studies published on these habitats (0.7% of studies). They were studied more frequently in multi-habitat studies (16 studies), where they were most commonly investigated in combination with pelagic habitats. Little is known about the flora and faunal communities of Gamay's freshwater habitats.

Threats and challenges

Gamay's long history of exploitation and modification in conjunction with the enormous changes within the catchment since European settlement has left little of the Gamay ecosystem untouched by anthropogenic influence.

The contamination status of Gamay has been well documented. Sediments in Gamay and Georges River are contaminated with heavy metals, polyaromatic hydrocarbons and phosphates that often exceed levels in other Australian estuaries. Contaminants have been detected in fish and invertebrates in Gamay. The impervious nature of the Gamay catchment means that stormwater runs quickly and directly into the main river channel and eventually into the bay, bringing with it all the common pollutants and nutrients. Rainfall induced urban runoff produces periodic stressors to planktonic communities, influencing phytoplankton and bacterial composition which may cause cascading impacts to the pelagic foodweb. Storm events often result in microbial communities associated with human waste entering coastal waterways with legacy impacts on Gamay's marine sediments. Blooms of the paralytic shellfish toxin (PST) producing species *Alexandrium pacificum* (as *A. catenella*) occur regularly in Gamay.

Dredging and land reclamation have had detrimental impacts on communities and habitats in Gamay. Configuration dredging at the entrance to the bay from 1980 to 1990 led to increased wave-action along the exposed Southern shoreline of the bay, negatively impacting seagrasses around Towra Point. Dredging has changed the depth of subtidal sediments, as well as the grain sizes, shifting once sandy sediments to muddy sediments and driving reductions in biodiversity and abundances of infaunal communities. Dredging can resuspend sediments in the pelagic environment of Gamay, some of which contain high levels of contaminants, which in turn impact filter feeding invertebrates. Dredging has also led to massive alterations to natural flushing in Gamay, negatively affecting water quality in the bay.

Gamay currently meets the NSW Office of Environment and Heritage condition thresholds for good ecosystem quality for coastal estuary/embayments for both chlorophyll *a* (Chl-*a*; annual average of 1.9 mg/L) and turbidity (annual average of 1.3 ntu). Although for Chl-*a* the current value sits exactly on the threshold, indicating the system is at best close to transitioning from a slightly to moderately disturbed state. The value and buffering capacity of remaining bushland is vital to the water quality of Gamay as is the control of nutrients and sediment input from all of its catchment's land uses.

Gamay supports extensive maritime industries and is home to the largest container port in NSW (Port Botany), making its ecosystems extremely vulnerable to marine invasive species. Only one introduced marine pest species (Australian Ballast Water Management Advisory Council target) has been found at Port Botany, the toxic dinoflagellate *Alexandrium* sp. An additional 33 introduced and/or cryptogenic (i.e., status unknown)

species were, however, also detected. Introduced and cryptogenic species have also been recorded in sediment habitats in Gamay. Little information currently exists on the type, extent and proportion of exotic and invasive species specifically inhabiting artificial substrates in Gamay, however, artificial substrates in other regions in NSW have been found to harbor disproportionately high abundances of exotic invertebrate species.

Commercial fishing was banned in Gamay in 2002 and the bay was declared a Recreational Fishing Haven. Despite this long history of commercial fishing and the continued use of the bay by recreational fishers, there has been little scientific examination of Gamay's fisheries (20 studies). The recreational fishing community within the bay is engaged in efforts to improve fish stocks and habitats, supporting a variety of efforts in this space such as catch-and-release. But there remain challenges as even catch-and-release fishing within the bay has been shown to be associated with significant post-release mortality for some species.

The impacts associated with climate change have been poorly studied for Gamay but will likely pose a significant threat in the future. Research from outside Gamay suggests that whilst mobile species may be able to migrate south to stay within their thermal limits, increasing ocean temperature will likely have significant negative impacts on sessile species. Ocean acidification associated with an increase in atmospheric carbon dioxide will likely impair the ability of calcifying organisms to make shells and grow. Rising sea-level combined with urban encroachment is likely to have a significant negative impact on saltmarsh habitats in Gamay. These negative impacts will be further compounded as rising sea levels give mangrove forests the room to expand landwards further reducing saltmarsh habitats.

Knowledge gaps and opportunities

Overall, invertebrates and fish were the most thoroughly studied taxa across multiple habitat types, whilst epibiota and birds were the most poorly studied taxa. Under one half of the 577 studies published on Gamay considered threats to Gamay. Of those studies that did look at threats to Gamay, research effort has been heavily focused on contamination impacts (60 studies, 23% single habitat studies). Most of these contamination studies were concerned with non-taxa specific impacts, followed by impacts to invertebrates. Impacts associated with habitat modification have been studied across most taxa, however, only in low numbers. Contamination impacts to soft sediment habitats were also well studied, followed by the impacts of disease and pathogens to oyster reefs and habitat modification in artificial substrates.

In recent years, there has been a push to bring back degraded systems either by reducing or reversing the negative impacts associated with urbanisation or by actively re-establishing or restoring systems that have been lost. Seagrass restoration has recently been undertaken in multiple locations in Gamay. The project appears to be successful, but continued monitoring is still needed into the future to assess the long-term viability of such projects in Gamay. Seagrass and saltmarsh habitat restoration has also been undertaken on Gamay's northern shoreline as part of the Port Botany expansion Penrhyn Estuary habitat enhancement plan. Promising results from these projects suggest there is potential to restore other areas of Gamay. The first large scale oyster reef restoration project in Gamay and Georges River was established in 2021 by the Nature Conservancy, Greater Sydney Local Land Services and New South Wales Department of Primary Industries. The project aims to restore up to five hectares of oyster reef in Gamay, but as yet, has not begun on-ground works.

Despite Gamay containing a diversity of habitat types, seascape connectivity in the bay remains poorly studied. Understanding how habitats and communities are connected is particularly important in urban estuaries such as Gamay where vegetated habitats are declining and becoming more fragmented.

There has been little in the way of research or planning into how climate change will impact the Gamay ecosystem. The availability of high-resolution digital terrain modelling for the Gamay foreshores makes possible the modelling of habitat redistribution under projected sea-level rise. This would be particularly useful to explore the impacts of sea-level rise on saltmarsh, which because of significant urbanisation in Gamay has no room to expand landwards.

Since QX disease decimated oyster production in 1992 much effort has gone into selective breeding programs to develop disease-resistant oyster lines. Whilst knowledge gaps still surround the transfer of disease and interbreeding between cultured and wild oysters Gamay's well documented history with oyster aquaculture means that Gamay could be used as a case study for aquaculture within large cities. Compared to most other habitats that occur within Gamay, oyster reefs remain some of the most poorly studied. To maximise the ecosystem benefits of oyster reefs to Gamay more research is needed into developing and testing different methods of farming and restoration, as well as exploring optimal sites, locations and configurations for oysters to be grown within the bay.

Much of the pioneering research that has revolutionised our understanding of marine microbes has been undertaken in Gamay. Continued investment into projects such as the Australian Microbiome Initiative will not only assist in furthering our understanding of these microbial communities but will also allow this to be expanded to other, currently unstudied microbiota.

Unfortunately, the ecological knowledge of First Nations people of Australia remains largely undocumented, meaning that significant knowledge gaps exist surrounding how the First Nations people of Gamay used the flora, fauna and habitats of Gamay. A recent shift in our appreciation of this Traditional Ecological Knowledge has meant it is increasingly being recognised as an important and valuable source of ecological information. The recognition of this knowledge as being ecologically significant paves the way for collaborations between scientists, managers and the First Nations

people of Australia, offering opportunities to not only advance scientific knowledge but also share power and responsibilities amongst stakeholders as well as develop novel management approaches.

It could be argued that Gamay is amongst the most well studied estuaries in Australia. But it is also a place of enormous ecological and social complexity and in many ways the extensive amount of knowledge documented on Gamay represents just the baseline of what is needed to effectively manage the bay. Research efforts to date have not spanned all taxa and habitats and many threats to Gamay's ecosystems remain unstudied, highlighting that there remains many knowledge and data gaps to fill. This review has, however, also highlighted the numerous opportunities which this work has generated, creating paths that stakeholders and managers can walk together towards a sustainable future for the bay.

The weedy seadragon (*Phyllopteryx taeniolatus*) is endemic to seaweed dominated subtidal reefs in southern Australia. They can be found in subtidal reef habitat in Gamay. Image: John Turnbull www.marineexplorer.org



Introduction to Gamay

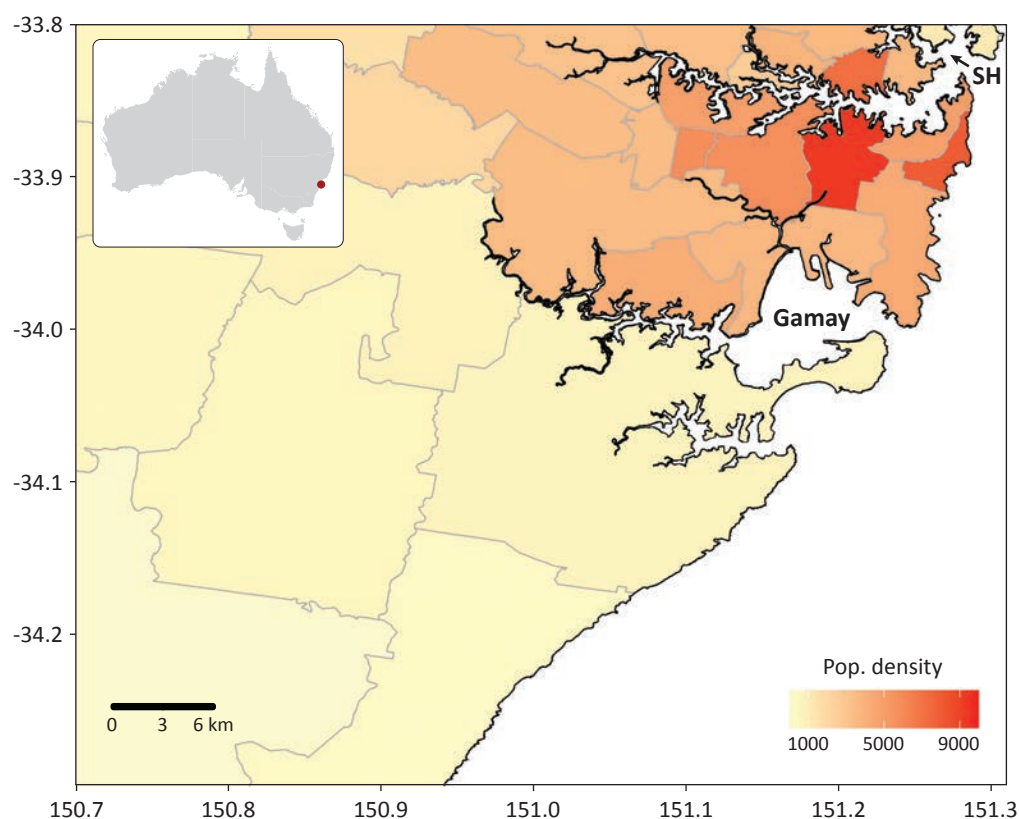
History of Gamay

Botany Bay, or Gamay (alternatively spelt *Kamay*) as it is called by First Nations people has a long history of human settlement, being home to the several First Nation clans for thousands of years. The country around Gamay and the lower Georges River belonged to the Dharawal people (Attenbrow 2010b, Goodall 2017). Of the Dharawal people, the Gameygal clan (also spelt Kameygal) resided on the north-western shore of Gamay, the Gweagal clan on the southern shore and the Bideegàl clan resided on the northern headland of Gamay (Attenbrow 2010b).

Gamay is where British explorers first arrived in Australia in 1770. The British explorers originally called the bay Stingray Bay, but soon after changed it to Botanist Bay (later shortened to Botany Bay) in response to the extensive diversity of botanical specimens that they collected from along the bay's shoreline (Adam 1997). Perhaps in response to this high biodiversity, Gamay was selected as the location to establish the first European colony in Australia (Adam 1997). Consequently, Gamay is a place of great cultural significance for both First Nations people of Gamay and those Australia's that migrated or were transported to Australia from abroad.

However, in 1788, when the British returned to establish the first colony, Gamay was deemed unsuitable for the settlement due to the shallow nature of the bay which made anchoring difficult, as well as its swampy foreshore and the lack of fresh water close by. Instead, the settlement was established at Port Jackson (Sydney Cove) just to the north of Gamay. Gamay and its surrounding areas continued to be a valuable resource, however, and were extensively harvested for building materials and later was used for industrial practices (Reid, 2021). Trees were logged along the catchment presumably starting the changes to the catchment for the bay from 1800, and by 1845 almost all of the large trees had been felled for timber in the immediate surrounds of the bay. Similar levels of clearing would have occurred though-out the larger catchment. Cattle (five that had escaped from the settlement soon after arrival) moved into the catchment and grazed the immediate surrounds of the bay, and by 1806 had grown to 3,000. These initial land-use changes would have started affecting run-off and groundwater and had flow-on effects for sediment and to a lesser degree nutrient levels within the estuary (as seen elsewhere in the world: Roberts 2007; catchment modelling: SMCMA 2011). Market gardens were developed from the 1830s onwards within the catchment adding further nutrients and suspended sediments to the estuary (SMCMA 2011).

Figure 1. Estimated resident population density (persons/km²) of Local Government Areas surrounding Gamay for 2020. Data: Australia Bureau of Statistics. Grey lines are the borders of Local Government Areas within the catchment. 'SH' = Sydney Harbour.



In the years since European settlement the population surrounding Gamay has exponentially increased. For example, between 2010 and 2020, the population of the Greater Sydney area grew by 15.1% (NSW Government 2020). As of 2020, 5,367,139 people were estimated to live in the Greater Sydney area (NSW Government 2020), with over 40% (an estimated 2,164,696 people) living in the Gamay catchment (Australia Bureau of Statistics 2021). This population growth has not been even across the entire Greater Sydney region and is disproportionately concentrated around coastal areas and adjacent to major waterways (Figure 1). For example, the Local Government Areas of Bayside and Randwick, which make up Gamay's northern and western shorelines, have population densities of 3637.4 and 4179.6 people per square kilometre respectively (Figure 1, Australia Bureau of Statistics 2021). In comparison, the 2020 population density for the entire Greater Sydney area is only 442.3 persons per square kilometre (NSW Government 2020).

Marine resource harvesting in Gamay

The harvest and use of marine resources are deeply intertwined with the identity and traditions of First Nations people (National Oceans Office 2002). First Nations people belonging to coastal land refer to themselves as saltwater people, and for these people marine resources are inexplicably tied to their social, cultural and economic values (Clarkson *et al.* 2017, Smyth *et al.* 2018). As saltwater people, fishing and the gathering marine resources is important not only for food collection and cultural practices, but also for connection to country and ancestors (Smyth *et al.* 2018). Excavated middens highlight the important role Gamay played historically as the major source of food for First Nations people of Gamay. Local middens often contained oyster shells, the remains of various fish (or maguro to First Nations people of Australia), marine mammals (e.g., Fur seal *Arctocephalus* sp. and cetacean bones), unidentified crustaceans as well as some land animals and birds (Haworth *et al.* 2004, Attenbrow 2010a, 2012). Flat oysters (*Ostrea angasi*) and Sydney Rock oysters (*Saccostrea glomerata*) were collected by First Nations people along the eastern coast of Australia (Nell 2001). Fishing was one of the most common activities described in historical accounts, paintings and drawings of European encounters with First Nations people of Australia. There was a division of labour in fishing activities; women used hook and line with shellfish-hooks from canoes, whereas the men used multi-pronged spears from canoes and rock platforms (Attenbrow 2010a, 2012).

Early writings from European settlers suggest First Nations people around Sydney acted as guides for settlers in the initial stages of the colony, also providing fish for the settlers to eat and sharing their knowledge of the land and fishing skills (Goodall 2017). Oysters were particularly popular with European settlers, as they were a familiar food for many who had lived along the coast back in the United Kingdom (Goodall 2017). The early settlers also burnt oyster shells to provide lime for building works (Reid and Bone 2020). The demand for oysters peaked in the 1860's when dredging for both *S. glomerata* and *O. angasi* occurred at depths of 4–15 m, with breath-hold divers employed to harvest the subtidal beds that could not be dredged. Such was the efficiency of dredging and the demand for oysters that it only took a few years for the oyster beds to become exhausted. The colonial Government closed the Georges River to oyster harvesting in 1870 and a Royal Commission was established in 1876 to inquire into the state and management of NSW's oysters (Roughley 1922). Despite this, however, by 1896 *O. angasi* was declared functionally extinct in Gamay.

The demise of Gamay and Georges River wild oyster fisheries stimulated the emergence of an iconic and valuable Sydney rock oyster aquaculture industry (Reid and Bone 2020). Early cultivation techniques included placing juvenile oysters transported from Port Hacking or other estuaries onto the sediment (Roughley 1922). Another early attempt at aquaculture involved the construction of French style 'claires', which were a series of shallow canals (Roughley 1922; Nell 1993). However, like many other European agricultural techniques transferred to Australia, the claires were a failure, with the oysters dying from heat accumulated in the stagnant shallow water on hot summer days (Roughley, 1922). Aquaculture in Gamay was then moved to the intertidal by placing substrate in the intertidal zone, either stone slabs or lengths of timber which oysters naturally recruit onto (Roughley 1922, Nell 2001). By the 1900's almost all oyster aquaculture in Gamay was done using these types of intertidal infrastructure and over time methods improved to include using juvenile oysters that had settled on sticks or shell for cultivation in trays and later into bags (Nell, 2001).

During the 1970's, oyster production in the Georges River and Gamay peaked at approx. 40,000 bags y^{-1} . As the catchment of the Georges River became increasingly urbanised with a growing human population, pollution became a significant issue. Pollution from heavy metals, lead and copper, and the antifouling compound tributyltin (TBT) negatively impacted oyster production (Reid and Bone, 2020). As a result, oyster production in Gamay steadily declined until 1990, and then in 1992 the discovery of QX disease reduced the output of oysters further to about 500 bags y^{-1} (NSW



Current commercial cultivation of the Sydney rock oyster *Saccostrea glomerata* (Gould, 1850) in plastic trays on wooden racks in Woollooware Bay, Gamay. Racks are separated by laneways for access using flat-bottomed boats. Image: RJ Whittington, University of Sydney.

DPI production records 1930–2001; Reid and Bone, 2020). Oyster production data in the Georges River since 2001 are not available due to commercial in confidence protecting the remaining few oyster producers.

An 1880 Royal Commission into the state of Australian fisheries identified Gamay as Sydney’s most productive fishing ground, noting “*Botany, though never equal to the Long Reef and Broken Bay grounds for school-fish, has always held its own for net-fish; indeed it is doubtful whether even Broken Bay, with its far greater extent of net grounds, has ever been or is now more productive than are the beaches and flats of Botany. This inlet, though shallow, covers many thousand acres of water, and as two salt-water rivers – Georges and Cooks – flow into it, there is no lack of spawning or nursery grounds*” (Macleay *et al.* 1880). Ominously, the same report also noted, however, that “*unless arrested by legislative restraints, these prolific grounds will in a very short time succumb to the stake-nets and the small mesh and surely as our other fishing-grounds have succumbed*” (Macleay *et al.* 1880), and so in 1881 the Fisheries Act was introduced. Under the Fisheries Act of 1881, a fisheries inspection

system was developed and legal procedures covering offences and penalties were defined. A system of licences applied to fishermen, fishing boats, oyster bed dredging, oyster dealing, and fish selling.

In 2000 Gamay was designated a Recreational Fishing Haven, with a complete buy back of all commercial fishing licenses by the NSW State Government, and all commercial fishing in the estuary was prohibited from 2002 (Taylor and Suthers 2008). Prior to its closure to commercial fishing, approximately 60 commercial fishers were reported to be fishing in Gamay, using prawn trawling, net hauling, mesh netting and fish trapping (Saintilan *et al.* 2008). Commercial catches were dominated by (in order), sea mullet (*Mugil cephalus*), luderick (*Girella tricuspidata*), yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliate*), Eastern king prawn (*Melicertus plebejus*), longfin eel (*Anguilla reinhardtii*), dusky flathead (*Platycephalus fuscus*) and Eastern school prawn (*Metapenaeus macleaya*) (Saintilan *et al.* 2008). The annual catch prior to closure was estimated to be 220 tonnes (Scriber and Kathuria 1996).

Since becoming a Recreational Fishing Haven recreational fishers have reported an increase in the numbers of fish present in Gamay (pers. comm.). Key species targeted by recreational fishers in Gamay are dusky flathead, yellowfin bream, mulloway (*Argyrosomus japonicus*) and silver trevally (*Pseudocaranx georgianus*) (NSW Department of Primary Industries 2019). Tailor (*Pomatomus saltatrix*), Australian salmon (*Arripis truttaceus*), yellowtail kingfish (*Seriola lalandi*) and bonito (*Sarda australis*) can also be caught in the bay in the warmer months. Sand whiting, luderick (*Girella tricuspidate*) and several species of flounder and squid are also present throughout the year and can be specifically targeted. Estuary perch (*Macquaria colonorum*) and Australian bass (*Macquaria novemaculeata*) can be found in some sections of the rivers (in particular, the upper sections of the Georges River) (NSW Department of Primary Industries 2019). Blue swimmer crabs (*Portunus pelagicus*) can be targeted in hoop nets around seagrass meadows (NSW Department of Primary Industries 2019). Some recreational fishers have noted over the years that the composition of fish species caught in Gamay has changed. Where previously benthic, habitat-associated fish species had been common in the bay (e.g., sand whiting, flounder), more recently they have noticed pelagic species are dominating catches (e.g., yellowtail kingfish, Australia salmon) (per. comm.). In line with this, there is a perception amongst these recreational fishers that this shift is in response to past dredging in Gamay, as this process removed much of the subtidal vegetation that was historically present in Gamay and shifted the bay from being a shallow, sand-dominated bay to a deep, mud-dominated bay.

Survey data from the NSW Department of Primary Industries (see Murphy *et al.* 2020 for survey methods and complete results) suggests the estimated total catch for recreational fishers in Gamay was much lower in 2017/18 compared to 2013/14 (Figure 2). This was the opposite pattern to other major estuaries to the north and south of Gamay, which saw an increase in total catch over that same period (Port Hacking & Sydney Harbour, Figure 2). Large error bars for some sites/years suggest, however, total catch was highly variable in some locations and in certain years. Snapper tended to dominate recreational fisher catch in 2013/14 (50.47% to total catch), followed by bream (13.7%; NSW Department of Primary Industries survey data). In comparison, in 2017/18 snapper comprised only 11.6% of total recreational fisher catch (NSW Department of Primary Industries survey data). Instead, recreational fisher catch was dominated by yellowtail scad (41.5% total catch) and crab species other than blue swimmer crab (25.3%).

Survey data from the NSW Department of Primary Industries also suggests the popularity of recreational fishing in Gamay appears to be decreasing, with less recreational fisher effort days estimated in 2017/18 compared to 2013/14 (Figure 2). This contrasts with other major estuaries in the Sydney region, where recreational fisher effort days increased between 2013/14 and 2017/18 (Figure 2). Large error bars suggest, however, that number of fisher effort days varied greatly between individual fishers at Port Hacking in 2017/2018.

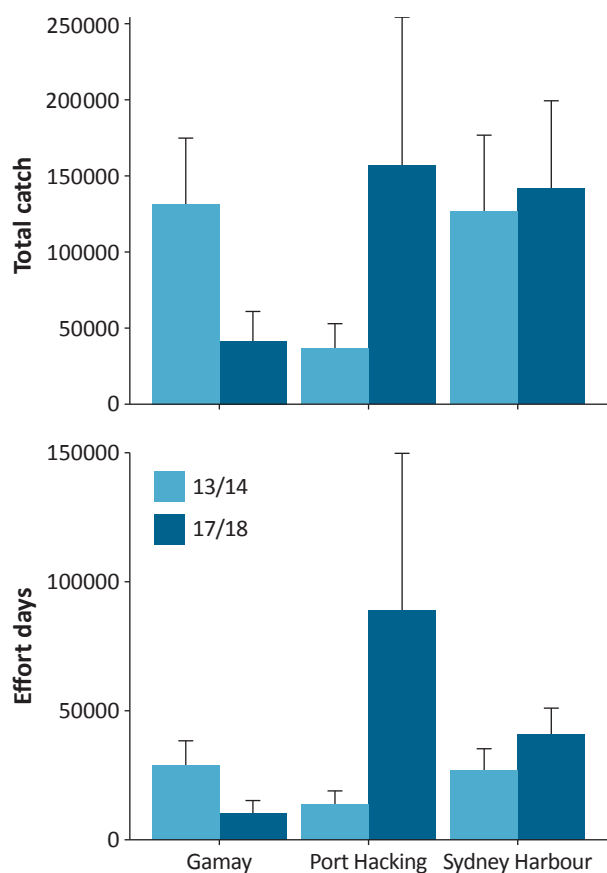


Figure 2. Estimated total catch (no. of individuals) (top) and estimated fisher effort days (bottom) for recreational fishers in three major estuaries in the Sydney region for 2013/2014 and 2017/18. Error bars are standard error. Data is based on preliminary estimates obtained by Murphy *et al.* (2020). Data source: NSW Department of Primary Industries survey data.

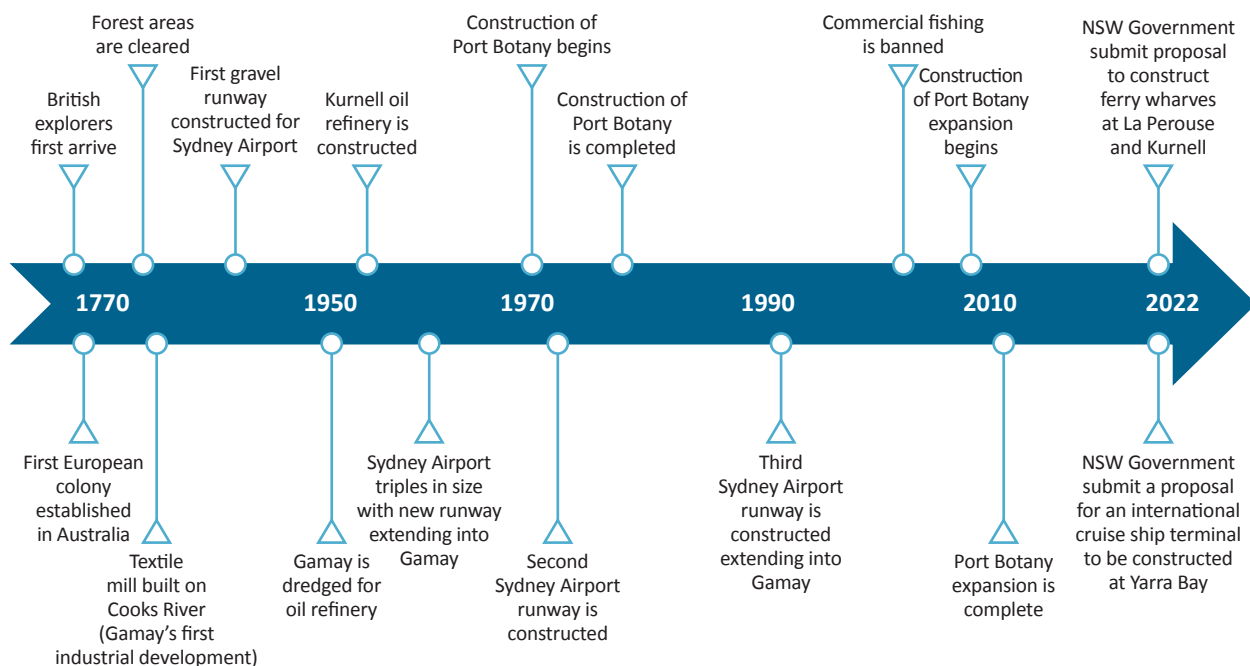


Figure 3. Timeline highlighting significant human disturbance events in Gamay since European settlement.

Industrial history of Gamay

Gamay has an extensive history of human disturbance since European settlement (Figure 3). The first industrial development in the catchment was a textile mill on the Cooks River in 1815 and since then industry continued to develop in the catchments of the Cooks and Georges Rivers and later on the shores of Gamay. By the early 1900's many factories were built in the Cooks River and Gamay Catchment areas, often discharging pollutants directly into the waterways.

More recent industrial developments have involved significant physical modifications to Gamay. The first of these major developments was the construction of the Kurnell oil refinery in 1956. The project included dredging for the construction of pipelines across Gamay. At the time, it was one of Australia's largest oil refineries, and remained in operation until 2014. Currently, the oil refinery functions as a fuel storage terminal.

Gamay is also home to Australia's busiest airport, Sydney Kingsford-Smith airport. The first gravel runway for the airport was built in 1933. By the 1940s, however, the airport was deemed too small and so in 1947 the mouth of the Cooks River was moved further west to

provide room for the airport to be expanded. By 1959, the airport had tripled from its original size with one runway extending into Gamay on reclaimed land built from dredged sediments. The second and third runways were built in 1972 and 1989, respectively, with the third runway extending entirely into Gamay on reclaimed land. As of 2018, Sydney Kingsford-Smith airport was the busiest airport in Australia, being used by 44.4 million people annually and serving over 100 countries around the world.



View of Port Botany from across the bay. Some recreational fishers can be seen in the foreground. Image: John Turnbull www.marineexplorer.org

Gamay also contains Australia's second largest port, Port Botany. Construction began in 1971 and involved huge modifications to the physical state of Gamay, with extensive dredging and land reclamation as well as the construction of a large revetment wall (1.8 km) to protect port infrastructure from wave action and storm surges (Black *et al.* 2018). Construction was completed in 1979. Only a few decades later, however, it was determined that the existing container terminals at Port Botany were approaching capacity and expansion was needed. The expansion required further land reclamation, which was constructed from sediment dredged from the bay (Davies and McIlquham 2011). The port expansion was completed in 2011. Currently, Port Botany handles over two million containers each year, but the NSW State Government intends for it to soon become Australia's largest port and handle seven million containers per year (Black *et al.* 2018).

The Gamay environment

The Gamay catchment covers an area of around 1,165 km² (SPCC 1977) and includes two major waterways, the Georges River (84% of land area) and the Cooks River (9% of land area) (Figure 4 & SMCMA 2011). The Woronora River is also located in the catchment and flows into the Georges River before it reaches Gamay. Combined, the Georges and Woronora Rivers drain nearly 90% of the bay, with the Cooks River and other minor tributaries draining the rest (Figure 4 & SPCC 1977). Human activities in the Gamay catchment have led to extensive contamination of these freshwater tributaries (Cooks and Georges Rivers) (Reid 2021). However, despite this, water quality within Gamay remains relatively good, likely due, in part, to its marine-dominated waters (Roy *et al.* 2001).

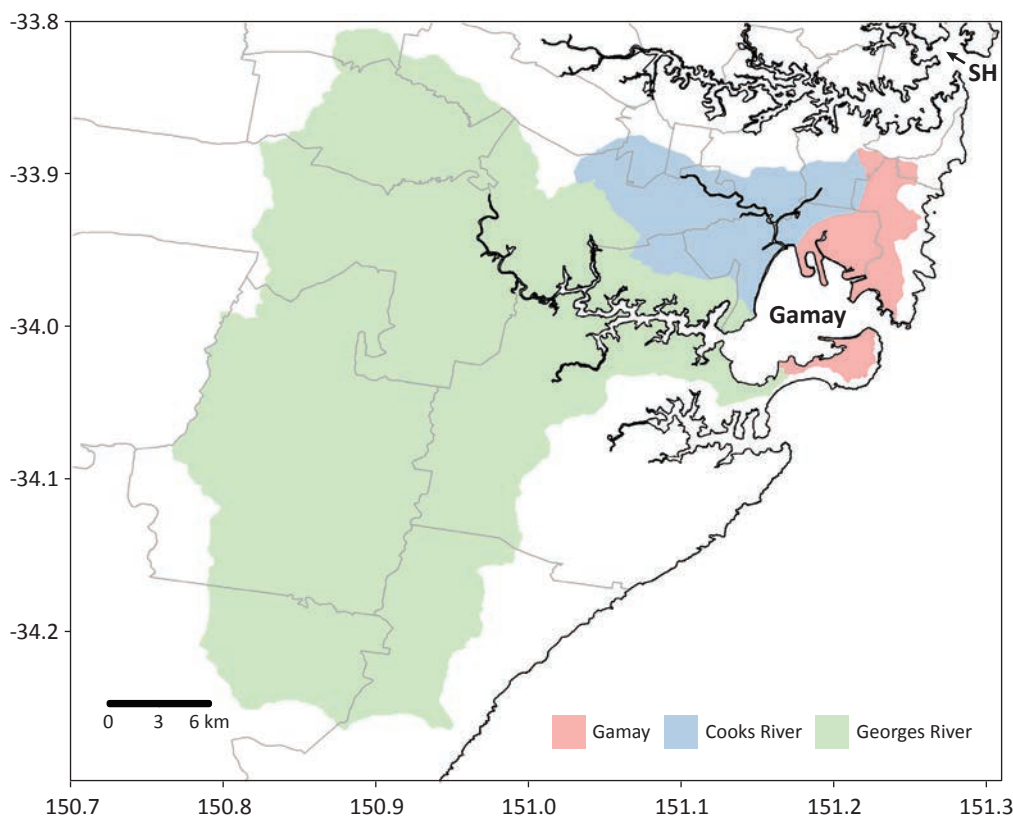


Figure 4. Major subcatchments of Gamay catchment. Grey lines are the borders of Local Government Areas within the catchment. 'SH' = Sydney Harbour.

Historically, the bay contained an extensive diversity of aquatic habitats. The Georges River was once home to highly productive oyster reefs but overharvesting and disease have since decimated populations (Reid and Bone 2020). Similarly, sediment cores suggest Gamay once contained extensive seagrass beds, dominated by *Zostera muelleri* subsp. *capricorni* and the threatened *Posidonia australis* (Larkum 1976b, Reid and Bone 2020), that likely supported a wide variety of aquatic species (Middleton *et al.* 1984, Smith and Suthers 2000, Upston and Booth 2003, Blandon and Zu Ermgassen 2014). Over the years, however, much of the bay's seagrass habitat has been lost due to habitat modification and contamination associated with industrial and urban activities (Larkum and West 1990, Reeds 2018, Blount 2019).

Some of the Gamay's natural features have, however, managed to persist. On Gamay's southern shoreline the Towra Point Nature Reserve and the adjacent Towra Point Aquatic Reserve together comprise the largest and most diverse wetland complex in the Sydney region (Kermode *et al.* 2016). Together this wetland complex supports ecologically significant communities and habitats including saltmarsh, seagrass, mangroves, tidal mudflats and remnant terrestrial vegetation, which are generally under threat in the Sydney region. The Towra Point Nature Reserve provides habitat for many native plant, reptile and mammal species (ALS 1977), as well as providing feeding and roosting habitats for a number of waders and shorebirds including protected migratory species and a breeding colony of locally endangered Little Terns (Keating and Jarman 2004). Whilst in the



Bare Island Fort in the La Perouse area of the Gamay Botany National Park.
Image: John Turnbull www.marineexplorer.org

adjacent Towra Point Aquatic Reserve over 230 fish and invertebrate species have been recorded (NPWS 2001). For these reasons, the significance of this area is internationally recognised under six international conventions including the Ramsar convention.

Similarly, there is an aquatic reserve located at Cape Banks on the northern headland of Gamay which covers an area of approximately 20 hectares. The reserve is partially surrounded on the landward side by the Botany Bay National Park which forms a barrier against direct impacts of coastal urbanisation (Matias 2008). The area was designated as a marine research site in the 1940's and is a world-renowned site for marine research in intertidal invertebrates (McGuinness 1988, Matias 2008).

The legacy of human interaction with Gamay has meant that over the years it has been the subject of much research and study, making it arguably one of Australia's best studied waterways. Despite this, Gamay is also a complex waterway, particularly from a management perspective. Its shorelines are managed under three separate coastal management plans; the Cooks River alliance, Georges Riverkeeper and Eastern beaches, which collectively comprise 13 local councils. Additionally, the Port Authority and Sydney Airport also play a role in the bay's environmental management, undertaking risk mitigation, environmental monitoring and habitat rehabilitation in the areas surrounding their infrastructure. The Gamay Rangers also care and manage land owned by the La Perouse Local Aboriginal

Land Council as well as other cultural areas around the bay. There are also several other stakeholder groups that have interests in Gamay (e.g., recreation fishers, scuba dive clubs etc.), meaning that successful management of the bay requires consideration of the competing interests of industry, commercial activity, national and international transport, residents, First Nations people of Gamay, recreational users and the environment.

To this day the most comprehensive study of Gamay and its tributaries is the Environmental Control Study undertaken by the State Pollution Control Commission in conjunction with the

Maritime Services Board of NSW and the Port Authority of Botany Bay, which produced a series of technical reports published between 1978 and 1981. Since this time the bay has, however, been extensively modified and much of the original habitats sampled in these reports no longer exist or no longer exist as they did. Therefore, given Gamay's history of modification, and the high likelihood of future modification, it is necessary to provide a synthesis of historical and more recent research involving Gamay in order to understand the biophysical nature of the bay as it stands today, in order to gauge how it might fair in the face of future development and to improve management of the bay.



Example of Gamay's bursting underwater life.
Image: John Turnbull www.marineexplorer.org

Human modification of Gamay has also led to the creation of novel habitats within the bay. For example, revetment walls and groynes on the northern and western sides of the bay support high numbers of fish species commonly targeted by fishers (Burchmore *et al.* 1985). More recently, the port revetment has also become host to a non-breeding colony of New Zealand fur seals (Taylor 2015). Whilst in Yarra Bay, purpose built artificial reef balls (ReefBalls™) support several recreationally important fish species (Folpp *et al.* 2020, Becker *et al.* 2022).

Systematic review

This report comprehensively reviews the current science concerning natural and man-made environments within Gamay, with a strong focus on identifying knowledge gaps and opportunities that are significant to the future sustainability of the bay. We systematically review the published literature, and we also include many of the easily accessible non-published literature including technical literature (so called 'Grey Literature'), books and other relevant literature. An attempt is therefore made to include most of the relevant studies that can be accessed easily by managers, scientists, the public and other stakeholders. Some information is also presented as unpublished work by this review's authors, representing ongoing study, however, this occurs rarely.

First Nations people have actively cultivated and managed natural landscapes for tens of thousands of years (Rowland 2004). Traditional Ecological Knowledge is a form of local ecological knowledge held by First Nations people that encompasses experience of human interaction with the environment over time (Berkes 1993). In this review we synthesise current knowledge of all habitat types in Gamay, the natural drivers of these systems and the distribution of the flora and fauna, utilising the scientific literature and Traditional Ecological Knowledge uncovered during our systematic review process (described below). We then present our understanding of the threats, challenges and opportunities relevant to Gamay and discuss current knowledge gaps. Importantly, some areas and systems of Gamay are well studied leading to a more comprehensive summary of our current knowledge. In comparison, some areas have received little attention, and for these habitats or processes, much of our understanding comes from examples outside of Gamay. All references used in the writing of this review are included in the [References](#) section at the end of this review. Additionally, we include a database of all references uncovered during our Science of Gamay review of current knowledge in a separate section ([Gamay Literature Database](#)) at the end of this document and intend the reader to use this list as a guide for further research of the available published literature.

Our review of current knowledge used four search methods to uncover information:

- a) a systematic literature search of databases;
- b) a voluntary questionnaire to researchers associated with the Sydney Institute of Marine Science;
- c) two workshop discussions with all the authors of this document to further interrogate the current state of knowledge of Gamay; and
- d) one workshop discussion with recreational fishing stakeholder representatives to discuss their perspectives on the future sustainability of Gamay.

Using all these methods allowed us to comprehensively review the historical and contemporary literature featuring Gamay. We focus on the core areas of geology, oceanography, chemistry, ecology and environmental threats to the bay. Historical literature was also included in this review as these early accounts contain some of the only records of Gamay and First Nations people of Gamay prior to British colonisation.

Systematic literature search

We utilised the Web of Science search engine to examine journal titles within the Science Citation Index Expanded Social Sciences Citation Index, Arts and Humanities Citation Index, and the Conference Proceedings Citation Index. Titles from 1898 to 2021 were available. Titles and 'Topic Keywords' were examined using the search terms 'Botany Bay' or 'Georges River' or 'Cooks River'. We examined the titles and abstracts of each citation, and the study was included in our review if it discussed or assessed any physical, chemical or biological aspect of Gamay (see definition of extent below).

Questionnaire

A google form questionnaire ([Science of Kamay Questionnaire](#)) was distributed to researchers and affiliates of the Sydney Institute of Marine Science (a network of approximately 50 scientists and managers). The questionnaire asked respondents to state their area of expertise, list and briefly describe any research they had conducted in Gamay, including any literature that was published on the research. The questionnaire also included a question where respondents could suggest additional scientists not directly associated with the Sydney Institute of Marine Science that could contribute to the review. Scientists identified in this way were then sent the questionnaire directly and so on.



A mixture of shells and coralline algae washed up on the beach.
Image: John Turnbull www.marineexplorer.org

Workshops

Scientific workshop

On 8th and 13th October 2021, the authors of this review attended a virtual workshop. During this workshop, the combined group examined the literature from their fields of expertise and added to the database any work not found in our initial Web of Science search. This allowed relatively obscure yet important texts to be included, as well as highlighting unpublished works and grey literature not available on searchable databases. This was a key component of our search methods, as many important texts failed to include 'Botany Bay', 'Georges River' or 'Cooks River' or similar search terms in either the article title, its keyword list or abstract.

Recreational fisher stakeholder workshop

On 22nd November 2021 we held a virtual discussion forum with several leading representatives from the Gamay recreational fishing community. During the forum each participant was given the option to speak on

three key discussion topics covering: 1) their concerns and future visions for Gamay, 2) their engagement and involvement in the management of Gamay (past, present and future), and 3) they were given the option to suggest additional stakeholders (individuals or organisations) that were missing from the forum.

Analysis

Articles and reports were included in the review if they presented data wholly or partially collected from Gamay. Gamay was defined to include the main bay and the lower, estuarine regions of the Georges River and the Cooks River. This included a distance of 200 km extending seaward from the mouth of the bay and the coastal waters off the headlands, Cape Banks and Cape Solander. It also included terrestrial areas associated with the Towra Point Aquatic Reserve (e.g., mudflats, mangroves and saltmarsh habitat) as this area is an important region for wading birds. Each study was assigned, where appropriate, to a Field of Study (e.g., Ecology, Oceanography etc.), a Habitat Type (e.g., rocky intertidal shores, seagrass etc.) and a Threat Term (e.g., contamination, fisheries etc.).

Much of the Georges River catchment is bushland. Photo is of the upper Georges River which remains largely unmodified by humans. Image: J. Dahlenburg



Results

Some 577 different studies were included in this systematic review, including 477 journal articles, 75 reports, 13 books as well as 12 additional resources of other types. The earliest study included in this systematic review was published in 1876. Since the late 1970's the number of peer-reviewed studies published each year steadily increased to peak around 2010 and has decreased slightly since then (Figure 5). There were 10 times the number of publications on the ecology of Gamay (408 studies) compared to those describing any other aspect of the Gamay (Figure 6). Despite the long history of commercial fishing and the continued use of the bay by recreational fishers, there has been little scientific examination of its fisheries published in the peer reviewed literature (20 studies, Figure 6).

Single habitat studies were by far most common (Figure 7 insert plot). Rocky intertidal shore habitats were the most common habitat featured in single habitat studies (Figure 7), with much of this research being undertaken in the Cape Banks aquatic reserve on the bay's northern headland. In comparison, freshwater habitats in Gamay represent the most poorly studied habitats in single habitat studies, whilst terrestrial habitats (which represent habitats dominated by littoral vegetation) were the most poorly studied habitat overall (including both single and multi-habitat studies; Figure 7). When studies did feature multiple habitats, soft sediment and pelagic habitats were most commonly featured together (Figure 7).

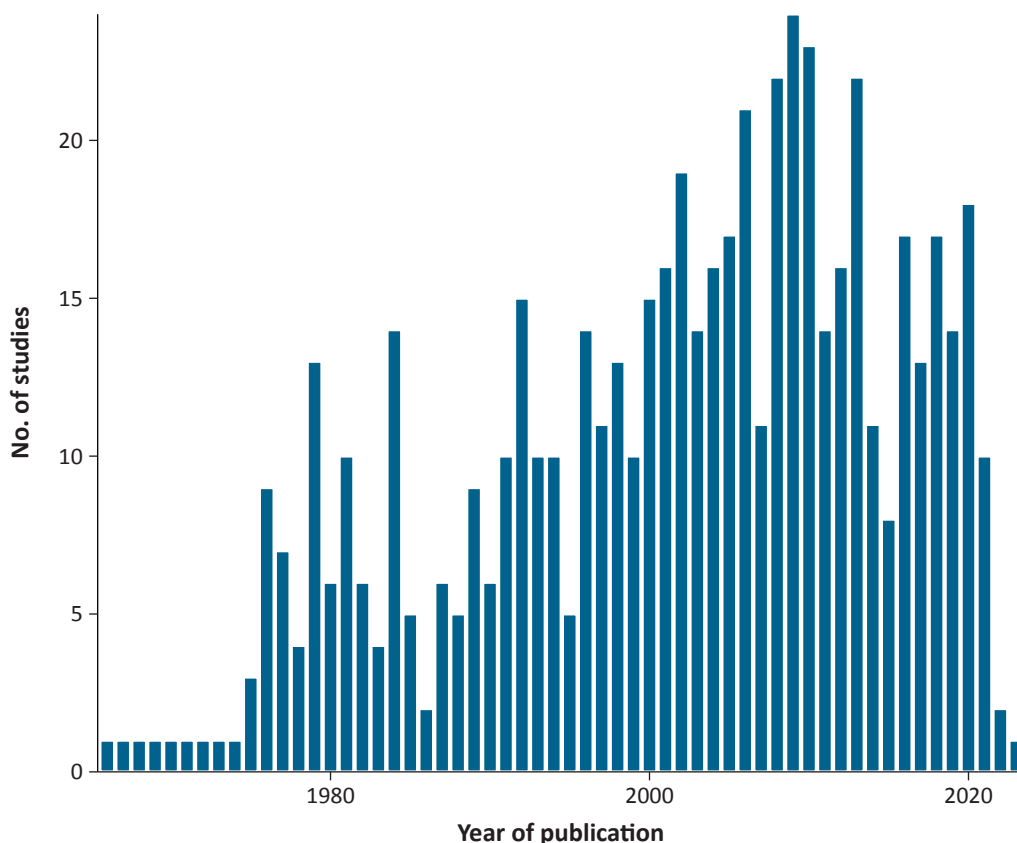


Figure 5. Temporal patterns of peer-reviewed studies published on Gamay (n = 477). Only peer-reviewed journal publications are included here (i.e., other literature types are not shown) as our search can only be considered exhaustive for peer-reviewed literature.

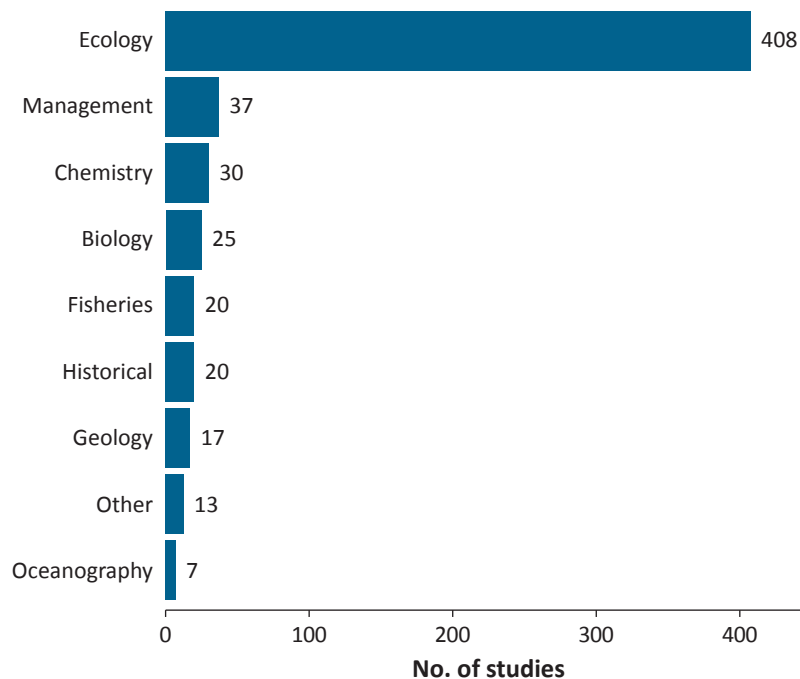


Figure 6. Studies were separated into basic Study Types. Ecology, or the use of logic and mathematics to determine patterns and processes in nature, is by far, the most studied scientific discipline in Gamay. ‘Other’ represents all studies that could not fit into standard categories (e.g., taxonomic-based papers and studies detailing industrial development). All literature types are included in this plot.

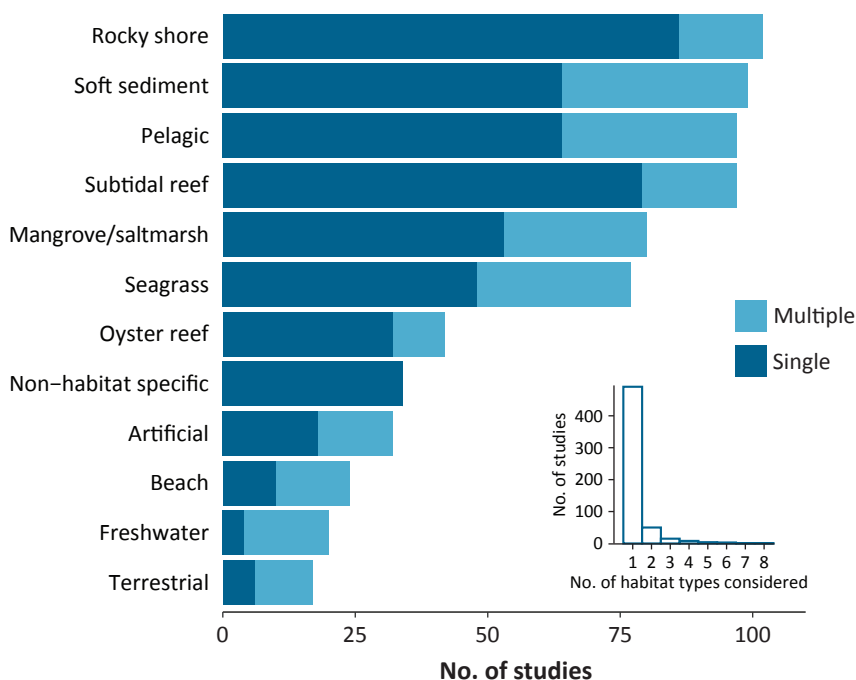


Figure 7. Studies were separated by Habitat Type. The number of studies that considered individual habitat types in isolation are shown in dark blue (‘single’). The number of studies that featured a given habitat type in addition to one or more other habitat types is shown in light blue (‘multiple’). Individual studies may therefore appear in multiple columns and thus the sum of all bars will be greater than the total number of studies included in the literature review. ‘Terrestrial’ represents habitats dominated by littoral vegetation. Inset plot shows the number of different habitat types considered by studies. Soft sediment habitats were mostly studied in combination with other (one or more) habitats, followed by pelagic habitats. Habitat types most commonly studied in combinations were soft sediment and beach habitats (6 studies), followed by soft sediments and rocky shores (4 studies) and subtidal reefs and artificial substrates (4 studies). All literature types are included in this plot.

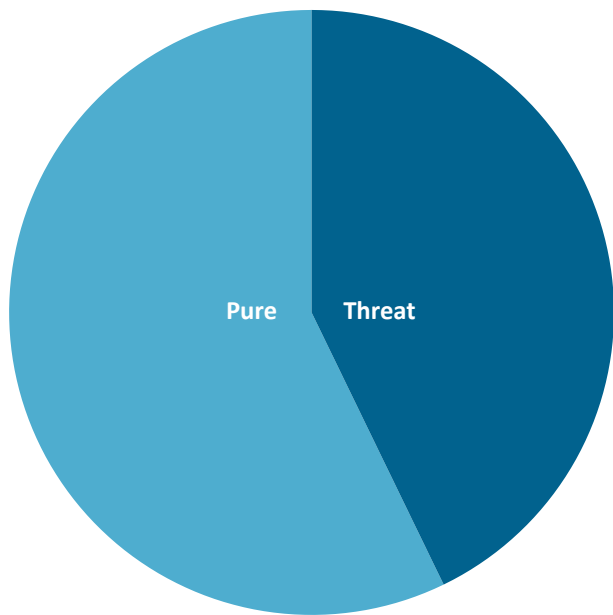


Figure 8. Studies were separated into Type of research. More than half of studies were ‘pure’ scientific research (light blue). All literature types are included in this plot.

In comparison, oyster reef habitats feature least often in multi-habitat studies (Figure 7). The habitat types most commonly studied in combination were soft sediment and beach habitats (6 studies), followed by soft sediment and rocky shore habitats (4 studies), and subtidal reef habitat and artificial substrates (4 studies).

Overwhelmingly, research concerning Gamay was ‘pure’ research, with less than half of studies (257 studies, 44.5% of studies) investigating threats or impacts to Gamay (Figure 8). Of those studies that did consider threats to Gamay, the impacts of contamination and habitat modification were most commonly studied individually (single threat studies), whilst also featuring most commonly in studies that investigated the impacts of multiple threats (multi-threat studies; Figure 9). Much of the research that had no habitat classification was historical literature about Gamay (for example see Rolfe 1931), considered the management of Gamay (for example see SMCMA 2009) or described geological surveys (for example see Bryant 1980).

In the following pages we present a synopsis of current knowledge of the Gamay ecosystem that arose from our search. We utilise the research uncovered in our review process, but also cite published science from many other locations in order to demonstrate a point or qualify a statement. This distinction is made clear in the reference section of this document. All literature cited within the review is listed under [References](#) (this includes studies from outside of Gamay), whereas the full list of all references uncovered during our Science of Gamay literature review is included separately in [Gamay Literature Database](#) (only contains studies directly relating to Gamay).

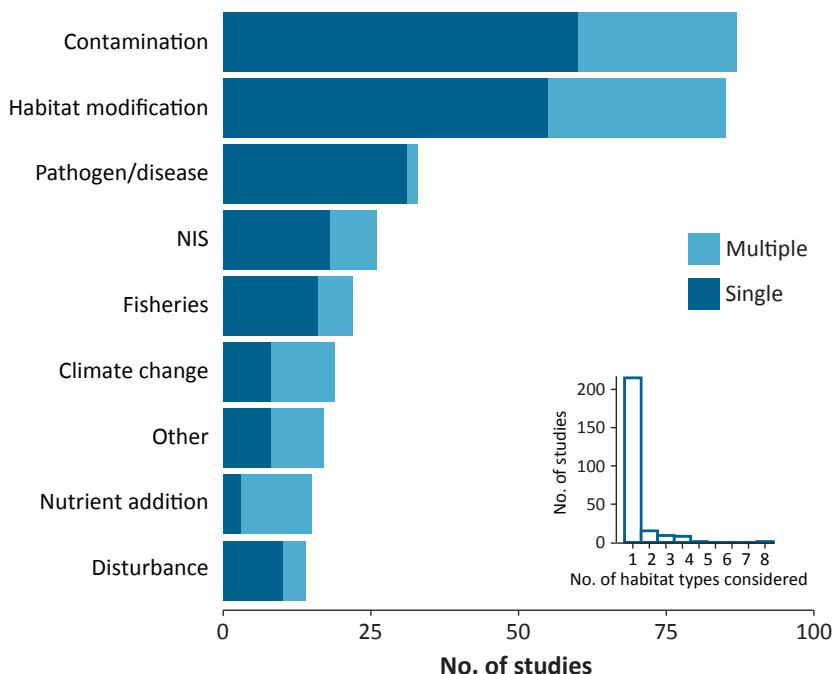


Figure 9. Studies were separated by Threat Type. The number of studies that considered individual threats in isolation are shown in dark blue (‘single’). The number of studies that considered a threat in addition to one or more other threats is shown in light blue (‘multiple’). Individual studies may therefore appear in multiple columns and thus the sum of all bars will be greater than the total number of studies included in the literature review. ‘NIS’ = Studies that considered threats associated with exotic and non-indigenous species. Inset plot shows the number of different threat types considered by studies. All literature types are included in this plot.

The shape and form of Gamay



Rock formation found at Cape Banks, on Gamay's northern headland. Image: John Turnbull www.marineexplorer.org

Geological history

Gamay is part of the greater Botany Basin, which covers an area from Bate Bay in the south to Centennial Park in the north (Roy and Crawford 1981). The Basin was originally carved out of Hawkesbury Sandstone by three ancient river systems (Albani *et al.* 1976). Bedrock mapping shows the Cooks River paleo-valley flowed southwards from the location of its present mouth at a depth of approximately 50–70 metre below sea level (mbsl) to Towra Point. Here it was joined by the ancient Georges River before continuing southward into Bate Bay and combining with the Port Hacking paleo-channel (Albani and Rickwood 1998). The third, smaller (unnamed) ancient river with its headwater at Centennial Park, flowed to the east of a bedrock high located beneath the airport main runway through a steep, deep (110 mbsl) channel before exiting at the present mouth of the bay.

Four sedimentary units are recognized in Gamay (Albani 1981, Roy 1983, Albani *et al.* 1988, Albani and Rickwood 1998). Two lower estuarine/marine deposits are separated from surficial sediments by a thick aeolian accumulation. The lowermost unit (Unit 1) grades from fluvial sands and gravels to estuarine muds

with foraminifera shells indicating a deep, open-tidal estuary. The overlying shallow, semi-enclosed lagoonal sequence (Unit 2) of mud, sand and peat was deposited on an erosional surface. Unit 3 comprises up to 30 m of well-sorted, shell-free quartzose aeolian sand, possibly sourced from older sands to the south. The uppermost layer (Unit 4) contains several lithologies, including dune, estuarine, beach ridge and terrestrial swamp representing a variety of environments. Shelly, quartzose sand occupies the central bay, and muddy fluvial deltas are located adjacent to the mouths of Cooks and Sheas Creeks (including *in situ* tree stumps at Sheas Creek).

The Quaternary geologic history of coastal environments, including Australian east coast estuaries, is largely controlled by glacial sea-level (Ribó *et al.* 2020), however, the ages of the Gamay units are not well established as previous chronologies are based on outdated sea-level curves (Bloom *et al.* 1974). Units 1 and 2 represent highstand sea-level stages, however, with maximum heights of -35 m and -20 m mbsl, respectively, these sequences are more likely related to Interstadial events (MIS 5.1/5.3) at approximately 106 to 73 thousand years before present (kyBP), rather than to the Last Interglacial period, unless the erosion observed on the upper surfaces of these units was



considerable (Ribó *et al.* 2020). A reliable date of 31 kyBP to 24 kyBP, i.e., immediately prior to the Last Glacial Maximum, has been established for the aeolian sands south of Rose Bay (Thom and Oliver 2019).

The environmental importance of the Towra Point area necessitates additional comments on the evolution and sustainability of this environment (Roy and Crawford 1981). At 9,000 yBP, with sea-level at approximately -20 mbsl, the combined Cooks and George paleo-rivers joined the ancient Port Hacking channel and exited to the ocean from Bate Bay. A proto-barrier spit formed between Port Hacking south Head and Kurnell Headland between 9,000 and 7,000 yBP, blocking exit to the ocean and diverting the combined rivers to exit between the Botany Heads. Between 7,000 and 4,000 yBP, the proto-barrier spit was destroyed and beach ridges formed along the present-day northern beaches of Bate Bay, forcing the Cooks/Georges River system northwards into Gamay. Between 1000 and 4,000 yBP, a northerly-prograding spit formed off what is now Towra Point, diverting the George River outflow further to the north and by 1000 yBP muddy sediment began to accumulate in the now Woollooware, Weeney and Quibray Bays. A 1981 survey predicted Towra Point spit to prograde further.

Hydrology and oceanography

In its existing form, the Gamay catchment is fed by the catchments of the Georges, Woronora and Cooks Rivers, with a catchment area of approximately 1165 km² (SPCC 1977). The Georges and Woronora Rivers drain nearly 90% of the bay, with the Cooks River and other minor tributaries draining the rest (Figure 4 & SPCC 1977). Oceanic influences dominate inflows during non-flooding periods.

Since British colonisation the region has undergone significant development which has influenced the region's hydrology. Constructed by convicts at the navigable limit of the Georges River in 1876, the Liverpool Weir is an early example of the hydrologic modifications within the catchment. Other major impoundments in the upper catchments include the Woronora Dam (completed in 1941) and Prospect Reservoir (completed in 1888).

The Georges, Woronora and Cooks River catchments have undergone extensive urbanisation since European settlement. The broad acre development of residential, urban, peri-urban and industrial settlements in the lower estuary, as well as landform modifications via reclamation (e.g., Sydney Airport and Port Botany)

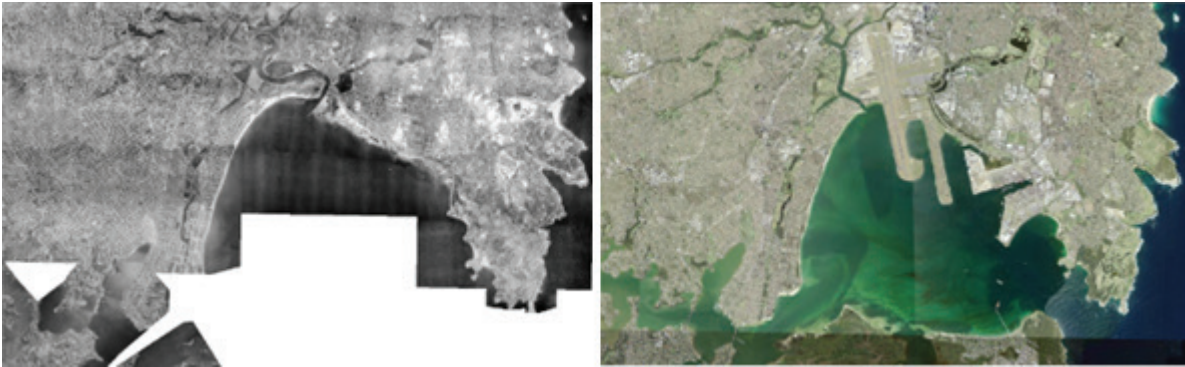


Figure 10. Aerial image of Gamay in 1945 (left) versus 2022 (right), highlighting urbanisation changes and alterations to circulation flow paths. Major changes include the additions of the airport runways, the Port Botany expansion and the realignment of the Cooks River entrance. Image source is SixMaps.com.

and dredging projects (e.g., Chipping Norton Sand Mines) has substantially altered the broader catchment and localised hydrology, including rainfall-runoff patterns, hydrodynamics and hydraulics (Figure 10).

Increased urbanisation has made large areas of the catchment impervious and has connected these areas directly to waterways via stormwater infrastructure (SMCMA 2011). This means water regularly runs directly off the land surface and quickly makes its way into the waterways, instead of being filtered through the soil and vegetation. Stormwater systems very effectively move water from urban areas into waterways, quickly transporting not only the water, but also any pollutants in that water, straight into streams, estuaries and bays. These fundamental changes in catchment hydrology mean that in urban areas storm hydrographs rise and fall much more rapidly than in undeveloped catchments, with higher peaks and greater volumes of water. This poses significant problems to the waterways of the catchment (SMCMA 2011).

Size /shape of Gamay

Gamay is a semi-enclosed low inflow embayment centred at $\sim 34^{\circ}\text{S}$, $151^{\circ}12'\text{E}$. It lies ~ 13 km south of the CBD of Sydney, Australia. The bay itself is approximately 40 km^2 , with a maximum length of ~ 8.8 km and width of ~ 7.8 km. The mouth is ~ 1.3 km wide (1 km at its narrowest), facing southeast, open to the Tasman Sea. Depths of the bay itself are shallow, less than 5 m across much of the bay, although the average depth is 11 m. The entrance is up to 25 m deep, with dredging occurring to expand the port, and reclaim land for two runways at Sydney Airport (Kinhill Engineers 1990) and Port Botany. The temperature stratification and circulation within the bay are affected by tides, wind forcing and riverine freshwater outflow each of which are discussed below.

Temperature

As a shallow embayment, open to the ocean, Gamay is characterized by marine waters. The surface temperatures range between $22\text{--}24^{\circ}\text{C}$ in Summer (maximum in February) and $15\text{--}18^{\circ}\text{C}$ in winter (minimum in August). Winter temperatures are slightly cooler than the offshore waters due to its shallow depth where it is cooled quickly through surface heat fluxes. Waters are generally well mixed, with low stratification. During one experiment, stratification of $\sim 1^{\circ}\text{C}$ was observed in 12 m of water through the summer season (Middleton and Morris 1997).

Tidal circulation

Circulation in the bay is largely barotropic due to its shallow nature and regular tidal forcing. The tidal range is up to 2.1 m during spring tides and 0.5 m during neap tides, with mean ranges of 1.3 m and 0.8 m respectively (URS Australia 2009a). The mean tidal period is ~ 12.4 hours, with two high and two low tides per day (semi-diurnal) (URS Australia 2009a). The dominant tidal constituents with their amplitude (m) and phase (degrees) are as follows: M2 (0.502, 307), S2 (0.125, 320), K1 (0.148, 329) and O1 (0.096, 300). Tidal elevations are almost simultaneous throughout the bay with a maximum lag of 4 minutes throughout the bay (Roughan and Hallam 2022).

Current speeds at the mouth of the bay are up to 0.3 ms^{-1} and oscillate periodically with the semi diurnal tide driving flood and ebb every 6 hours. At the western side of the bay velocities are weaker, ($\sim 0.1\text{ ms}^{-1}$) and also reverse periodically with the tide (Roughan and Hallam 2008). Near Kurnell, field experiments in the Summer of 1997 showed currents, oriented primarily west on the flood tide, and east



Aerial shot of Cape Banks. Image: John Turnbull www.marineexplorer.org

on the ebb, although with a mean drift to the north over the study period (Middleton and Morris 1987).

The mean volume of the bay is $234 \times 10^6 \text{ m}^3$. A volume of approximately $110 \times 10^6 \text{ m}^3$ is exchanged with the ocean at the spring tide, adding to the low tide volume, which is approximately $205 \times 10^6 \text{ m}^3$. Thus, the tides provide a major flushing mechanism for the bay (Middleton and Morris 1987).

Many land modifications and reclamations have resulted in complex topography around the bay which generates several recirculating eddies throughout the tidal cycle. Noticeably in the north-westerly corner near the Cooks River and the airport, and a second strong recirculation feature is located on the northeastern side of the bay that evolves during the tidal cycle. These features are strengthened under easterly wind forcing (Roughan and Hallam 2022). Currents measured by a vessel mounted acoustic Doppler current profiler (ADCP) near Kurnell show substantial variability in space and time, suggesting recirculating eddies which have a strong dispersive effect offshore of Gamay (Middleton and Morris 1987).

A series of idealised modelling experiments under different wind forcing conditions estimated tidal flushing times scales within the bay (Roughan and Hallam 2022). Results showed that flushing timescales and retention rates (which both impact the age of the water) varied significantly during different wind conditions. The retention of particles

seeded near the entrance to the bay (at Port Botany) ranged between 3.6 % and 34.5 % after 90 days, with the lowest (highest) retention occurring under the influence of an easterly (northerly) wind.

Retention within the bay is highly dependent upon prevailing wind conditions with at least a 30% variation in the retention rates under the different forcing wind scenarios. The Roughan and Hallam (2022) modelling experiment, however, was conducted in the absence of freshwater inflow, and with constant wind direction and could well be improved upon.

Freshwater inflow

While freshwater inflow is typically low (Roy *et al.* 2001), during periods of rainfall, freshwater inflow occurs from two modified shallow rivers (the Cooks River and the Georges River). After heavy rainfall (greater than 50 mm per day) the surface waters become stratified, with a buoyant freshwater plume 1–2 m thick overlaying saline oceanic water. This plume can cause mass mortalities of intertidal and shallow subtidal organisms such as sea urchins (Andrew 1991). This plume leaves the estuary within a few days reverting to low – flow state within a week of dry conditions (Kingsford and Suthers 1994). The tidal plume from the estuary generally extends only a few kms offshore (Li *et al.* 2022) on a spring tide ebb tide after significant rainfall, a tidal plume of 11 km has, however, been observed (Kingsford and Suthers 1994, 1996).



Aerial shot of waves washing up onto the rock platform of Cape Banks.
Image: John Turnbull www.marineexplorer.org

Waves and winds

Atmospheric data have been collected consistently at Sydney Airport resulting in one of the more accurate and reliable long term wind records. However, due to the size of Gamay it is thought to generate its own sea breeze, hence Sydney airport wind data are not representative of the offshore wind conditions and vice versa (Wood *et al.* 2012). Dominant wind directions are from the northeast and southwest (Wood *et al.* 2012).

Gamay is influenced by both locally generated wind waves and remotely generated oceanic swell waves that enter the bay through the seaward entrance. The diurnal sea breeze (from the northeast $\sim 8 \text{ ms}^{-1}$ during

summer) produces waves with periods typically about 2.5 seconds that affect beaches on the southern flanks of the bay (Towra and Silver beach). Strong winds from the south ($\sim 10 \text{ ms}^{-1}$), particularly late on summer afternoons, and during winter are usually of short duration, but can produce wind waves that influence water circulation in northern reaches of the bay. Westerly winds can persist for up to a week during winter and have long fetches over the bay. Remotely generated swell waves and infragravity waves that influence Gamay enter from the southeast and are generated by distant storms (Vila-Concejo *et al.* 2020). Impacts of these waves on beaches is discussed further in the [Soft bottom and beach habitats](#).

The environments of Gamay

Soft bottom and beach habitats

Beaches and sandflats

Gamay contains many beaches. Notable beaches include Congwong and Little Congwong, Currewol and Yarra Bay (Indigenous names for La Perouse, Frenchmans and Philip Bay) on the northeast shore near the entrance to the open ocean, Lady Robinsons on the western shore, and Towra Point and Kurnell on the southern shores (Short 2007). These beaches are narrow (< 30 m wide), low-lying (< 5 m above mean sea level (MSL)) and are backed by low dunes or seawalls (Gallop *et al.* 2020). They are considered low energy beaches when compared to beaches on the open coast but can still experience significant storm erosion, as seen following notable storms in 1974 (Fellowes *et al.* 2021) and 2016 (Gallop *et al.* 2020). Erosion can occur on estuarine shores when swell waves and infragravity waves propagate into the estuary from the open ocean, or from locally generated wind waves (Vila-Concejo *et al.* 2020).

The biodiversity of infauna inhabiting these beaches in Gamay has been assessed to a certain extent. They are dominated by peracarid crustaceans, with the

number of species being greater at the lower intertidal levels, and in areas with reduced wave action (Dexter 1984, 1985). Infaunal communities in the surf zone at La Perouse beach are dominated by amphipods and polychaetes, with the number of species increasing with depth. However, the environmental drivers of these patterns remain unknown (Barros *et al.* 2002). Natural rocky reef and artificial hard substrates (e.g., breakwalls and groynes) have been found to affect infauna across short distances (metres; Barros *et al.* 2001). These infaunal communities seem to be shaped by competition, as spatial separation between similar species is common (Dexter 1985, Jones *et al.* 1991). Additionally, beach wrack including stranded seagrass and algae might play a big role in fuelling densities of amphipods (Jones *et al.* 1991).

Infaunal communities in sand flats in Quibray Bay are more diverse than in sandy beaches, probably due to the lower exposure to waves. Here, infaunal distribution patterns are related to tidal height and the content of labile organic matter in sediments (Rossi and Underwood 2002, Bugnot *et al.* 2022). Interestingly, while wrack drives increases in capitellid, orbinid and nereid worms in sandflats, it does not seem to drive big changes in sediment infauna (Rossi and Underwood 2002). The soldier crab *Mictyris longicarpus* is highly

Beach wrack washed up on one of Gamay's sandy beaches.
Image: John Turnbull www.marineexplorer.org



abundant, but has a patchy distribution driven by topography, while their size distribution is driven by sediment characteristics (Rossi and Chapman 2003).

Fish communities in surf zones in Gamay are quite unique, having greater fish diversity in the upper reaches of Gamay and abundance of marine stragglers in the lower Gamay than other NSW bays (McKinley *et al.* 2011). Fish communities are more diverse and have greater biomass in surf zones of the upper river beaches when compared to the lower river beaches, patterns similar to other estuaries in NSW. In contrast, fish reach bigger sizes in lower river beaches and fish abundance patterns are variable between zones. Whiting (*Sillago* sp.), sand whiting (*S. ciliate*), roach (*Gerres subfasciatus*), and the long-finned goby (*Favonogobius lentiginosus*) are more common in surf zones of the upper river beaches, while the Port Jackson glassfish (*Ambassis jacksoniensis*) is more abundant in the lower river. These patterns seem to be driven by salinity, temperature and pH (McKinley *et al.* 2011).

Mudflats

Intertidal mudflats are common in Gamay, despite many being reclaimed during two centuries of coastal development. Gamay's existing mudflats are prevalent in sheltered coves, upper estuarine areas, rivers and creeks, as well as filling in the gaps around mangroves and built infrastructure. Mudflats are productive habitats rich in organic materials, which underpin microbial loops (Fenchel 1992) and detritus-based food webs (Bishop and Kelaher 2008, Kelaher *et al.* 2013). The detrital resources of mudflats fuel productive meio- and macro-infaunal communities, providing food resources for mud crabs, fish and wading birds (Mann 1988, Snelgrove *et al.* 2000). In particular, the mudflats of Gamay support resident and migratory wading bird populations, some of which are in serious decline (NSW Threatened Species Scientific Committee 1998).

The surface layers of the mudflats in Gamay are well-oxygenated and rich with micro-flora and fauna, such as deposit-feeding molluscs (e.g., *Pyrazus ebeninus*, Bishop

Extensive mudflat and marginal rock field colonised by oysters, including *Saccostrea glomerata* and *Crassostrea gigas*, near Limekiln Bar, Georges River.
Image: RJ Whittington, University of Sydney.



et al. 2007) and crustaceans (e.g., *Heloeccius cordiformis*, Kelaher *et al.* 1998). The top five centimetres of mud contain diverse meio- and macrofaunal assemblages, representing a suite of invertebrate phyla (Inglis 1995). The habitat provided by mudflats becomes increasingly anoxic deeper into the sediment, transitioning from nitrate-, to sulphur- and then methane-reducing bacteria (Fenchel 1992). While few animals live directly in the sulphurous, anoxic, black mud layers, borrowing crustaceans, molluscs and polychaetes can persist in this habitat (Inglis 1995). Burrows on mudflats provide a link between oxygenated surface waters and deep sediments. The bioturbation associated with burrowing and deposit-feeding is a vital ecosystem process on mudflats (Kristensen *et al.* 2012, Bugnot *et al.* 2022).

Organic material in mudflats is continuously replenished by external sources, such as leaf litter from terrestrial and aquatic vegetation (Bishop and Kelaher 2013a, Kelaher *et al.* 2013). The detrital sources for Gamay mudflats have been changing since European colonisation (Macreadie *et al.* 2012). Changes in detrital sources to Gamay mudflats influence decomposition rates, primary productivity, nutrient cycling and community metabolism, as well as the structure and function of macrofaunal communities (Bishop and Kelaher 2008, Bishop and Kelaher 2013a, Kelaher *et al.* 2013). Detrital dynamics on mudflats will continue to change in the coming decades because ocean warming influences decomposition and nutrient liberation (Kelaher *et al.* 2018, Litchfield *et al.* 2020).

Biogeochemical cycling in Gamay sediments has only recently been assessed, and data are still to be published (Bugnot A.B., pers. comm.).

Subtidal sediments

Subtidal soft sediments comprise the greatest extent of all habitat types in Gamay. Modern, surficial sediments mantling Gamay strongly influence the ecology and contamination in the environment and are a product of ambient energy and the present hydrologic regime. Basin muds and sandy muds in the northern bay merge with sand in the central region, beach ridges on the western foreshore and an ebb-tide delta at the mouth of Georges River. Mud and sandy muds are trapped in Weeney, Woollooware and Quibray Bays by the coastal barrier between Bate and Gamay bays and the transgressive Towra Point spit. Minor fine sediment in the central bay is due to resuspension and removal by high-energy tide and wave energy. Mud-rich holes dredged for airport construction and fine sediment in the northern bay act as temporary contaminant sinks and are a secondary source for dispersion of pollutants to other parts of the bay (Birch *et al.* 2022).

Subtidal soft sediments have changed significantly with respect to physico-chemical characteristics as a direct and indirect result of European colonisation

and land use changes (Reid 2021). Artificial hard shorelines have affected hydrodynamics and sediment deposition leading to shifts in grain sizes. Gamay has a predominantly sandy subtidal benthos with the muddy areas associated with dredging near the bay's entrance, around port infrastructure and the airport runways. Georges River has predominantly muddy embayments while the channels have muddy sand (Reid 2021). Sediment cores have revealed higher sedimentation rates in the last 30–50 years compared to the rest of the Holocene (Macreadie *et al.* 2012). The microalgal community signature in sediment records was also found to increase around the time of European settlement, potentially as a result of increased nutrient inputs. The overall shift from seagrass to microalgal detritus as represented in sediment records suggests that the carbon sink potential of Gamay has decreased.

No studies have directly investigated the demersal fish and macrobenthic communities in Gamay. By-catch from prawn trawling undertaken in Gamay did, however, find 37 taxa associated with sediment habitats, including, 115 finfish taxa, 11 crustaceans, 10 molluscs and 1 echinoderm (Liggins *et al.* 1996). Of these, Eastern fortesque (*Centropogon australis*), snapper (*Pagrus auratus*), two spot crab (*Ovalipes australiensis*), blue swimmer crab (*Portunus pelagicus*) and mantis shrimp (*Squilla* spp.) were found in numbers exceeding a mean of 100 individuals caught per fisher-day. Sand whiting (*Sillago ciliata*) were also highly abundant in sand habitats in Gamay (Ferrell and Bell 1991). Additional fauna identified on subtidal sediments included several sponge species such as *Callyspongia* sp., *Dactylia palmata* and *Myxillid* sp. (Pollard and Pethebridge 2002). The macrofaunal communities of these habitats are dominated by polychaetes, with Spionids and Capitellids observed to contribute approximately 25% and 15% of the community abundance, respectively (Dafforn *et al.* 2012). Malacostracan crustaceans are also abundant, and amphipods comprise ~4 % of the community (Dafforn *et al.* 2012). Most mollusc species are found in the outer parts of the bay where conditions are similar to the open coastline, but habitat degradation is thought to have reduced their distributions and abundance (Pollard and Pethebridge 2002).

The microbial communities of soft sediment habitats in Gamay have previously been assessed in several comparative studies of estuaries in NSW (Sun *et al.* 2012, Sun *et al.* 2013, Dafforn *et al.* 2014). Extensive coring of the subtidal sediments in Gamay provides the most comprehensive overview of the community composition (Pollard and Pethebridge 2002). Twenty-five species of dinoflagellate have been identified including *Alexandrium*, *Gonyaulax*, *Protoperidinium* and *Diplopsalids*, but there has been no evidence of toxic blooms in the bay. Dinocysts have also been found to correlate to organic carbon content in sediments (Tian *et al.* 2018).

Seagrasses

Seagrasses have been a key component of the ecology of Gamay for thousands of years. The primary seagrasses in Gamay are *Posidonia australis*, *Zostera muelleri* ssp. *capricorni*, *Halophila ovalis* and *Halophila minor* (Flora of Australia 2011). *Ruppia polycarpa* is today regarded as a seagrass and is present in many brackish water sites around Australia including the Georges River. *P. australis* in Gamay is one of six NSW populations listed as endangered under state legislation (*Fisheries Management Act 1994*) and was listed as a threatened ecological community under Commonwealth legislation (*EPBC Act 1999*).

Seagrasses provide essential ecological functions, many of which directly benefit humans. *P. australis*, the dominant seagrass of Eastern Australia, forms meadows that create habitats for a vast array of species, including recreationally and commercially important fishes and crustaceans. In addition to being an important primary producer, *P. australis* helps stabilise and trap sediments, attenuate waves (thereby protecting shorelines from erosion), plays a significant

role in carbon sequestration and improves water quality and water clarity (Costanza *et al.* 1997, Duarte 2002, Lavery *et al.* 2013). Neither *Zostera capricorni* nor *Halophila ovalis* provide much stabilisation against wave-action. These primary producers also support many food chains which add variety to the ecosystems of the bay, including the shorebird Ramsar site (set up in 1964) in the Towra Point Nature Reserve; especially important is the nesting site of the Little Tern.

The sediments of *P. australis* meadows also constitute a significant carbon store (Serrano *et al.* 2020), and this is true to a lesser extent for the other seagrass species but is dependent also on the position within the estuary (related to the percentage of fine sediments; Ricart *et al.* 2020). It has been claimed that the majority of sedimentary organic Carbon in seagrass meadows is derived from non-seagrass sources (Ricart *et al.* 2020). However, it should be noted that due to the long-lived fibrous nature of the underground rhizomes of *P. australis*, this species is regarded as a major storage site for “blue carbon”, the long-lived form of organic carbon, along with organic carbon stores from mangroves and saltmarsh plants (Ralph *et al.* 2018).

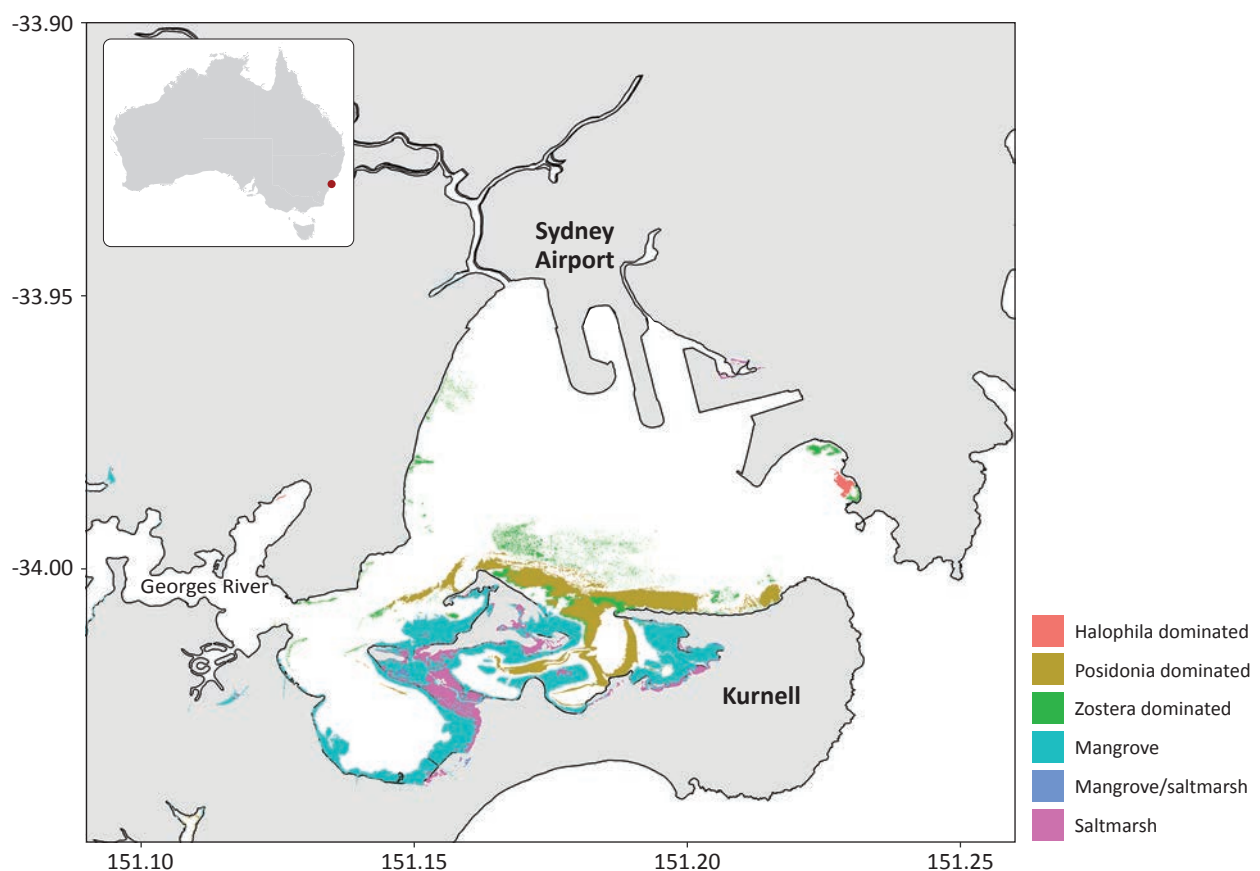


Figure 11. Distribution of estuarine macrophytes (seagrass, mangrove, saltmarsh) in Gamay (excluding Georges River – west of Captain Cook Bridge) in 2019 (NSW Department of Primary Industries 2020).

Fibrous remains of *P. australis* can be found in the sediments of Gamay many years after the disappearance of the living plants (Larkum and West 1990).

Seagrass beds provide some of the most ecologically significant habitats within estuaries, being particularly important habitat for many commercially and recreationally important fish species (Bell and Pollard 1989, Smith and Suthers 2000, Smith and Sinerchia 2004). Seagrass meadows also provide important nursery habitat for a wide range of fish and invertebrate species (Bell and Pollard 1989). McNeill *et al.* (1992) found a site on Gamay's northern shoreline supported significantly greater abundances of fish recruits of five economically important fish species, compared to 15 other sites across NSW (including multiple other sites within Gamay). This site, however, no longer exists and instead is the location of the third airport runway of Sydney Kingsford Smith airport. Middleton *et al.* (1984) found fish assemblages varied between different seagrass species, with larger species of Gobiidae and Syngnathidae occurring in *P. australis* whilst smaller species of these families dominated

Z. capricorni meadows. Temporal variation in these assemblages in addition to body size variability suggest these habitats were likely being used sequentially, with fish recruiting first to *Z. capricorni* and then moving into *P. australis* when they are older.

Whilst a considerable body of literature exists on seagrass-invertebrate interactions outside of Australia, comparatively little is known about how they interact in Gamay. One study found infaunal communities associated with *P. australis* were significantly more diverse and had higher invertebrate densities at marine dominated sites (some of which were in Gamay) compared to estuarine dominated sites along the NSW coast (Collett *et al.* 1984). Furthermore, this study found that the site at Towra Point on Gamay's southern shoreline had the highest abundance and highest number of species of all sites sampled. Infauna communities from Towra Point were dominated by (in decreasing order of abundance): *Heteromastus filiformis*, *Anadara trapezia*, *Spio pacifica*, *Ampelisciphotis* sp., *Eunice australis*, *Caprella scaura*, *Syllis* sp., *Mysella* sp., *Mediomastus californiensis* and *Birubius* sp.

Seagrass bed containing *Posidonia australis* and *Halophila ovalis* (foreground). Image: John Turnbull www.marineexplorer.org



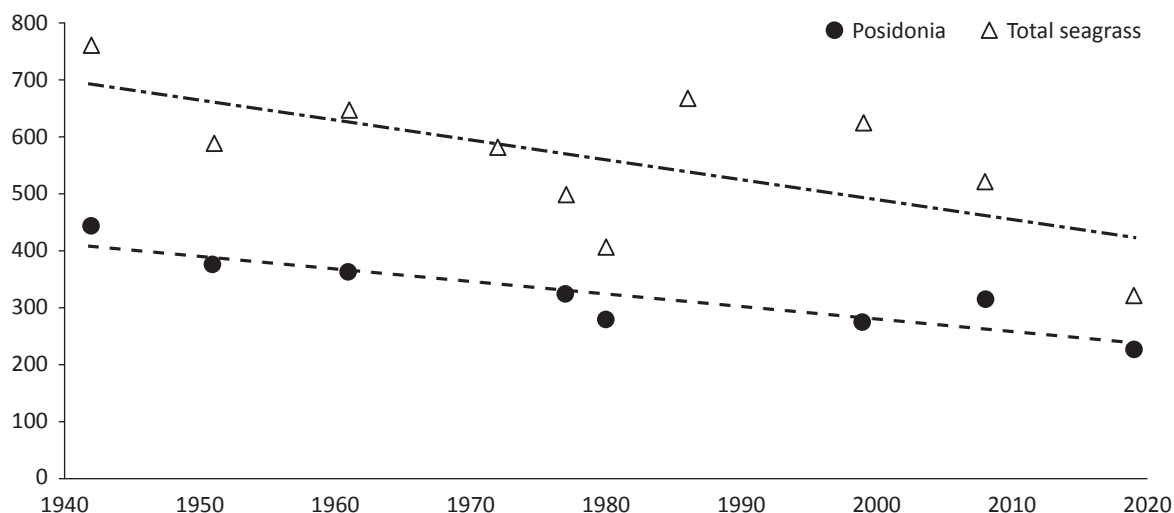


Figure 12. Mapped areas (hectares) of seagrass in Gamay. Data sources: Larkum & West (1990), Glasby & West (2021) and NSW Department of Primary Industries unpublished data (1972, 1986).

Today seagrasses cover a little over 300 hectares of Gamay, primarily along the southern shoreline (Figure 11). The current extent is potentially only a small fraction of the extent before European colonisation, when *P. australis* probably covered the majority of the bay floor (Larkum 1976b, Reid and Bone 2020). Analyses of aerial photos demonstrate that the area of all seagrasses in Gamay has been steadily declining since the 1940s (Figure 12). Total seagrass area includes more transient species of *Zostera* and *Halophila*, abundances of which can fluctuate greatly from year to year. Yet the long-term pattern of decline of the more temporally stable *Posidonia australis* is very similar to that for all seagrasses (Figure 12), suggesting that these are indeed true declines of all species, over and above any shorter-term natural fluctuations. The Cooks River, a highly disturbed and polluted tributary of Gamay, is one of the few NSW estuaries without any seagrass (West and Glasby 2021). The largest historical declines in seagrass in Gamay have occurred along the northern shoreline, possibly due to historical contamination in the 1800s and early 1900s (Larkum and West 1990) and more recently due to disruptions associated with the construction of both Port Botany (and its expansion) and the second and third airport runways (Reeds 2018, Blount 2019, Macbeth 2019). *P. australis* traditionally exerts a strong stabilising effect on the seabed where it exists, but if the wave-action is severe

enough, as it was in the 1970s, destabilisation of the seabed and shoreline can occur (Larkum and West 1990). The rates of decline of seagrass over the last 80 years has been $0.75\% \text{ yr}^{-1}$ (total seagrass) and $0.64\% \text{ yr}^{-1}$ (*P. australis*-dominated meadows) which, although on the lower range of rates recorded globally (Waycott *et al.* 2009, Dunic *et al.* 2021), are cause for concern. Once meadows get too small ($< 50\%$ of their maximum mapped area), or become fragmented, rates of decline can increase markedly (Larkum 1976b, Dunic *et al.* 2021).

The importance of symbiotic microorganisms (bacteria, fungi, and archaea) for plant growth is being increasingly recognised, however, remains a relatively new area of research for seagrass ecology (Nguyen *et al.* 2021b). There is growing evidence, however, that seagrasses have intimate relationships with their associated microbial communities, and that these communities may aid in resource acquisition and buffering seagrasses from environmental stress (Brodersen *et al.* 2014, Gribben *et al.* 2017, Tarquinio *et al.* 2019, Martin *et al.* 2020). In highly urbanised waterways, such as Gamay, it will also be important to understand how anthropogenic pressures and changing environmental conditions may impact sediment microbial communities in seagrass meadows, and how this might flow on to in turn impact seagrasses.



Extensive mangrove forest bordering mudflat with deeper channels, Towra Bay. Image: RJ Whittington, University of Sydney.

Mangrove and saltmarsh habitats

Much of Gamay's coastal wetland habitat lies within the Ramsar-listed Towra Point aquatic reserve on the southern shore of Gamay, although other small patches of habitat are found in Penrhyn estuary and further up the Georges and Cooks Rivers. The extensive wetlands in and around Towra Point equate to ~25% of the area of Gamay, and include typical mangrove (*Avicennia marina*, *Aegiceras corniculatum*), saltmarsh (*Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Juncus kraussii*) and floodplain forest species (*Casuarina glauca*, saltmarsh understory; Figure 11), but also includes small areas of littoral rainforest and terrestrial forest. There is a diversity of terrestrial vegetation types close to Gamay, including several that are recognized as Endangered Ecological Community under the *Biodiversity Conservation Act NSW 2016 (EEC, BCA)*. This includes littoral rainforest in the NSW North Coast, Sydney Basin and Southeast Corner bioregion.

Extensive research has identified diverse aquatic fauna that accesses, or resides within, the wetlands of Towra Point in Gamay, which provide both physical habitats and provisioning services. Mangroves are important as primary habitat-formers in wetland

habitats and also influence the functioning of these habitats via interactions with other habitat-forming organisms. Mangrove pneumatophores are covered by algae, *Bostrichyia/Caloglossa* association and in the seaward areas provide substrate for oyster settlement and macroinvertebrate communities (Ross 2006, Ross *et al.* 2009). Macroinvertebrate species occur in high densities in all areas of the mangrove forest and saltmarsh (Ross 2001, Hughes *et al.* 2014, Ross 2006; Ross *et al.*, 2009) including on all parts of mangrove trees and oysters (Bishop *et al.* 2012, Ross and Underwood 1997, Minchinton and Ross 1999). The intertidal vegetation at Towra Point supports roosting, breeding and feeding habitats for endangered and migratory waterbirds, as well as habitats for terrestrial vertebrates and insects (SMCMA 2010). In the Georges River, saltmarsh habitat supports one of only two extant populations of White-fronted chats (Major and Sladek 2012). Wetlands also play a significant role in shoreline stabilization and protection from wave action (Gedan *et al.* 2011). Historical dredging of Gamay significantly increased wave energy at Towra Point which caused major damage to its shores due to increased erosion and vegetation recession (ALS 1977, NPWS 2001). Mangroves and saltmarsh are also important for carbon sequestration, playing a significant role in climate change mitigation (Duarte *et al.* 2013).

Wetland habitats in Gamay also support the aquatic ecosystem throughout the broader bay, including fisheries species, via both provision of nursery habitat and outwelling of wetland production. Saltmarsh plants are a primary source of dietary carbon for the resident grazing herbivores in the Towra Point wetlands as shown in stable isotope analyses (Mazumder *et al.* 2011). Similarly, at high tide carnivorous fish hunt within mangrove-saltmarsh habitats at Towra Point (Mazumder *et al.* 2011). In Gamay, saltmarshes were found to support the highest densities of zooplankton of all estuarine habitats (saltmarsh, mangrove, seagrass, and open water) which are a major source of food for estuarine fish (Mazumder *et al.* 2009, Mazumder *et al.* 2011). A restored wetland in inner Gamay, Rockdale wetland, was found to provide an important nursery area, especially for yellowfin bream and mullet which were able to move through a permanently open 700 m long pipe into the modified wetlands (Gibbs *et al.* 1999).

Fish assemblages at Towra Point consist of relatively few species dominated by juveniles from the families Gerreidae, Sparidae and Mugilidae and other generally small species from the families Atherinidae, Ambassidae and Gobiidae (Bell *et al.* 1984). Studies comparing fish assemblages between mangrove and saltmarsh habitats have, however, found variable results. One study found mangrove habitats at Towra Point had higher species richness than nearby saltmarsh habitats, with fish density also slightly higher in mangrove than saltmarsh habitats (Mazumder *et al.* 2005). In comparison, however, another study reported saltmarsh habitats in Gamay had slightly higher species richness than mangrove habitats (Mazumder *et al.* 2006). Gastropods are some of the most ubiquitous invertebrate taxa on the surface of mangroves and saltmarshes at Woollooware Bay and other locations at Towra point, with species such as *Bembicium auratum*, *Cassidula zonata*, *Phallomedusa solida*, *Salinator fragilis*, *Ophicardelus* spp., *Cryptassiminea*

Mangrove forest, Woollooware Bay. Image: RJ Whittington, University of Sydney.



buccinoides and *Tatea rufilabris* all known to occur, whilst the dominant burrowing crab is *Heloecius cordiformis* (Warren 1990, McGuinness 1990, Ross 2006, Ross *et al.* 2009) and barnacles, *Austrominius covertus* and *Hexaminus foliorum* and *H. popeiana* are abundant on mangrove trees and other hard substrata including oysters (Bishop *et al.* 2012, Hughes *et al.* 2014, Ross 1996, Ross and Underwood 1997).

Reports dating back to the first fleet suggest First Nations people of Gamay used coastal wetland habitats for a variety of resources (ALS 1977). Whilst more specific reports of how these resources were used by First Nations people of Gamay are lacking, the use of wetland resources by First Nations people in other places around Australia have been recorded in more detail. The fruit of the mangrove tree *Avicennia marina* (called ngoor-ngoer-loo by the Bardi clan, Western Australia (Hegerl 1982); also known as egaie (Friess 2016)) were baked and eaten by First Nations people of

Australia (Hegerl 1982, Thozet 1985). The mangroves themselves were also used to make canoes (Wilson 1858, Martin 1865) and to make wood carvings (Hegerl 1982). Historical reports also describe the use of mangroves in burial ceremonies, where First Nations people in the Adelaide River region were seen covering new graves in mangrove saplings (Wake 1870).

Across the bay, there has been a steady decrease in the extent of saltmarsh since mapping in Gamay began in 1980 (Figure 13). From the Ramsar listed Towra Point wetland 30% of the saltmarsh has been lost since the 1930s (Saintilan and Williams 1999, Saintilan and Williams 2000). Mangroves have shown the opposite trend, with mangrove cover increasing in the bay (Figure 13). Aerial photographs from the 1930s and data from as early as 1882 show that this is a long-term trend for the bay (Mitchell and Adam 1989b, Mitchell and Adam 1989a).

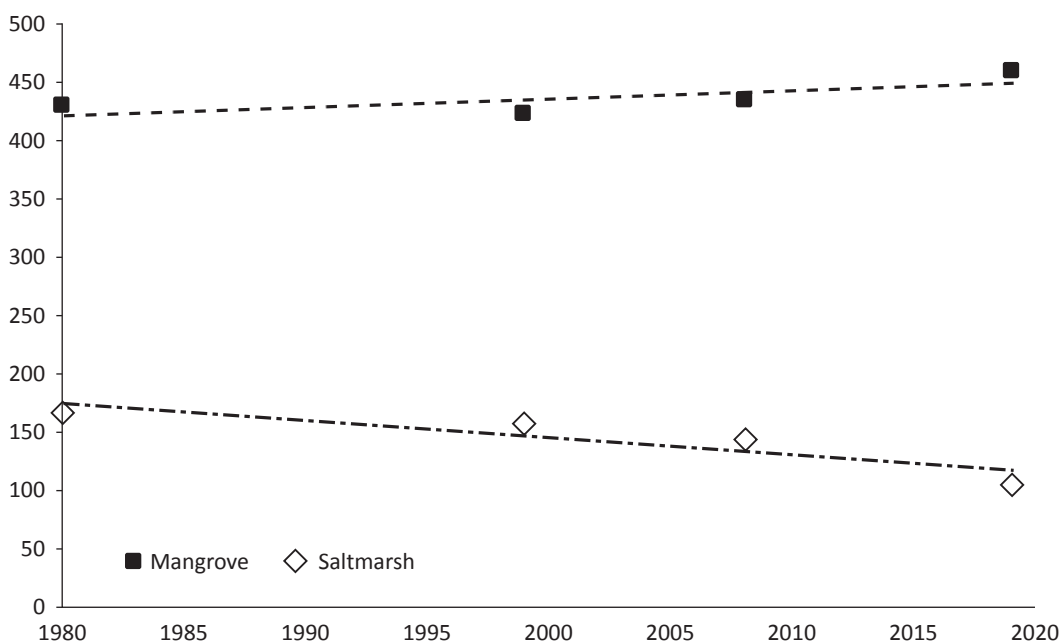


Figure 13. Mapped areas (hectares) of mangrove and saltmarsh in Gamay (excludes Cooks and Georges River) (NSW Department of Primary Industries).

Subtidal rocky reefs

Subtidal rocky reef is found predominantly around the mouth of Gamay, extending out around both headlands and along the oceanic coastline north and south of Gamay (Figure 14). Within Gamay, most subtidal reef habitat is shallow, extending down to a maximum of 24 m. Deeper subtidal reef (20–60 m) occurs in small, isolated patches at the mouth of Gamay, but dominates subtidal reef habitats outside the bay, on the oceanic side of each headland. Within the bay, the reefs tend to be algal dominated on the horizontal upward facing surfaces, while the vertical surfaces of the reefs tend to be dominated by sessile invertebrates (e.g., sponges, seaquirts, bryozoans) (Van Der Velde and King 1984, Underwood *et al.* 1991, Knott *et al.* 2004).

Much of the research on subtidal reefs in Gamay has been undertaken at Bare Island and at Cape Banks, on the bay's northern shore. Bare Island is a 1.4 ha rocky outcrop just offshore, where bottom depths range from 3–16 m (Figure 14, SPCC 1981d, Van Der Velde and King 1984). Cape Banks is an Aquatic Reserve located at the northern headland of Gamay and covers an area

of ~20 ha, with sandstone rocky reefs reaching ~17 m depth. The macroalgal community at these sites is diverse and 45 species of Rhodophyta, 13 species of Phaeophyta and three species of Chlorophyta have been documented at Bare Island (Van Der Velde and King 1984). The most common and/or abundant species are the foliose red alga *Delisea pulchra*, various brown algae (*Ecklonia radiata*, *Sargassum vestitum*, *Sargassum linearifolium*, *Zonaria diesingiana* and *Dilophus marginatus*), coralline turfing red algae (*Corallina officinalis* and *Amphiroa anceps*) and crustose red algae (*Sporolithon durum*, *Lithamnion* spp.) (Underwood *et al.* 1985, Underwood *et al.* 1991, Wright *et al.* 2005). The forest-forming furoid *Phyllospora comosa* was once abundant along shallow reefs on the northern headland but disappeared from the Sydney region in the 1970–80's, likely in response to near-shore sewage outfall discharges (Coleman *et al.* 2008). Recent restoration efforts for *P. comosa* populations in the Sydney region have had some success in Gamay (e.g., in Kurnell; Mead 2020) but herbivory (likely by fish) has limited the re-establishment of this species at Cape Banks (Campbell *et al.* 2014, Vergés *et al.* 2020).

Large bed of the habitat-forming brown alga, *Ecklonia radiata* at Bare Island. Image: John Turnbull www.marineexplorer.org





Figure 14. Distribution of mapped subtidal reef in Gamay. Data source = Cardno.

Macroalgae are an important source of food for the First Nations people of Australia, as well as being used in the catching, cooking and in the preparation of fish and invertebrates to eat (Thurstan *et al.* 2018). Historical reports suggest that macroalgae was also traditionally used in the construction of dwellings and clothing, however, if the First Nations people of Gamay undertook this practice remains unclear (Thurstan *et al.* 2018).

The subtidal reef at Bare Island is also known to host diverse communities of sessile invertebrates, dominated by sponges, soft corals and bryozoans (SPCC 1981d, Underwood *et al.* 1991, Poore *et al.* 2000, Knott *et al.* 2004, 2006). Deeper areas of reef to the east of Bare Island also support colonies of cool-temperate hard coral (SPCC 1981d). Together with macroalgal communities, the biogenic habitat provided by these habitat-forming species support abundant and diverse mobile invertebrate communities dominated by crustaceans, polychaetes and molluscs (Van Der Velde and King 1984, Underwood *et al.* 1991, Poore *et al.* 2000).

Kurnell Reef is another offshore subtidal reef that occurs just off Inscription point on the bay's southern shore. Diversity is low here when compared to Bare Island (SPCC 1981d). Subtidal reef also occurs along much of the bay's southern headland. The reef here is deep (~20 m) and traditionally was dominated by sponges (Davis *et al.* 1997) although there are extensive *Ecklonia* beds at ~10 m depth in close proximity to the cliffs (Marzinelli *et al.* 2015). In 1995, a rapid invasion of the native alga *Caulerpa scalpelliformis* was documented, leading to a corresponding decline in sessile invertebrates on the reef (Davis *et al.* 1997). There are also extensive *Ecklonia* beds in shallow reefs (~3–10 m) off Inscription point, interspersed with barrens formed by the sea urchin *Centrostephanus rodgersii* (Mead 2020).

A range of sea urchin species inhabit the subtidal in Gamay, with several species identified as key in determining the abundance and composition of benthic algae (Hill *et al.* 2003, Wright *et al.* 2005). The most well-known is the long-spined sea urchin *Centrostephanus*



Bare Island contains extensive sponge gardens, where the endangered soft coral, *Dendronephthya australis* also grows. Image: John Turnbull www.marineexplorer.org

rodgersii, which can cause density-related, non-linear regime shifts from kelp forest to barrens in other areas in south-eastern Australia (Ling 2008). Cape Banks has extensive areas of barrens at depths from 3–20 m (Ettinger-Epstein and Kingsford 2008) that are some of the most persistent in the state, with the area having not changed since at least 1950 (Glasby and Gibson 2020). The short-spined sea urchin *Heliocidaris erythrogramma* is, however, the most abundant regular urchin in Gamay, and while usually occurring at densities $< 10 \text{ m}^{-2}$, can occur in high-density aggregations, or ‘fronts’, exceeding $100 \text{ urchins m}^{-2}$ (Wright and Steinberg 2001). In Gamay, these *H. erythrogramma* fronts have been documented to cause shifts from a foliose algal-dominated community to one that is dominated by crustose algae (Wright *et al.* 2005). Another well studied species is the short-spined sea urchin *Holopneustes purpurascens*, which lives largely enmeshed in the canopy of the algae that it consumes by using its tube feet to wrap the algae over its short spines to create a nest that facilitates other organisms (Williamson *et al.* 2004, Bell *et al.* 2014, Connolly *et al.* 2017). A range of other species of sea urchins also occur within the subtidal habitat of Gamay, such as *Heliocidaris tuberculata*, *Holopneustes*

inflatus, *Tripneustes gratilla*, *Pseudoboletia indiana* and *Phyllacanthus parvispinus*, however, their impacts on the subtidal habitat in Gamay are less known.

The subtidal reefs of Gamay are also home to abalone (*Haliotis brazeri*, *Haliotis coccoradiata* and *Haliotis rubra*). They were historically harvested for food and trade purposes around the La Perouse area by First Nations people of Gamay (Cruse *et al.* 2005), and more recently have become popular catch for free diving fishers. Between 2005 and 2012 the collection of abalone from Gamay was heavily restricted or banned. At present the collection of abalone in NSW is subject to strict bag limits, and in Gamay is restricted to weekends and public holiday days only.

There is surprising little in the way of comprehensive assessments of subtidal rocky reef fish assemblages in Gamay in the peer-reviewed literature. A series of studies by the State Pollution Control Board (SPCC 1981c, b, d, a) identified 100 different species of fish associated with hard substrata (out of 229 overall) making it one of the three most speciose geomorphic zones in the bay (behind seagrass *Zostera capricorni* with 104 species and deep soft substrate in the western region of the bay with 102 species).

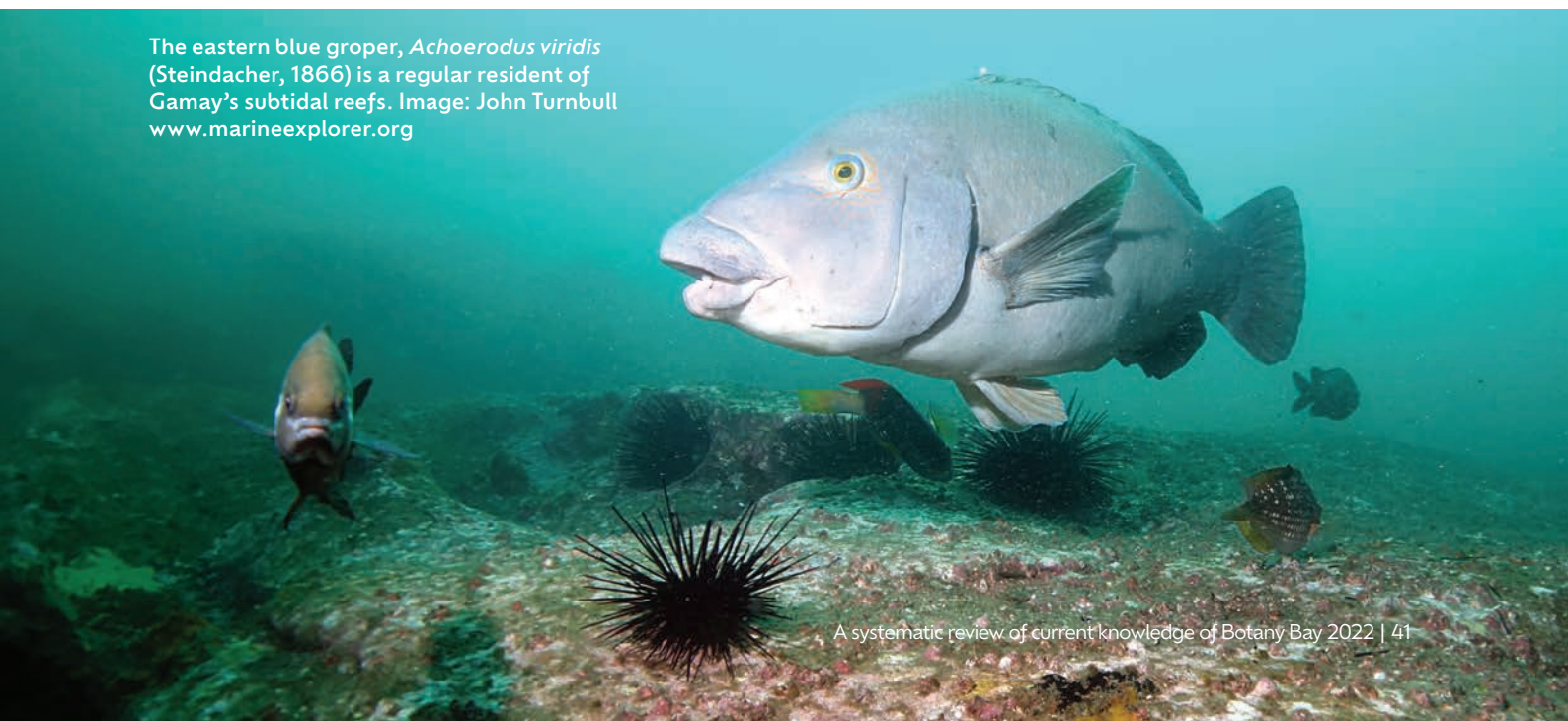
The presence of many artificial structures within the bay has motivated several comparisons of fish assemblages between them and nearby natural rocky reefs. Early studies (Burchmore *et al.*, 1985) suggested natural rocky reef sites had greater total abundance (especially of sub-adult stages) than nearby artificial breakwalls (revetments). Richness was also elevated on natural reefs, but this pattern was not as consistent over time as was that of richness. Interesting, more recent studies have indicated that richness on rocky reefs may actually be lower than on nearby breakwalls (Fowler and Booth 2013, Porter *et al.* 2018) but beta-diversity is higher, most likely due to the elevated range of micro-habitats available on rocky reefs compared to the relatively homogenous breakwalls (Porter *et al.* 2018). This pattern may be driven by more sub-adults on breakwalls (Fowler and Booth 2013). A study on the ReefBalls™ installed in Yarra Bay (north side Gamay) suggested these habitats serve to actually produce more fish in the system rather than just attracting them from nearby habitats (Folpp *et al.* 2020) (for full discussion see [Artificial substrates](#)).

There are several studies completed partly within Gamay on species that spend at least part of their life history on subtidal reefs. Juvenile snapper tend to strongly associate with rocky reef habitats around the mouth of Gamay (and elsewhere in NSW) but abundance, especially of adults, tends to be lower around Gamay (and the Greater Sydney region in general) than in other estuaries to the north and south of Sydney (Rees *et al.* 2021). Work on the iconic blue grouper indicated no obvious association with a specific habitat though the amount of habitat did vary by area. There is some evidence that more small fish are found in macroalgal habitats dominated by *Ecklonia radiata* than in the urchin barrens that characterise much of the subtidal reef habitats around NSW (Gillanders and Kingsford 1998). Although Curley *et al.* (2002) found more fish

in barrens (study included sites at Cape Banks). This work also identified ontogenetic habitat associations whereby small fish tended to be found in shallow habitats while larger ones were more common on deep and exposed reefs. Interestingly, fish recruits were found in both rocky reef and seagrass habitats (Gillanders 1997) and recently on Sydney Rock Oyster reefs (though not as common on reefs in Gamay as other estuaries in the study; Pine *et al.* 2022).

Gamay subtidal rocky reefs have been a focal point of marine microbial research in Australia since the beginning of the new millennium, through a combination of field surveys and *ex situ* experimental manipulations aimed at understanding the ecology of marine free-living and host-associated microbes, and how these interact with benthic macroorganisms (e.g., Taylor *et al.* 2005, Huggett *et al.* 2006, Swanson *et al.* 2006, Longford *et al.* 2007, Zozaya-Valdes *et al.* 2015). Temporal sampling of microbial communities associated with kelp, sponges and corals from Bare Island (as well as water, sediments and seagrass from elsewhere in the bay) have generated unprecedented data on microbial diversity (via amplicon sequencing) and function (via metagenomics and metatranscriptomics) which are currently being used to understand environmental drivers of, and connectivity amongst marine microbiomes (e.g., Phelps *et al.* 2021, Taylor *et al.* 2022). More broadly, microbial samples of kelp-associated microbes at Cape Banks and Kurnell were included in a global effort to characterise microbial diversity and function across Earth's habitats as part of the Earth Microbiome Project (Thompson *et al.* 2017b). This research also revealed the strong association between the health of the kelp host and the structure of its associated microbiota (Marzinelli *et al.* 2015), with *ex situ* experiments demonstrating how environmental change can disturb host-associated microbes, resulting in strong impacts on host health (Qiu *et al.* 2019).

The eastern blue groper, *Achoerodus viridis* (Steindacher, 1866) is a regular resident of Gamay's subtidal reefs. Image: John Turnbull www.marineexplorer.org





The extensive rock platforms at Cape Banks contain many natural rockpools.
Image: John Turnbull www.marineexplorer.org

Rocky intertidal shores

Approximately 30% of the shoreline in Gamay is comprised of intertidal rocky substrata (SPCC, 1981d). Most of the natural rocky shore area is located around the two headlands of the bay (Cape Banks and Sutherland Point), with some additional sections being found around La Perouse (Bare Island and La Perouse Point) (SPCC, 1981d) and some patchy smaller intertidal shores are found along the Cooks River and Georges River estuary (Courtenay *et al.* 2005, Gall *et al.* 2013).

In Gamay, natural intertidal rocky shores generally consist of gently sloping sandstone platforms, interspaced with crevices, rockpools, cobbles and boulders. In some areas, the rock platforms are backed by vertical cliff walls (SPCC 1981d, Fairweather and Underwood 1991), whilst at Cape Banks on the northern headland, rock platforms are backed by the Gamay Botany Bay National Park and the NSW Golf course (Matias 2008). Storms and large swells are predominantly from the south-southeast along the NSW coast (Short and Trenaman 1992, Kulmar 1995) meaning that intertidal habitats on Gamay's northern shoreline experience high wave action, particularly during storms. The intertidal rocky shore area around

Cape Banks became a Marine Scientific Research Area in 1975 (McGuinness 1988, Matias 2008), before transitioning to an Aquatic Reserve in 2002. The area is a prominent site for research on key ecological processes, including inter- and intraspecific competition (e.g., Creese and Underwood 1982) and habitat-species interactions (e.g., Creese 1982), with this review finding 96 studies including this site. Much of this ecological research used innovative manipulative experiments to test hypotheses. For example, in 1986, the site was permanently modified by the drilling of artificial rockpools to facilitate further examination of these ecological theories (Underwood and Skilleter 1996).

The intertidal communities of the rocky shores found around the Gamay headlands generally display distribution patterns similar to those found on other rocky shores in NSW (SPCC 1981d, Underwood *et al.* 1983). Small topographical features on the rock shelf including pits, crevices and rockpools can provide microhabitats and have been found to drive small scale patchiness in mobile organisms like gastropods across intertidal habitats (Underwood and Chapman 1992, Chapman and Underwood 1994, Beck 2000, Underwood 2004). In the Cape Banks area, sea-squirts (*Pyura stolonifera*), various macroalgae and/or tube-

dwelling polychaetes cover the low levels of the shore and provide important habitat for associated macro-faunal assemblages (Kelaheer *et al.* 2001, Monteiro *et al.* 2002, Kelaheer 2003a, Kelaheer 2003b). The mid-levels are characterised by encrusting algae, gastropods and barnacles, with periwinkles dominating high levels on the shore (Denley and Underwood 1979, Underwood and Chapman 1996). In comparison, on more sheltered sites around Bare Island and Sutherland Point, the substratum is mostly bare, with some encrusting algae, but little foliose macroalgae (Beck 2000). Overall, the range of species inhabiting the shoreline is higher at the mouth of the estuary than further up the estuary in the channels (Attenbrow 2010a).

Excavated middens in the Gamay area suggest shellfish, namely bivalves and limpets, were a significant part of the diet of the First Nations people of Gamay prior to European settlement (Attenbrow 2010a). First Nations people of Gamay gathered shellfish from the subtidal by diving or by collecting them from rocks along the intertidal (Attenbrow 2010a). The species and relative abundances of shellfish vary among middens and are thought to reflect locational and season variation in availability rather than community structure (Attenbrow 2010a). In Quibray Bay, the most abundant shell found in an excavated midden was the Sydney whelk (*Pyrauxa herculeus*) (Rolfe 1931). Small shellfish species (<15 mm) also found in middens were unlikely to have been harvested as a source of food, and instead are thought to have either been collected to make jewellery such as necklaces, or accidentally as they were attached to larger shellfish (Attenbrow 2010a). Molluscan shells were also used by First Nations people of Gamay to make hooks for line fishing, where the robust shells of the turban snail *Turbo torquata* were ground down into a hook shape, with only the pearly nacreous inside surface showing (Attenbrow 2010b).

Oyster reefs

Oysters were historically a key component of Gamay ecosystem (Roughley 1922, Gillies *et al.* 2020). Captain Cook, in his 1770 exploration of Gamay, reported the largest oysters he had ever seen (Ogburn *et al.* 2007). John Hawkesworth, official record keeper of HMS Endeavour reported “great quantities of oysters, mussels, cockles, and other shellfish”. Further, the large numbers of oyster shells in middens (Attenbrow 2010b) as well as place names such as ‘Oyster Bay’ and ‘Lime Kiln Bay’ (Gillies *et al.* 2018) are suggestive of historically abundant oyster reefs. These oyster reefs were a valued resource to both First Nations people of Gamay and later to European colonists who ultimately exploited these to near extinction. Despite the estimated loss of over 90% of Gamay oyster reefs (Gillies *et al.* 2020), the estuary continues to support

some of the best examples of remnant Sydney rock oyster (*Saccostrea glomerata*) reefs along the New South Wales coast, that are of high ecological value.

First Nations people of Gamay have used oysters as an important food source for over 6000 years (Jackson and Forbes 2018). Flat oysters (*Ostrea angasi*) and Sydney rock oysters (*Saccostrea glomerata*) have been found within middens from the Gamay area in large quantities, suggesting that these species were a valuable subsistence resource (Jackson and Forbes 2018). Observations from Captain Cook’s journal note that there was clear evidence of shellfish farming by First Nations men of Gamay, and that campfires were made on boats and on shore to cook oysters (Bowdler 1976). The shells of oysters were also fashioned into tools, such as fishing hooks or spear heads, including a tool that was used to pry oysters off the rocks and used to collect other resources (Bowdler 1976, Attenbrow 2010a). While there is no specific mention of the trade of oysters occurring between groups or clans within Gamay, the importance of oyster trading and its role in the economies of First Nations people of Australia is well documented (Baumhoff 1963, Evans 1969, Bailey 1975) with oysters found transported to the inland regions of the Murray Darling Basin (Clark and Hope 1985). Given the vast supply of oysters within Gamay, both flat and Sydney rock oysters, it is likely that they were also a valuable trade item.

Today, only 0.098 km² of Sydney rock oyster reef remains in Gamay, with oyster reef habitat confined to the intertidal (NSW Department of Primary Industries 2020). Much of this reef is protected by the Towra Point Aquatic Reserve. Despite its small area, this remnant reef has considerable biodiversity and fisheries value. Quarterly unbaited video sampling at Quibray Bay and Carter’s Island in Gamay from December 2017 to February 2019 revealed 44 species of fish associated with oyster reefs – a comparable number to *Posidonia australis* seagrass beds (48 species), which are commonly considered important nursery habitats, and over 60% greater than sedimentary habitat (27 species) and mangrove habitat (29 species; Martinez-Baena *et al.* 2022). Not only did oyster reefs support a greater than or equal species richness of fish to adjacent habitats, but they also supported greater fish observations (Martínez-Baena *et al.* 2022) with fish using oyster reefs to feed, rest and as nursery habitat. Ten species, including Gunther’s Wrasse (*Pseudolabrus guentheri*), several species of cryptic blennies and gobies (e.g., *Callogobius mucosus*, *Parablennius intermedius*) as well as a number of transient species were found only on oyster reefs and not in adjacent habitats (Martinez-Baena *et al.* 2022). More recently, threatened juvenile blue groper have been observed utilising remanent oyster reefs in Gamay suggesting that these rare habitats may be

an important, yet poorly known, recruitment habitat for blue groper (Pine *et al.* 2022). Further studies are needed to assess the extent to which these oyster reefs enhance fisheries productivity (as opposed to simply attracting fish away from other habitats), and the temporal and spatial scales across which fish migrate between oyster reefs and adjacent habitats.

Separate studies have addressed the spatial configuration of often patchy oyster reef in Gamay, and how this might influence its fisheries value. These found that reef-associated fish communities displayed greater richness and diversity at the edge than the interior of reefs (Erickson 2019, Pine 2020). Additionally, smaller oyster patches, proximate to other oyster patches, supported a greater richness of fish than those that were large and/or isolated (Erickson 2019, Pine 2020).

This research has contributed to the definitions of oyster reefs that are being used by the Department of Agriculture, Water and the Environment to nationally list oyster reef as an Endangered Ecological Community. Censuses of invertebrate populations associated with Gamay oyster reefs have not been conducted due to the destructive sampling methods that are required and the protected status of much of the remnant reef. However, censuses in other NSW estuaries have found a five-fold greater density, biomass and productivity of macroinvertebrates on oyster reefs as compared to adjacent sediments (McLeod *et al.* 2019), suggesting a similar habitat value may be expected in Gamay. Sampling and experiments in Woollooware and Quibray Bays mangrove forest indicate the important role oysters play in enhancing invertebrate abundances and richness in mangroves (Minchinton and Ross 1999, Bishop *et al.* 2009, Bishop *et al.* 2012, Hughes *et al.* 2014).

Intertidal oyster reef and sand flats, Towra Point. Both *Saccostrea glomerata* and *Crassostrea gigas* are present in the same colonies. The City of Sydney skyline is visible in the background. Image: RJ Whittington, University of Sydney.





Yellowtail scad, *Trachurus novaezelandiae* (Richardson, 1843) move about Gamay in large schools. Image: John Turnbull www.marineexplorer.org

Open water and pelagic systems

Open water or pelagic regions are significant habitats in estuaries and marine embayments. These habitats provide corridors for the movement and transport of species and resources important for all levels of the estuarine food web. In Gamay, the biota inhabiting open water regions consist of microbes (Bacteria, Archaea, protists, phytoplankton) as well as zooplankton, larvae, fish, invertebrates, and mammals.

Gamay is a well-studied system in terms of planktonic processes, generating a highly productive tidal discharge plume and associated tidal front (Kingsford and Suthers 1994, 1996, Reid 2021) throughout the daily tidal cycle. The highest concentrations of fish eggs and larvae, and invertebrate (barnacle) larvae have been found in the plume or front. Additionally, tidal phase is a major influence on patterns of abundance and composition of ichthyoplankton with highest abundances (primarily postflexion and juvenile) mainly occurring in fronts at low tide (Kingsford and Suthers 1996). Accumulation of marine spawned fish larvae in the plume and tidal front facilitates their transport into estuarine nursery habitats in the bay on flood tides. Conversely, larvae of estuarine spawning fish may be exported out of the estuary on the ebb tides (Kingsford and Suthers 1994). The distribution of plankton is

greatly influenced by plumes and fronts with some plankton taxa being rarely advected from the plume, whereas others were only found to occur in fronts. These flow dynamics within Gamay have the ability to influence small scale distribution patterns of fish and plankton, via retention within plumes and advection within fronts, allowing for both self-recruitment and genetic connectivity along the NSW coast. Temporally, the highest abundance of ichthyoplankton occurs in February, naturally leading to peak recruitment in April (Autumn) with a secondary peak in Spring (SPCC 1981c, b). Spatially the northern shore of Gamay has the highest levels of fish recruitment. This is likely due to the artificial structures (Port Botany and Sydney Airport runway) forming eddies whereby planktonic larvae are directed towards the northern shore and retained by these eddies (Smith and Suthers 2000).

Significant fish species within the pelagic ecology of Gamay include schooling baitfish such as sandy sprat (*Hyperlophus vittatus*) and Australian anchovy (*Engraulis australis*), and the commercially and recreationally important yellowtail scad (*Trachurus novaezelandiae*), silver trevally (*Pseudocaranx georgianus*) and yellowtail kingfish (*Seriola lalandi*). Larger fishes such as whale shark (*Rhincodon typus*) and bump-head sunfish (*Mola alexandrine*) have been sighted within the bay. Little penguins (*Eudyptula minor*) can also be seen foraging for baitfish within Gamay (Carter 2020). Mullet (*Mugil cephalus*) is also particularly important

for First Nations people of Gamay, where harvesting of Mullet around March to June is associated with a time of celebration at Frenchmans Bay and Yarra Bay, La Perouse (Fay and Linkhorn 2021). Humpback whales (*Megaptera novaeangliae*) are regularly observed off Cape Solander (southern headland of Gamay) as they migrate northwards, with occasional sightings of dolphins (*Tursiops truncatus*, *T. aduncus* and *Delphinus delphissea*), green sea turtles (*Chelonia mydas*) and fur seals (*Arctocephalus* spp.) amongst several other whale species such as dwarf minke whale (*Balaenoptera acutorostrata*), Southern right whale (*Eubalaena australis*), blue whale (*Balaenoptera musculus*), killer whales (*Orcinus orca*) and false killer whales (*Pseudorca crassidens*) also reported (Pirotta *et al.* 2020). Excavated bones of *Dugong* from an indigenous midden near Gamay suggest dugongs occurred in the area historically (Haworth *et al.* 2004), however, recent sightings along the NSW coast are rare and none have been reported in Gamay (Allen *et al.* 2004). Jelly blubbers, *Catostylus mosaicus*, have also been reported to occur in open water habitats in Gamay's main bay and the Georges River (Reid 2021).

While the macrobiota of Gamay's open water is relatively well studied, microbial components are less well documented. Ajani *et al.* (2013) documented the presence of 33 species of potentially harmful phytoplankton taxa at Woollooware Bay, close to oyster production leases. Whilst recent sequencing of 18S ribosomal RNA (V4) from water column samples collected from Towra Point and Bare Island detected 644 unique phytoplankton amplicon sequence variants (ASVs) in 428 genera from Towra Point, and 623 ASVs in 419 genera from Bare Island (McLennan *et al.* 2021). Only 43% of all phytoplankton ASVs in that study were able to be classified to species level, indicating the presence of much undocumented diversity (McLennan *et al.* 2021).

Planktonic microbe communities in Gamay are highly dynamic both temporally and spatially (McLennan *et al.* 2021). Factors impacting this variability include seasonality, which has been shown to play a role in the distribution of the 'red tide' forming microalgal species *Noctiluca scintillans*, which was highly abundant in Gamay in Spring and late Summer, forming visible water discolouration at times, and present at low levels in Winter (Murray and Suthers 1999). Spatial variability is also found in phytoplankton communities in Gamay, as a more riverine influenced site had divergent composition compared to open ocean locations (Murray and Suthers 1999, McLennan *et al.* 2021). Nutrient inputs due to riverine inflow, land runoff, and other

processes influence phytoplankton communities in an episodic manner, as can be seen by the periodic blooms of the dinoflagellate *Prorocentrum minimum*, which was significantly correlated to decreased salinity and water column CO₂ (McLennan *et al.* 2021). Movement of taxa between benthic and pelagic habitats is likely to play an important role in some planktonic processes, as temporary benthic resting stages such as cysts of planktonic species have been found in Gamay (Pollard and Pethebridge 2002, Doblin *et al.* 2010, Tian *et al.* 2018), differing spatially in relation to sediment properties. Some microbial eukaryotes from Gamay inhabit both benthic sediment, epiphytic and planktonic habitats, including bloom-forming taxa such as species of *Amphidinium*, *Prorocentrum* and *Peridinium quinquecorne* (Murray and Patterson 2010). Processes driving movement of taxa between benthic and pelagic habitats are factors such as seasonality, which is relevant for cyst germination, transport via currents, and dispersal after storms or mechanical processes.

Within coastal environments like Gamay, planktonic bacteria are both key regulators of important chemical and nutrient cycling processes at the base of the foodweb (Falkowski *et al.* 2008) and potential indicators of contamination (Newton *et al.* 2011). However, while bacterial communities associated with macrophytes and sediments have been extensively examined (Burke *et al.* 2011, Sun *et al.* 2012, Sun *et al.* 2013, Phelps *et al.* 2021), planktonic bacterial communities within Gamay have not been widely characterised to date. One exception is the work by Carney *et al.* (2019), who performed time-series analysis of bacterial communities at Foreshore Beach. This study revealed 388 bacterial Operational Taxonomic Units (OTUs), spanning 35 different bacterial genera. Notably, the bacterial community composition displayed highly dynamic temporal patterns, with rapid and intense shifts between bacterial communities dominated by a small core 'marine' assemblage (of only 5 OTUs) that were permanently present, to a 'transient' bacterial assemblage characterised by bacterial taxa flushed into the environment in, sometimes sewage-contaminated, stormwater. Notably, 52% of all bacterial OTUs at this site were present in <90% of samples, indicating a highly transient community. While seasonality was not found to influence bacterial communities within Gamay to the same extent as other coastal sites, Marine Heat Waves (MHW) impacted some planktonic bacterial populations (Carney *et al.*, 2020). MHW influenced short-lived increases (i.e., blooms) in some bacterial taxa, including members of the potentially pathogenic genus *Vibrio*, in a pattern consistent with trends emerging globally (Vezzulli *et al.* 2013).

Artificial substrates

Similar to urbanised estuaries globally, a considerable amount of artificial substrate has been added to Gamay and its associated river systems (e.g., breakwalls, groynes, piers, seawalls, pontoons). In 1981, it was estimated that 20% of the shoreline was 'hardened' through the addition of infrastructure (SPCC 1981c). A more recent estimate by the authors using satellite images available from Google Earth estimates that 40% of the shoreline of Gamay, excluding Georges and Cook Rivers, has now been altered through the addition of artificial substrate. Seawalls dominate the shoreline of the main bay (20%), followed by revetments (12%). Recent estimates made by the NSW Department of Primary Industries (DPI, unpublished) found a total of 33 jetties and pontoons in the main bay, and 39 rock groynes, which occupy an area of 22,513 m² and 32,196 m², respectively. Three-hundred and eighty artificial reef units have also been added to the main bay (see below for details).

We distinguish artificial structures installed for industrial (e.g., airport runways), recreational (e.g., jetties and pontoons), and/or coastal defence purposes, (e.g., seawalls and breakwaters) from purpose-built artificial reefs designed to enhance biological communities. Studies to date have either investigated human-made rock walls along the shoreline of Gamay (see review by Reid 2020), or concrete reef modules (reef balls) deployed subtidally to enhance recreational fishing opportunities (Folpp *et al.* 2013).

Most studies on artificial habitats in Gamay have focused on fish assemblages and how artificial reefs and/or breakwaters have influenced those (Burchmore *et al.* 1985, Folpp *et al.* 2013, Porter *et al.* 2018, Folpp *et al.* 2020). Other studies have considered the effects of artificial surfaces (e.g., fibreglass, concrete, aluminium) on biofilms (Anderson 1995) or on fouling assemblages (e.g., Underwood and Anderson 1994), or have used sites in Gamay to answer more general questions (e.g., Clark *et al.* 2015). Furthermore, although some studies used artificial substrate as sampling units, their main

Gamay contains many artificial structures that create novel habitat for the flora and fauna of Gamay. Here, the brown alga, *Ecklonia radiata* can be seen growing on the submerged part of a marine structure in Gamay. Image: John Turnbull www.marineexplorer.org



objective was to describe or explain patterns found in natural rocky shores (Anderson and Underwood 1994, Mayer-Pinto *et al.* 2016). There are no published studies conducted on fish assemblages associated with artificial substrates in either the Georges or Cooks Rivers.

The few studies of fish assemblages on rock walls have produced mixed results and they tended to make comparisons to assemblages on nearby subtidal rocky reefs (as discussed above in the [Subtidal rocky reefs](#)). Fish abundance and species richness were higher, similar, or lower than natural rocky reefs, and assemblage structure was either similar or different (Burchmore *et al.* 1985, Fowler and Booth 2013, Porter *et al.* 2018).

On the northern side of the bay, assemblage differences between smaller rock groynes and sandstone reefs of a similar size were driven by sub-adult life stages of numerous species (Fowler and Booth 2013), while mid-water piscivores were more abundant on a large revetment wall relative to nearby rocky reefs (Porter *et al.* 2018). The mixed results among studies may be due to the different types and sizes of rock walls investigated, which differ in their habitat characteristics. In contrast to other assemblage parameters, diversity was similar between rock walls and natural reefs in both studies that investigated it (Fowler and Booth 2013, Porter *et al.* 2018).

Only two papers have specifically measured the fouling assemblages on artificial habitats in Gamay (Knott *et al.* 2004, McKenzie *et al.* 2011). This is low compared to the number of studies done at the neighbouring estuary, Sydney Harbour, where > 20 studies have documented these assemblages and associated ecological processes on artificial habitats. Knott *et al.* (2004), in a study that looked at differences in the subtidal fouling assemblages between natural rocky reefs and concrete breakwalls, found that many invertebrate taxa showed clear differences regarding their cover between the two habitat types. The total cover of serpulid polychaetes and ascidians was greater on breakwalls than on natural reefs. The latter was mainly due to the large solitary ascidian *Herdmania momus*. The authors found many sponges only on natural reefs e.g., *Polymastia* sp., *Chondropsis* sp., *Cymbastela concentrica*, *Ircinia* sp., *Sponge* sp. 1 and *Dendroceratid* sp., as well as the soft coral *Capnella gaboensis*. Oysters were also mainly found on natural reefs. Only one species of sponge appeared to cover a larger area on breakwalls than on natural reefs, but this was not statistically significant.

Gamay was declared a recreational fishing haven in 2002, bringing to a halt a commercial fishery that operated for over a century. At the same time, NSW DPI Fisheries deployed reef balls in three estuaries to enhance rocky

substrate and recreational fishing opportunities (0.5 m tall, 80 kg, footprint of 0.45 m²). In June 2006, 180 reef balls were deployed in six groups on the northeastern side of Gamay (and in two other estuaries, Lake Macquarie and Sussex Inlet; Folpp *et al.* 2013). These were mostly deployed at the mouth of Yarra Bay, east of Bare Island in 5–10 m depth. The artificial reefs provided ~80 m² of artificial substrate (30 m³ reef volume), representing a ~16% increase in total area (Folpp *et al.* 2020). An additional 200 reef balls were deployed west of Bare Island during 2009. The fish communities on reef balls are often different among estuaries (Folpp *et al.* 2013, Goddard *et al.* 2021), largely due to the deployment location being near or far from the entrance (e.g., Gamay). Nearly half of the fish biomass on the reef balls in Gamay is based on plankton (the rest on algal or benthic production), which is similar to the adjacent coastal reefs (Truong *et al.* 2017, Holland *et al.* 2020). In contrast, the reef balls in Lake Macquarie, had approximately a third of fish community biomass more evenly based on plankton, macrophytes and detritus.

Mckenzie *et al.* (2011) investigated the development of epibenthic assemblages over a 2-year period on six artificial reefs, each composed of 30 Mini Bay Reef Balls® deployed in Gamay, Lake Macquarie and Georges Basin. The authors found a total of 16 taxa on the Gamay reef, which was the highest number found among the three deployments. Lake Macquarie had only four taxa and Georges Basin had nine taxa in total. Taxa found in Gamay included bryozoans, ascidians, barnacles, polychaetes, sponges, molluscs and different types of red, brown and green algae, including the habitat-forming kelp *Ecklonia radiata*.

Freshwater habitats

Gamay has two primary rivers feeding into it, the Cooks and the Georges Rivers. The Cooks River catchment is one of the most heavily urbanised catchments in Australia, dominated by commercial, industrial, and residential areas (92%), with only one small area of bushland within the Wolli Creek tributary (SMCMA 2011). The lower reaches of the Georges River catchment are also urban (Bundury Curran, Cabramatta and Prospect Creeks) but the upper reaches are in surprisingly good condition being protected in part by National Parks and the Holsworthy military areas and remain largely forested (52% of the catchment is bushland or parks) (SMCMA 2011). The bushland dominated catchment is vital to the health of the Georges River, particularly in terms of water quality influencing rainfall events. A coal mine does, however, also operate in the upper reaches with discharge into Brennans Creek (Price and Wright 2016).

Water regulation in the catchment has been significant. The freshwater wetlands around Gamay were used as a source of freshwater from 1859 up until 1889, after which these areas dried up due to the use of this water by industry (SMCMA 2011). The Georges River is about 96 km long with a catchment of around 96,000 ha and a discharge of >300 GL per year. The Cooks River is small by comparison, just 23 km long with a catchment size of 10,900 ha entirely within the City of Sydney. With a discharge of around 200 GL per year, the Cooks freshwater reach is nearly entirely comprised of concrete drainage ditches and much of the flow occurs through pipes (89% is artificial). The Cooks River is mostly estuarine whereas the Georges is estuarine for nearly half its length up to the Liverpool Weir. Water capture and regulation for drinking water, agriculture and industry occurred at several locations in the Georges River Catchment. Some examples include a weir built at Liverpool to damn the Georges River and block saltwater intrusion in 1836, the Prospect Reservoir dammed the headwaters of one of the north-western tributary flows into the Georges River in 1888 and the Woronora Dam was built in 1941 which contains water from most of the undeveloped catchment to the south of the estuary. These structures created significant barriers to fish passage along the estuaries.

Few studies have investigated the flora and faunal communities of Gamay's freshwater habitats. However, water quality, benthic diatoms and macroinvertebrates in Gamay's freshwater tributaries are monitored by both the Cooks River Alliance and the Georges Riverkeeper program. The Georges River is also known to be home to the endangered Macquarie Perch (Faulks *et al.* 2011). Other native freshwater fish species known to occur in the river include several species of gudgeons (Hammer *et al.* 2019), galaxids, smelt, Australian bass (Harris 1985) and long and short-finned eels. Mullet also migrate upstream but it is unclear how they navigate the weirs and penetrate into freshwater reaches. Multiple fish ways have been installed but fish passage for anadromous and catadromous fishes is of concern. Far more research is needed examining the freshwater fishes of the catchment. In the Georges River, platypus can still be found but they are restricted to an area near Campbelltown (Hawke *et al.* 2019). Whilst there are no formal records of freshwater mussels occurring in the Georges River, there are reports of First Nations people of Gamay eating them in the area (Attenbrow 2010b). First Nations people of Gamay are also reported to have sourced eels and wood boring worms, which they called *cahbro* from the upper reaches of the river.

Photo shows the highly modified banks of the Cooks River. An example of traditional shoreline hardening can be seen on the far side of the river, with the near side showing a hardened shoreline that has been naturalised using a technique called channel naturalisation.
Image: J. Dahlenburg



Threats and challenges to Gamay

Gamay's long history of exploitation and modification in conjunction with the enormous changes within the catchment including land-clearing, industrialisation and urbanisation since European settlement has left little of the Gamay ecosystem untouched by anthropogenic influence (see [History of Gamay](#)). Historically, untreated industrial, commercial and urban waste was disposed of directly into the bay, its aquifer and tributaries. During these times, multiple closures of these waterways to swimming and/or fishing occurred, with the Cooks River still being considered one of Australia's most polluted waterways. As a result, Gamay has been left with a legacy of contamination. Since European settlement, pressures associated with urbanisation of the Gamay catchment have intensified due to population growth and urban development. Extensive modification of the bay through dredging, land reclamation and shoreline hardening has significantly altered the size and shape of Gamay. Dredging directly removed much of the shallow, sandy habitats in the bay, whilst associated changes to the bay's bathymetry have hydrodynamics and sediment movement in the bay. The construction of Port Botany

(and later expansion to increase transport capacity) required land reclamation and shoreline hardening which not only significantly modified the shape of Gamay but also encouraged connectivity between Gamay and the rest of the world. This has led to changes in circulation and an increased likelihood of exotic and non-indigenous species being detected in Gamay. At the time of writing, there are multiple infrastructure development projects in the proposal phase for Gamay, suggesting that the habitats and communities of Gamay will likely continue to face threats and challenges associated with human activities well into the future.

In this section, we review and present what is currently known about these threats and challenges. We then use the results of our systematic literature review process to discuss how these threats and stressors relate specifically to Gamay, and present what we believe to be the most concerning gaps in our current knowledge. Further discussion of the threats facing Gamay can be found in the NSW Government's threat and risk assessment for the Hawkesbury Shelf Marine Bioregion which incorporates Gamay (BMT WBM 2015).

Sandy beach and public foreshore reserve, Gamay Botany Bay National Park, with adjacent wharf installation and commercial shipping. Image: RJ Whittington, University of Sydney.



Contamination

Sediment contamination

Industrial discharges, until regulation in the 1970s, have caused an accumulation of legacy contaminants in Gamay. Sediments in Gamay and Georges River are contaminated with heavy metals, polyaromatic hydrocarbons and phosphates that often exceed levels in other Australian estuaries (Brown and Maher 1992, Birch 1996, Hayes *et al.* 1998, Spooner *et al.* 2003, Albani and Kollias 2005). Birch (1996) found that copper (Cu), zinc (Zn), nickel (Ni) and lead (Pb) are concentrated in the upper reaches of the estuary and bay ends, while the lower reaches and mouth areas tend to be at background levels. The uncontrolled discharge of waste from manufacturing into Salt Pan Creek created a significant contaminant hotspot (Alyazichi *et al.* 2016). Inputs from point and non-point discharges of stormwater provide an ongoing source of dissolved and gross pollutants. Recent subtidal sediment cores found Cu (0–30 ug/g in the bay and 20–149 ug/g in the river), Pb (2–27 ug/g in the bay and 3–98 ug/g in the river) and Zn (6–210 ug/g in the bay and 15–330 ug/g in the river) concentrations to be highest around the Caltex Wharf and lowest at Brighton-Le-Sands (Dafforn *et al.* 2012). Metal concentrations were generally lower further up the river towards Bottle and Glass Head, while Cu was highest in the Kogarah Bay storm drain and Pb/Zn were highest at Horse Rock Pt. Sources of polycyclic aromatic hydrocarbons (PAHs) in Gamay are likely combustion products entering through point discharges from marinas and boating activities as well as more generally through atmospheric fallout (Brown and Maher 1992). Individual PAH concentrations range from <0.1–5600 ug/kg indicating levels that exceed ANZECC sediment guideline values in some locations (Simpson *et al.* 2007). The highest contaminant values are associated with finer grain sizes and organic matter suggesting that the distribution of these contaminants after entering the estuary and bay are influenced by sedimentation processes. The distribution of contaminants is strongly influenced by sediment size and hydrodynamic processes in Gamay resulting in reduced ecological risk in the bay and enhanced risk in low-energy areas of Cooks River estuary and some tributaries of Georges River (Birch *et al.* 2022).

Extensive research has been undertaken on sediment quality in Penrhyn estuary (AGEE and Woodward Clyde 1990, Kinhill Engineers 1990, Kinhill Engineers 1991, Woodward-Clyde 1996, URS Australia 2004b). Here, concentrations of mercury in sediments were found to exceed ANZECC (2000) Interim Sediment Quality Guidelines ISQG in samples collected in December 2003 at most sites within Penrhyn Estuary, with

concentrations up to 183 mg kg⁻¹. Mercury was not detected in sediments collected in the outer estuary near the derelict groyne and jetty (URS Australia 2004b). The maximum chromium concentration was 130 mg kg⁻¹, exceeding the ANZECC (2000) ISQG-L guideline value, but the mean concentration of chromium was 17.3 mg kg⁻¹. Hexachlorobenzene (HCB) has been recorded in concentrations up to 2.2 mg kg⁻¹, ANZECC (2000) has no guideline for this compound (URS Australia 2004b). The semivolatile CHC hexachlorobutadiene (HCBd) is likely present in sediments, but there are no data on current sediment concentrations in Penrhyn Estuary. These semivolatile CHCs adhere to sediment particles and have the potential to accumulate in sediment ingesting benthic invertebrates, fish and other aquatic animals. Sediment sampling has also been undertaken in the Scarborough Ponds and these were found to exceed ANZECC guidelines for a number of heavy metals (see SMCMA 2008). The likely source of the heavy metals is from past industrial practices (tanneries, electroplaters) and current urban stormwater runoff.

Water contamination

The impervious nature of the Gamay catchment means that stormwater often runs quickly and directly into the main river channel and eventually into the bay, bringing with it all the usual pollutants and nutrients (Tippler *et al.* 2012). Rainfall induced urban runoff produces periodic stressors to planktonic communities, influencing phytoplankton and bacterial communities, that may cause cascading impacts to the pelagic foodweb. At Foreshore Beach within Gamay, stormwater inputs and periodic wet weather sewer overflow events are the principal drivers of changes in planktonic bacterial communities. Notably, Carney *et al.* (2019, 2020) revealed strong correlations between stormwater input and the relative abundances of enteric bacterial genera belonging to the *Arcobacter*, *Acinetobacter*, *Bacteroides*, and *Cloacibacterium* genera, with some of these organisms representing potentially dangerous human pathogens. This is consistent with the data collected in the regional water quality monitoring program [Beachwatch](#), which uses Faecal Indicator Bacteria (FIB) and has revealed that this site is regularly characterised by high FIB counts, indicative of sewage-associated microbial contamination.

Additional work by Carney *et al.* (2020) also revealed that the shifts in microbial communities associated with stormwater and wet weather sewage over-flow events coincide with significant increases in bacteria possessing antibiotic resistance (AbR) genes, which represents a potential human health risk for recreational users of Gamay. Cumulatively, this body of work indicates that run-off from stormwater, which in this system is occasionally contaminated with sewage, can

influence the composition of bacterial assemblages within Gamay, leading to a shift in the community from archetypal marine genera to enteric bacteria, which potentially threatens both the ecosystem and human health. Sewage impacts on intertidal organisms in Gamay have also been detected, with proximity to a shoreline sewage outfall on Kurnell Peninsula affecting the abundance of some intertidal organisms on adjacent rocky shores (Bishop *et al.* 2002). This study also highlights the potential for contamination sources outside the bay to influence communities within Gamay.

There are several deep groundwater plumes up the gradient of Penrhyn Estuary and Gamay characterised by high concentrations of ethylene dichloride (EDC). The Southern Plume is currently discharging approximately 350 m³ day⁻¹ of contaminants, mainly EDC and TCE into the intertidal areas between Springvale and Floodvale drain channels with representative surface concentrations of EDC in the range of 1.1 to 0.019 mgL⁻¹ and concentrations at 2 m depth ranging from 0.112 to 19.2 mgL⁻¹. The maximum concentration of EDC occurs at low tide, when there is no dilution by seawater, and is at a minimum at high tide. Similar trends occur for other contaminants. It is estimated that approximately 0.2 kg day⁻¹ of volatile chlorinated hydrocarbons (CHCs) enters Penrhyn Estuary from the Southern Plume (URS Australia 2004a). Modelling has demonstrated that reduction of ethene compounds in the intertidal zone is due largely to dilution with seawater within a zone of groundwater diffusion rather than degradation of the compounds *in situ*. The Northern Plumes extend in a southwest direction from Botany Industrial Park and have core concentrations of EDC in the range of 100 to 200 mgL⁻¹. Its front, with EDC concentrations of 10 mgL⁻¹ is about 300 m wide at present. The Central Plume was predicted to discharge in the intertidal zone between Floodvale and Springvale drains by February 2006 and is the focus of Orica's groundwater interception activities. It has higher core concentrations of volatile halogenated compounds (VHCs) compared to the southern plume (greater than 5000 mgL⁻¹) and therefore potential to result in higher concentrations being discharged to the estuary. Interception and treatment of the central plume is the focus of the current cleanup activities and of this report.

Biota contamination

Heavy metals have a significant effect on benthic macrofauna (Chariton *et al.* 2010, Dafforn *et al.* 2013, Birch *et al.* 2018) and microbial communities (Sun *et al.* 2012, Sun *et al.* 2013) in estuaries in the Sydney basin, including Gamay. Specifically, copper pollution affects cumaceans, amphipods, and spionid, syllid and

capitellid worms (Morrisey *et al.* 1995, 1996). Cooks River has the most contaminated sediments in the bay. Toxicological studies have characterised them as 'highly toxic', meaning that they increase death of infauna by 20 times in comparison to a reference site (McCready *et al.* 2004). Metal contamination has been detected in beaches, but minimal effects of these contaminants were observed on fish communities (McKinley *et al.* 2011), while there have been no assessments of their effects on infaunal communities in these habitats.

Multiple studies have identified the presence of contaminants in fish and invertebrates in Penrhyn Estuary, particularly hexachlorobenzene (HCB) and mercury (The Ecology Lab 1995, 1998). HCB was detected in every species of fish, in a total of 88% of individuals, with sea mullet having the largest concentrations (maximum: 0.479 mg kg⁻¹ ww), followed by silver biddy (0.340–0.343 mg kg⁻¹ ww; The Ecology Lab 1998). Mercury was detected in the muscle tissue of sea mullet, silver biddy, dusky flathead and bream. The presence of contaminants in fish tissue have also been detected in fish in the Georges River, with fishing now [banned](#) in some parts of the Georges River and all of the Cooks River due to significant health concerns (Roach and Runcie 1998). Experimental research undertaken at Cape Banks has shown that chemical disturbances can negatively impact rocky intertidal communities, both directly by reducing the abundance of organisms, and indirectly by reducing biofilm food availability in intertidal habitats (Mayer-Pinto and Ignacio 2015, Mayer-Pinto *et al.* 2015b, Mayer-Pinto *et al.* 2016).

Habitat modification

Gamay has undergone enormous levels of modification. By the 1980s, over 12 km (approximately 20%) of Gamay's shoreline was already composed of artificial substrata in the form of rock groynes, revetment walls, training walls and wharves (SPCC 1981d). Substantial areas of the bay have been converted into land (e.g., Port Botany, Sydney Airport runways) with the loss of seagrass, mangroves, saltmarsh, intertidal and subtidal soft sediments and the water-column (see [Artificial substrates](#)). The loss of these habitats has had direct costs for the ecological functioning of the bay and negative effects on the cultural, social and economic values of these habitats. Visual estimations from Google Earth suggest currently, however, this value sits closer to 40% of the shoreline (excluding Georges and Cook Rivers) now consisting of artificial substrate. This value is likely to increase over time as properties along the shoreline install seawalls to try and protect their assets from rising sea levels.

Numerous small artificial structures have also altered the biological diversity, the localised habitats and movement of water and sediments (e.g., groynes, pier pilings, jetties, pontoons, marinas) of the bay. Although less intrusive than the large-scale modifications, these small-scale modifications are becoming more frequent and have small-scale effects as well as potentially cumulative effects. Infaunal communities in sediments 2 m from a breakwater in Gamay were observed to be different to those 10–13 m from the breakwater, indicating effects of foreshore infrastructure on the ecology of surrounding sediments (Barros 2005). It is unclear, however, what those community changes are, the full extent of these effects around the structure, and the generality of these findings (as this study was done in only one location). Moreover, it is unclear if the effects of foreshore infrastructure on surrounding sediments are similar to those observed for natural habitats such as rocky shores (Barros *et al.* 2001, Barros 2005) and oyster reefs (Bugnot *et al.* 2022) in Gamay.

Dredging of the bay's shipping channels has also affected the connectivity of the bay (see [Hydrology and oceanography](#)). Estimates from the 1980s, indicated 550 ha of the bay had been dredged and 140 ha reclaimed, together representing about 15% of the bay area having been modified (Jones 1981). Since then, a further 220 000 m³ has been dredged and 63 ha reclaimed for the Port Botany expansion (URS Australia 2009b, Davies and McIlquham 2011). Dredging and land reclamation practices have had detrimental impacts on the beaches in Gamay that have required interventions including extensive sand nourishment and the construction of rock groynes to maintain their shorelines (Aijaz and Treloar 2003, Frost 2011). Furthermore, in the case of Currewol and Yarra Bay, the construction of the adjacent port revetment wall may have amplified the erosive effects of the storms in 1974 and 2016 by reflecting waves onto previously sheltered shores (McGuinness 1988, Gallop *et al.* 2020). Beaches in Gamay can take decades to recover lost sediment, while some (e.g., south end of Lady Robinsons) have struggled to recover and persist as eroding *storm-relicts* (exhibit negligible recovery between storms) (Fellowes *et al.* 2021). In comparison, Congwong, Little Congwong and Towra Point present *quasi-stable* behaviours (limited decadal-scale change). Currewol, Yarra Bay and Kurnell showed *retreating* behaviours (partially recover between storms) (Fellowes *et al.* 2021) before groyne construction and stitching to *quasi-stable* after, and the north end of Lady Robinson that is now sheltered by the Airport is *prograding* (shoreline migrating seaward) (Fellowes *et al.* 2021).

Dredging has changed the depth of subtidal sediments (Sydney Metropolitan Catchment Management Authority 2008), as well as the grain sizes, shifting once sandy sediments to muddy, and driving reductions in biodiversity and abundance of infaunal communities (Jones 1981, Jones and Candy 1981). Dredging is a strong disturbance, which completely depletes sediment infauna over short time frames, and even though there is some evidence of recovery one year after dredging, particularly in sandy sediments, it is unclear whether full recovery is achieved (Wilson 1998). Interestingly, it seems that dredged areas at the mouth of the bay might be having a positive effect on infauna biodiversity, possibly by creating deeper areas more protected from waves (Jones and Candy 1981).

Dredging can resuspend sediments in the pelagic environment of Gamay, some of which contain high levels of heavy metals, which in turn impact filter feeding invertebrates (Hayes *et al.* 1998). Habitat loss and degradation associated with dredging and land-reclamation practices have also likely had a negative influence on wild oyster reefs in the bay (Esquivel-Muelbert *et al.* 2022, Beck *et al.* 2011, Gillies *et al.* 2020, Reid and Bone 2020), where populations have not recovered despite fishing restrictions being in place in Gamay since 2002. Dredging also likely led to the destabilisation of seagrass beds in Gamay, resulting in significant fragmentation and declines (Larkum 1976a, Reeds 2018, Blount 2019). More recently, configuration dredging in the entrance to the bay in 1980 to 1990 led to increased wave-action along the exposed Southern shoreline of the bay, negatively impacting seagrasses around Towra Point (Larkum 1976a). Groynes built from 1990 to 2010 have acted to stabilise the seabed along Silver Beach on the southern side of the bay (Blount 2019), whilst modification of the configurational dredging in the entrance to the bay following 1990 alleviated some of the severe wave-action on southern side of the bay following that date.

Artificial structures (e.g., boating-related infrastructure) create and modify environments by modifying natural habitats and introducing novel habitats for marine communities. They can also negatively impact communities if habitats are changed or altered to the point where those communities can no longer persist. Boat moorings are ubiquitous in sheltered bays and embayments in urban areas and can have significant negative impacts on marine communities (Glasby and West 2018, NSW Department of Primary Industries 2020). Seagrass loss can occur in the regions directly surrounding moorings as heavy chains attached to the mooring scour the benthos as the boat moves on the

surface (Demers *et al.* 2013, Glasby and West 2018). This process can fragment seagrass meadows and reduce their resilience to other stressors (Demers *et al.* 2013). Similarly, shading from marine infrastructure (e.g., jetties and pontoons) can restrict the growth of macrophytes and if persistent for long periods of time and may lead to permanent loss (Fitzpatrick and Kirkman 1995).

At present, most of the permanent moorings, jetties and pontoons in Gamay are in the Georges River, with few occurring in Gamay's main bay. At the time of writing, however, the NSW Government has multiple boating-related developments for Gamay in the proposal phase. Gamay has been identified as the most viable location to construct a third international cruise ship terminal for Sydney (NSW Government 2018). Also, a proposal is currently being put forward to construct wharves on Gamay's north and southern headlands to accommodate commuter ferries (Fay and Linkhorn 2021). Developments such as these will likely place additional pressure on many ecological communities and habitats, either directly via the removal or degradation of habitats and/or shading from permanent infrastructure, or indirectly via artificial light, sedimentation, turbidity and altered circulation patterns (Fay and Linkhorn 2021). Propeller wash from ferries and other vessels using the wharfs can also create scour channels which harm and destroy nearby habitat and their associated fauna, with many habitats unable to re-establish with continuous vessel usage (Fay and Linkhorn 2021).

Human recreational activities such as walking or the use of recreational vehicles are common in the coastal wetland habitats in Gamay. These activities directly impact habitat by changing the topography of the saltmarsh surface causing mounds and ruts, and altering drainage patterns (e.g., salinity and waterlogging). They can also cause significant damage to vegetation and disturb/kill macroinvertebrates and shorebirds (Clarke 1993, Ross *et al.* 2009, Adam 2010). Indirectly they can also impact macroinvertebrate recruitment and larval supply from these habitats into estuarine waters which can affect fisheries production (Mazumder *et al.* 2006, Ross 2006, Taylor *et al.* 2018).

In addition to the physical impacts to habitat discussed above, there have been modifications to some habitats that although not as obvious, have nonetheless been detrimental to some ecological communities. Foreshore development within Penrhyn Estuary, in the north of Gamay, has increased disturbance generally to shorebirds by increasing noise, artificial light and visual amenity. Changes to turbidity and flushing have also modified subtidal habitats in these areas (see [Nutrients and turbidity](#) for further details on this threat).

Habitat modification has also removed environmental signals for recruitment in Gamay, this can lead to an urbanised fishery based on higher trophic level bream and predatory sportfish, rather than prawns and planktivores (Taylor and Suthers 2021). With increasing urbanisation in Gamay, fish recruitment will likely continue to be supplemented by semi-annual restocking of hatchery reared, juvenile fish (e.g., mulloway, kingfish, flathead; Becker *et al.* 2022), with further artificial reef deployment also highly likely, particularly in the broad areas of unconsolidated sandy sediments.

Changes to hydrology and circulation

The enormity of modifications to Gamay's shoreline and its main basin from dredging has not only led to the requirement for regular beach nourishment at many of Gamay's beaches to mitigate erosion (see [Soft bottom and beach habitats](#)) but has also led to massive alterations to natural flushing. Circulation and flushing not only control how effectively poor-quality water (in terms of nutrient levels, dissolved oxygen and contaminants) around point sources of pollution or stormwater inflows can be dispersed and ultimately transported out of the bay and into the ocean, but also the efficiency of critical inputs to some habitats. The sustainability of seagrass beds, for example, is as much reliant on good water quality as it is on the dispersal of seeds into previously occupied areas that may have been destroyed by storms. Likewise, fish and invertebrate communities can be dependent on water quality and larval supply.

The effects of changes to hydrology and circulation in Gamay that are a consequence of modifications to its shoreline are most evident in its northwestern parts where extensions to Sydney Airport's runways and port arms have created obstructions to circulation and pockets of less well-flushed water. The historical losses of large beds of seagrass at Foreshore Beach (see [Seagrasses](#)) are the most obvious example of the potential consequences of this type of threat.

Neo biota: exotic and non-indigenous species in Gamay

Gamay supports extensive maritime industries and is home to one of the largest container ports in NSW (Port Botany). Gamay is accessed by international and inter-state shipping, making its ecosystems vulnerable to marine invasive species. These non-indigenous species are likely to be introduced to the port by one of three mechanisms: 1. directly to the port by

ships using the port, either in ballast water or by hull fouling; 2. by domestic translocation via fishing and recreational vessels; or 3. by natural range expansion of species introduced to other parts of the south-eastern coast of the Australian mainland. One study undertaken in Port Botany, interestingly found only one Australian Ballast Water Management Advisory Council target for introduced marine pest species, the toxic dinoflagellate *Alexandrium* sp. (Pollard and Pethebridge 2002). An additional 33 introduced and/or cryptogenic (i.e., status unknown) species were, however, also detected. These included two species of algae, two species of polychaetes, four species of hydrozoans, one anthozoan, ten species of crustaceans, thirteen species of bryozoans and one ascidian.

Whilst shipping related activities remain a major avenue for the introduction of species into Gamay, the artificial substrate of infrastructure related to shipping activities can also foster the establishment of non-indigenous species. Little information currently exists on the type, extent and proportion of exotic and invasive species specifically inhabiting artificial substrates in Gamay, however, artificial substrates in other regions have been found to harbor disproportionately high abundances of exotic invertebrate species (Sheehy and Vik 2010). If structures in Gamay develop similar assemblages, the removal and transport of existing structures, as well as the addition of new structures, may increase the spread of such species.

In comparison, despite being less susceptible to pest invasion than hard substrata, introduced and cryptogenic species have been recorded in sediment habitats in Gamay (Pollard and Pethebridge 2002). *Caulerpa taxifolia* is an introduced green alga which when it was first introduced was particularly abundant in Quibray Bay (Glasby 2013), although also occurred in other areas including along Silver Beach. *C. taxifolia* is still present in Gamay, but not abundant. *C. taxifolia* can substantially change the habitat provided by unvegetated sediment, impacting the structure and function of faunal assemblages (Gribben *et al.* 2009a, Gribben *et al.* 2009b). The impacts of *C. taxifolia* also go well beyond its beds because its decomposing fronds negatively affect macroinvertebrate assemblages in unvegetated sediments in Gamay (Taylor *et al.* 2010, Bishop and Kelaher 2013b). Experiments in Quibray Bay and in Port Hacking demonstrated, however, that although *C. taxifolia* grew amongst seagrass and was occasionally more abundant in areas that had previously been colonised by seagrass, the alga was not directly impacting seagrass and instead was an opportunistic invader that primarily colonised non-vegetated areas (Glasby 2013).

The European green crab (*Carcinus maenas*) is another introduced species and has been recorded in sediment habitats in many estuaries in southern NSW and, historically, in Gamay (Pollard and Pethebridge 2002). *C. maenas* is a generalist benthic predator that has impacted aquaculture and native species overseas (Garside *et al.* 2014). The current impact of *C. maenas* in Gamay is negligible, as recent surveys failed to find any individuals (Pollard and Pethebridge 2002). Its potential threat will decrease in the future as the range of *C. maenas* shifts further south in response to ocean warming.

The non-native Pacific oyster *Crassostrea gigas* (also named *Magallana gigas*) is present within Gamay. The exact arrival of *C. gigas* to Gamay remains unclear, however Pacific oysters were likely illegally introduced for aquaculture and have been present in NSW estuaries in low abundances from 1967 (Medcof and Wolf 1975, Scanes *et al.* 2016).

There are also several species of introduced polychaetes that have been found in Gamay including, *Boccardia chilensis* and *Capitella capitata* (Pollard and Pethebridge 2002). Originally from California, *C. capitata* is relatively common in Gamay, particularly in organically enriched sediments. *C. capitata* is part of a complex set of sibling species with different reproductive modes (Grassle and Grassle 1976). Taking advantage of reproductive flexibility, populations of *C. capitata* can grow rapidly. As *C. capitata* is a non-selective subsurface deposit feeder, its burrowing activities contribute to the biomineralization of organic matter in enriched sediments.

The most recent known introduced species in Gamay is the polychaete *Sabella spallanzanii*, which was detected in 2013 on rocks and dead shells near the mouth of the bay in 10–12 m of water (Murray and Keable 2013). Subsequent surveys have detected the species on a range of artificial substrata throughout the bay, although it is relatively uncommon (DPI unpublished data). The species is, however, capable of colonising large areas of soft sediment, modifying the composition of associated macrofauna and microphytobenthos and indirectly affecting nutrient cycling (Ross *et al.* 2013).

The introduced Spiny Rush *Juncus acutus* has also been found in wetlands in Gamay where it displaces the Native Rush, *Juncus kraussii* and changes saltmarsh dynamics (Harvey *et al.* 2011). Invasive fish species are also a significant threat in Gamay, with European Carp (*Cyprinus carpio*) and Mosquito Fish (*Gambusia holbrooki*) present in the freshwater reaches (Sydney Water 2018) as well as invasive gastropods (Shield *et al.* 2014).

Pathogens and disease

Gamay is a well-connected and highly modified bay, with an extensive history of human interference, making it highly susceptible to pathogens and disease. Intense urbanisation of coastal areas often results in microbial communities associated with human waste entering coastal waterways. In Gamay, storm events were found to increase microbial diversity in the sediments of Foreshore beach (Carney *et al.* 2019). An increase in human pathogens in sediments was also detected after storm events (Carney *et al.* 2020) (see [Contamination](#) for more details). Algal and cyanobacterial contamination has also been registered after rainfall in waters from Foreshore Beach, and in lower levels in Oatley Bay Baths and Crass Point Baths, with Foreshore Beach classified as the least swimmable beach in Gamay (State of NSW 2019).

Harmful algal blooms are a threat to the aquaculture industry, recreational fishing and ecosystems in Gamay, as they can lead to deaths of marine life. Species producing harmful toxins occur 10–30 times per year at detectable levels (Ajani *et al.* 2013) and high biomass blooms of other phytoplankton species (Murray and Suthers 1999, McLennan *et al.* 2021) are also common. Blooms of the paralytic shellfish toxin (PST) producing species *Alexandrium pacificum* (as *A. catenella*) occur regularly in Gamay, including up to 10^3 cells L^{-1} , a level which results in PST uptake into shellfish and the closure of shellfish harvesting (Murray *et al.* 2011). Cysts of this species have also been found in the area (Tian *et al.* 2018).

Diseases and parasites have been a major source of oyster mortality in Gamay, both within wild oyster reefs and aquaculture populations, with the two often situated in close proximity. The principal problems are mudworm, QX and winter mortality in *S. glomerata* and ostreid herpesvirus in *C. gigas*. Little is known about the source of these pathogens or their exchange between wild and cultivated oysters. Mudworm (*Polydora websteri*) was first recorded in *S. glomerata* in Gamay in 1888 and is thought to have been introduced with oysters from New Zealand (Nell 2001). The larvae of this polychaete form cavities in oyster shells increasing susceptibility to stressors and often causing mortality in the oyster (Nell 2001). Some claim that the mudworm was responsible for the loss of all subtidal oyster reefs in NSW coast including in Gamay (Nell 2001, Ogburn *et al.* 2007). These claims, however, need to be balanced with the impacts of overharvesting.

The disease named ‘winter mortality’ was first observed in *S. glomerata* in Gamay around 1920 (Roughley 1922) and its cause, although probably infectious, remains unclear. QX (short for Queensland Unknown) disease, which is caused by a protistan parasite, causes major economic losses in *S. glomerata*. These species have served as a major selective pressure on oysters in Gamay, with wild *S. glomerata* displaying low genetic diversity relative to hatchery-sourced aquaculture stock (Thompson *et al.* 2017a). To address disease-mortality of aquaculture stock, adaptive husbandry and selective breeding of oysters resistant to QX disease and winter mortality have been used based on natural exposure to disease in Gamay (reviewed in Reid and Bone 2020). The products of research into QX disease conducted in Gamay have been exported to oyster producers throughout NSW (Dove *et al.* 2013).

Government-approved, commercial production of functionally sterile triploid *C. gigas*, otherwise an introduced pest species, escalated in Gamay as a replacement for disease-prone *S. glomerata*. However, within a few years *C. gigas* was afflicted by ostreid herpesvirus (*OsHV-1*) (Jenkins *et al.* 2013). Research has identified an environmental source of the virus, including planktonic carriers of the infection, warmer water, husbandry responses and the exchange of infection between wild and cultivated oysters and other invertebrates (reviewed in Whittington *et al.* 2018, Whittington *et al.* 2019). A national breeding program to develop *OsHV-1* resistant oysters is also centred in research in Gamay (Australian Seafood Industries 2017).

Apart from the mass mortalities of sea urchins recorded in the 1980s and summarised by Reid (2021), most information associated with stressors and threats to sea urchins in subtidal habitat in Gamay must be gleaned from studies elsewhere. The exception to this is a long-term study on the increase in prevalence of the opportunistic pathogen, *Vibrio anguillarum*, on *H. purpurascens* that positively correlates with increases in sea surface temperature in the bay (Sweet *et al.* 2016). Transmission of the pathogen is also temperature-dependent for *H. purpurascens* and *H. erythrogramma*, suggesting that any observed increases in disease in these species are likely to increase at a greater than linear rate in the future (Sweet *et al.* 2016). Recent research has also shown that changing environmental conditions can disrupt host-pathogen interactions in macroalgae, having significant implications for algal health on subtidal reefs in Gamay (e.g., Campbell *et al.* 2011, Campbell *et al.* 2012, Fernandes *et al.* 2012). Any future declines in kelp or algae in subtidal habitat at Gamay is also likely to be coupled with a decrease in health of the urchins residing in the bay, and potential mortality.



Recreational fishers can often be seen fishing along the shores of Gamay.
Image: John Turnbull www.marineexplorer.org

Fisheries in an urban estuary

An 1880 Royal commission into the state of Australian fisheries identified Gamay as Sydney's most productive fishing ground, but also stipulated that without legislation this would likely be short lived. In response to this in 1881 the Fisheries Act was introduced. Commercial fishing continued in Gamay, however, until 2002 when the bay was declared a Recreational Fishing Haven (RFH). This action reflected the importance of recreational fishing within the bay. Since the declaration of the RFH, it is likely that recreational fishing in the bay has grown in popularity.

The recreational fishing community within the bay is quite engaged in efforts to improve fish stocks and habitats, supporting a variety of efforts in this space.

This ethos and a focus on catch-and-release, provides the basis for ongoing opportunities for effective management within the bay. But of course, there remain challenges as even catch-and-release fishing within the bay has been shown to be associated with significant post-release mortality (about 30%) and hold time seems important. Popular species such as snapper and bream tended to die within 3 hours of release while trevally and flathead mortality was somewhat more delayed, extending out over 4 days (Broadhurst *et al.* 2005). There is also more general evidence that overall anthropogenic activity, as occurs within Gamay and the greater Sydney region in general, can have negative effects on the occurrence of a key recreational fisheries species, snapper (Rees *et al.* 2021).

The collection of intertidal organisms in NSW is regulated but remains difficult to enforce, meaning that little is known about the ecological implications the removal of these organisms may have on biotic interactions and wider ecosystem functioning (but see Kingsford *et al.* 1991, Monteiro *et al.* 2002). At Cape Banks, the area from the bridge to the Endeavour Light House at the Henry Head and 100 m seaward from the mean low water mark is an Aquatic Reserve covering c. 20 ha (NSW Department of Primary Industries ND). Within the reserves, the collection of marine invertebrates or empty shells is prohibited, except abalone and rock lobsters (NSW Department of Primary Industries ND). Of the marine vegetation, only sea lettuce and bait weed can be collected (NSW Department of Primary Industries ND). Gamay is, however, impacted by occasional illegal collection, with Fisheries Officers recording 469 offences in the past 10 years (2011–2021, data extracted 30.11.2021) in the areas of Cape Banks, La Pouse, Bare Island and Inscription Point. All offences were related to the collection of intertidal invertebrates, with some offences related to multiple activity types. The most common items seized were Turban snails and sea urchins, although other items (e.g., other molluscs, crabs, fish) were found as well.

Nutrients and turbidity

The Gamay catchment contains a mix of bushland and rural areas, largely to the southwestern side of the catchment as well as urban areas, including commercial, industrial and residential areas, primarily focused in the Lower Georges River Catchment, the Cooks River catchment and areas draining directly into the Gamay. Although a large proportion of the catchment is still bushland (42%) and parkland (5%), historical changes to land-use in the catchment have affected run-off and groundwater and had flow on effects on sediment and to a lesser degree nutrient levels within Gamay (as seen elsewhere in the world – Roberts 2007; catchment modelling by SMCMA 2011).

NSW Office of Environment and Heritage determined that indicators of good ecosystem quality for coastal estuary/embayments would be high water clarity, low Chl-*a* concentrations and very small amounts of green nuisance macroalgae among the seagrass (SMCMA 2011). Gamay currently meets condition thresholds for both Chl-*a* (annual average of 1.9 mg/L) and turbidity (annual average of 1.3 ntu) although for Chl-*a* the current value sits exactly on the threshold, indicating the system is at best close to transitioning to a slightly to moderately disturbed state. The value and buffering capacity of remaining bushland is vital to the water quality of Gamay as is the control of nutrients and sediment input from all of its catchment's land uses.

Climate change

Sea-surface temperature rise

Gamay is located off the south-eastern coast of Australia, a region experiencing accelerated oceanic warming associated with climate change (Ridgway 2007). Estuaries in eastern Australia are generally warming even faster than this, with urbanised catchments showing some of the most significant warming (Scanes *et al.* 2020). Warming temperatures have the potential to alter the structure of marine food webs as species expand or contract their ranges as they track changing thermal gradients. Ocean warming can also affect macroalgae directly (e.g., affecting their morphology or physiology) and/or indirectly, through changes to ecological interactions with other species, such as herbivores and microbial pathogens (Campbell *et al.* 2011, Campbell *et al.* 2012). Temperature increases are perhaps less likely to be an issue for seagrasses in Gamay given that the species are not near the edges of their geographical (thermal) limits. Interactive effects of warming and other human stressors are, however, also of concern (Nguyen *et al.* 2021a).

Acidification

Anthropogenic activities have increased the amount of carbon dioxide entering the atmosphere, with around 25% of emitted carbon dioxide entering oceans (Canadell *et al.* 2007). In the ocean, the carbon dioxide reacts with water to produce carbonic acid which decreases the pH (and increases the acidity) of the ocean (Sabine *et al.* 2004). A recent study (Scanes *et al.* 2020) found that estuaries in Australia were acidifying (pH decreased) faster than was projected by the IPCC (0.00625 pH units year⁻¹, pH 7.7) for the year 2100 under “business as usual” emission scenarios for the open ocean (Stocker 2014). The study identified seagrass cover and increased nitrogen loads as drivers of pH, with estuaries with high seagrass cover acidifying at a slower rate (Scanes *et al.* 2020). Seagrass and algae increase the pH of estuarine waters as they use carbon dioxide and nutrients to photosynthesise, thereby slowing or potentially mitigating ocean acidification in estuaries. Unfortunately, however, extensive modification of Gamay has led to significant declines in seagrass cover likely reducing the capacity for Gamay to withstand the impacts associated with acidification.

The change in oceanic carbon chemistry associated with ocean acidification is particularly harmful for calcifying organisms, negatively impacting their survival, calcification, growth and reproduction (Havenhand *et al.* 2008, Ross *et al.* 2011). In Gamay, ocean acidification together with inflow of mineral acidification from acid sulphate run off impairs the ability of oysters to

make their shells and grow, as these agents perturb the carbonate conditions required for calcification (Parker *et al.* 2010, Parker *et al.* 2013, Fitzer *et al.* 2018). When combined with ocean warming, these effects are also likely to manifest in altered sex ratios and microbiomes of *S. glomerata* (Parker *et al.* 2018, Scanes *et al.* 2021). This will have direct implications for the ecology of Gamay as oysters are important drivers of ecosystem functioning there. Ocean acidification is also likely to reduce the economic benefits associated with oysters, as production is reduced and estuarine condition declines (O'Connor and Dove 2009, Parker *et al.* 2009, Ross *et al.* 2011).

Sea-level rise

In Sydney, sea level is rising at a rate of between 0.65 (± 0.05) mm yr⁻¹ (using data from 1886 to 2010) and 0.98 (± 0.07) mm yr⁻¹ (using data from 1914 to 2010) (White *et al.* 2014). This sea level rise will have the greatest influence on intertidal communities in Gamay, particularly where the landward side is experiencing urban encroachment. “Coastal squeeze” as this is called, is likely to have a significant impact on saltmarsh habitats, for whilst mangrove forests have the room to expand landwards, saltmarshes experience the dual stress of mangrove encroachment and sea level rise (Townend and Pethick 2002, Loarie *et al.* 2009, Saintilan *et al.* 2019). If inland movement of saltmarsh cannot occur, then there will be a spatial decrease of saltmarsh vegetation which will limit the number of macroinvertebrates and crabs which are associated with the vegetation (Ross and Adam 2013). In comparison, Schaefer *et al.* (2020) found that even under extreme climate change scenarios sea-level rise is not expected to significantly diminish the extent of the intertidal rocky shore habitat at Cape Banks on Gamay’s northern headland.

Increased frequency of storms and extreme climate events

Climate change is predicted to increase the frequency and severity of storms and extreme events (Cai *et al.* 2014, IPCC 2014, Cai *et al.* 2015, Oliver *et al.* 2018). On the western coast of Australia, a marine heat wave (MHW) had a detrimental effect on subtidal reef habitats, causing local extinctions of habitat forming kelp and shifting distributions of other macroalgae as well as associated invertebrate and fish species (Wernberg 2021). Whilst Gamay has not experienced an extreme weather event such as what occurred on the west coast, weather associated with El Niño events was found to affect the condition of canopy forming kelps, which in turn negatively influenced the abundance of an associated herbivorous gastropod (Ettinger-Epstein and Kingsford 2008). Extreme weather events have

also been shown to cause significant erosion to sandy beaches in Gamay (Gallop *et al.* 2020, Vila-Concejo *et al.* 2020) and can cause fires in saltmarsh and mangrove forests (Ross *et al.* 2019). Climate change could also affect seagrasses via more frequent and intense heat waves (especially if coupled with high turbidity that can lead to oxygen stress; Zimmerman 2021), but also increased frequency of high intensity storms.

Pollution export

Modelling for the potential impacts of climate change on pollution export for Gamay suggests both stream hydrology and pollutant exports appears to overshadow the potential impacts of land use change to the Gamay ecosystem. The climate change scenarios used for this modelling indicate a general drying of the catchment resulting in less runoff and pollutant export, which could have significant ecological impacts to natural wetland hydrology in undisturbed parts of the catchment. Under median climate change scenarios, reductions in pollutant exports are expected, even after land use change is accounted for. Under extreme climate change scenarios, pollutant exports are further reduced and, in some cases, result in total loads less than that modelled for the predevelopment condition. However, these results need to be cautiously considered because changes in catchment characteristics (other than urban density changes) have not been considered in the model. Many other possible changes to vegetation cover and soil characteristics may occur under climate change also resulting in altered hydrologic and pollutant export responses (Dahlenburg and Weber 2008).

Contemporary and emerging threats

The Botany Bay and Catchment Water Quality Improvement Plan (SMCMA 2011) identifies many emerging threats to Gamay and possible solutions to these threats have been identified in the recommendations section of the Plan. The Plan explores ‘best’ and ‘worst’ case scenario options for the Catchment, in line with expected population growth (as described in the Sydney Metropolitan Strategy). The ‘best’ case involving application of water sensitive urban design (WSUD) to infill redevelopment areas to meet growing population needs and rehabilitation of some riparian areas could lead to reductions of stormwater pollutants delivered to the bay by 2030 of: TSS (turbidity) 17%, TP (phosphorus) 13% and TN (nitrogen) 9% (reductions in TP and TN will reduce the amount of nutrients available in the water and hence reduce Chl-*a* levels). These reductions in turbidity and nutrients will lead to improved local waterway conditions throughout the Gamay catchment. The ‘worst’ case involving

greenfield development without WSUD to meet growing population needs could lead to increases of stormwater pollutants delivered to the bay by 2030 of: TSS 10%, TP 10% and TN 12% respectively. These changes are also associated with significant local declines in river condition, particularly in the Georges River Catchment.

Multiple stressors and stressor interactions

Above we have summarised individual threats and how they impact the communities, habitats and processes that occur within Gamay. Whilst such investigations are important, they disregard the potential interaction of threats that may co-occur in space or time, and thereby influence systems simultaneously. Interactions between threats can be complex, and more commonly than not the impacts associated with multiple threats

do not accumulate in a linear, additive way. Non-additive (synergistic or antagonistic) effects have been found to occur more commonly than additive effects in natural marine systems (Crain *et al.* 2008).

Of the 257 papers identified in this systematic literature review that investigated threats to Gamay only 48 looked at impacts associated with more than one threat, highlighting a lack of research into the impacts associated with multiple stressors and stressor interactions to the Gamay ecosystem. This is particularly concerning as interactions between important human stressors for Sydney Harbour, a similar urban estuary in the Sydney region, are predicted to be mostly synergistic in nature (Mayer-Pinto *et al.* 2015a). In Gamay, many of these interactions have not been explicitly investigated and instead remain significant knowledge gaps for estuaries in urban areas (Mayer-Pinto *et al.* 2015a).

Litter quickly becomes marine debris as it is readily flushed into urban waterways.
Image: John Turnbull www.marineexplorer.org



Knowledge gaps and opportunities for Gamay

In order to identify areas where further fundamental research is needed in Gamay, we cross-referenced the number of studies published on different taxa within each habitat type (Figure 15). Invertebrates and fish were the most thoroughly studied taxa across multiple habitat types (Figure 15), whilst epibiota and birds were the most poorly studied taxa (Figure 15).

We also identified gaps in our knowledge surrounding how different threats or stressors impact the taxa (Figure 16) and habitats (Figure 17) that occur in Gamay. Figures 16 & 17 show many white cells which highlight the fact that only around half of the 577 studies published on Gamay investigated threats to Gamay's species and habitats (Figure 8). Of those studies that did consider threats to Gamay, research effort has been heavily

focused on impacts associated with contamination and habitat modification (Figure 9). Non-taxa specific impacts associated with contamination were most commonly studied, followed by contamination impacts to invertebrates (Figure 16). Impacts associated with habitat modification have been studied across most taxa, however, only in low numbers (Figure 16). Contamination impacts to soft sediment habitats were also comparatively well studied, followed by the impacts of diseases and pathogens to oyster reefs and habitat modification to artificial substrates (Figure 17).

Below we summarise the results of this gap analysis grouped into common themes which are relevant to all or parts of Gamay.

Figure 15. Studies were separated out by Major taxa and Habitat type to identify areas of low and high research effort (quantified as the number of studies). 'Multiple' categories represent studies that considered more than one taxon or more than one habitat. Dark blue grid cells identify taxa-habitat interactions that have been comparatively well studied, whilst white grid cells identify taxa-habitat interactions that have not been studied. Grey grid cells identify taxa-habitat interactions that are not possible/not applicable to Gamay. The number of studies was log transformed for visualisation as invertebrates on intertidal rocky shore habitats has been an area of intense research effort (79 studies) compared to the next most well studied taxa-habitat interaction, invertebrates in soft sediment habitats (36 studies).

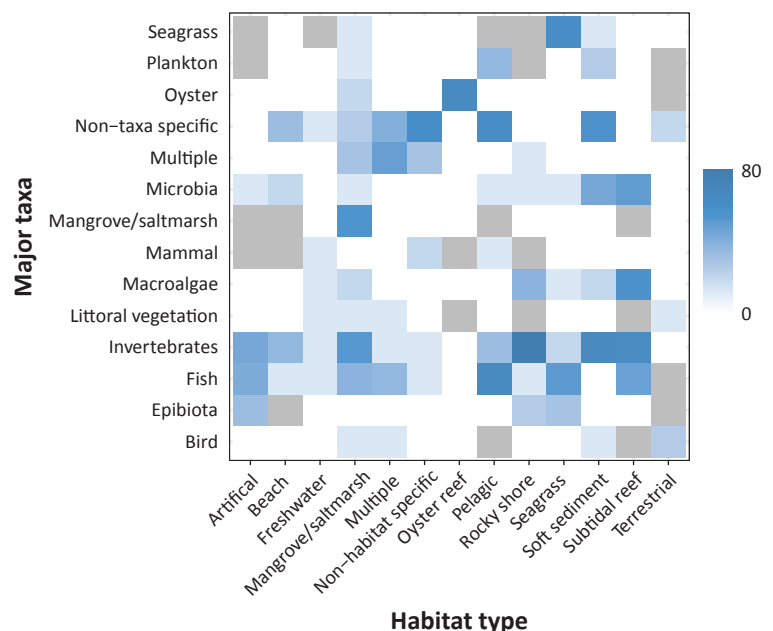


Figure 16. Studies were separated out by Major taxa and Threat type to identify areas of low and high research effort (quantified as the number of studies). 'Multiple' categories represent studies that considered more than one taxon or more than one threat. 'NIS' = Studies that considered threats associated with exotic and non-indigenous species. Dark blue grid cells identify threats to specific taxa interactions that have been comparatively well studied, whilst white grid cells identify threats to specific taxa interactions that have not been studied. Grey grid cells identify threats to specific taxa interactions that are not possible/not applicable to Gamay.

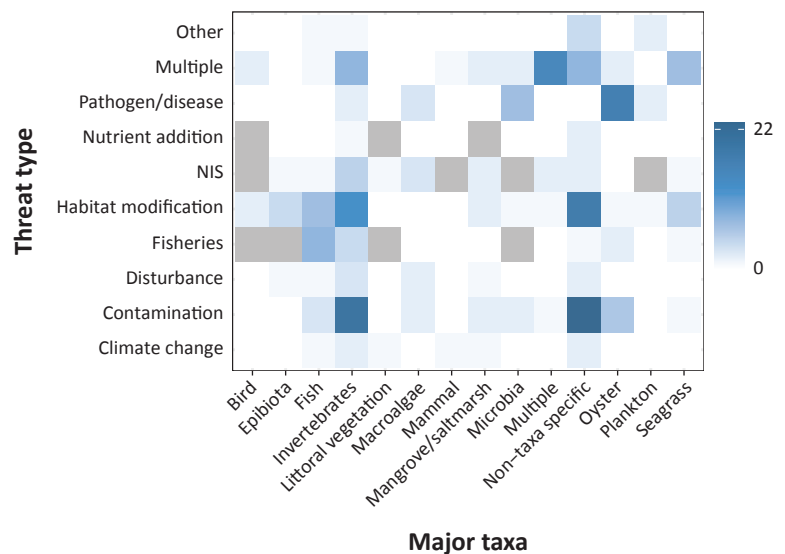
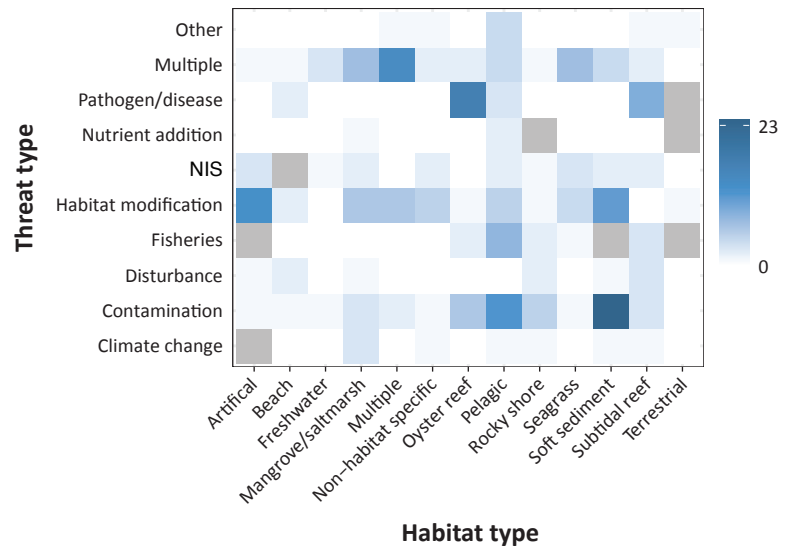


Figure 17. Studies were separated out by Major habitat and Threat type to identify areas of low and high research effort (quantified as the number of studies). ‘Multiple’ categories represent studies that considered more than one habitat or more than one threat. ‘NIS’ = Studies that considered threats associated with exotic and non-indigenous species. Dark blue grid cells identify threats to specific habitat interactions that have been comparatively well studied, whilst white grid cells identify threats to specific habitat interactions that have not been studied. Grey grid cells identify threats to specific habitat interactions that are not possible/not applicable to Gamay.



Habitat restoration and remediation

A legacy of extensive urbanisation has led to the degradation and loss of many habitats and communities in Gamay. Locally in Gamay, Quibray Bay and Weeney Bay have central areas devoid of seagrass. All the known seagrasses in the area grow down to much deeper depths than this. It suggests that anaerobic conditions (lack of oxygen in these central regions) or high hydrogen sulphide levels possibly poison the seagrasses preventing growth in these areas. Testing these hypotheses would be relatively simple and would provide important information for both management and restoration efforts.

Seagrass restoration is becoming increasingly viable and is seen as a crucial management tool for addressing seagrass losses (Sinclair *et al.* 2021). There have been recent successful seagrass transplantation projects in Gamay. Over 2,300 m² of *P. australis* was lost during the laying of electricity cables across the bay (which involved jetting high pressure water into the sediments). Restoration by NSW Department of Primary Industries involved sediment rehabilitation followed by transplantation of *P. australis* rhizomes (collected from the meadow prior to damage) secured with biodegradable jute mats (similar to the method described in Ferretto *et al.* 2021). Numbers of transplanted shoots doubled over 8.5 years and there was extensive vegetative regrowth from the surrounding meadow into the rehabilitated sediments, resulting in the restoration of some 600 m² of *P. australis*, albeit at a reduced density (Glasby unpubl. data). Interestingly, however, the success of rhizome transplanting in deeper

(3–4 m) parts of the meadow was substantially reduced relative to the shallower areas (2–3 m), suggesting there are still gaps in our understanding of the mechanisms that regulate the success of this process.

Seagrass restoration has also been undertaken on Gamay’s northern shoreline as part of the Port Botany expansion Penrhyn Estuary habitat enhancement plan. This involved transplanting *P. australis* from Foreshore beach to Quibray Bay prior to the commencement of dredging and reclamation for the port expansion. The experiment was more successful for whole or trimmed plants, compared with plants with rhizomes only, and when plants were transplanted to large bare areas within meadows of seagrass as opposed to bare areas at the edges of meadows (Blount 2019). New saltmarsh habitat was also recently created there as part of the Port Botany expansion Penrhyn Estuary habitat enhancement plan. These results suggest potential opportunities for creating or restoring seagrass or saltmarsh in other areas in Gamay.

Cape Banks was one of the first sites where macroalgal restoration was first tested in Australia (i.e., *Phyllospora comosa* restoration; Layton *et al.* 2020). Such trials showed that restoration of macroalgal forests via adult transplantation is feasible and necessary where natural recovery fails, but that managing species’ interactions (e.g., herbivory) can be critical to achieve restoration success (Campbell *et al.* 2014, Vergés *et al.* 2020). Subsequent trials in Kurnell showed that coupling *Phyllospora* transplantation with urchin (*Centrostephanus*) removal can enhance *Phyllospora* restoration, as well as the recovery of other habitat-forming macroalgae such as *Sargassum* and *Ecklonia* (Mead 2020). Habitat restoration relies heavily on

financial support (Eger *et al.* 2020), but we still have limited understanding of the costs and benefits associated with macroalgal restoration in Australia (and globally, but see Eger *et al.* 2020, Mead 2020) – particularly those that relate to ecosystem services such as carbon sequestration and nutrient cycling.

Recent reductions in contaminant inputs into Gamay and the Cooks River provide a great opportunity to implement remediation strategies to combat legacy pollution in the water and sediments. One way to do this is through the reintroduction of lost biodiversity, such as oyster reefs (Gillies *et al.* 2020, McAfee *et al.* 2020) and sediment infauna (Bugnot *et al.* 2022), which can boost biogeochemical processes in sediments. The first large scale oyster reef restoration project in Gamay and Georges River was established in 2021 by the Nature Conservancy, Greater Sydney Local Land Services and NSW Department of Primary Industries. The project aims to restore up to five hectares of the locally extinct Australian flat Oyster (*O. angasi*) and depleted Sydney rock Oyster (*S. glomerata*) reefs, across four sites in Gamay and the Georges River estuary: Kurnell, Taren Point, Coronation Bay and Audrey Bay flat (TNC 2022). Although inground works are yet to begin, the restoration project will utilize locally quarried igneous rock as a substrate for restoration, and for flat oysters couple this substrate provision with seeding of hatchery reared spat. By recovering oyster habitat, the project hopes to increase biodiversity, improve water quality, and increase production of recreationally and commercially important fish. This project will provide an acid test of how well we understand oyster reef ecology, and if successful opens up opportunities for oyster reef restoration in other estuaries.

Many of these restoration projects represent pioneering work for habitat restoration, highlighting that there are significant opportunities to trial management strategies in Gamay. These endeavours will, however, have flow-on effects for the fauna and flora of Gamay and in order for such projects to be successful more needs to be known about species-specific habitat dependencies as well as transfers and linkages between different habitats.

Seascape connectivity

Understanding how habitats and communities are connected is particularly important in urban estuaries such as Gamay, where vegetated habitats are declining and becoming more fragmented. While the importance of seagrass, mangrove and saltmarsh as fish habitat is well documented (Mazumder *et al.* 2011, Saintilan and Mazumder 2017), the movement of fish and other biota between habitats remains poorly understood (Saintilan *et al.* 2007). Similarly, little is known about how sediment infauna biodiversity and their functions

are driven by seascape connectivity and patterns such as proximity to habitat-forming species and rocky reefs. The mudflats at Towra Point are important foraging grounds for endangered and migratory shorebirds, yet we know little of how the productivity of these habitats and nearby soft sediment habitats are influenced by adjacent oyster reefs. The contribution of oyster reefs to the present-day fisheries productivity of Gamay is also unknown. Given that Gamay is a designated recreational fishing haven this information will be important to ensure effective fisheries management of the bay. Seascape connectivity information can also be used by scientists and managers to select optimal habitat restoration sites, allowing for conservation, restoration and/or fisheries related goals to be reached simultaneously in a more efficiently and effectively way.

Climate change

Climate change and sea-level rise are overarching drivers already altering the distribution and function of habitats and the wise management of Gamay requires planning for a range of possible futures. However, as yet, there has been little in the way of research or planning into how climate change will impact the Gamay ecosystem. In particular, there is an urgent need to plan for the impacts of climate change to wetland ecosystems in Gamay. This includes the consequences of sea-level rise on saltmarsh, which because of significant urbanisation and mangrove encroachment will have no room to expand landwards (Ross and Adam 2013). The availability of high-resolution digital terrain modelling for the Gamay foreshores makes possible the modelling of habitat redistribution under projected sea-level rise. Currently, sea-level rise flooding risk tools, such as [Coastal Risk Australia](#) project inundation against existing surfaces. The Sea Level Affecting Marshes Model (SLAMM) is the best known of a number of models incorporating the dynamic relationship between sea-level rise and sediment accumulation to project changes to habitat elevation under sea-level rise scenarios (Rogers *et al.* 2012, Runtz *et al.* 2017, Sadat-Noori *et al.* 2021). If the elevation preferences of habitat types are known, habitat redistribution can also be modelled, as recently demonstrated by [NOAA](#) for the US coastline.

Carbon stocks within Gamay habitats have been estimated (Kelleway *et al.* 2016), though greenhouse gas and lateral dissolved organic carbon fluxes have received little attention, despite their importance to the quantification of blue carbon opportunities (Kroeger *et al.* 2017, Lovelock and Duarte 2019). SLAMM models can facilitate the identification of opportunities for tidal reinstatement for habitat creation and ‘blue carbon’ capture and storage (Rogers *et al.* 2014, Kelleway *et al.* 2020). Management of the Gamay foreshores would be enhanced by the application of landscape-scale

models projecting habitat distribution under possible climate futures, and the implications of these changes for ecosystem services including carbon sequestration. Furthermore, given some of the shifts in microalgal and macrophyte communities in Gamay there has likely been changes to the potential for carbon burial. It would therefore be useful to develop a full carbon budget for Gamay following the strategy Tanner and Eyre (2020).

Southeast Australia is a hotspot for ocean warming due to climate change and as such the region can expect to see continued increases in ocean temperatures. These increases bring with them the potential for the shifts in the structure of marine food webs as species ranges expand or contract as they track thermal gradients. While there has been little direct work on species range dynamics within Gamay, work on tropicalisation within the NSW region has shown that while currently many tropical species have their ranges limited by declining ocean temperatures into winter (Figueira and Booth 2010, Booth *et al.* 2018) and community interactions with resident species (Figueira *et al.* 2019), winter thresholds are being overcome and the long-term pattern shows strong increased temperatures drive increased seasonal richness of tropical vagrants (Monaco *et al.* 2021). Amongst the largest effects of these tropical vagrants observed to date is that of herbivores on temperate algal communities (Vergés *et al.* 2016). These habitat-forming organisms are considered foundational and thus the impact of novel grazing can extend to ecosystem function (Vergés *et al.* 2019). It will be important to carefully monitor the arrival of novel tropical species into the Gamay region to better understand the potential impacts they may have on the ecology of the bay into the future.

Oyster aquaculture in Gamay

The discovery of QX disease in the Georges River in 1992 led to significant declines in oyster production in Gamay (Reid and Bone 2020). Since then, selective breeding programs have been implemented to develop disease-resistant oyster lines (Nell and Hand 2003, Nell and Perkins 2006, Dove *et al.* 2013). Knowledge gaps, however, still surround the transfer of disease and interbreeding between cultured and wild oysters (both *C. gigas* and *S. glomerata*). Greater investment in oyster research will not only benefit the oyster aquaculture industry in Gamay but could provide important information for urban aquaculture generally. Gamay's well documented history with oyster aquaculture means that Gamay could be used as a case study for aquaculture within a large Australian city. Similarly, future oyster disease research could use Gamay as a natural laboratory, allowing controlled experiments to be undertaken in natural, real-world settings.

The ecosystem service benefits provided by oysters (natural reef/aquaculture/restored reef) could have far reaching benefits for the entire Gamay ecosystem. Despite this, however, compared to most other habitats that occur within Gamay, oyster reefs remain some of the most poorly studied. To maximise these ecosystem benefits for Gamay more research will be needed into developing and testing different methods of farming and restoration, as well as exploring optimal sites, locations and configurations for oysters to be grown within the bay. Understanding how multiple climate change stressors (warming, acidification, heatwaves, low salinity) impact oysters will also be important to ensure a sustainable future for oyster reefs in Gamay.

Oyster aquaculture research infrastructure with water quality monitoring equipment, within a farming lease, Woollooware Bay. Image: RJ Whittington, University of Sydney.



Gaps in baseline data

Much of the research of Gamay's hydrology and oceanography has focused on the main bay, with its two major tributaries (Georges and Cooks River) often excluded from modelling studies due to their low inflow (e.g., Roughan and Hallam 2022), however, their inclusion should be considered for future work, if gauge data is available, particularly as freshwater inflow is projected to change in the future.

Important knowledge gaps remain concerning processes within the vegetated habitats of Gamay relevant to ecosystem service provisioning. Whilst a recent review identified Australia as the second largest contributor to seagrass research globally, several areas of weakness in Australia's seagrass research knowledge were also recognised across 10 key research fields, ranging from taxonomy to mapping and management (see York *et al.* 2017 for full list). There are also gaps in our understanding of littoral rainforest and other vegetated terrestrial communities. Whilst much attention has been given to *Casuarina* forest, little attention has been paid to other terrestrial communities, which include Eastern Suburbs Banksia Scrub, which has just been upgraded under the EPBC Act to 'critically endangered' status.

Similarly, whilst Gamay has been the focal point of much intertidal research, the vast majority of published studies of the rocky intertidal have been limited to the Cape Banks area, with rocky shores in other areas of Gamay receiving much less attention. Surveys assessing the diversity and distribution of rocky shore biota across the entire bay are needed, particularly the southern headland, to establish baseline data that can be used to evaluate and predict the response of these communities to present and future stressors. The generality of patterns described for the Cape Banks area has also not been sufficiently explored along neighbouring stretches of rocky shore to the north and south of Gamay. Knowledge of how applicable these patterns are to other rocky shores is important if we are to understand how local conditions and other site-based factors may influence these patterns, as well as to understand how the communities at Cape Banks compare to rocky shore communities from other locations.

In comparison to other habitats in Gamay, scientific understanding of the significance of artificial substrates in Gamay is superficial and generally small-scale. For example, all three of the investigations into fish assemblages associated with artificial shoreline structures have been conducted on the northern side of the main bay (Burchmore *et al.* 1985, Fowler and Booth 2013, Porter *et al.* 2018). There is a need to examine the bay-wide extent and the influence of artificial substrate, both to understand the type and magnitude

of ecological change that may have already occurred and to predict future change if further substrate is added. To achieve this, comprehensive faunal surveys on all major structure types are required, along with information on the amount and distribution of those substrates within the bay and associated rivers. Knowledge of how biological communities interact and function on artificial substrates is also required, to understand the potential effects of differences in community structure observed in numerous studies and the best management practices to mitigate some of these impacts.

Despite the popularity of recreational fishing within Gamay, the most recent systematic surveys of fish assemblages within the bay are close to 30 years old. Information on the fish assemblages within the bay are a critical benchmark against which to evaluate any perceived effects of processes like habitat alteration, fishing and climate change related processes. This information is also necessary to deepen understanding of the role of fish assemblages in providing connectivity amongst different habitats within the bay and the degree to which bay resilience depends upon this (as discussed in [Seascape connectivity](#)). Currently little information also exists on the biodiversity of sediment bioturbators such as large sediment macrofauna, rays and fish, as most studies to date have focused on small macroinvertebrates that can be captured from surface layers using grabs. These larger macrofauna can, however, significantly affecting sediment functioning and as such more information about these communities is essential to understand the functioning of sediments and nutrient cycling in the bay.

On-going and long-term monitoring

There are several sites in Gamay where the monitoring of open water sites has been conducted on a regular basis over a period of years. For example, as part of the Australian Microbiome coastal project conducted by Bioplatforms Australia and the Integrated Marine Observing System, fortnightly water column plankton and bacterial samples have been collected at a site close to Quibray Bay for the past 5 years (McLennan *et al.* 2021). In relation to this project, a real time temperature and salinity sensor, with data that is publicly available, has also been deployed close to the sampling site. If such monitoring can continue at these sites, a long-term time series can be invaluable to show changes to the environment in response to short and long-term perturbations. Similarly, Beachwatch monitors Gamay and Georges River swimming sites every 6 days throughout the summer swimming season (October to April), and monthly during winter

(May to September). Developments in water quality assessments using molecular approaches are resulting in more refined diagnostics of faecal contamination that are providing clearer advice to councils about sources of inputs and enhancing opportunities to guide management interventions and improve human health outcomes (Seymour *et al.* 2020, 2021). Furthermore, Gamay would be an ideal place to refine e-DNA and other techniques for rapid assessment of biodiversity in soft sediment habitats, particularly in the context of environmental impact assessment. Places like Penrhyn Estuary could be ideal testing grounds for this.

The rich history of field surveys and experiments on subtidal habitats in Gamay provide a unique background to assess long-term impacts of such stressors on macroalgae and to unravel mechanisms, which are necessary to develop sound management strategies. In the context of predicted environmental change, there are significant opportunities to incorporate novel molecular tools to monitor rocky reef assemblages in Gamay. For example, the extensive microbial datasets that exist for Gamay's subtidal reef (as discussed in [Subtidal rocky reefs](#)) can be used to develop and test microbial strains/genes as indicators of poor reef health (e.g., Ferrari *et al.* 2021) and water quality (e.g., Carney *et al.* 2019). For kelp and crayweed in particular, the combination of host genetics and host-associated microbiome data can be used to test their independent and combined role in potentially enhancing resilience of macroalgal forests to future environmental conditions (Wood *et al.* 2019, Wood *et al.* 2020, Wood *et al.* 2021, Wood *et al.* 2022).

Microbial research

The rapid advancement of molecular technologies and the increase in computing power has led to a revolution in our understanding of the diversity and abundance of marine microorganisms. Pioneering microbial research undertaken in Gamay has led the way in developing this field (e.g., Taylor *et al.* 2005, Huggett *et al.* 2006, Swanson *et al.* 2006, Longford *et al.* 2007, Zozaya-Valdes *et al.* 2015). An example of the success of this research is the Marine Microbes Framework Data Initiative, now part of the [Australian Microbiome Initiative](#) – a collaborative effort underpinned by a partnership among government agencies and various universities, facilitated by [BioPlatforms Australia](#) as part of the Commonwealth Government National Collaborative Research Infrastructure Strategy (NCRIS). Most of the research on Gamay's marine microbiota on rocky reefs has focused on bacteria and archaea, and we still have limited understanding of the role of other microorganisms such as fungi, microalgae and viruses representing an opportunity for future microbial research in Gamay (but see Ferrari *et al.* 2021, McLennan *et al.* 2021).

Traditional Ecological Knowledge of First Nations people of Gamay

The First Nations people of Gamay successfully and harmoniously fished and farmed the waters of Gamay for tens of thousands of years prior to the arrival of European settlers. Unfortunately, Traditional Ecological Knowledge of First Nations people of Gamay remains largely undocumented, meaning that significant knowledge gaps exist surrounding how the First Nations people of Gamay used the species and habitats of Gamay prior to European settlement. In cases where Traditional Ecological Knowledge has been documented, it is often recorded as anecdotal observations by early European settlers that lack important detail such as location, dates etc. making it difficult to use such information in scientific research.

In addition to this, historically Traditional Ecological Knowledge from First Nations people of Australia has generally not been recognised as ecological information, which has led to it often being overlooked by scientists and managers. More recently however, Traditional Ecological Knowledge is being increasingly recognised as an important and valuable source of ecological information paving the way for collaborative efforts between scientists, managers and First Nations people of Australia (Bohensky *et al.* 2013). Such collaborations can open opportunities to advance scientific knowledge as well as share power and responsibilities amongst stakeholders and develop novel management approaches that can be used to ensure a sustainable future for Gamay (Houde 2007).

Shoreline and bathymetry monitoring

The shorelines of Gamay are already in different stages of erosion and we have little knowledge of the sediment transport patterns and magnitudes in the bay. The presence/absence of channels or shoals next to the beaches seem to control beach recovery after erosive events. Future studies should focus on understanding these sediment fluxes and the relationships between the beaches and the sediment sinks and sources. A mix of marine geomorphology and biology seems the most appropriate pathway here.

Dredging is an ongoing management need in Gamay and creates disturbances that have a significant ecological impact in space and persist over long periods of time. This also creates an opportunity to investigate novel strategies for dredging that control and mitigate ecological impacts as well as enhance the speed of restoration afterwards (Knott *et al.* 2009).

Planning and engagement

Water sensitive urban design

The Water Quality Improvement Plan (WQIP) for Gamay sets targets for pollutant load reductions (in terms of total nitrogen [TN], total phosphorus [TP] and suspended sediment [TSS]) required to protect its condition (SMCMA 2011). The WQIP, however, relies on local and state government planning policies including water sensitive urban design (WSUD) practices in urban development and renewal.

Socio-economic opportunities

Socio-economic opportunities for Gamay include the development of a recreational artificial reef plan for the bay involving several stakeholders (e.g., Ports and recreational fishers), which would develop recreational reefs that meet the needs of users and the ecosystem in the face of future climate change.

Eco-engineering opportunities

The existing infrastructure of the bay would likely be favoured by eco-engineering interventions such as [Living Seawalls](#), accompanied by rigorous ecological monitoring.

Management opportunities

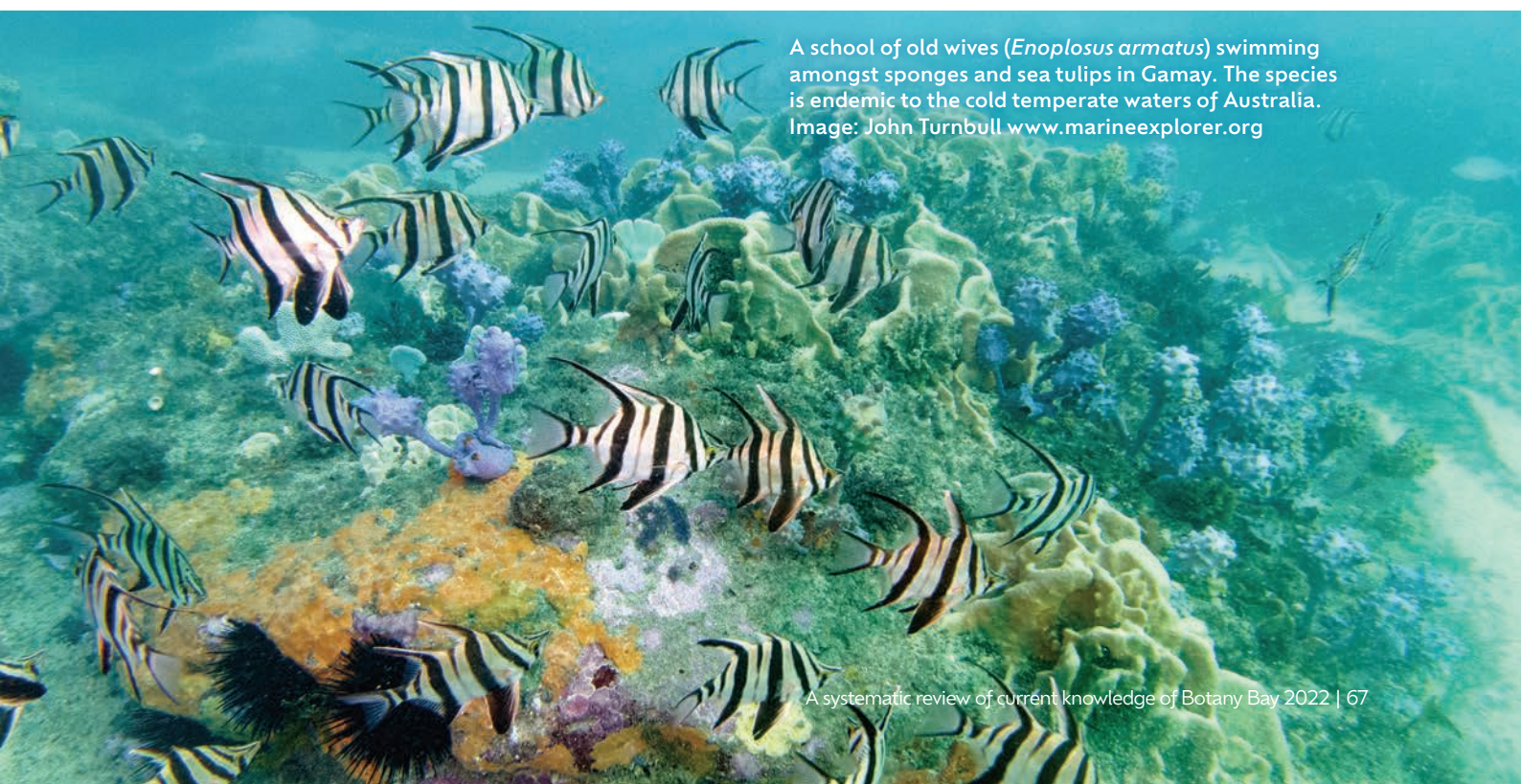
The ecology of fisheries in urban estuaries presents important challenges and opportunities for fisheries research and managers who must consider their unique socio-ecological systems. Taylor & Suthers (2021) propose three focal goals for urban estuarine fisheries

ecology: (1) define the socio-economic objectives and motivations that are important to the urban fishing community; (2) seek to measure and define ecosystem attributes with a goal to identifying bottlenecks to desirable fisheries outcomes; and (3) provide a scientific basis for design and implementation of management activities that move towards these social and economic goals. More research in this area will pave the way for the development of novel management practices than enhance the productivity of fisheries in urban estuaries.

Other management opportunities might also include the assessment of human use, such as boat and tourism activity (e.g., diving), in response to management changes to MPA zonation and other interventions (e.g., restocking artificial reefs with small fish), eco-engineering and improving catchment conditions.

Citizen science opportunities

Projects that involve citizen science are growing, particularly in ecology and the environmental sciences (Silvertown 2009). Citizen science programs are particularly useful when addressing ecological questions that span large spatial and temporal scales as such large-scale collection of data is often difficult for small research groups. This makes them highly attractive to scientists. These programs can also be beneficial to the participants as they expand their own scientific knowledge and contribute towards greater knowledge of the environment they interact with. Currently few citizen science programs have been undertaken in Gamay highlighting this as a significant area of opportunity into the future.



A school of old wives (*Enoplosus armatus*) swimming amongst sponges and sea tulips in Gamay. The species is endemic to the cold temperate waters of Australia. Image: John Turnbull www.marineexplorer.org

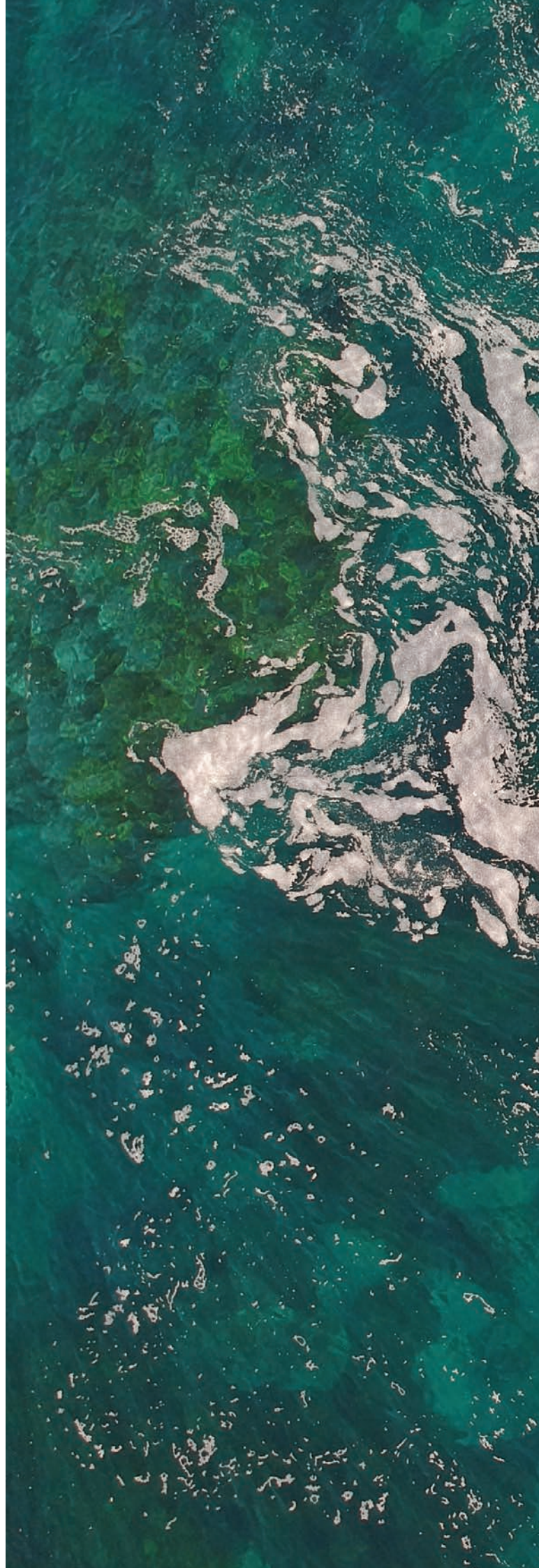
Conclusion

It could be argued that Gamay is amongst one the most well studied estuaries in Australia, if not the world. It is a place of enormous ecological and social complexity and in many ways the extensive amount of research having been undertaken in Gamay represents just the baseline of what's needed to effectively manage the bay. Through this comprehensive review we have synthesised current ecological knowledge from scientific peer-reviewed literature and a wide range of non-scientific sources and have identified major knowledge gaps that should be filled if we are to manage this iconic ecosystem for all its residents, including both the people that live on its shores and the biota that live within its aquatic habitats.

From this review it is evident that humans and their activities pose the biggest challenge for Gamay both now and into the future, with pressures from urbanisation and continued land-use changes in the Gamay catchment being major concerns for the future sustainability of Gamay. It is not all doom and gloom for the bay, however, as this review also highlights the numerous opportunities which current work has generated, creating paths that stakeholders and managers can walk together towards a sustainable future for Gamay. The success of many of these opportunities will, however, rely on co-operation and collaboration, not only between scientists and managers, but also between the multitude of Gamay's other stakeholders that use and care for the bay (e.g., First Nations People of Gamay, recreational fishing groups, local councils, community groups, commercial operators, residents etc.).

Furthermore, whilst this review has identified a vast amount of published knowledge that exists for the bay, we also recognise there has been much valuable data collected in Gamay that is not immediately accessible. We would therefore echo the recommendations put forth by those that came before us and continue to encourage strategic and integrated research programs that combine disciplines, and cross industry boundaries. For it is only through co-operation, collaboration and partnerships between stakeholders that a sustainable future for Gamay can truly be ensured.

Aerial shot of a dive boat in Gamay.
Image: John Turnbull www.marineexplorer.org





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Subtidal rocky reef habitat in Gamay.
Image: John Turnbull www.marineexplorer.org



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Gamay literature database

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Adam, P. 1997. Introduction to the Botany Bay symposium. <i>Wetlands Australia</i> 16.	Non-habitat specific	Habitat modification	Peer-reviewed
Adlard, R. 1995. Extended range of the oyster pathogen <i>Marteilia sydneyi</i> . <i>Bulletin of European Association of Fish Pathologists</i> 15:119-121.	Oyster reef	Pathogen/disease	Peer-reviewed
Ahyong, S. T. 2005. Range extension of two invasive crab species in eastern Australia: <i>Carcinus maenas</i> (Linnaeus) and <i>Pyromaia tuberculata</i> (Lockington). <i>Marine Pollution Bulletin</i> 50:460-462.	Beach	No threat considered	Peer-reviewed
Ahyong, S. T., E. Kupriyanova, I. Burghardt, Y. Sun, P. A. Hutchings, M. Capa, and S. L. Cox. 2017. Phylogeography of the invasive Mediterranean fan worm, <i>Sabella spallanzanii</i> (Gmelin, 1791), in Australia and New Zealand. <i>Marine Biological Association of the United Kingdom. Journal of the Marine Biological Association of the United Kingdom</i> 97:985.	Artificial	NIS	Peer-reviewed
Aijaz, S., and D. Treloar. 2003. Beach management options at Lady Robinsons Beach, Botany Bay, Australia. <i>Proceedings of Oceans 2003 Symposia</i> , San Diego, USA.	Multiple	Multiple	Other
Ajani, P., S. Brett, M. Krogh, P. Scanes, G. Webster, and L. Armand. 2013. The risk of harmful algal blooms (HABs) in the oyster-growing estuaries of New South Wales, Australia. <i>Environmental Monitoring and Assessment</i> 185:5295-5316.	Pelagic/open water	Pathogen/disease	Peer-reviewed
Albani, A. D. 1981a. Pleistocene foraminifera from Botany Bay, New South Wales. <i>Alcheringa</i> 5:147-160.	Soft sediment	No threat considered	Peer-reviewed
Albani, A. D. 1981b. Sedimentary environments and Pleistocene chronology of the Botany Basin, NSW, Australia. <i>Geo-Marine Letters</i> 1:163-167.	Soft sediment	No threat considered	Peer-reviewed
Albani, A. D., and G. Kollias. 2005. Cooks River survey. Report for the Environmental Services of the Marrickville Council.	Soft sediment	Multiple	Report/grey literature
Albani, A. D., and P. C. Rockwood. 2010. An Environmental Assessment of the Georges River: The bottom sediments of the Georges River and its Bays and tributaries. Prepared as part of the Botany Bay Water Quality Improvement Program, Sydney Metro CMA.	Soft sediment	Contamination	Report/grey literature
Albani, A. D., P. C. Rickwood, B. D. Johnson, and J. W. Tayton. 1976. <i>The ancient river systems of Botany Bay</i> . Council of the Shire of Sutherland.	Soft sediment	No threat considered	Book
Albani, A., and I. Yassini. 1989. Taxonomy and distribution of shallow-water <i>Lagenid Foraminiferida</i> from the south-eastern coast of Australia. <i>Marine and Freshwater Research</i> 40:369-401.	Soft sediment	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Albani, A., P. Rickwood, P. Quilty, and J. Tayton. 2015. The morphology and late Quaternary paleogeomorphology of the continental shelf off Sydney, NSW. <i>Australian Journal of Earth Sciences</i> 62:681-694.	Soft sediment	No threat considered	Peer-reviewed
Albani, A.D. and Rickwood, P.C. 1998. The Botany Basin: Its bedrock topography and Recent geological history. In: McNally, G.H. and Jancowski, J. (eds). <i>Collected case studies in Engineering Geology, Hydrology and Environmental Geology</i> , Geological Society of Australia:190-195.	Non-habitat specific	No threat considered	Book
Albani, A.D., J.W. Tayton, P.C. Rickwood, A.D. Gordon, and J.G. Hoffman. 1988. Cainozoic morphology of the inner continental shelf near Sydney, NSW. <i>Journal and Proceedings of the Royal Society of New South Wales</i> 121:11-28.	Non-habitat specific	No threat considered	Peer-reviewed
Allaway, W. 1982. Mangrove die-back in Botany Bay. <i>Wetlands Australia</i> 2.	Mangrove/saltmarsh	Contamination	Peer-reviewed
Allen, S., H. Marsh, and A. Hodgson. 2004. Occurrence and conservation of the dugong (<i>Sirenia: Dugongidae</i>) in New South Wales. <i>Proceedings of the Linnean Society of New South Wales</i> 125:211-216.	Non-habitat specific	No threat considered	Peer-reviewed
Alluvium. 2020. Georges River Coastal Management Program Scoping Study. Report by Alluvium for Georges River Keeper.	Multiple	Multiple	Report/grey literature
ALS. 1977. An investigation of management options for Towra Point, Botany Bay: A report. Report by Australian Littoral Society for Australian National parks and Wildlife Service, St. Lucia, Qld.	Non-habitat specific	No threat considered	Report/grey literature
Altalyan, H. N., B. Jones, J. Bradd, L. D. Nghiem, and Y. M. Alyazichi. 2016. Removal of volatile organic compounds (VOCs) from groundwater by reverse osmosis and nanofiltration. <i>Journal of Water Process Engineering</i> 9:9-21.	Soft sediment	Contamination	Peer-reviewed
Alyazichi, Y. M., B. G. Jones, and E. McLean. 2016. Lead isotope fingerprinting used as a tracer of lead pollution in marine sediments from Botany Bay and Port Hacking estuaries, southern Sydney, Australia. <i>Regional Studies in Marine Science</i> 7:136-141.	Soft sediment	Contamination	Peer-reviewed
Alyazichi, Y. M., B. G. Jones, E. McLean, J. Pease, and H. Brown. 2017. Geochemical assessment of trace element pollution in surface sediments from the Georges River, Southern Sydney, Australia. <i>Archives of Environmental Contamination and Toxicology</i> 72:247-259.	Soft sediment	Contamination	Peer-reviewed
AMBS. 1993. Australian Museum Biological Survey of Botany Bay. Phase 1—Final Report. Report by Australian Museum Business Services for Federal Airports Corporation.	Soft sediment	Habitat modification	Report/grey literature

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Anderson, M. 1995. Variations in biofilms colonizing artificial surfaces: seasonal effects and effects of grazers. <i>Journal of the Marine Biological Association of the United Kingdom</i> 75:705-714.	Artificial	Habitat modification	Peer-reviewed
Anderson, M., and A. Underwood. 1994. Effects of substratum on the recruitment and development of an intertidal estuarine fouling assemblage. <i>Journal of Experimental Marine Biology and Ecology</i> 184:217-236.	Artificial	Habitat modification	Peer-reviewed
Anderson, M., and A. Underwood. 1997. Effects of gastropod grazers on recruitment and succession of an estuarine assemblage: a multivariate and univariate approach. <i>Oecologia</i> 109:442-453.	Artificial	Habitat modification	Peer-reviewed
Andrew, N. 1991. Changes in subtidal habitat following mass mortality of sea urchins in Botany Bay, New South Wales. <i>Australian Journal of Ecology</i> 16:353-362.	Subtidal reef	Other	Peer-reviewed
Andrew, N. 1993. Spatial heterogeneity, sea urchin grazing, and habitat structure on reefs in temperate Australia. <i>Ecology</i> 74:292-302.	Subtidal reef	No threat considered	Peer-reviewed
Andrew, N. 1994. Survival of kelp adjacent to areas grazed by sea urchins in New South Wales, Australia. <i>Australian Journal of Ecology</i> 19:466-472.	Subtidal reef	No threat considered	Peer-reviewed
Andrew, N., and A. Underwood. 1989. Patterns of abundance of the sea urchin <i>Centrostephanus rodgersii</i> (Agassiz) on the central coast of New South Wales, Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 131:61-80.	Subtidal reef	No threat considered	Peer-reviewed
Andrew, N., and A. Underwood. 1992. Associations and abundance of sea urchins and abalone on shallow subtidal reefs in southern New South Wales. <i>Marine and Freshwater Research</i> 43:1547-1559.	Subtidal reef	No threat considered	Peer-reviewed
Andrew, N., and A. Underwood. 1993. Density-dependent foraging in the sea urchin <i>Centrostephanus rodgersii</i> on shallow subtidal reefs in New South Wales, Australia. <i>Marine Ecology-Progress Series</i> 99:89-89.	Subtidal reef	No threat considered	Peer-reviewed
Andrew, N., and G. Jones. 1990. Patch formation by herbivorous fish in a temperate Australian kelp forest. <i>Oecologia</i> 85:57-68.	Subtidal reef	No threat considered	Peer-reviewed
Andrews, V., P. Middelfart, R. Creese, A. Broad, and A. R. Davis. 2010. Distribution and abundance of the introduced gastropod <i>Zeacumantus subcarinatus</i> in the Sydney Region. <i>Molluscan Research</i> 30:131.	Rocky shore	NIS	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Arnold, R. J., R. Harcourt, and T. W. Pietsch. 2014. A new genus and species of the frogfish family Antennariidae (Teleostei: Lophiiformes: Antennarioidei) from New South Wales, Australia, with a diagnosis and key to the genera of the Histiophryninae. <i>Copeia</i> 2014:534-539.	Subtidal reef	No threat considered	Peer-reviewed
Arrontes, J., and A. Underwood. 1991. Experimental studies on some aspects of the feeding ecology of the intertidal starfish <i>Patiriella exigua</i> . <i>Journal of Experimental Marine Biology and Ecology</i> 148:255-269.	Rocky shore	No threat considered	Peer-reviewed
Attenbrow, V. 2009. Aboriginal placenames around Port Jackson and Botany Bay, New South Wales, Australia: Sources and uncertainties. In: H. Koch and L. Hercus (eds). <i>Aboriginal placenames: naming and re-naming the Australian landscape</i> . Canberra: ANU e-Press.	Non-habitat specific	No threat considered	Book
Attenbrow, V. 2010a. Aboriginal fishing on Port Jackson, and the introduction of shell fish-hooks to coastal New South Wales, Australia. In: P. Hutching, D. Lunney & D. Hochuli (eds). <i>The natural history of Sydney</i> . 16–34. Mosman: Royal Zoological Society of New South Wales.	Multiple	No threat considered	Book
Attenbrow, V. 2010b. <i>Sydney's Aboriginal past: investigating the archaeological and historical records</i> . Sydney: UNSW Press.	Multiple	No threat considered	Book
Attenbrow, V. 2012. The Aboriginal prehistory and archaeology of Royal National Park and environs: a review. <i>Proceedings of the Linnean Society of New South Wales</i> 134.	Non-habitat specific	No threat considered	Peer-reviewed
Bain, K. F., and A. G. Poore. 2016. Use of near-infrared reflectance spectroscopy to quantify diet mixing in a generalist marine herbivore. <i>Marine Biology</i> 163:79.	Subtidal reef	No threat considered	Peer-reviewed
Banks, S. C., M. P. Piggott, J. E. Williamson, U. Bové, N. J. Holbrook, and L. B. Beheregaray. 2007. Oceanic variability and coastal topography shape genetic structure in a long-dispersing sea urchin. <i>Ecology</i> 88:3055-3064.	Subtidal reef	Fisheries	Peer-reviewed
Barros, F. 2005. Evaluating the importance of predation on subtidal benthic assemblages in sandy habitats around rocky reefs. <i>Acta Oecologica</i> 27:211-223.	Multiple	Habitat modification	Peer-reviewed
Barros, F., A. Underwood, and M. Lindegarth. 2001. The influence of rocky reefs on structure of benthic macrofauna in nearby soft-sediments. <i>Estuarine, Coastal and Shelf Science</i> 52:191-199.	Soft sediment	No threat considered	Peer-reviewed
Barros, F., A. Underwood, and M. Lindegarth. 2002. A preliminary analysis of the structure of benthic assemblages of surf zones on two morphodynamic types of beach. <i>Journal of the Marine Biological Association of the United Kingdom</i> 82:353-357.	Soft sediment	No threat considered	Peer-reviewed

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Barros, F., A. Underwood, and P. Archambault. 2004. The influence of troughs and crests of ripple marks on the structure of subtidal benthic assemblages around rocky reefs. <i>Estuarine, Coastal and Shelf Science</i> 60:781-790.	Soft sediment	No threat considered	Peer-reviewed
Batley, G., C. Fuhua, C. Brockbank, and K. Flegg. 1989a. Accumulation of tributyltin by the Sydney rock oyster, <i>Saccostrea commercialis</i> . <i>Marine and Freshwater Research</i> 40:49-54.	Oyster reef	Contamination	Peer-reviewed
Batley, G., K. Mann, C. Brockbank, and A. Maltz. 1989b. Tributyltin in Sydney harbour and Georges River waters. <i>Marine and Freshwater Research</i> 40:39-48.	Pelagic/open water	Contamination	Peer-reviewed
Beck, M. W. 1998. Comparison of the measurement and effects of habitat structure on gastropods in rocky intertidal and mangrove habitats. <i>Marine Ecology Progress Series</i> 169:165-178.	Multiple	No threat considered	Peer-reviewed
Beck, M. W. 2000. Separating the elements of habitat structure: independent effects of habitat complexity and structural components on rocky intertidal gastropods. <i>Journal of Experimental Marine Biology and Ecology</i> 249:29-49.	Rocky shore	No threat considered	Peer-reviewed
Becker, A., M. B. Lowry, D. S. Fielder, and M. D. Taylor. 2021. Dispersal of yellowtail kingfish (<i>Seriola lalandi</i>) from a coastal embayment following a recreational fisheries enhancement stocking program: attempts to integrate aquaculture and habitat-based initiatives. <i>Bulletin of Marine Science</i> 4:615-630.	Artificial	No threat considered	Peer-reviewed
Bell, J. D., and M. Westoby. 1986. Variation in seagrass height and density over a wide spatial scale: effects on common fish and decapods. <i>Journal of Experimental Marine Biology and Ecology</i> 104:275-295.	Seagrass	No threat considered	Peer-reviewed
Bell, J. D., D. A. Pollard, J. J. Burchmore, B. C. Pease, and M. J. Middleton. 1984. Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. <i>Marine and Freshwater Research</i> 35:33-46.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Bell, J. E., M. J. Bishop, R. B. Taylor, and J. E. Williamson. 2014. Facilitation cascade maintains a kelp community. <i>Marine Ecology Progress Series</i> 501:1-10.	Subtidal reef	No threat considered	Peer-reviewed
Benson, D. 2020. Joseph Banks and Daniel Solander at Botany Bay: How serious was the science in 1770; where did they go? 30-259.	Terrestrial	No threat considered	Other
Benson, D., and G. Eldershaw. 2007. Backdrop to encounter: the 1770 landscape of Botany Bay, the plants collected by Banks and Solander and rehabilitation of natural vegetation at Kurnell. <i>Cunninghamia</i> 10:113-137.	Multiple	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Bickford, G., J. Toll, J. Hansen, E. Baker, and R. Keessen. 1999. Aquatic ecological and human health risk assessment of chemicals in wet weather discharges in the Sydney region, New South Wales, Australia. <i>Marine Pollution Bulletin</i> 39:335-345.	Pelagic/open water	Contamination	Peer-reviewed
Birch, G. 1996. Sediment-bound metallic contaminants in Sydney's estuaries and adjacent offshore, Australia. <i>Estuarine, Coastal and Shelf Science</i> 42:31-44.	Soft sediment	Contamination	Peer-reviewed
Birch, G., D. Evenden, and M. Teutsch. 1996. Dominance of point source in heavy metal distributions in sediments of a major Sydney estuary (Australia). <i>Environmental Geology</i> 28:169-174.	Soft sediment	Contamination	Peer-reviewed
Birch, G., M. O'Donnell, and S. McCready. 2018. Complex relationships between shallow muddy benthic assemblages, sediment chemistry and toxicity in estuaries in southern New South Wales, Australia. <i>Marine Pollution Bulletin</i> 129:573-591.	Soft sediment	Contamination	Peer-reviewed
Bishop, M. J., and B. P. Kelaher. 2008. Non-additive, identity-dependent effects of detrital species mixing on soft-sediment communities. <i>Oikos</i> 117:531-542.	Soft sediment	No threat considered	Peer-reviewed
Bishop, M. J., and B. P. Kelaher. 2013a. Context-specific effects of the identity of detrital mixtures on invertebrate communities. <i>Ecology and Evolution</i> 3:3986-3999.	Soft sediment	No threat considered	Peer-reviewed
Bishop, M. J., and B. P. Kelaher. 2013b. Replacement of native seagrass with invasive algal detritus: impacts to estuarine sediment communities. <i>Biological Invasions</i> 15:45-59.	Soft sediment	NIS	Peer-reviewed
Bishop, M. J., B. P. Kelaher, R. Alquezar, P. H. York, P. J. Ralph, and C. Greg Skilbeck. 2007a. Trophic cul-de-sac, <i>Pyrazus ebeninus</i> , limits trophic transfer through an estuarine detritus-based food web. <i>Oikos</i> 116:427-438.	Soft sediment	No threat considered	Peer-reviewed
Bishop, M. J., B. P. Kelaher, S. M. Sharp, and M. Verhoeven. 2007b. Dispersal of the estuarine gastropod <i>Pyrazus ebeninus</i> is only weakly influenced by pneumatophore density. <i>Journal of Experimental Marine Biology and Ecology</i> 340:62-69.	Soft sediment	No threat considered	Peer-reviewed
Bishop, M. J., J. E. Byers, B. J. Marcek, and P. E. Gribben. 2012. Density-dependent facilitation cascades determine epifaunal community structure in temperate Australian mangroves. <i>Ecology</i> 93:1388-1401.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Bishop, M. J., M. A. Coleman, and B. P. Kelaher. 2010. Cross-habitat impacts of species decline: response of estuarine sediment communities to changing detrital resources. <i>Oecologia</i> 163:517-525.	Soft sediment	Multiple	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Bishop, M. J., M. R. Cole, S. L. Taylor, E. M. Wilkie, and B. P. Kelaher. 2008. Size-specific predation by dominant consumers maintains a 'trophic cul-de-sac'. <i>Marine Ecology Progress Series</i> 354:75-83.	Soft sediment	No threat considered	Peer-reviewed
Bishop, M. J., T. Morgan, M. A. Coleman, B. P. Kelaher, L. K. Hardstaff, and R. W. Evenden. 2009. Facilitation of molluscan assemblages in mangroves by the fucalean alga <i>Hormosira banksii</i> . <i>Marine Ecology Progress Series</i> 392:111-122.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Bishop, M., A. Underwood, and P. Archambault. 2002. Sewage and environmental impacts on rocky shores: necessity of identifying relevant spatial scales. <i>Marine Ecology Progress Series</i> 236:121-128.	Rocky shore	Contamination	Peer-reviewed
Bishop, M.J. and B.P. Kelaher. 2007. Impacts of detrital enrichment on estuarine assemblages: disentangling effects of frequency and intensity of disturbance. <i>Marine Ecology Progress Series</i> . 341:25-36.	Soft sediment	No threat considered	Peer-reviewed
Black, J., V. Roso, E. Marušić, and N. Brnjac. 2018. Issues in dry port location and implementation in metropolitan areas: The case of Sydney, Australia. <i>Transactions on Maritime Science</i> 7:41-50.	Non-habitat specific	No threat considered	Report/grey literature
Blount, C. 2019. Port Botany post construction environmental monitoring. Report for Port Authority of New South Wales.	Multiple	Multiple	Report/grey literature
Blumstein, D. T., L. L. Anthony, R. Harcourt, and G. Ross. 2003. Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait? <i>Biological Conservation</i> 110:97-100.	Terrestrial	No threat considered	Peer-reviewed
Bos, J. J., R. R. Brown, M. Farrelly, and F. J. de Haan. 2013. Enabling sustainable urban water management through governance experimentation. <i>Water Science and Technology</i> 67:1708-1717.	Pelagic/open water	Other	Peer-reviewed
Bowdler, S. 1976. Hook, line and dilly bag: An interpretation of an Australian coastal shell midden. <i>The Australian Journal of Anthropology</i> 10:248.	Non-habitat specific	No threat considered	Peer-reviewed
Broadhurst, M. K., C. A. Gray, D. D. Reid, M. E. Wooden, D. J. Young, J. A. Haddy, and C. Damiano. 2005. Mortality of key fish species released by recreational anglers in an Australian estuary. <i>Journal of Experimental Marine Biology and Ecology</i> 321:171-179.	Pelagic/open water	Fisheries	Peer-reviewed
Broadhurst, M., S. Kennelly, and B. Isaksen. 1996. Assessments of modified codends that reduce the by-catch of fish in two estuarine prawn-trawl fisheries in New South Wales, Australia. <i>Fisheries Research</i> 27:89-111.	Pelagic/open water	Fisheries	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Brown, G., and W. Maher. 1992. The occurrence, distribution and sources of polycyclic aromatic hydrocarbons in the sediments of the Georges River estuary, Australia. <i>Organic Geochemistry</i> 18:657-668.	Soft sediment	Contamination	Peer-reviewed
Brown, K., and R. McPherson. 1992. Concentrations of copper, zinc and lead in the Sydney rock oyster, <i>Saccostrea commercialis</i> (Iredale and Roughley) from the Georges River, New South Wales. <i>Science of the Total Environment</i> 126:27-33.	Oyster reef	Contamination	Peer-reviewed
Browne, J., and M. Kingsford. 2005. A commensal relationship between the scyphozoan medusae <i>Catostylus mosaicus</i> and the copepod <i>Paramacrochiron maximum</i> . <i>Marine Biology</i> 146:1157-1168.	Pelagic/open water	No threat considered	Peer-reviewed
Bryant, E. 1980. Bathymetric changes in three estuaries of the central New South Wales coast. <i>Marine and Freshwater Research</i> 31:553-571.	Non-habitat specific	No threat considered	Peer-reviewed
Burchmore, J., D. Pollard, J. Bell, M. Middleton, B. Pease, and J. Matthews. 1985. An ecological comparison of artificial and natural rocky reef fish communities in Botany Bay, New South Wales, Australia. <i>Bulletin of Marine Science</i> 37:70-85.	Artificial	Habitat modification	Peer-reviewed
Burchmore, J., D. Pollard, M. Middleton, J. Bell, and B. Pease. 1988. Biology of four species of whiting (Pisces: Sillaginidae) in Botany Bay, NSW. <i>Marine and Freshwater Research</i> 39:709-727.	Pelagic/open water	No threat considered	Peer-reviewed
Burfeind, D. D., I. R. Tibbetts, and J. W. Udy. 2009. Grazing rates of <i>Elysia tomentosa</i> on native and introduced <i>Caulerpa taxifolia</i> . <i>Hydrobiologia</i> 632:355-358.	Subtidal reef	NIS	Peer-reviewed
Burke, C., T. Thomas, M. Lewis, P. Steinberg, and S. Kjelleberg. 2011. Composition, uniqueness and variability of the epiphytic bacterial community of the green alga <i>Ulva australis</i> . <i>The ISME Journal</i> 5:590-600.	Rocky shore	No threat considered	Peer-reviewed
Butcher, P. A., M. K. Broadhurst, B. A. Orchard, and M. T. Ellis. 2010. Using biotelemetry to assess the mortality and behaviour of yellowfin bream (<i>Acanthopagrus australis</i>) released with ingested hooks. <i>ICES Journal of Marine Science</i> 67:1175-1184.	Pelagic/open water	Fisheries	Peer-reviewed
Campbell, A. H., A. Vergés, and P. D. Steinberg. 2014b. Demographic consequences of disease in a habitat-forming seaweed and impacts on interactions between natural enemies. <i>Ecology</i> 95:142-152.	Subtidal reef	Pathogen/disease	Peer-reviewed
Campbell, A. H., A. Vergés, T. Harder, and P. D. Steinberg. 2012. Causes and ecological consequences of a climate-mediated disease. <i>Wildlife and climate change: Towards robust conservation strategies for Australian fauna</i> . Royal Zoological Society of NSW:52-58.	Subtidal reef	Pathogen/disease	Peer-reviewed

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Campbell, A. H., E. M. Marzinelli, A. Vergés, M. A. Coleman, and P. D. Steinberg. 2014a. Towards restoration of missing underwater forests. <i>PLoS ONE</i> 9:e84106.	Subtidal reef	Contamination	Peer-reviewed
Campbell, A. H., E. M. Marzinelli, J. Gelber, and P. D. Steinberg. 2015. Spatial variability of microbial assemblages associated with a dominant habitat-forming seaweed. <i>Frontiers in Microbiology</i> 6:230.	Subtidal reef	NIS	Peer-reviewed
Campbell, A. H., T. Harder, S. Nielsen, S. Kjelleberg, and P. D. Steinberg. 2011. Climate change and disease: bleaching of a chemically defended seaweed. <i>Global Change Biology</i> 17:2958-2970.	Subtidal reef	Pathogen/disease	Peer-reviewed
Carney, R. L., M. Labbate, N. Siboni, K. A. Tagg, S. M. Mitrovic, and J. R. Seymour. 2019. Urban beaches are environmental hotspots for antibiotic resistance following rainfall. <i>Water Research</i> 167:115081.	Beach	Pathogen/disease	Peer-reviewed
Carney, R. L., M. V. Brown, N. Siboni, J.-B. Raina, T. Kahlke, S. M. Mitrovic, and J. R. Seymour. 2020. Highly heterogeneous temporal dynamics in the abundance and diversity of the emerging pathogens <i>Arcobacter</i> at an urban beach. <i>Water research</i> 171:115405.	Beach	Pathogen/disease	Peer-reviewed
Chanell, M. 1997. Planning for the catchment of Botany Bay. <i>Wetlands Australia</i> 16.	Terrestrial	Other	Peer-reviewed
Chapman, M., and A. Underwood. 1994. Dispersal of the intertidal snail, <i>Nodilittorina pyramidalis</i> , in response to the topographic complexity of the substratum. <i>Journal of Experimental Marine Biology and Ecology</i> 179:145-169.	Rocky shore	No threat considered	Peer-reviewed
Chapman, M., and A. Underwood. 1996a. Experiments on effects of sampling biota under intertidal and shallow subtidal boulders. <i>Journal of Experimental Marine Biology and Ecology</i> 207:103-126.	Rocky shore	No threat considered	Peer-reviewed
Chapman, M., and A. Underwood. 1996b. Influences of tidal conditions, temperature and desiccation on patterns of aggregation of the high-shore periwinkle, <i>Littorina unifasciata</i> , in New South Wales, Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 196:213-237.	Rocky shore	No threat considered	Peer-reviewed
Chapman, M., and A. Underwood. 1998. Inconsistency and variation in the development of rocky intertidal algal assemblages. <i>Journal of Experimental Marine Biology and Ecology</i> 224:265-289.	Rocky shore	No threat considered	Peer-reviewed
Chapman, M., and A. Underwood. 1999. Ecological patterns in multivariate assemblages: information and interpretation of negative values in ANOSIM tests. <i>Marine Ecology Progress Series</i> 180:257-265.	Rocky shore	No threat considered	Peer-reviewed

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Chapman, M., and A. Underwood. 2008. Scales of variation of gastropod densities over multiple spatial scales: comparison of common and rare species. <i>Marine Ecology Progress Series</i> 354:147-160.	Rocky shore	No threat considered	Peer-reviewed
Chariton, A. A., A. C. Roach, S. L. Simpson, and G. E. Batley. 2010. Influence of the choice of physical and chemistry variables on interpreting patterns of sediment contaminants and their relationships with estuarine macrobenthic communities. <i>Marine and Freshwater Research</i> 61:1109-1122.	Soft sediment	Contamination	Peer-reviewed
Clark, G. F., B. P. Kelaher, K. A. Dafforn, M. A. Coleman, N. A. Knott, E. M. Marzinelli, and E. L. Johnston. 2015. What does impacted look like? High diversity and abundance of epibiota in modified estuaries. <i>Environmental Pollution</i> 196:12-20.	Artificial	Habitat modification	Peer-reviewed
Clark, G. F., N. A. Knott, B. M. Miller, B. P. Kelaher, M. A. Coleman, S. Ushiamo, and E. L. Johnston. 2018. First large-scale ecological impact study of desalination outfall reveals trade-offs in effects of hypersalinity and hydrodynamics. <i>Water Research</i> 145:757-768.	Artificial	Disturbance	Peer-reviewed
Clarke, L. D., and N. J. Hannon. 1967. The mangrove swamp and salt marsh communities of the Sydney district: I. Vegetation, soils and climate. <i>The Journal of Ecology</i> :753-771.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Clarke, P., and P. Myerscough. 1993. The intertidal distribution of the grey mangrove (<i>Avicennia marina</i>) in southeastern Australia: the effects of physical conditions, interspecific competition, and predation on propagule establishment and survival. <i>Australian Journal of Ecology</i> 18:307-315.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Clarke, P., and W. Allaway. 1993. The regeneration niche of the grey mangrove (<i>Avicennia marina</i>): effects of salinity, light and sediment factors on establishment, growth and survival in the field. <i>Oecologia</i> 93:548-556.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Claus, S. C., P. M. Ross, and B. J. Richardson. 2003. Ecological genetics of the barnacle, <i>Hexaminius foliorum</i> , within mangrove forests near Sydney, Australia. <i>Marine Biology</i> 143:883-888.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Cohen, P. 1892. The marine fish and fisheries of New South Wales, past and present, in their commercial aspect. Sydney: Government Printer.	Multiple	No threat considered	Report/grey literature
Coleman, R., A. Underwood, and M. Chapman. 2004. Absence of costs of foraging excursions in relation to limpet aggregation. <i>Journal of animal ecology</i> 73:577-584.	Rocky shore	No threat considered	Peer-reviewed

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Collett, L., P. Hutchings, P. Gibbs, and A. Collins. 1984. A comparative study of the macro-benthic fauna of <i>Posidonia australis</i> seagrass meadows in New South Wales. <i>Aquatic Botany</i> 18:111-134.	Seagrass	No threat considered	Peer-reviewed
Conacher, M., W. Lanzing, and A. Larkum. 1979. Ecology of Botany Bay. II. Aspects of the Feeding Ecology of the Fanbellied Leatherjacket, <i>Monacanthus chinensis</i> (Pisces: Monacanthidae), in <i>Posidonia australis</i> Seagrass Beds in Quibray Bay, Botany Bay, New South Wales. <i>Marine and Freshwater Research</i> 30:387-400.	Seagrass	No threat considered	Peer-reviewed
Connolly, D. M., T. Desvignes, and J. E. Williamson. 2017. Influence of body size on tube feet morphology and attachment capacity in the sea urchin <i>Holopneustes purpurascens</i> (Temnopleuridae). <i>Marine Biology</i> 164:1-12.	Subtidal reef	No threat considered	Peer-reviewed
Cooke, S. J., and I. G. Cowx. 2006. Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. <i>Biological Conservation</i> 128:93-108.	Non-habitat specific	No threat considered	Peer-reviewed
Courtenay, G. C., W. Gladstone, and M. Schreider. 2005. Assessing the response of estuarine intertidal assemblages to urbanised catchment discharge. <i>Environmental Monitoring and Assessment</i> 107:375-398.	Rocky shore	Contamination	Peer-reviewed
Cowell, P.J., and A. Kannane. 2000. Review of Changes to the Shores and Bed of Botany Bay: Past and Future. <i>New South Wales Healthy Rivers Commission Occasional Paper 1005</i> .	Multiple	Multiple	Report/grey literature
CRA. 2018. Cooks River Ecological Health Report Card 2016-2017. Report by Cooks River Alliance.	Multiple	Multiple	Report/grey literature
CRA. 2019. Cooks River Catchment Coastal Management Program: Stage One - Scoping Study Summary. Report by Cooks River Alliance.	Multiple	Multiple	Report/grey literature
Creese, R. 1980a. An analysis of distribution and abundance of populations of the high-shore limpet, <i>Notoacmea petterdi</i> (Tenison-Woods). <i>Oecologia</i> 45:252-260.	Rocky shore	No threat considered	Peer-reviewed
Creese, R. 1980b. Reproductive cycles and fecundities of four common eastern Australian archaeogastropod limpets (Mollusca: Gastropoda). <i>Marine and Freshwater Research</i> 31:49-59.	Rocky shore	No threat considered	Peer-reviewed
Creese, R. 1980c. Reproductive cycles and fecundities of two species of <i>Siphonaria</i> (Mollusca: Pulmonata) in south-eastern Australia. <i>Marine and Freshwater Research</i> 31:37-47.	Rocky shore	No threat considered	Peer-reviewed
Creese, R. 1981. Patterns of growth, longevity and recruitment of intertidal limpets in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 51:145-171.	Rocky shore	No threat considered	Peer-reviewed

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Creese, R. 1982. Distribution and abundance of the acmaeid limpet, <i>Patelloida latistrigata</i> , and its interaction with barnacles. <i>Oecologia</i> 52:85-96.	Rocky shore	No threat considered	Peer-reviewed
Creese, R., and A. Underwood. 1976. Observations on the biology of the trochid gastropod <i>Austrocochlea constricta</i> (Lamarck) (Prosobranchia). I. Factors affecting shell-banding pattern. <i>Journal of Experimental Marine Biology and Ecology</i> 23:211-228.	Rocky shore	No threat considered	Peer-reviewed
Creese, R., and A. Underwood. 1982. Analysis of inter-and intra-specific competition amongst intertidal limpets with different methods of feeding. <i>Oecologia</i> 53:337-346.	Rocky shore	No threat considered	Peer-reviewed
Creese, R., T. Glasby, G. West, and C. Gallen. 2009. Mapping the habitats of NSW estuaries. NSW Fisheries Final Report Series 113. Industry & Investment NSW, Port Stephens, NSW, Australia.	Non-habitat specific	No threat considered	Report/grey literature
Crowe, T. P., and A. Underwood. 1999. Differences in dispersal of an intertidal gastropod in two habitats: the need for and design of repeated experimental transplantation. <i>Journal of Experimental Marine Biology and Ecology</i> 237:31-60.	Multiple	No threat considered	Peer-reviewed
Cruse, B., L. Stewart, and S. Norman. 2005. <i>Mutton fish: the surviving culture of Aboriginal people and abalone on the south coast of New South Wales</i> . Canberra: Aboriginal Studies Press.	Subtidal reef	Fisheries	Book
Cunningham, D., and P. Birtles. 2013. The benefits of constructing an undersized wetland. In: <i>Proceedings of water sensitive urban design 2013: WSUD 2013</i> . Engineers Australia, Barton, ACT, Australia.	Multiple	Contamination	Other
Curley, B. G., M. J. Kingsford, and B. M. Gillanders. 2002. Spatial and habitat-related patterns of temperate reef fish assemblages: implications for the design of Marine Protected Areas. <i>Marine and Freshwater Research</i> 53:1197-1210.	Subtidal reef	No threat considered	Peer-reviewed
Dafforn, K. A., B. P. Kelaher, S. L. Simpson, M. A. Coleman, P. A. Hutchings, G. F. Clark, N. A. Knott, M. A. Doblin, and E. L. Johnston. 2013. Polychaete richness and abundance enhanced in anthropogenically modified estuaries despite high concentrations of toxic contaminants. <i>PLoS ONE</i> 8:e77018.	Soft sediment	Contamination	Peer-reviewed
Dafforn, K. A., D. J. Baird, A. A. Chariton, M. Y. Sun, M. V. Brown, S. L. Simpson, B. P. Kelaher, and E. L. Johnston. 2014. Faster, higher and stronger? the pros and cons of molecular faunal data for assessing ecosystem condition. <i>Advances in Ecological Research</i> 51:1-40.	Soft sediment	Multiple	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Dafforn, K. A., S. L. Simpson, B. P. Kelaher, G. F. Clark, V. Komyakova, C. K. Wong, and E. L. Johnston. 2012. The challenge of choosing environmental indicators of anthropogenic impacts in estuaries. <i>Environmental Pollution</i> 163:207-217.	Soft sediment	Contamination	Peer-reviewed
Davies, P. 2012. The fortifications of Sydney, Australia: adaptive re-use and issues around public access. In: C. Clark and C.A. Brebbia (eds). <i>Defence Sites: Heritage and Future</i> . WIT Transactions on The Built Environment. WIT Press.	Non-habitat specific	No threat considered	Book
Davies, P. R., and J. D. McIlquham. 2011. Geotechnical design for the Port Botany expansion project, Sydney. <i>Proceedings of the Institution of Civil Engineers. Geotechnical Engineering</i> 164:149-167.	Non-habitat specific	No threat considered	Peer-reviewed
Davis, A., D. Roberts, and S. Cummins. 1997. Rapid invasion of a sponge-dominated deep-reef by <i>Caulerpa scalpelliformis</i> (Chlorophyta) in Botany Bay, New South Wales. <i>Australian Journal of Ecology</i> 22:146-150.	Subtidal reef	NIS	Peer-reviewed
Dempster, T., and M. J. Kingsford. 2004. Drifting objects as habitat for pelagic juvenile fish off New South Wales, Australia. <i>Marine and Freshwater Research</i> 55:675-687.	Pelagic/open water	No threat considered	Peer-reviewed
Denley, E., and A. Underwood. 1979. Experiments on factors influencing settlement, survival, and growth of two species of barnacles in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 36:269-293.	Rocky shore	No threat considered	Peer-reviewed
Dexter, D. 1983. A guide to sandy beach fauna in New South Wales. <i>Wetlands Australia</i> 3.	Beach	No threat considered	Peer-reviewed
Dexter, D. M. 1984. Temporal and spatial variability in the community structure of the fauna of four sandy beaches in south-eastern New South Wales. <i>Marine and Freshwater Research</i> 35:663-672.	Beach	No threat considered	Peer-reviewed
Dexter, D. M. 1985. Distribution and life histories of abundant crustaceans of four sandy beaches of south-eastern New South Wales. <i>Marine and Freshwater Research</i> 36:281-289.	Beach	No threat considered	Peer-reviewed
Doblin, M. A., K. R. Murphy, and G. M. Ruiz. 2010. Thresholds for tracing ships' ballast water: an Australian case study. <i>Marine Ecology Progress Series</i> 408:19-32.	Pelagic/open water	NIS	Peer-reviewed
Dove, M. C., J. A. Nell, and W. A. O'Connor. 2013. Evaluation of the progeny of the fourth-generation Sydney rock oyster <i>Saccostrea glomerata</i> (Gould, 1850) breeding lines for resistance to QX disease (<i>Marteilia sydneyi</i>) and winter mortality (<i>Bonamia roughleyi</i>). <i>Aquaculture Research</i> 44:1791-1800.	Oyster reef	Pathogen/disease	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Downes, A., G. Withycombe, T. Doyle, M. Broadfoot, and D. Machado. 2020. Eastern Beaches CMP Stage 1 Scoping Study.	Multiple	Multiple	Report/grey literature
DPI. 2019. Go Fishing: Botany Bay. NSW fishing location guide by Department of Primary Industries.	Multiple	No threat considered	Other
DPIE, 2019. State of the Beaches 2018-2019. Report by Department of Planning, Industry and Environment for State of New South Wales. Sydney.	Beach	Multiple	Report/grey literature
Druce, B. E., and M. J. Kingsford. 1995. An experimental investigation on the fishes associated with drifting objects in coastal waters of temperate Australia. <i>Bulletin of Marine Science</i> 57:378-392.	Pelagic/open water	No threat considered	Peer-reviewed
Dunstan, D. 2009. Some early environmental problems and guidelines in New South Wales estuaries. <i>Wetlands Australia</i> 9.	Multiple	Multiple	Peer-reviewed
Eklöf, J., M. De la Torre-Castro, M. Gullström, J. Uku, N. Muthiga, T. Lyimo, and S. Bandeira. 2008. Sea urchin overgrazing of seagrasses: a review of current knowledge on causes, consequences, and management. <i>Estuarine, Coastal and Shelf Science</i> 79:569-580.	Subtidal reef	Multiple	Peer-reviewed
Ettinger-Epstein, P., and M. J. Kingsford. 2008. Effects of the El Niño southern oscillation on <i>Turbo torquatus</i> (Gastropoda) and their kelp habitat. <i>Austral Ecology</i> 33:594-606.	Subtidal reef	Disturbance	Peer-reviewed
Evans, M., and R. Williams. 2001. Historical distribution of estuarine wetlands at Kurnell Peninsula, Botany Bay. <i>Wetlands Australia</i> 19.	Mangrove/saltmarsh	Multiple	Peer-reviewed
Evans, O., I. Paul-Pont, and R. J. Whittington. 2017. Detection of ostreid herpesvirus 1 microvariant DNA in aquatic invertebrate species, sediment and other samples collected from the Georges River estuary, New South Wales, Australia. <i>Diseases of Aquatic Organisms</i> 122:247-255.	Oyster reef	Pathogen/disease	Peer-reviewed
Evans, O., P. Hick, and R. J. Whittington. 2016a. Comparison of two external tagging methods used for the identification of individual adult Pacific oysters, <i>Crassostrea gigas</i> . <i>Journal of Shellfish Research</i> 35:837-840.	Oyster reef	No threat considered	Peer-reviewed
Evans, O., P. Hick, and R. J. Whittington. 2017a. Detection of Ostreid herpesvirus-1 microvariants in healthy <i>Crassostrea gigas</i> following disease events and their possible role as reservoirs of infection. <i>Journal of Invertebrate Pathology</i> 148:20-33.	Oyster reef	Pathogen/disease	Peer-reviewed
Evans, S. M., A. Vergés, and A. G. Poore. 2017b. Genotypic diversity and short-term response to shading stress in a threatened seagrass: does low diversity mean low resilience? <i>Frontiers in Plant Science</i> 8:1417.	Seagrass	Multiple	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Evans, S. M., E. A. Sinclair, A. G. Poore, K. F. Bain, and A. Vergés. 2016b. Genotypic richness predicts phenotypic variation in an endangered clonal plant. <i>PeerJ</i> 4:e1633.	Seagrass	Multiple	Peer-reviewed
Evans, S. M., E. A. Sinclair, A. G. Poore, P. D. Steinberg, G. A. Kendrick, and A. Vergés. 2014. Genetic diversity in threatened <i>Posidonia australis</i> seagrass meadows. <i>Conservation Genetics</i> 15:717-728.	Seagrass	Multiple	Peer-reviewed
Evans, S. M., K. J. Griffin, R. A. Blick, A. G. Poore, and A. Vergés. 2018. Seagrass on the brink: Decline of threatened seagrass <i>Posidonia australis</i> continues following protection. <i>PLoS ONE</i> 13:e0190370.	Seagrass	Multiple	Peer-reviewed
Eyles, M., and G. Davey. 1988. <i>Vibrio cholerae</i> and enteric bacteria in oyster-producing areas of two urban estuaries in Australia. <i>International Journal of Food Microbiology</i> 6:207-218.	Oyster reef	Pathogen/disease	Peer-reviewed
Fairweather, P., and A. Underwood. 1983. The apparent diet of predators and biases due to different handling times of their prey. <i>Oecologia</i> 56:169-179.	Rocky shore	No threat considered	Peer-reviewed
Fairweather, P., and A. Underwood. 1991. Experimental removals of a rocky intertidal predator: variations within two habitats in the effects on prey. <i>Journal of Experimental Marine Biology and Ecology</i> 154:29-75.	Rocky shore	No threat considered	Peer-reviewed
Fay, C., and B. Linkhorn. 2021. Gamay Ferry Wharves - Environmental Impact Statement. NSW Government.	Multiple	Multiple	Report/grey literature
Fellowes, T. E., A. Vila-Concejo, S. L. Gallop, R. Schosberg, V. De Staercke, and J. L. Largier. 2021. Decadal shoreline erosion and recovery of beaches in modified and natural estuaries. <i>Geomorphology</i> 390:107884.	Beach	Habitat modification	Peer-reviewed
Ferguson, C. M., B. G. Coote, N. J. Ashbolt, and I. M. Stevenson. 1996. Relationships between indicators, pathogens and water quality in an estuarine system. <i>Water Research</i> 30:2045-2054.	Pelagic/open water	Contamination	Peer-reviewed
Fernandes, N., P. Steinberg, D. Rusch, S. Kjelleberg, and T. Thomas. 2012. Community structure and functional gene profile of bacteria on healthy and diseased thalli of the red seaweed <i>Delisea pulchra</i> . <i>PLoS ONE</i> 7:e50854.	Subtidal reef	Pathogen/disease	Peer-reviewed
Fernandes, N., R. J. Case, S. R. Longford, M. R. Seyedsayamdost, P. D. Steinberg, S. Kjelleberg, and T. Thomas. 2011. Genomes and virulence factors of novel bacterial pathogens causing bleaching disease in the marine red alga <i>Delisea pulchra</i> . <i>PLoS ONE</i> 6:e27387.	Subtidal reef	Pathogen/disease	Peer-reviewed

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Ferrell, D. J., and J. D. Bell. 1991. Differences among assemblages of fish associated with <i>Zostera capricorni</i> and bare sand over a large spatial scale. <i>Marine Ecology Progress Series</i> 72:15-24.	Seagrass	No threat considered	Peer-reviewed
Fletcher, W. 1987. Interactions among subtidal Australian sea urchins, gastropods, and algae: effects of experimental removals. <i>Ecological Monographs</i> 57:89-109.	Rocky shore	No threat considered	Peer-reviewed
Fletcher, W., and A. Underwood. 1987. Interspecific competition among subtidal limpets: effect of substratum heterogeneity. <i>Ecology</i> 68:387-400.	Subtidal reef	No threat considered	Peer-reviewed
Fletcher, W., and R. Creese. 1985. Competitive interactions between co-occurring herbivorous gastropods. <i>Marine Biology</i> 86:183-191.	Rocky shore	No threat considered	Peer-reviewed
Folpp, H. R., H. T. Schilling, G. F. Clark, M. B. Lowry, B. Maslen, M. Gregson, and I. M. Suthers. 2020. Artificial reefs increase fish abundance in habitat-limited estuaries. <i>Journal of Applied Ecology</i> 57:1752-1761.	Artificial	No threat considered	Peer-reviewed
Folpp, H., M. Lowry, M. Gregson, and I. M. Suthers. 2013. Fish assemblages on estuarine artificial reefs: natural rocky-reef mimics or discrete assemblages? <i>PLoS ONE</i> 8:e63505.	Artificial	No threat considered	Peer-reviewed
Forrest, R., M. Chapman, and A. Underwood. 2001. Quantification of radular marks as a method for estimating grazing of intertidal gastropods on rocky shores. <i>Journal of Experimental Marine Biology and Ecology</i> 258:155-171.	Rocky shore	No threat considered	Peer-reviewed
Fowler, A. M., and D. J. Booth. 2013. Seasonal dynamics of fish assemblages on breakwaters and natural rocky reefs in a temperate estuary: consistent assemblage differences driven by sub-adults. <i>PLoS ONE</i> 8:e75790.	Artificial	Habitat modification	Peer-reviewed
Fraser, C., P. Hutchings, and J. Williamson. 2006. Long-term changes in polychaete assemblages of Botany Bay (NSW, Australia) following a dredging event. <i>Marine Pollution Bulletin</i> 52:997-1010.	Soft sediment	Habitat modification	Peer-reviewed
Gall, M. L., S. P. Holmes, K. A. Dafforn, and E. L. Johnston. 2013. Differential tolerance to copper, but no evidence of population-level genetic differences in a widely-dispersing native barnacle. <i>Ecotoxicology</i> 22:929-937.	Rocky shore	Contamination	Peer-reviewed
Gallop, S. L., A. Vila-Concejo, T. E. Fellowes, M. D. Harley, M. Rahbani, and J. L. Largier. 2020. Wave direction shift triggered severe erosion of beaches in estuaries and bays with limited post-storm recovery. <i>Earth Surface Processes and Landforms</i> 45:3854-3868.	Beach	Disturbance	Peer-reviewed

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Ganassin, C., and P. J. Gibbs. 2008. A review of seagrass planting as a means of habitat compensation following loss of seagrass meadow. Fisheries Final Report Series 96, NSW Department of Primary Industries.	Seagrass	Multiple	Report/grey literature
Gannon, R., M. D. Taylor, I. M. Suthers, C. A. Gray, D. E. van der Meulen, J. A. Smith, and N. L. Payne. 2014. Thermal limitation of performance and biogeography in a free-ranging ectotherm: insights from accelerometry. <i>Journal of Experimental Biology</i> 217:3033-3037.	Pelagic/open water	Climate change	Peer-reviewed
Georges river combined councils committee. 2013. Georges River estuary coastal zone management plan: Executive summary.	Multiple	Multiple	Report/grey literature
Georges Riverkeeper. 2018. Georges Riverkeeper Report Card 2017-18. Report by Georges Riverkeeper.	Multiple	Contamination	Report/grey literature
Gibbs, P., T. McVea, and B. Loudon. 1999. Utilisation of restored wetlands by fish and invertebrates. NSW Fisheries Final Report Series No. 16, Fisheries Research and Development Corporation.	Multiple	No threat considered	Report/grey literature
Gillanders, B. M. 1997. Patterns of abundance and size structure in the blue groper, <i>Achoerodus viridis</i> (Pisces, Labridae): evidence of links between estuaries and coastal reefs. <i>Environmental Biology of Fishes</i> 49:153-173.	Non-habitat specific	No threat considered	Peer-reviewed
Gillanders, B. M., and M. J. Kingsford. 1996. Elements in otoliths may elucidate the contribution of estuarine recruitment to sustaining coastal reef populations of a temperate reef fish. <i>Marine Ecology Progress Series</i> 141:13-20.	Seagrass	No threat considered	Peer-reviewed
Gillanders, B., and M. Kingsford. 1998. Influence of habitat on abundance and size structure of a large temperate-reef fish, <i>Achoerodus viridis</i> (Pisces: Labridae). <i>Marine Biology</i> 132:503-514.	Subtidal reef	No threat considered	Peer-reviewed
Glasby, T. M. 2013. <i>Caulerpa taxifolia</i> in seagrass meadows: killer or opportunistic weed? <i>Biological Invasions</i> 15:1017-1035.	Mangrove/saltmarsh	Contamination	Peer-reviewed
Glasby, T. M., and K. Lobb. 2008. Assessing likelihoods of marine pest introductions in Sydney estuaries: a transport vector approach. Fisheries Final Report Series 105, NSW Department of Primary Industries.	Seagrass	NIS	Report/grey literature
Glasby, T. M., and P. T. Gibson. 2020. Decadal dynamics of subtidal barrens habitat. <i>Marine Environmental Research</i> 154:104869.	Subtidal reef	No threat considered	Peer-reviewed
Glasby, T. M., P. T. Gibson, and J. J. Cruz-Motta. 2017. Differences in rocky reef habitats related to human disturbances across a latitudinal gradient. <i>Marine Environmental Research</i> 129:291-303.	Rocky shore	Multiple	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Glasby, T., and M. Kingsford. 1994. <i>Atypichthys strigatus</i> (Pisces: Scorpididae): An opportunistic planktivore that responds to benthic disturbances and cleans other fishes. Australian Journal of Ecology 19:385-394.	Subtidal reef	Disturbance	Peer-reviewed
Goddard, B. K., A. Becker, D. Harasti, J. A. Smith, and I. M. Suthers. 2021. The trophic basis of fish assemblages in temperate estuarine and coastal ecosystems. Marine Biology. 169:1-14.	Multiple	No threat considered	Peer-reviewed
Goodall, H. 2017. Negotiating survival: Aborigines, settlers and environmental knowledge on Sydney's Botany Bay and Georges River. Australian Zoologist 39:76-80.	Non-habitat specific	No threat considered	Peer-reviewed
Goodall, H., S. Wearing, D. Byrne, and A. Cadzow. 2009. Fishing the Georges River: cultural diversity and urban environments. In: A. Wise and S. Velayutham (eds). <i>Everyday Multiculturalism</i> . New York: Palgrave Macmillan.	Non-habitat specific	Habitat modification	Book
Grant, D.L., Clarke, P.J. and Allaway, W.G., 1993. The response of grey mangrove (<i>Avicennia marina</i> (Forsk.) Vierh.) seedlings to spills of crude oil. Journal of Experimental Marine Biology and Ecology, 171:273-295.	Mangrove/saltmarsh	Contamination	Peer-reviewed
Gray, C., S. Kennelly, K. Hodgson, C. Ashby, and M. Beatson. 2001. Retained and discarded catches from commercial beach-seining in Botany Bay, Australia. Fisheries Research 50:205-219.	Pelagic/open water	Fisheries	Peer-reviewed
Grella, C., A. Renshaw, and I. A. Wright. 2018. Invasive weeds in urban riparian zones: the influence of catchment imperviousness and soil chemistry across an urbanization gradient. Urban Ecosystems 21:505-517.	Freshwater	Contamination	Peer-reviewed
Griffin, R. J. 1963. <i>The Botany Basin</i> . Geological Survey of New South Wales. Sydney.	Multiple	No threat considered	Report/grey literature
Hair, C., J. Bell, and M. Kingsford. 1994. Effects of position in the water column, vertical movement and shade on settlement of fish to artificial habitats. Bulletin of Marine Science 55:434-444.	Artificial	Habitat modification	Peer-reviewed
Hammer, M. P., M. Adams, C. E. Thacker, J. B. Johnson, and P. J. Unmack. 2019. Comparison of genetic structure in co-occurring freshwater eleotrids (Actinopterygii: <i>Philypnodon</i>) reveals cryptic species, likely translocation and regional conservation hotspots. Molecular Phylogenetics and Evolution 139:106556.	Freshwater	No threat considered	Peer-reviewed
Harris, J. H. 1985. Diet of the Australian bass, <i>Macquaria novemaculeata</i> (Perciformes: Percichthyidae), in the Sydney basin. Marine and Freshwater Research 36:219-234.	Pelagic/open water	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Harvey, K. J., D. R. Britton, and T. E. Minchinton. 2010. Insect diversity and trophic structure differ on native and non-indigenous congeneric rushes in coastal salt marshes. <i>Austral Ecology</i> 35:522-534.	Mangrove/saltmarsh	NIS	Peer-reviewed
Harvey, K. J., D. R. Britton, and T. E. Minchinton. 2011. Mortality of a herbivorous insect is greater on non-indigenous congeneric compared to native rush in coastal salt marsh. <i>Australian Journal of Entomology</i> 50:52-60.	Mangrove/saltmarsh	NIS	Peer-reviewed
Hatcher, A. M., and A. W. D. Larkum. 1982. The effect of oil and dispersant on photosynthesis, respiration and growth of <i>Posidonia australis</i> in laboratory culture. <i>Aquatic Botany</i> 12:219- 227.	Seagrass	Contamination	Peer-reviewed
Hatfield, E. 1997. Management of the Botany Bay environment. <i>Wetlands Australia</i> 16.	Multiple	Other	Peer-reviewed
Hawke, T., G. Bino, and R. T. Kingsford. 2019. A silent demise: Historical insights into population changes of the iconic platypus (<i>Ornithorhynchus anatinus</i>). <i>Global Ecology and Conservation</i> 20:e00720.	Freshwater	Multiple	Peer-reviewed
Haworth, R. J. 2002. Changes in mangrove/salt-marsh distribution in the Georges River estuary, Southern Sydney, 1930-1970. <i>Wetlands (Australia)</i> 20:80–103.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Haworth, R. J., R. Baker, and P. Flood. 2004. A 6000 Year-old Fossil Dugong from Botany Bay: Inferences about Changes in Sydney's Climate, Sea Levels and Waterways. <i>Australian Geographical Studies</i> 42:46-59.	Non-habitat specific	Climate change	Peer-reviewed
Hayes, W., I. Anderson, M. Gaffoor, and J. Hurtado. 1998. Trace metals in oysters and sediments of Botany Bay, Sydney. <i>Science of the Total Environment</i> 212:39-47.	Soft sediment	Contamination	Peer-reviewed
Healthy river commission of NSW. 2001. Independent inquiry into Georges River – Botany Bay system.	Multiple	Multiple	Report/grey literature
Hedge, L., N. Knott, and E. Johnston. 2009. Dredging related metal bioaccumulation in oysters. <i>Marine Pollution Bulletin</i> 58:832-840.	Oyster reef	Contamination	Peer-reviewed
Hick, P. M., O. Evans, A. Rubio, N. K. Dhand, and R. J. Whittington. 2018. Both age and size influence susceptibility of Pacific oysters (<i>Crassostrea gigas</i>) to disease caused by Ostreid herpesvirus-1 (OsHV-1) in replicated field and laboratory experiments. <i>Aquaculture</i> 489:110-120.	Oyster reef	Pathogen/disease	Peer-reviewed
Hickey, D., and E. Bruce. 2010. Examining tidal inundation and salt marsh vegetation distribution patterns using spatial analysis (Botany Bay, Australia). <i>Journal of Coastal Research</i> 26:94-102.	Mangrove/saltmarsh	No threat considered	Peer-reviewed

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Huggett, M. J., J. E. Williamson, R. De Nys, S. Kjelleberg, and P. D. Steinberg. 2006. Larval settlement of the common Australian sea urchin <i>Heliocidaris erythrogramma</i> in response to bacteria from the surface of coralline algae. <i>Oecologia</i> 149:604-619.	Subtidal reef	No threat considered	Peer-reviewed
Hughes, A. R., P. E. Gribben, D. L. Kimbro, and M. J. Bishop. 2014. Additive and site-specific effects of two foundation species on invertebrate community structure. <i>Marine Ecology Progress Series</i> 508:129-138.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Hughes, L. E., and A. G. Poore. 2016. <i>Biancolina japonica</i> Ishimaru 1996: first record of this burrowing amphipod from Australia and a review of host use in the genus <i>Biancolina</i> (Amphipoda: Peracarida: Crustacea). <i>Marine Biodiversity Records</i> 9:1-7.	Subtidal reef	No threat considered	Peer-reviewed
Hughes, M. G., K. Rogers, and L. Wen. 2019. Saline wetland extents and tidal inundation regimes on a micro-tidal coast, New South Wales, Australia. <i>Estuarine, Coastal and Shelf Science</i> 227:106297.	Mangrove/saltmarsh	Climate change	Peer-reviewed
Hunt, J., G. Birch, and M. S. J. Warne. 2010. Site-specific probabilistic ecological risk assessment of a volatile chlorinated hydrocarbon-contaminated tidal estuary. <i>Environmental Toxicology and Chemistry</i> 29:1172-1181.	Pelagic/open water	Contamination	Peer-reviewed
Inglis, G. 1994. Contrasting effects of habitat structure on the recruitment and mortality of an epibiotic macroalga. <i>Oecologia</i> 99:352-365.	Seagrass	No threat considered	Peer-reviewed
Inglis, G. J., and M. P. L. Smith. 1995. An examination of observer bias as a source of error in surveys of seagrass shoots. <i>Australian Journal of Ecology</i> 20:273-281.	Seagrass	No threat considered	Peer-reviewed
Inglis, G. J., and M. P. L. Smith. 1998. Synchronous flowering of estuarine seagrass meadows. <i>Aquatic Botany</i> 60:37-48.	Seagrass	No threat considered	Peer-reviewed
Jackson, G., and P. Forbes. 2018. Oysters on the Georges River. <i>Sutherland Shire Heritage Society Inc Bulletin</i> 210.	Oyster reef	Multiple	Other
Jahan, S., and V. Strezov. 2018. Comparison of pollution indices for the assessment of heavy metals in the sediments of seaports of NSW, Australia. <i>Marine Pollution Bulletin</i> 128:295-306.	Soft sediment	Contamination	Peer-reviewed
Jahan, S., and V. Strezov. 2020. Effect of shipping on the distribution of trace elements and petroleum hydrocarbons in the coastal basins of Australia: a review. <i>Marine and Freshwater Research</i> 71:794-809.	Multiple	Contamination	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Jeffery, C., and A. Underwood. 2000. Consistent spatial patterns of arrival of larvae of the honeycomb barnacle <i>Chamaesipho tasmanica</i> Foster and Anderson in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 252:109-127.	Rocky shore	No threat considered	Peer-reviewed
Jeffery, C., and A. Underwood. 2001. Longevity determines sizes of an adult intertidal barnacle. <i>Journal of Experimental Marine Biology and Ecology</i> 256:85-97.	Rocky shore	No threat considered	Peer-reviewed
Jenkins, C., P. Hick, M. Gabor, Z. Spiers, S. A. Fell, X. Gu, A. Read, J. Go, M. Dove, and W. O. Connor. 2013. Identification and characterisation of an ostreid herpesvirus-1 microvariant (OsHV-1 μ -var) in <i>Crassostrea gigas</i> (Pacific oysters) in Australia. <i>Diseases of Aquatic Organisms</i> 105:109-126.	Oyster reef	Pathogen/disease	Peer-reviewed
Jennings, J., R. De Nys, T. Charlton, M. Duncan, and P. Steinberg. 1996. Phenolic compounds in the nearshore waters of Sydney, Australia. <i>Marine and Freshwater Research</i> 47:951-959.	Pelagic/open water	Contamination	Peer-reviewed
Johnson, B., A. Albani, P. Rickwood, and J. Tayton. 1977. The bedrock topography of the botany basin, New South Wales. <i>Journal of the Geological Society of Australia</i> 24:403-408.	Soft sediment	No threat considered	Peer-reviewed
Jones, A. 1997. Botany Bay benthos: status and management. <i>Wetlands Australia</i> 16.	Multiple	Habitat modification	Peer-reviewed
Jones, A. R., A. Murray, T. A. Lasiak, and R. E. Marsh. 2008. The effects of beach nourishment on the sandy-beach amphipod <i>Exoediceros fossor</i> : impact and recovery in Botany Bay, New South Wales, Australia. <i>Marine Ecology</i> 29:28-36.	Beach	Habitat modification	Peer-reviewed
Jones, A., A. Murray, and R. Marsh. 1991. Patterns of abundance of exoedicerotid amphipods on sandy beaches near Sydney, Australia. <i>Hydrobiologia</i> 223:119-126.	Soft sediment	No threat considered	Peer-reviewed
Jones, G. 1981. Effects of dredging and reclamation on the sediments of Botany Bay. <i>Marine and Freshwater Research</i> 32:369-377.	Soft sediment	Habitat modification	Peer-reviewed
Jones, G., and S. Candy. 1981. Effects of dredging on the macrobenthic infauna of Botany Bay. <i>Marine and Freshwater Research</i> 32:379-398.	Soft sediment	Habitat modification	Peer-reviewed
Keable, S. J. 2006. Taxonomic revision of <i>Natatolana</i> (Crustacea: Isopoda: Cirolanidae). <i>Records – Australian Museum</i> 58:133.	Subtidal reef	No threat considered	Other
Kelaher, B. 2003a. Changes in habitat complexity negatively affect diverse gastropod assemblages in coralline algal turf. <i>Oecologia</i> 135:431-441.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B. P. 2002. Influence of physical characteristics of coralline turf on associated macrofaunal assemblages. <i>Marine Ecology Progress Series</i> 232:141-148.	Rocky shore	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Kelaher, B. P. 2003b. Effects of frond length on diverse gastropod assemblages in coralline turf. <i>Journal of the Marine Biological Association of the United Kingdom</i> 83:159-163.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B. P. 2005. Does colonization contribute to spatial patterns of common invertebrates in coralline algal turf? <i>Austral Ecology</i> 30:40-48.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B. P., M. J. Bishop, J. Potts, P. Scanes, and G. Skilbeck. 2013. Detrital diversity influences estuarine ecosystem performance. <i>Global Change Biology</i> 19:1909-1918.	Mangrove/saltmarsh	Multiple	Peer-reviewed
Kelaher, B., A. Underwood, and M. Chapman. 2003. Experimental transplantations of coralline algal turf to demonstrate causes of differences in macrofauna at different tidal heights. <i>Journal of Experimental Marine Biology and Ecology</i> 282:23-41.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B., and G. W. Rouse. 2003. The role of colonization in determining spatial patterns of <i>Prosclopplos bondi</i> sp. nov. (Orbiniidae: Annelida) in coralline algal turf. <i>Marine Biology</i> 143:909-917.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B., and J. Lowry. 2002. A new species of <i>Elasmopus</i> from Australia and its variation in density with respect to physical architecture of coralline algal turf. <i>Journal of Crustacean Biology</i> 22:861-873.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B., and V. Cole. 2005. Variation in abundance and size-structure of populations of the small chiton, <i>Acanthochitona retrojecta</i> . <i>Journal of Molluscan Studies</i> 71:145-151.	Rocky shore	No threat considered	Peer-reviewed
Kelaher, B., M. Chapman, and A. Underwood. 1998. Changes in benthic assemblages near boardwalks in temperate urban mangrove forests. <i>Journal of Experimental Marine Biology and Ecology</i> 228:291-307.	Mangrove/saltmarsh	Habitat modification	Peer-reviewed
Kelaher, B., M. Chapman, and A. Underwood. 2001. Spatial patterns of diverse macrofaunal assemblages in coralline turf and their associations with environmental variables. <i>Journal of the Marine Biological Association of the United Kingdom</i> 81:917-930.	Rocky shore	No threat considered	Peer-reviewed
Kelleway, J. 2006. Ecological impacts of recreational vehicle use on saltmarshes of the Georges River, Sydney. <i>Wetlands Australia</i> 22:52-66.	Mangrove/saltmarsh	Habitat modification	Peer-reviewed
Kelleway, J. J., N. Saintilan, P. I. Macreadie, C. G. Skilbeck, A. Zawadzki, and P. J. Ralph. 2016. Seventy years of continuous encroachment substantially increases 'blue carbon' capacity as mangroves replace intertidal salt marshes. <i>Global Change Biology</i> 22:1097-1109.	Mangrove/saltmarsh	Climate change	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Kennelly, S., and A. Underwood. 1992. Fluctuations in the distributions and abundances of species in sublittoral kelp forests in New South Wales. <i>Australian Journal of Ecology</i> 17:367-382.	Subtidal reef	No threat considered	Peer-reviewed
Kennelly, S., and A. Underwood. 1993. Geographic consistencies of effects of experimental physical disturbance on understorey species in sublittoral kelp forests in central New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 168:35-58.	Subtidal reef	Disturbance	Peer-reviewed
Kenworthy, J. M., D. M. Paterson, and M. J. Bishop. 2016. Response of benthic assemblages to multiple stressors: comparative effects of nutrient enrichment and physical disturbance. <i>Marine Ecology Progress Series</i> 562:37-51.	Mangrove/saltmarsh	Multiple	Peer-reviewed
Kermode, S. J., H. Heijnis, H. Wong, A. Zawadzki, P. Gadd, and A. Permana. 2016. A Ramsar-wetland in suburbia: wetland management in an urbanised, industrialised area. <i>Marine and Freshwater Research</i> 67:771-781.	Mangrove/saltmarsh	Multiple	Peer-reviewed
King, W. L., N. Siboni, T. Kahlke, M. Dove, W. O'Connor, K. R. Mahbub, C. Jenkins, J. R. Seymour, and M. Labbate. 2020. Regional and oyster microenvironmental scale heterogeneity in the Pacific oyster bacterial community. <i>FEMS Microbiology Ecology</i> 96:fiaa054.	Oyster reef	No threat considered	Peer-reviewed
Kingsford, M., A. Underwood, and S. Kennelly. 1991. Humans as predators on rocky reefs in New South Wales, Australia. <i>Marine ecology progress series</i> . Oldendorf 72:1-14.	Rocky shore	Fisheries	Peer-reviewed
Kingsford, M., and I. Suthers. 1994. Dynamic estuarine plumes and fronts: importance to small fish and plankton in coastal waters of NSW, Australia. <i>Continental Shelf Research</i> 14:655-672.	Pelagic/open water	Other	Peer-reviewed
Kingsford, M., and I. Suthers. 1996. The influence of tidal phase on patterns of ichthyoplankton abundance in the vicinity of an estuarine front, Botany Bay, Australia. <i>Estuarine, Coastal and Shelf Science</i> 43:33-54.	Pelagic/open water	Other	Peer-reviewed
Kinhill Engineers. 1990. Proposed third runway Sydney (Kingsford Smith) Airport: Draft environmental impact statement 0949397369, Report by Kinhill Engineers PTY LTD for Federal Airports Corporation, Canberra.	Multiple	Habitat modification	Report/grey literature
Klanten, O. S., M. R. Gaither, S. Greaves, K. Mills, K. O'Keeffe, J. Turnbull, R. McKinnon, and D. J. Booth. 2020. Genomic and morphological evidence of distinct populations in the endemic common (weedy) seadragon <i>Phyllopteryx taeniolatus</i> (Syngnathidae) along the east coast of Australia. <i>PLoS ONE</i> 15:e0243446.	Subtidal reef	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Knott, N. A., J. P. Aulbury, T. H. Brown, and E. L. Johnston. 2009. Contemporary ecological threats from historical pollution sources: impacts of large-scale resuspension of contaminated sediments on sessile invertebrate recruitment. <i>Journal of Applied Ecology</i> 46:770-781.	Soft sediment	Contamination	Peer-reviewed
Knott, N., A. Underwood, M. Chapman, and T. Glasby. 2004. Epibiota on vertical and on horizontal surfaces on natural reefs and on artificial structures. <i>Journal of the Marine Biological Association of the United Kingdom</i> 84:1117-1130.	Artificial	Habitat modification	Peer-reviewed
Knott, N., A. Underwood, M. Chapman, and T. Glasby. 2006. Growth of the encrusting sponge <i>Tedania anhelans</i> (Lieberkuhn) on vertical and on horizontal surfaces of temperate subtidal reefs. <i>Marine and Freshwater Research</i> 57:95-104.	Artificial	Habitat modification	Peer-reviewed
Laegdsgaard, P., M. Byrne, and D. Anderson. 1991. Reproduction of sympatric populations of <i>Heliocidaris erythrogramma</i> and <i>H. tuberculata</i> (Echinoidea) in New South Wales. <i>Marine Biology</i> 110:359-374.	Seagrass	No threat considered	Peer-reviewed
Larkum, A. 1976a. Botany Bay: national asset or national disaster. <i>Operculum</i> (Australian Littoral Society) 5:67-75.	Multiple	Multiple	Peer-reviewed
Larkum, A. 1976b. Ecology of Botany Bay. I. Growth of <i>Posidonia australis</i> (Brown) Hook. f. in Botany Bay and other bays of the Sydney basin. <i>Marine and Freshwater Research</i> 27:117-127.	Seagrass	No threat considered	Peer-reviewed
Larkum, A. W., A. McComb, and S. Shephard. 1989. <i>Biology of seagrasses: a treatise on the biology of seagrasses with special reference to the Australian region</i> . Elsevier Science Pub.	Seagrass	No threat considered	Book
Larkum, A., and R. West. 1983. Stability, depletion and restoration of seagrass beds. <i>Proceedings of the Linnean Society of New South Wales</i> 106:201-212.	Seagrass	Multiple	Peer-reviewed
Larkum, A., and R. West. 1990. Long-term changes of seagrass meadows in Botany Bay, Australia. <i>Aquatic Botany</i> 37:55-70.	Seagrass	Habitat modification	Peer-reviewed
Larkum, A., L. Collett, and R. Williams. 1984. The standing stock, growth and shoot production of <i>Zostera capricorni</i> aschers. in Botany Bay, New South Wales, Australia. <i>Aquatic Botany</i> 19:307-327.	Seagrass	No threat considered	Peer-reviewed
Laursen, W., and R. King. 2000. The distribution and abundance of mangrove macroalgae in Woolloomare Bay, New South Wales, Australia. <i>Botanica Marina</i> 43:377-384.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Laursen, W., and R. King. 2000. The free-living <i>Hormosira banksii</i> in Botany Bay, Australia: twenty years on. <i>Wetlands Australia</i> 18.	Mangrove/saltmarsh	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Leadbitter, D. 1986. The relationships between seagrasses and the processes at accretion and erosion at Towra Bay, Botany Bay. <i>Wetlands Australia</i> 6.	Mangrove/saltmarsh	Habitat modification	Peer-reviewed
Lee, K. M., M. A. Beal, and E. L. Johnston. 2006. A new predatory flatworm (Platyhelminthes, Polycladida) from Botany Bay, New South Wales, Australia. <i>Journal of Natural History</i> 39:3987-3995.	Artificial	No threat considered	Peer-reviewed
Lee, W. J. 2012. Free-living benthic heterotrophic euglenids from Botany Bay, Australia. <i>Marine Biology Research</i> 8:3-27.	Soft sediment	No threat considered	Peer-reviewed
Lee, W. J., and D. J. Patterson. 2000. Heterotrophic flagellates (Protista) from marine sediments of Botany Bay, Australia. <i>Journal of Natural History</i> 34:483-562.	Soft sediment	No threat considered	Peer-reviewed
Lee, W., and D. Patterson. 2002. Abundance and biomass of heterotrophic flagellates, and factors controlling their abundance and distribution in sediments of Botany Bay. <i>Microbial Ecology</i> 43:467-481.	Soft sediment	No threat considered	Peer-reviewed
Liggins, G., S. Kennelly, and M. Broadhurst. 1996. Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. <i>Marine and Freshwater Research</i> 47:877-888.	Pelagic/open water	Fisheries	Peer-reviewed
Liu, O., I. Paul-Pont, A. Rubio, N. Dhand, and R. J. Whittington. 2020. Detection of ostreid herpesvirus-1 in plankton and seawater samples at an estuary scale. <i>Diseases of Aquatic Organisms</i> 138:1-15.	Pelagic/open water	Pathogen/disease	Peer-reviewed
Longford, S. R., A. H. Campbell, S. Nielsen, R. J. Case, S. Kjelleberg, and P. D. Steinberg. 2019. Interactions within the microbiome alter microbial interactions with host chemical defences and affect disease in a marine holobiont. <i>Scientific Reports</i> 9:1-13.	Subtidal reef	Pathogen/disease	Peer-reviewed
Longford, S. R., N. A. Tujula, G. R. Crocetti, A. J. Holmes, C. Holmström, S. Kjelleberg, P. D. Steinberg, and M. W. Taylor. 2007. Comparisons of diversity of bacterial communities associated with three sessile marine eukaryotes. <i>Aquatic Microbial Ecology</i> 48:217-229.	Subtidal reef	No threat considered	Peer-reviewed
Loveless, A. 2009. A multi-dimensional receiving water quality model for Botany Bay (Sydney, Australia). In: <i>Proceedings of the 18th World IMAC/MODSIM Congress</i> , Cairns, Australia, 13–17 July 2009.	Pelagic/open water	No threat considered	Other
Lowry, M., H. Folpp, M. Gregson, and I. Suthers. 2012. Comparison of baited remote underwater video (BRUV) and underwater visual census (UVC) for assessment of artificial reefs in estuaries. <i>Journal of Experimental Marine Biology and Ecology</i> 416:243-253.	Artificial	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Lowry, M., T. Glasby, C. Boys, H. Folpp, I. Suthers, and M. Gregson. 2014. Response of fish communities to the deployment of estuarine artificial reefs for fisheries enhancement. <i>Fisheries Management and Ecology</i> 21:42-56.	Artificial	No threat considered	Peer-reviewed
Lynch, T., C. Smallwood, F. Ochwada-Doyle, J. Williams, K. Ryan, C. Devine, B. Gibson, M. Burton, A. Hegarty, J. Lyle, Foster, S. and A. Jordan. 2019. Recreational fishing in Commonwealth waters. Report for National Environmental Science Program, Marine Biodiversity Hub. (CSIRO).	Multiple	No threat considered	Report/grey literature
Macbeth, W. G. 2019. Port Botany Long-term Seagrass Monitoring. Report for Port Authority of New South Wales.	Seagrass	Habitat modification	Report/grey literature
Mackay, D., and A. Underwood. 1977. Experimental studies on homing in the intertidal patellid limpet <i>Cellana tramoserica</i> (Sowerby). <i>Oecologia</i> 30:215-237.	Rocky shore	No threat considered	Peer-reviewed
Mackay, N., R. Williams, J. Kacprzac, M. Kazacos, A. Collins, and E. Auty. 1975. Heavy metals in cultivated oysters (<i>Crassostrea commercialis</i> = <i>Saccostrea cucullata</i>) from estuaries of New South Wales. <i>Marine and Freshwater Research</i> 26:31-46.	Oyster reef	Contamination	Peer-reviewed
Macleay, W., J. C. Cox, W. B. Dalley, H. C. Danger, R. Driver, J. S. Farnell, R. Hill, F. Hixson, T. Holt, A. Oliver, E. P. Ramsay, C. C. Skarratt, G. Thornton, and G. F. Want. 1880. Report of the Royal Commission appointed on the 8th January, 1880, to inquire into and report upon the actual state and prospect of the fisheries of this colony: together with the minutes of evidence and appendices. Government Printer, Sydney.	Multiple	Fisheries	Report/grey literature
Macnamara, J., and C. Derry. 2017. Pollution removal performance of laboratory simulations of Sydney's street stormwater biofilters. <i>Water</i> 9:907.	Non-habitat specific	Contamination	Peer-reviewed
MacPherson, J. 1931. Aboriginal fish and emu poisons. <i>The Australian Journal of Anthropology</i> 1:157.	Multiple	No threat considered	Peer-reviewed
MacPherson, J. 1935. Australia: Ethno-Botany. More Aboriginal Fish Poisons. <i>Mankind</i> 1:9-12.	Multiple	No threat considered	Peer-reviewed
Macreadie, P. I., K. Allen, B. P. Kelaher, P. J. Ralph, and C. G. Skilbeck. 2012. Paleoreconstruction of estuarine sediments reveal human-induced weakening of coastal carbon sinks. <i>Global Change Biology</i> 18:891-901.	Soft sediment	Climate change	Peer-reviewed
Major, R. E., and J. Sladek. 2012. Is an island reserve enough? The decline and fall of the white-fronted chat (Aves: Meliphagidae) in southern Sydney. <i>Proceedings of the Linnean Society of New South Wales</i> . 134:B205-B214.	Soft sediment	Climate change	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Mapstone, B., A. Underwood, and R. Creese. 1984. Experimental analyses of the commensal relation between intertidal gastropods <i>Patelloida mufria</i> and the trochid <i>Austrocochlea constricta</i> . Marine Ecology Progress Series. Oldendorf 17:85-100.	Rocky shore	No threat considered	Peer-reviewed
Marzinelli, E. M., A. H. Campbell, E. Zozaya Valdes, A. Vergés, S. Nielsen, T. Wernberg, T. De Bettignies, S. Bennett, J. G. Caporaso, and T. Thomas. 2015. Continental-scale variation in seaweed host-associated bacterial communities is a function of host condition, not geography. Environmental microbiology 17:4078-4088.	Subtidal reef	No threat considered	Peer-reviewed
Matias, M. G. 2008. Cape Banks: A shore from the other side of the world. In: <i>Algas</i> . Spanish Phycological Society.	Rocky shore	No threat considered	Book
May, V., A. Collins, and L. C. Collett. 1978. A comparative study of epiphytic algal communities on two common genera of sea-grasses in eastern Australia. Australian Journal of Ecology 3:91-104.	Seagrass	No threat considered	Peer-reviewed
Mayer-Pinto, M., A. J. Underwood, and E. M. Marzinelli. 2015. The matrix influences direct and indirect effects of an anthropogenic disturbance on marine organisms. Environmental Research 136:15-20.	Rocky shore	Contamination	Peer-reviewed
Mayer-Pinto, M., and B. L. Ignacio. 2015. Effects of chemical disturbances on intertidal benthic assemblages. Science of the Total Environment 506:10-17.	Rocky shore	Contamination	Peer-reviewed
Mayer-Pinto, M., M. G. Matias, and R. A. Coleman. 2016. The interplay between habitat structure and chemical contaminants on biotic responses of benthic organisms. PeerJ 4:e1985.	Artificial	Multiple	Peer-reviewed
Mazumder, D., and N. Saintilan. 2010a. A comparison of sampling techniques in the assessment of burrowing crab abundance in saltmarsh and mangrove environments. Wetlands Australia 21.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., and N. Saintilan. 2010b. Mangrove leaves are not an important source of dietary carbon and nitrogen for crabs in temperate Australian mangroves. Wetlands 30:375-380.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., N. Saintilan, and R. J. Williams. 2005. Temporal variations in fish catch using pop nets in mangrove and saltmarsh flats at Towra Point, NSW, Australia. Wetlands Ecology and Management 13:457-467.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., N. Saintilan, and R. J. Williams. 2006. Fish assemblages in three tidal saltmarsh and mangrove flats in temperate NSW, Australia: a comparison based on species diversity and abundance. Wetlands Ecology and Management 14:201-209.	Mangrove/saltmarsh	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Mazumder, D., N. Saintilan, and R. J. Williams. 2009. Zooplankton inputs and outputs in the saltmarsh at Towra Point, Australia. <i>Wetlands Ecology and Management</i> 17:225-230.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., N. Saintilan, R. J. Williams, and R. Szymczak. 2011. Trophic importance of a temperate intertidal wetland to resident and itinerant taxa: evidence from multiple stable isotope analyses. <i>Marine and Freshwater Research</i> 62:11-19.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., R. J. Williams, D. Reid, N. Saintilan, and R. Szymczak. 2008. Variability of stable isotope ratios of glassfish (<i>Ambassis jacksoniensis</i>) from mangrove/saltmarsh environments in southeast Australia and implications for choosing sample size. <i>Environmental Bioindicators</i> 3:114-123.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mazumder, D., Saintilan, N. and Williams, R.J., 2006. Trophic relationships between itinerant fish and crab larvae in a temperate Australian saltmarsh. <i>Marine and Freshwater Research</i> , 57:193-199.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
McCready, S., C. R. Greely, R. V. Hyne, G. F. Birch, and E. R. Long. 2005. Sensitivity of an indigenous amphipod (<i>Corophium colo</i>) to chemical contaminants in laboratory toxicity tests conducted with sediments from Sydney Harbor, Australia, and vicinity. <i>Environmental Toxicology and Chemistry: An International Journal</i> 24:2545-2552.	Soft sediment	Contamination	Peer-reviewed
McCready, S., G. Spyrikis, C. Greely, G. Birch, and E. Long. 2004. Toxicity of surficial sediments from Sydney Harbour and vicinity, Australia. <i>Environmental Monitoring and Assessment</i> 96:53-83.	Soft sediment	Contamination	Peer-reviewed
McGuinness, K. 1987. Disturbance and Organisms on Boulders. I. Patterns in the Environment and the Community. <i>Oecologia</i> 71:420-430.	Rocky shore	No threat considered	Peer-reviewed
McGuinness, K. A. 1984. Species-area relations of communities on intertidal boulders: testing the null hypothesis. <i>Journal of Biogeography</i> 439-456.	Rocky shore	No threat considered	Peer-reviewed
McGuinness, K. A. 1988. The Ecology of Botany Bay & the Effects of Man: Summary Report. Institute of Marine Ecology, University of Sydney.	Multiple	Multiple	Book
McGuinness, K. A. 1990. Effects of oil spills on macro-invertebrates of saltmarshes and mangrove forests in Botany Bay, New South Wales, Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 142:121-135.	Mangrove/saltmarsh	Contamination	Peer-reviewed

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McGuinness, K., and A. Underwood. 1986. Habitat structure and the nature of communities on intertidal boulders. <i>Journal of Experimental Marine Biology and Ecology</i> 104:97-123.	Rocky shore	No threat considered	Peer-reviewed
McGuinness, K., and K. McGuinness. 1987. Disturbance and organisms on boulders. II. Causes of patterns in diversity and abundance. <i>Oecologia</i> 420-430.	Rocky shore	No threat considered	Peer-reviewed
McKinley, A. C., A. Miskiewicz, M. D. Taylor, and E. L. Johnston. 2011b. Strong links between metal contamination, habitat modification and estuarine larval fish distributions. <i>Environmental Pollution</i> 159:1499-1509.	Pelagic/open water	Contamination	Peer-reviewed
McKinley, A. C., K. A. Dafforn, M. D. Taylor, and E. L. Johnston. 2011a. High levels of sediment contamination have little influence on estuarine beach fish communities. <i>PLoS ONE</i> 6:e26353.	Beach	Contamination	Peer-reviewed
McLennan, K., R. Ruvindy, M. Ostrowski, and S. Murray. 2021. Assessing the Use of Molecular Barcoding and qPCR for Investigating the Ecology of <i>Prorocentrum minimum</i> (Dinophyceae), a Harmful Algal Species. <i>Microorganisms</i> 9:510.	Pelagic/open water	Multiple	Peer-reviewed
McMinn, A. 1989. Late Pleistocene dinoflagellate cysts from Botany Bay, New South Wales, Australia. <i>Micropaleontology</i> 35:1-9.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
McNeill, S., D. Worthington, D. Ferrell, and J. Bell. 1992. Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. <i>Australian Journal of Ecology</i> 17:359-365.	Seagrass	No threat considered	Peer-reviewed
Melville, F., and M. Burchett. 2002. Genetic variation in <i>Avicennia marina</i> in three estuaries of Sydney (Australia) and implications for rehabilitation and management. <i>Marine Pollution Bulletin</i> 44:469-479.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Middleton, J. H., and B. D. Morris. 1987. Circulation and Exchange within Botany Bay Technical Report submitted to the commission of Inquiry. The University of New South Wales.	Pelagic/open water	No threat considered	Report/grey literature
Middleton, M., J. Bell, J. Burchmore, D. Pollard, and B. Pease. 1984. Structural differences in the fish communities of <i>Zostera capricorni</i> and <i>Posidonia australis</i> seagrass meadows in Botany Bay, New South Wales. <i>Aquatic Botany</i> 18:89-109.	Seagrass	No threat considered	Peer-reviewed
Minchinton, T. E., and L. A. McKenzie. 2008. Nutrient enrichment affects recruitment of oysters and barnacles in a mangrove forest. <i>Marine Ecology Progress Series</i> 354:181-189.	Mangrove/saltmarsh	Nutrient addition	Peer-reviewed
Minchinton, T. E., and P. M. Ross. 1999. Oysters as habitat for limpets in a temperate mangrove forest. <i>Australian Journal of Ecology</i> 24:157-170.	Mangrove/saltmarsh	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Mitchell, M. L., and P. Adam. 1989a. The decline of saltmarsh in Botany Bay. <i>Wetlands (Australia)</i> 8:2.	Mangrove/saltmarsh	Disturbance	Peer-reviewed
Mitchell, M. L., and P. Adam. 1989b. The relationship between mangrove and saltmarsh communities in the Sydney region. <i>Wetlands (Australia)</i> 8:37-46.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Mo, M. 2016. The Beach Stone-Curlew (<i>Esacus magnirostris</i>) in the Sydney Basin and South East Corner Bioregions of New South Wales. <i>Proceedings of the Linnean Society of New South Wales</i> 136:69-81.	Terrestrial	No threat considered	Peer-reviewed
Monro, K., A. G. Poore, and R. Brooks. 2007. Multivariate selection shapes environment-dependent variation in the clonal morphology of a red seaweed. <i>Evolutionary Ecology</i> 21:765-782.	Subtidal reef	No threat considered	Peer-reviewed
Monro, K., and A. G. Poore. 2004. Selection in modular organisms: is intraclonal variation in macroalgae evolutionarily important? <i>The American Naturalist</i> 163:564-578.	Subtidal reef	No threat considered	Peer-reviewed
Monro, K., and A. G. Poore. 2005. Light quantity and quality induce shade-avoiding plasticity in a marine macroalga. <i>Journal of Evolutionary Biology</i> 18:426-435.	Subtidal reef	No threat considered	Peer-reviewed
Monro, K., and A. G. Poore. 2009a. The evolvability of growth form in a clonal seaweed. <i>Evolution: International Journal of Organic Evolution</i> 63:3147-3157.	Subtidal reef	No threat considered	Peer-reviewed
Monro, K., and A. G. Poore. 2009b. Performance benefits of growth-form plasticity in a clonal red seaweed. <i>Biological Journal of the Linnean Society</i> 97:80-89.	Subtidal reef	No threat considered	Peer-reviewed
Monro, K., and A. G. Poore. 2009c. The potential for evolutionary responses to cell-lineage selection on growth form and its plasticity in a red seaweed. <i>The American Naturalist</i> 173:151-163.	Subtidal reef	No threat considered	Peer-reviewed
Monteiro, S., M. Chapman, and A. Underwood. 2002. Patches of the ascidian <i>Pyura stolonifera</i> (Heller, 1878): structure of habitat and associated intertidal assemblages. <i>Journal of Experimental Marine Biology and Ecology</i> 270:171-189.	Rocky shore	Fisheries	Peer-reviewed
Moran, M., P. Fairweather, and A. Underwood. 1984. Growth and mortality of the predatory intertidal whelk <i>Morula marginalba</i> Blainville (Muricidae): the effects of different species of prey. <i>Journal of Experimental Marine Biology and Ecology</i> 75:1-17.	Rocky shore	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Morrisey, D. J., A. Underwood, L. Howitt, and J. Stark. 1992c. Temporal variation in soft-sediment benthos. <i>Journal of Experimental Marine Biology and Ecology</i> 164:233-245.	Soft sediment	No threat considered	Peer-reviewed
Morrisey, D., A. Underwood, and L. Howitt. 1992b. Scales of spatial patchiness in the distribution of marine soft sediment faunas. In: <i>Proceedings of the Second International Temperate Reef Symposia</i> . Wellington, NIWA Marine.	Soft sediment	No threat considered	Other
Morrisey, D., A. Underwood, and L. Howitt. 1995. Development of sediment-quality criteria – A proposal from experimental field-studies of the effects of copper on benthic organisms. <i>Marine Pollution Bulletin</i> 31:372-377.	Soft sediment	Contamination	Peer-reviewed
Morrisey, D., A. Underwood, and L. Howitt. 1996. Effects of copper on the faunas of marine soft-sediments: an experimental field study. <i>Marine Biology</i> 125:199-213.	Soft sediment	Contamination	Peer-reviewed
Morrisey, D., A. Underwood, J. Stark, and L. Howitt. 1994b. Temporal variation in concentrations of heavy metals in marine sediments. <i>Estuarine, Coastal and Shelf Science</i> 38:271-282.	Soft sediment	Contamination	Peer-reviewed
Morrisey, D., J. Stark, L. Howitt, and A. Underwood. 1994a. Spatial variation in concentrations of heavy metals in marine sediments. <i>Marine and Freshwater Research</i> 45:177-184.	Soft sediment	Contamination	Peer-reviewed
Morrisey, D., L. Howitt, A. Underwood, and J. Stark. 1992a. Spatial variation in soft-sediment benthos. <i>Marine Ecology Progress Series</i> . Oldendorf 81:197-204.	Soft sediment	No threat considered	Peer-reviewed
Motta, J. C., A. Underwood, M. Chapman, and F. Rossi. 2003. Benthic assemblages in sediments associated with intertidal boulder-fields. <i>Journal of Experimental Marine Biology and Ecology</i> 285:383-401.	Soft sediment	No threat considered	Peer-reviewed
Murphy, R. J., A. Underwood, and M. H. Pinkerton. 2006. Quantitative imaging to measure photosynthetic biomass on an intertidal rock-platform. <i>Marine Ecology Progress Series</i> 312:45-55.	Rocky shore	No threat considered	Peer-reviewed
Murphy, R., and T. Tolhurst. 2009. Effects of experimental manipulation of algae and fauna on the properties of intertidal soft sediments. <i>Journal of Experimental Marine Biology and Ecology</i> 379:77-84.	Soft sediment	No threat considered	Peer-reviewed
Murphy, R., T. Tolhurst, M. Chapman, and A. Underwood. 2008. Spatial variation of chlorophyll on estuarine mudflats determined by field-based remote sensing. <i>Marine Ecology Progress Series</i> 365:45-55.	Soft sediment	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Murray, A., and S. J. Keable. 2013. First Report of <i>Sabella spallanzanii</i> (Gmelin, 1791) (Annelida: Polychaeta) from Botany Bay, New South Wales, a northern range extension for the invasive species within Australia. <i>Zootaxa</i> 3670:391-395.	Artificial	NIS	Peer-reviewed
Murray, D. R., and A. Larkum. 1991. Seed proteins of the seagrass <i>Zostera capricorni</i> . <i>Aquatic Botany</i> 40:101-108.	Seagrass	No threat considered	Peer-reviewed
Murray, D. R., and A. Larkum. 1992a. Nitrogen content of seeds of <i>Zostera capricorni</i> and <i>Zostera marina</i> . <i>Aquatic Botany</i> 43:87-91.	Seagrass	No threat considered	Peer-reviewed
Murray, D. R., and A. W. D. Larkum. 1992b. <i>Zostera</i> seeds are low in nitrogen content. <i>Aquatic Botany</i> 43:87-91.	Seagrass	No threat considered	Peer-reviewed
Murray, S. A., M. Wiese, A. Stüken, S. Brett, R. Kellmann, G. Hallegraeff, and B. A. Neilan. 2011. sxtA-based quantitative molecular assay to identify saxitoxin-producing harmful algal blooms in marine waters. <i>Applied and Environmental Microbiology</i> 77:7050-7057.	Pelagic/open water	Pathogen/disease	Peer-reviewed
Murray, S., and D. J. Patterson. 2002a. <i>Amphidiniopsis korewalensis</i> sp. nov., a new heterotrophic benthic dinoflagellate. <i>Phycologia</i> 41:382-388.	Soft sediment	No threat considered	Peer-reviewed
Murray, S., and D. J. Patterson. 2002b. The benthic dinoflagellate genus <i>Amphidinium</i> in south-eastern Australian waters, including three new species. <i>European Journal of Phycology</i> 37:279-298.	Soft sediment	No threat considered	Peer-reviewed
Murray, S., and D. J. Patterson. 2004. <i>Cabra matta</i> , gen. nov., sp. nov., a new benthic, heterotrophic dinoflagellate. <i>European Journal of Phycology</i> 39:229-234.	Soft sediment	No threat considered	Peer-reviewed
Murray, S., and I. M. Suthers. 1999. Population ecology of <i>Noctiluca scintillans</i> Macartney, a red-tide-forming dinoflagellate. <i>Marine and Freshwater Research</i> 50:243-252.	Pelagic/open water	No threat considered	Peer-reviewed
Nell, J. 2007. Diseases of Sydney rock oysters. NSW Fisheries Final Report Series No. 49. Sydney, NSW: NSW Fisheries and Fisheries Research and Development Corporation.	Oyster reef	Pathogen/disease	Report/grey literature
Nell, J. A. 1993. Farming the Sydney rock oyster (<i>Saccostrea commercialis</i>) in Australia. <i>Reviews in Fisheries Science</i> 1:97-120.	Oyster reef	Pathogen/disease	Peer-reviewed
Nell, J. A. 2001. The history of oyster farming in Australia. <i>Marine Fisheries Review</i> 63:14-25.	Oyster reef	Fisheries	Peer-reviewed
Nell, J. A., and B. Perkins. 2006. Evaluation of the progeny of third-generation Sydney rock oyster <i>Saccostrea glomerata</i> (Gould, 1850) breeding lines for resistance to QX disease <i>Marteilia sydneyi</i> and winter mortality <i>Bonamia roughleyi</i> . <i>Aquaculture Research</i> 37:693-700.	Oyster reef	Pathogen/disease	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Nell, J. A., and R. E. Hand. 2003. Evaluation of the progeny of second-generation Sydney rock oyster <i>Saccostrea glomerata</i> (Gould, 1850) breeding lines for resistance to QX disease <i>Marteilia sydneyi</i> . <i>Aquaculture</i> 228:27-35.	Oyster reef	Pathogen/disease	Peer-reviewed
Nell, J. A., I. R. Smith, and C. C. McPhee. 2000. The Sydney rock oyster <i>Saccostrea glomerata</i> (Gould 1850) breeding programme: progress and goals. <i>Aquaculture Research</i> 31:45-49.	Oyster reef	Pathogen/disease	Peer-reviewed
Nguyen, M., Wemheuer, B., Laffy, P.W., Webster, N.S. and Thomas, T., 2021. Taxonomic, functional and expression analysis of viral communities associated with marine sponges. <i>PeerJ</i> , 9, p.e10715.	Subtidal reef	No threat considered	Peer-reviewed
Nguyen, M.T. and Thomas, T., 2018. Diversity, host-specificity and stability of sponge-associated fungal communities of co-occurring sponges. <i>PeerJ</i> , 6, p.e4965.	Subtidal reef	No threat considered	Peer-reviewed
Nimmo, J., 2001. From river to ridge: a blueprint for sustainable management in the Georges River Catchment. <i>Water Science and Technology</i> , 43:251-262.	Multiple	No threat considered	Peer-reviewed
NPWS. 2001. Towra Point Nature Reserve plan of management. By National Parks and Wildlife Service for Office of Environment and Heritage, Hurstville.	Mangrove/saltmarsh	No threat considered	Report/grey literature
O'Connor, W. A., and M. C. Dove. 2009. The changing face of oyster culture in New South Wales, Australia. <i>Journal of Shellfish Research</i> 28:803-811.	Oyster reef	No threat considered	Peer-reviewed
Ogburn, D. M., I. White, and D. P. McPhee. 2007. The disappearance of oyster reefs from eastern Australian estuaries—impact of colonial settlement or mudworm invasion? <i>Coastal Management</i> 35:271-287.	Oyster reef	Pathogen/disease	Peer-reviewed
Olabarria, C. 2002. Role of colonization in spatio-temporal patchiness of microgastropods in coralline turf habitat. <i>Journal of Experimental Marine Biology and Ecology</i> 274:121-140.	Rocky shore	No threat considered	Peer-reviewed
Olabarria, C., A. Underwood, and M. Chapman. 2002. Appropriate experimental design to evaluate preferences for microhabitat: an example of preferences by species of microgastropods. <i>Oecologia</i> 132:159-166.	Rocky shore	No threat considered	Peer-reviewed
Olabarria, C., and M. Chapman. 2001. Comparison of patterns of spatial variation of microgastropods between two contrasting intertidal habitats. <i>Marine Ecology Progress Series</i> 220:201-211.	Rocky shore	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Olabarria, C., and M. Chapman. 2002. Inconsistency in short-term temporal variability of microgastropods within and between two different intertidal habitats. <i>Journal of Experimental Marine Biology and Ecology</i> 269:85-100.	Rocky shore	No threat considered	Peer-reviewed
Otway, N. M., and W. G. Macbeth. 1999. Physical effects of hauling on seagrass. NSW Fisheries Final Report Series No. 15. Cronulla: NSW Fisheries.	Seagrass	Fisheries	Report/grey literature
Otway, N., and A. Underwood. 1987. Experiments on orientation of the intertidal barnacle <i>Tesseropora rosea</i> (Krauss). <i>Journal of Experimental Marine Biology and Ecology</i> 105:85-106.	Rocky shore	No threat considered	Peer-reviewed
Parkinson, K., and D. Booth. 2016. Rapid growth and short life spans characterize pipefish populations in vulnerable seagrass beds. <i>Journal of Fish Biology</i> 88:1847-1855.	Seagrass	No threat considered	Peer-reviewed
Paul-Pont, I., N. K. Dhand, and R. J. Whittington. 2013a. Influence of husbandry practices on OsHV-1 associated mortality of Pacific oysters <i>Crassostrea gigas</i> . <i>Aquaculture</i> 412:202-214.	Oyster reef	Pathogen/disease	Peer-reviewed
Paul-Pont, I., N. K. Dhand, and R. J. Whittington. 2013b. Spatial distribution of mortality in Pacific oysters <i>Crassostrea gigas</i> : reflection on mechanisms of OsHV-1 transmission. <i>Diseases of Aquatic Organisms</i> 105:127-138.	Oyster reef	Pathogen/disease	Peer-reviewed
Payne, N. L., D. E. van der Meulen, R. Gannon, J. M. Semmens, I. M. Suthers, C. A. Gray, and M. D. Taylor. 2013. Rain reverses diel activity rhythms in an estuarine teleost. <i>Proceedings of the Royal Society B: Biological Sciences</i> 280:20122363.	Pelagic/open water	No threat considered	Peer-reviewed
Payne, N. L., J. A. Smith, D. E. van der Meulen, M. D. Taylor, Y. Y. Watanabe, A. Takahashi, T. A. Marzullo, C. A. Gray, G. Cadiou, and I. M. Suthers. 2016. Temperature dependence of fish performance in the wild: links with species biogeography and physiological thermal tolerance. <i>Functional Ecology</i> 30:903-912.	Pelagic/open water	No threat considered	Peer-reviewed
Pegler, J. 1997. Intertidal waders at Botany Bay – a fifty year retrospective. <i>Wetlands Australia</i> 16.	Terrestrial	Habitat modification	Peer-reviewed
Perrett, L. A., E. L. Johnston, and A. G. Poore. 2006. Impact by association: direct and indirect effects of copper exposure on mobile invertebrate fauna. <i>Marine Ecology Progress Series</i> 326:195-205.	Artificial	Contamination	Peer-reviewed
Petratits, P. 1992. Effects of body size and water temperature on grazing rates of four intertidal gastropods. <i>Australian Journal of Ecology</i> 17:409-414.	Rocky shore	No threat considered	Peer-reviewed

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Phelps, C. M., K. McMahon, A. Bissett, R. Bernasconi, P. D. Steinberg, T. Thomas, E. M. Marzinelli, and M. J. Huggett. 2021. The surface bacterial community of an Australian kelp shows cross-continental variation and relative stability within regions. <i>FEMS Microbiology Ecology</i> 97:faib089.	Subtidal reef	No threat considered	Peer-reviewed
Piola, R. F., and E. L. Johnston. 2006. Differential tolerance to metals among populations of the introduced bryozoan <i>Bugula neritina</i> . <i>Marine Biology</i> 148:997-1010.	Artificial	NIS	Peer-reviewed
Pirotta, V., W. Reynolds, G. Ross, I. Jonsen, A. Grech, D. Slip, and R. Harcourt. 2020. A citizen science approach to long-term monitoring of humpback whales (<i>Megaptera novaeangliae</i>) off Sydney, Australia. <i>Marine Mammal Science</i> 36:472-485.	Pelagic/open water	No threat considered	Peer-reviewed
Pitt, K. A., and M. J. Kingsford. 2003. Temporal and spatial variation in recruitment and growth of medusae of the jellyfish, <i>Catostylus mosaicus</i> (Scyphozoa: Rhizostomeae). <i>Marine and Freshwater Research</i> 54:117-125.	Pelagic/open water	No threat considered	Peer-reviewed
Pitt, K., and M. Kingsford. 2000a. Geographic separation of stocks of the edible jellyfish <i>Catostylus mosaicus</i> (Rhizostomeae) in New South Wales, Australia. <i>Marine Ecology Progress Series</i> 196:143-155.	Pelagic/open water	No threat considered	Peer-reviewed
Pitt, K., and M. Kingsford. 2000b. Reproductive biology of the edible jellyfish <i>Catostylus mosaicus</i> (Rhizostomeae). <i>Marine Biology</i> 137:791-799.	Pelagic/open water	No threat considered	Peer-reviewed
Pollard, D. A., and R. L. Pethebridge. 2002. Report on Port of Botany Bay introduced marine pest species survey. Report for Sydney Ports Corporation.	Non-habitat specific	NIS	Report/grey literature
Poore, A. G., and J. K. Lowry. 1997. New amphithoid amphipods from Port Jackson, New South Wales, Australia (Crustacea: Amphipoda: Ampithoidae). <i>Invertebrate Systematics</i> 11:897-941.	Subtidal reef	No threat considered	Peer-reviewed
Poore, A. G., and P. D. Steinberg. 2001. Host-plant adaptation in an herbivorous marine amphipod: genetic potential not realized in field populations. <i>Evolution</i> 55:68-80.	Subtidal reef	No threat considered	Peer-reviewed
Poore, A. G., M. J. Watson, R. de Nys, J. K. Lowry, and P. D. Steinberg. 2000. Patterns of host use among alga-and sponge-associated amphipods. <i>Marine Ecology Progress Series</i> 208:183-196.	Subtidal reef	No threat considered	Peer-reviewed
Porter, A., R. Ferrari, B. Kelaher, S. Smith, R. Coleman, M. Byrne, and W. Figueira. 2018. Marine infrastructure supports abundant, diverse fish assemblages at the expense of beta diversity. <i>Marine Biology</i> 165:1-13.	Artificial	Habitat modification	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Prado, P., and T. Thibaut. 2008. Differences between epiphytic assemblages on introduced <i>Caulerpa taxifolia</i> and coexisting eelgrass (<i>Zostera capricorni</i>) in Botany Bay (NSW, Australia).	Seagrass	NIS	Peer-reviewed
Price, P., and I. A. Wright. 2016. Water quality impact from the discharge of coal mine wastes to receiving streams: comparison of impacts from an active mine with a closed mine. <i>Water, Air, & Soil Pollution</i> 227:155.	Pelagic/open water	Contamination	Peer-reviewed
Pursche, A. R., I. M. Suthers, and M. D. Taylor. 2014. The effect of targeted stocking on behaviour and space utilization of a released finfish. <i>ICES Journal of Marine Science</i> 71:1100-1106.	Pelagic/open water	No threat considered	Peer-reviewed
Pursche, A., I. Suthers, and M. Taylor. 2013. Post-release monitoring of site and group fidelity in acoustically tagged stocked fish. <i>Fisheries Management and Ecology</i> 20:445-453.	Pelagic/open water	No threat considered	Peer-reviewed
Range, P., M. Chapman, and A. Underwood. 2008. Field experiments with “cageless” methods to manipulate grazing gastropods on intertidal rocky shores. <i>Journal of Experimental Marine Biology and Ecology</i> 365:23-30.	Rocky shore	No threat considered	Peer-reviewed
Reeds, K. 2018. Port Botany Long-term Seagrass Monitoring. Report for Port Authority of New South Wales.	Seagrass	Habitat modification	Report/grey literature
Rees, M., N. Knott, M. Hing, M. Hammond, J. Williams, J. Neilson, D. Swadling, and A. Jordan. 2021. Habitat and humans predict the distribution of juvenile and adult snapper (Sparidae: <i>Chrysophrys auratus</i>) along Australia's most populated coastline. <i>Estuarine, Coastal and Shelf Science</i> 257:107397.	Subtidal reef	Multiple	Peer-reviewed
Reid, D. 2020. A review of the ‘natural’ ecological features of waterways in the Botany Bay catchment, in southern Sydney, Australia. <i>Regional Studies in Marine Science</i> :101545.	Multiple	Multiple	Peer-reviewed
Reid, D. 2021. A review of intensified land use effects on the ecosystems of Botany Bay and its rivers, Georges River and Cooks River, in southern Sydney, Australia. <i>Regional Studies in Marine Science</i> :101396.	Multiple	Multiple	Peer-reviewed
Reid, D., and C. Tippler. 2019. Access to natural substrates in urban streams does not counter impoverishment of macroinvertebrate communities: a comparison of engineered and non-engineered reaches. <i>Water, Air, & Soil Pollution</i> 230:1-15.	Artificial	Habitat modification	Peer-reviewed
Reid, D., and E. Bone. 2020. The rise and fall of oyster cultivation in the highly urbanized Georges River estuary, Sydney, Australia: A review of lessons learned. <i>Regional Studies in Marine Science</i> 35:101246.	Oyster reef	Habitat modification	Peer-reviewed

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Rissik, D., and I. Suthers. 1996. Feeding in a larval fish assemblage: the nutritional significance of an estuarine plume front. <i>Marine Biology</i> 125:233-240.	Pelagic/open water	Other	Peer-reviewed
Roach, A. 1998. Effects of predation on the size structure of the gastropod <i>Salinator solida</i> (Martens) populations at Towra Point, NSW, Australia. <i>Marine and Freshwater Research</i> 49:779-784.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Roach, A. 2000. Variation in the population dynamics of the intertidal pulmonate gastropod <i>Salinator solida</i> Martens (Gastropoda: Amphibolidae) at Towra Point, NSW, Australia. <i>Wetlands Ecology and Management</i> 8:53-69.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Roach, A., and J. Runcie. 1998. Levels of selected chlorinated hydrocarbons in edible fish tissues from polluted areas in the Georges/Cooks Rivers and Sydney Harbour, New South Wales, Australia. <i>Marine Pollution Bulletin</i> 36:323-344.	Pelagic/open water	Contamination	Peer-reviewed
Roberts, D. A., A. G. Poore, and E. L. Johnston. 2006. Ecological consequences of copper contamination in macroalgae: effects on epifauna and associated herbivores. <i>Environmental Toxicology and Chemistry: An International Journal</i> 25:2470-2479.	Subtidal reef	Contamination	Peer-reviewed
Roberts, D. A., E. L. Johnston, S. Müller, and A. G. Poore. 2008. Field and laboratory simulations of storm water pulses: behavioural avoidance by marine epifauna. <i>Environmental Pollution</i> 152:153-162.	Subtidal reef	Contamination	Peer-reviewed
Robinson, K., P. Gibbs, J. Van Der Velde, and J. Barclay. 2010. Temporal changes in the estuarine benthic fauna of Towra Point, Botany Bay. <i>Wetlands Australia</i> 3.	Multiple	No threat considered	Peer-reviewed
Robinson, W. A., W. A. Maher, F. Krikowa, J. A. Nell, and R. Hand. 2005. The use of the oyster <i>Saccostrea glomerata</i> as a biomonitor of trace metal contamination: intra-sample, local scale and temporal variability and its implications for biomonitoring. <i>Journal of Environmental Monitoring</i> 7:208-223.	Oyster reef	Contamination	Peer-reviewed
Rogers, C. N., J. E. Williamson, D. G. Carson, and P. D. Steinberg. 1998. Diel vertical movement by mesograzers on seaweeds. <i>Marine Ecology Progress Series</i> 166:301-306.	Subtidal reef	No threat considered	Peer-reviewed
Rogers, K., L. A. Mogensen, P. Davies, J. Kelleway, N. Saintilan, and G. Withycombe. 2019. Impacts and adaptation options for estuarine vegetation in a large city. <i>Landscape and Urban Planning</i> 182:1-11.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Rolfe, J. 1931. An Aboriginal midden at Quibray Bay. <i>The Australian Journal of Anthropology</i> 1:61.	Multiple	No threat considered	Peer-reviewed

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Roper, T., B. Creese, P. Scanes, K. Stephens, R. Williams, J. Dela-Cruz, G. Coade, B. Coates, and M. Fraser. 2011. Assessing the condition of estuaries and coastal lake ecosystems in NSW, Monitoring, Evaluation and Reporting Program. Technical report series. Office of Environment and Heritage, Sydney.	Multiple	No threat considered	Report/grey literature
Ross, P. 1996. Differences in morphology and reproduction of the barnacles <i>Elminius coervetus</i> and <i>Hexaminus</i> spp. from mangrove forests in the Sydney region of New South Wales. Marine and Freshwater Research 47:715-721.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Ross, P. M. 2001. Larval supply, settlement and survival of barnacles in a temperate mangrove forest. Marine Ecology Progress Series 215:237-249.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Ross, P. M. 2006. Macrofaunal loss and microhabitat destruction: the impact of trampling in a temperate mangrove forest, NSW Australia. Wetlands Ecology and Management 14:167-184.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Ross, P., and A. Underwood. 1997. The distribution and abundance of barnacles in a mangrove forest. Australian Journal of Ecology 22:37-47.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Rossi, F., and A. Underwood. 2002. Small-scale disturbance and increased nutrients as influences on intertidal macrobenthic assemblages: experimental burial of wrack in different intertidal environments. Marine Ecology Progress Series 241:29-39.	Soft sediment	Disturbance	Peer-reviewed
Rossi, F., and M. Chapman. 2003. Influence of sediment on burrowing by the soldier crab <i>Mictyris longicarpus</i> Latreille. Journal of Experimental Marine Biology and Ecology 289:181-195.	Beach	No threat considered	Peer-reviewed
Rotherham, D., and R. West. 2002. Do different seagrass species support distinct fish communities in south-eastern Australia? Fisheries Management and Ecology 9:235-248.	Seagrass	No threat considered	Peer-reviewed
Roth-Schulze, A. J., E. Zozaya-Valdés, P. D. Steinberg, and T. Thomas. 2016. Partitioning of functional and taxonomic diversity in surface-associated microbial communities. Environmental Microbiology 18:4391-4402.	Seagrass	No threat considered	Peer-reviewed
Roughan, M., and B. Hallam. 2022. The transport and retention of passive particles in Sydney Harbour and Botany Bay, Australia Zenodo. Version 1:42.	Pelagic/open water	No threat considered	Report/grey literature
Roughan, M., H. S. Macdonald, M. E. Baird, and T. M. Glasby. 2011. Modelling coastal connectivity in a Western Boundary Current: Seasonal and inter-annual variability. Deep Sea Research Part II: Topical Studies in Oceanography 58:628-644.	Pelagic/open water	NIS	Peer-reviewed

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Roughley, T. C. 1922. Oyster Culture on the Georges River, New South Wales. Technical Education Series No. 25. Technological Museum, Sydney.	Oyster reef	Multiple	Report/grey literature
Roy, P. S. 1983. Quaternary geology – physical setting. In Geology of the Sydney 1:100,000 Sheet 9130. Geological Survey of New South Wales. Department of Mineral Resources.	Non-habitat specific	No threat considered	Report/grey literature
Roy, P., and E. Crawford. 1981. Holocene Geological Evolution of the Southern Botany Bay – Kurnell Region, Central New South Wales Coast. Department of Mineral Resources.	Non-habitat specific	No threat considered	Report/grey literature
Roy, P., R. Williams, A. Jones, I. Yassini, P. Gibbs, B. Coates, R. West, P. Scanes, J. Hudson, and S. Nichol. 2001. Structure and function of south-east Australian estuaries. Estuarine, Coastal and Shelf Science 53:351-384.	Non-habitat specific	No threat considered	Peer-reviewed
Royal Commission Appointed to Inquire into Cultivating the Oyster. 1877. Report of the Royal Commission, appointed on the 29 September, 1876, to inquire into the best mode of cultivating the oyster, of utilising, improving, and maintaining the natural oyster beds of the colony, and also as to the legislation necessary to carry out these objects; together with the minutes of evidence, and appendices. Government Printer, Sydney.	Oyster reef	No threat considered	Report/grey literature
Ryan, P. 2020. Georges River CMP: Stakeholder and community engagement strategy.	Multiple	Multiple	Report/grey literature
Saintilan, N. 2004. Relationships between estuarine geomorphology, wetland extent and fish landings in New South Wales estuaries. Estuarine, Coastal and Shelf Science 61:591-601.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Saintilan, N., and D. Mazumder. 2010. Fine-scale variability in the dietary sources of grazing invertebrates in a temperate Australian saltmarsh. Marine and Freshwater Research 61:615-620.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Saintilan, N., and D. Mazumder. 2017. Mass spawning of crabs: ecological implications in subtropical Australia. Hydrobiologia 803:239-250.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Saintilan, N., and R. J. Williams. 1999. Mangrove transgression into saltmarsh environments in south-east Australia. Global Ecology and Biogeography 8:117-124.	Mangrove/saltmarsh	Multiple	Peer-reviewed
Saintilan, N., and R. Williams. 2000. Short Note: The decline of saltmarsh in southeast Australia: Results of recent surveys. Wetlands Australia 18.	Mangrove/saltmarsh	Habitat modification	Peer-reviewed
Saintilan, N., D. Mazumder, and K. Cranney. 2008. Changes to fish assemblages visiting estuarine wetlands following the closure of commercial fishing in Botany Bay, Australia. Aquatic Ecosystem Health & Management 11:441-449.	Multiple	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Saintilan, N., K. Hossain, and D. Mazumder. 2007. Linkages between seagrass, mangrove and saltmarsh as fish habitat in the Botany Bay estuary, New South Wales. <i>Wetlands Ecology and Management</i> 15:277-286.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Sanchez-Camara, J., and D. J. Booth. 2004. Movement, home range and site fidelity of the weedy seadragon <i>Phyllopteryx taeniolatus</i> (Teleostei: Syngnathidae). <i>Environmental Biology of Fishes</i> 70:31-41.	Subtidal reef	No threat considered	Peer-reviewed
Sanchez-Camara, J., D. J. Booth, J. Murdoch, D. Watts, and X. Turon. 2006. Density, habitat use and behaviour of the weedy seadragon <i>Phyllopteryx taeniolatus</i> (Teleostei: Syngnathidae) around Sydney, New South Wales, Australia. <i>Marine and Freshwater Research</i> 57:737-745.	Subtidal reef	No threat considered	Peer-reviewed
Sanchez-Camara, J., K. Martin-Smith, D. J. Booth, J. Fritschi, and X. Turon. 2011. Demographics and vulnerability of a unique Australian fish, the weedy seadragon <i>Phyllopteryx taeniolatus</i> . <i>Marine Ecology Progress Series</i> 422:253-264.	Subtidal reef	No threat considered	Peer-reviewed
Sanchez-Jerez, P., B. Gillanders, and M. Kingsford. 2002. Spatial variation in abundance of prey and diet of trumpeter (<i>Pelates sexlineatus</i> : Teraponidae) associated with <i>Zostera capricorni</i> seagrass meadows. <i>Austral Ecology</i> 27:200-210.	Seagrass	No threat considered	Peer-reviewed
Scanes, P., and A. Roach. 1999. Determining natural background concentrations of trace metals in oysters from New South Wales, Australia. <i>Environmental Pollution</i> 105:437-446.	Oyster reef	Contamination	Peer-reviewed
Schaefer, N., M. Mayer-Pinto, K. J. Griffin, E. L. Johnston, W. Glamore, and K. A. Dafforn. 2020. Predicting the impact of sea-level rise on intertidal rocky shores with remote sensing. <i>Journal of Environmental Management</i> 261:110203.	Rocky shore	Climate change	Peer-reviewed
Schilling, H., P. Reis-Santos, J. Hughes, J. Smith, J. Everett, J. Stewart, B. Gillanders, and I. Suthers. 2018. Evaluating estuarine nursery use and life history patterns of <i>Pomatomus saltatrix</i> in eastern Australia. <i>Marine Ecology Progress Series</i> 598:187-199.	Pelagic/open water	No threat considered	Peer-reviewed
Schlegel, P., J. N. Havenhand, M. R. Gillings, and J. E. Williamson. 2012. Individual variability in reproductive success determines winners and losers under ocean acidification: a case study with sea urchins. <i>PLoS ONE</i> 7:e53118.	Subtidal reef	Climate change	Peer-reviewed
Schreider, M., T. Glasby, and A. Underwood. 2003. Effects of height on the shore and complexity of habitat on abundances of amphipods on rocky shores in New South Wales, Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 293:57-71.	Rocky shore	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Shield, K., C. Tippler, A. Renshaw, and I. A. Wright. 2014. The invasive freshwater gastropods, <i>Physa acuta</i> and <i>Potamopyrgus antipodarum</i> : distribution in urban and non-urban streams in the Georges River catchment. In: G. Vietz, I.D. Rutherford and R. Hughes (eds). <i>Proceedings of the 7th Australian Stream Management Conference</i> , Townsville.	Multiple	Multiple	Other
Short, G., and A. Trevor-Jones. 2020. <i>Stigmatopora harastii</i> , a new species of pipefish in facultative associations with finger sponges and red algae from New South Wales, Australia (Teleostei, Syngnathidae). <i>Zookeys</i> 994:105.	Subtidal reef	No threat considered	Peer-reviewed
Silberschneider, V., and C. A. Gray. 2005. Arresting the decline of the commercial and recreational fisheries for mulloway (<i>Argyrosomus japonicus</i>). Fisheries Final Report Series 82, NSW Department of Primary Industries.	Pelagic/open water	Fisheries	Report/grey literature
SMCMA. 2007a. Modelling the catchments of Botany Bay. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Multiple	Report/grey literature
SMCMA. 2007b. Scoping study for water improvement plan for Botany Bay. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Nutrient addition	Report/grey literature
SMCMA. 2008a. Environmental assessment of Botany Bay: Sediments, sediment chemistry & foraminifera. Report by Sydney Metropolitan Catchment Management Authority.	Soft sediment	Multiple	Report/grey literature
SMCMA. 2008b. Modelling the catchments of Botany Bay: Council pollutant loads E2 modelling results. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Contamination	Report/grey literature
SMCMA, 2009a. Catchment Management Options to Improve Ecological Responses in the Georges and Cooks Estuaries. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Contamination	Report/grey literature
SMCMA. 2009b. Predicting climate change & future land use changes (2030 & 2070) modelling results. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Multiple	Report/grey literature
SMCMA. 2009c. Results of a multi-dimensional receiving water quality model for Botany Bay (Sydney, Australia). Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Nutrient addition	Report/grey literature
SMCMA. 2010. Towra Point nature reserve Ramsar site: Ecological character description. Report by Sydney Metropolitan Catchment Management Authority.	Multiple	Multiple	Report/grey literature
SMCMA. 2011. Botany Bay & catchment water quality improvement. Report by Sydney Metropolitan Catchment Management Authority.	Pelagic/open water	Contamination	Report/grey literature

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Smith, A., and D. Pollard. 1997. Management of the Towra Point Aquatic Reserve by NSW Fisheries. <i>Wetlands Australia</i> 16.	Non-habitat specific	No threat considered	Peer-reviewed
Smith, I. R., J. A. Nell, and R. Adlard. 2000. The effect of growing level and growing method on winter mortality, <i>Mikrocytos roughleyi</i> , in diploid and triploid Sydney rock oysters, <i>Saccostrea glomerata</i> . <i>Aquaculture</i> 185:197-205.	Oyster reef	No threat considered	Peer-reviewed
Smith, K. A., and I. M. Suthers. 2000. Consistent timing of juvenile fish recruitment to seagrass beds within two Sydney estuaries. <i>Marine and Freshwater Research</i> 51:765-776.	Seagrass	No threat considered	Peer-reviewed
Smith, K. A., and M. Sinerchia. 2004. Timing of recruitment events, residence periods and post-settlement growth of juvenile fish in a seagrass nursery area, south-eastern Australia. <i>Environmental Biology of Fishes</i> 71:73-84.	Seagrass	No threat considered	Peer-reviewed
Song, W., B. Wemheuer, P. D. Steinberg, E. M. Marzinelli, and T. Thomas. 2021. Contribution of horizontal gene transfer to the functionality of microbial biofilm on a macroalgae. <i>The ISME Journal</i> 15:807-817.	Subtidal reef	No threat considered	Peer-reviewed
SPCC. 1977a. Distribution of aquatic weeds in New South Wales. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Freshwater	NIS	Report/grey literature
SPCC. 1977b. Environmental Control Study of Botany Bay: Outline of study. Report by State Pollution Control Commission, Sydney.	Non-habitat specific	Multiple	Report/grey literature
SPCC. 1977c. Report on the classification of the Georges River and its tributaries. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Non-habitat specific	Habitat modification	Report/grey literature
SPCC. 1978a. Bottom sediments of Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Soft sediment	Habitat modification	Report/grey literature
SPCC. 1978b. Seagrasses of Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Seagrass	Habitat modification	Report/grey literature
SPCC. 1979a. Commercial Fisheries and Oyster Cultivation. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Multiple	Fisheries	Report/grey literature
SPCC. 1979b. Effects of dredging on macrobenthic infauna of Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Soft sediment	Habitat modification	Report/grey literature

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SPCC. 1979c. Nutrients and phytoplankton in Georges River. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Pelagic/open water	Habitat modification	Report/grey literature
SPCC. 1979d. Port development and operation. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Multiple	Habitat modification	Report/grey literature
SPCC. 1979e. Tidal water movement in Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Pelagic/open water	Habitat modification	Report/grey literature
SPCC. 1979f. Turbidity of Botany Bay and Georges River. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Pelagic/open water	Habitat modification	Report/grey literature
SPCC. 1979g. Water and wading birds of the Botany Bay Estuary. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Terrestrial	Habitat modification	Report/grey literature
SPCC. 1979h. Wave action in Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Pelagic/open water	Habitat modification	Report/grey literature
SPCC. 1979i. Wetlands of Botany Bay and its tidal waters. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Mangrove/saltmarsh	Habitat modification	Report/grey literature
SPCC. 1980. Environmental Control Study of Botany Bay: Summary Report. Report by State Pollution Control Commission, Sydney.	Non-habitat specific	Multiple	Report/grey literature
SPCC. 1981a. The Ecology of fish in Botany Bay. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Multiple	Habitat modification	Report/grey literature
SPCC. 1981b. The ecology of fish in Botany Bay: Biology of commercially and recreationally valuable species. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Multiple	Habitat modification	Report/grey literature
SPCC. 1981c. The ecology of fish in Botany Bay: Community structure. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Multiple	Habitat modification	Report/grey literature
SPCC. 1981d. Rocky shores of Botany Bay and their benthic flora and fauna. Environmental Control Study of Botany Bay. Report by State Pollution Control Commission, Sydney.	Rocky shore	Habitat modification	Report/grey literature
Spooner, D., W. Maher, and N. Otway. 2003. Trace metal concentrations in sediments and oysters of Botany Bay, NSW, Australia. Archives of Environmental Contamination and Toxicology 45:0092-0101.	Soft sediment	Contamination	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Stampar, S. N., V. S. Mills, and S. J. Keable. 2020. Ceriantharia (Cnidaria) from Australia, New Zealand and Antarctica with descriptions of four new species. Records of the Australian Museum 72:81-100.	Soft sediment	No threat considered	Other
Steffe, A. S., and J. J. Murphy. 2011. Recreational fishing surveys in the Greater Sydney Region. Fisheries Final Report Series 131. NSW Department of Primary Industries.	Pelagic/open water	No threat considered	Report/grey literature
Sun, M. Y., K. A. Dafforn, E. L. Johnston, and M. V. Brown. 2013. Core sediment bacteria drive community response to anthropogenic contamination over multiple environmental gradients. Environmental Microbiology 15:2517-2531.	Soft sediment	Contamination	Peer-reviewed
Sun, M. Y., K. A. Dafforn, M. V. Brown, and E. L. Johnston. 2012. Bacterial communities are sensitive indicators of contaminant stress. Marine Pollution Bulletin 64:1029-1038.	Soft sediment	Contamination	Peer-reviewed
Swanson, R. L., J. E. Williamson, R. De Nys, N. Kumar, M. P. Bucknall, and P. D. Steinberg. 2004. Induction of settlement of larvae of the sea urchin <i>Holopneustes purpurascens</i> by histamine from a host alga. The Biological Bulletin 206:161-172.	Subtidal reef	No threat considered	Peer-reviewed
Swanson, R. L., R. De Nys, M. J. Huggett, J. K. Green, and P. D. Steinberg. 2006. <i>In situ</i> quantification of a natural settlement cue and recruitment of the Australian sea urchin <i>Holopneustes purpurascens</i> . Marine Ecology Progress Series 314:1-14.	Subtidal reef	No threat considered	Peer-reviewed
Sweet, M., M. Bulling, and J. E. Williamson. 2016. New disease outbreak affects two dominant sea urchin species associated with Australian temperate reefs. Marine Ecology Progress Series 551:171-183.	Subtidal reef	Pathogen/disease	Peer-reviewed
Taylor, J. A., C. Díez-Vives, S. Nielsen, B. Wemheuer, and T. Thomas. 2022. Communal in microbial stress response and differential metabolic interactions revealed by time-series analysis of sponge symbionts. Environmental Microbiology.	Subtidal reef	No threat considered	Peer-reviewed
Taylor, M. D., A. V. Fairfax, and I. M. Suthers. 2013a. The race for space: Using acoustic telemetry to understand density-dependent emigration and habitat selection in a released predatory fish. Reviews in Fisheries Science 21:276-285.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, M. D., and D. Mazumder. 2010. Stable isotopes reveal post-release trophodynamic and ontogenetic changes in a released finfish, mulloway (<i>Argyrosomus japonicus</i>). Marine and Freshwater Research 61:302-308.	Pelagic/open water	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Taylor, M. D., and I. M. Suthers. 2008. A predatory impact model and targeted stock enhancement approach for optimal release of mulloway (<i>Argyrosomus japonicus</i>). Reviews in Fisheries Science 16:125-134.	Multiple	No threat considered	Peer-reviewed
Taylor, M. D., D. S. Fielder, and I. M. Suthers. 2006a. Spatial and ontogenetic variation in the diet of wild and stocked mulloway (<i>Argyrosomus japonicus</i> , Sciaenidae) in Australian estuaries. Estuaries and Coasts 29:785-793.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, M. D., L. McPhan, D. E. van der Meulen, C. A. Gray, and N. L. Payne. 2013b. Interactive drivers of activity in a free-ranging estuarine predator. PLoS ONE 8:e80962.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, M. W., P. J. Schupp, R. De Nys, S. Kjelleberg, and P. D. Steinberg. 2005. Biogeography of bacteria associated with the marine sponge <i>Cymbastela concentrica</i> . Environmental Microbiology 7:419-433.	Subtidal reef	No threat considered	Peer-reviewed
Taylor, M. W., S. D. Laffan, D. S. Fielder, and I. M. Suthers. 2006b. Key habitat and home range of mulloway <i>Argyrosomus japonicus</i> in a south-east Australian estuary: finding the estuarine niche to optimise stocking. Marine Ecology Progress Series 328:237-247.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, M., and R. Piola. 2008. Scale stocking checks to differentiate between hatchery-reared and wild mulloway <i>Argyrosomus japonicus</i> . Fisheries Management and Ecology 15:211-216.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, M., D. Fielder, and I. Suthers. 2009. Growth and viability of hatchery-reared <i>Argyrosomus japonicus</i> released into open and semi-closed systems. Fisheries Management and Ecology 16:478-483.	Pelagic/open water	No threat considered	Peer-reviewed
Taylor, S. L., M. J. Bishop, B. P. Kelaher, and T. M. Glasby. 2010. Impacts of detritus from the invasive alga <i>Caulerpa taxifolia</i> on a soft sediment community. Marine Ecology Progress Series 420:73-81.	Soft sediment	No threat considered	Peer-reviewed
Thomas, T., D. Rusch, M. Z. DeMaere, P. Y. Yung, M. Lewis, A. Halpern, K. B. Heidelberg, S. Egan, P. D. Steinberg, and S. Kjelleberg. 2010. Functional genomic signatures of sponge bacteria reveal unique and shared features of symbiosis. The ISME Journal 4:1557-1567.	Subtidal reef	No threat considered	Peer-reviewed
Thompson, J. A., A. J. Stow, and D. A. Raftos. 2017. Lack of genetic introgression between wild and selectively bred Sydney rock oysters <i>Saccostrea glomerata</i> . Marine Ecology Progress Series 570:127-139.	Oyster reef	No threat considered	Peer-reviewed

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Thurstan, R. H., Z. Brittain, D. S. Jones, E. Cameron, J. Dearnaley, and A. Bellgrove. 2018. Aboriginal uses of seaweeds in temperate Australia: an archival assessment. <i>Journal of Applied Phycology</i> 30:1821-1832.	Subtidal reef	No threat considered	Peer-reviewed
Tian, C., M. A. Doblin, K. A. Dafforn, E. L. Johnston, H. Pei, and W. Hu. 2018. Dinoflagellate cyst abundance is positively correlated to sediment organic carbon in Sydney Harbour and Botany Bay, NSW, Australia. <i>Environmental Science and Pollution Research</i> 25:5808-5821.	Soft sediment	No threat considered	Peer-reviewed
Tippler, C., I. A. Wright, and A. Hanlon. 2012a. Development of regional water quality and catchment guidelines for the conservation of aquatic ecosystems: a case study from the Georges River catchment. In: J.R. Grove and I.D. Rutherford (eds). <i>Proceedings of the 6th Australian Stream Management Conference, Managing for Extremes</i> . 6 – 8 February 2012, Canberra, Australia. Canberra: River Basin Management Society.	Pelagic/open water	Multiple	Other
Tippler, C., I. A. Wright, and A. Hanlon. 2012b. Is catchment imperviousness a keystone factor degrading urban waterways? A case study from a partly urbanised catchment (Georges River, South-Eastern Australia). <i>Water, Air, & Soil Pollution</i> 223:5331-5344.	Multiple	Multiple	Peer-reviewed
Tippler, C., I. A. Wright, P. J. Davies, and A. Hanlon. 2014. The influence of concrete on the geochemical qualities of urban streams. <i>Marine and Freshwater Research</i> 65:1009-1017.	Pelagic/open water	Habitat modification	Peer-reviewed
Tyerman, S., A. Hatcher, R. West, and A. Larkum. 1984. <i>Posidonia australis</i> growing in altered salinities: leaf growth, regulation of turgor and the development of osmotic gradients. <i>Functional Plant Biology</i> 11:35-47.	Seagrass	No threat considered	Peer-reviewed
Tzioumis, V., and M. J. Kingsford. 1999. Reproductive biology and growth of the temperate damselfish <i>Parma microlepis</i> . <i>Copeia</i> :348-361.	Subtidal reef	No threat considered	Peer-reviewed
Underwood, A. 1975a. Comparative studies on the biology of <i>Nerita atramentosa</i> Reeve, <i>Bembicium nanum</i> (Lamarck) and <i>Cellana tramoserica</i> (Sowerby) (Gastropoda: Prosobranchia) in SE Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 18:153-172.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1975b. Intertidal zonation of prosobranch gastropods: analysis of densities of four co-existing species. <i>Journal of Experimental Marine Biology and Ecology</i> 19:197-216.	Rocky shore	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Underwood, A. 1976a. Analysis of patterns of dispersion of intertidal prosobranch gastropods in relation to macroalgae and rock-pools. <i>Oecologia</i> 25:145-154.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1976b. Food competition between age-classes in the intertidal neritacean <i>Nerita atramentosa</i> Reeve (Gastropoda: Prosobranchia). <i>Journal of Experimental Marine Biology and Ecology</i> 23:145-154.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1976c. Nearest neighbour analysis of spatial dispersion of intertidal prosobranch gastropods within two substrata. <i>Oecologia</i> 26:257-266.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1977. Movements of intertidal gastropods. <i>Journal of Experimental Marine Biology and Ecology</i> 26:191-201.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1978. An experimental evaluation of competition between three species of intertidal prosobranch gastropods. <i>Oecologia</i> 33:185-202.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1980. The effects of grazing by gastropods and physical factors on the upper limits of distribution of intertidal macroalgae. <i>Oecologia</i> 46:201-213.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1984a. Microalgal food and the growth of the intertidal gastropods <i>Nerita atramentosa</i> Reeve and <i>Bembicium nanum</i> (Lamarck) at four heights on a shore. <i>Journal of Experimental Marine Biology and Ecology</i> 79:277-291.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1984b. Vertical and seasonal patterns in competition for microalgae between intertidal gastropods. <i>Oecologia</i> 64:211-222.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1984c. The vertical distribution and seasonal abundance of intertidal microalgae on a rocky shore in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 78:199-220.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. <i>Journal of Experimental Marine Biology and Ecology</i> 161:145-178.	Rocky shore	Disturbance	Peer-reviewed
Underwood, A. 1993. How not to design an environmental monitoring program: a case study from the FAC (up in Botany Bay). <i>Austral Biology</i> 6:194-197.	Soft sediment	Habitat modification	Peer-reviewed
Underwood, A. 1998. Grazing and disturbance: an experimental analysis of patchiness in recovery from a severe storm by the intertidal alga <i>Hormosira banksii</i> on rocky shores in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 231:291-306.	Rocky shore	Disturbance	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Underwood, A. 2004. Landing on one's foot: small-scale topographic features of habitat and the dispersion of juvenile intertidal gastropods. <i>Marine Ecology Progress Series</i> 268:173-182.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. 2006. Why overgrowth of intertidal encrusting algae does not always cause competitive exclusion. <i>Journal of Experimental Marine Biology and Ecology</i> 330:448-454.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A. J. 1978. An experimental evaluation of competition between three species of intertidal prosobranch gastropods. <i>Oecologia</i> 33: 185-202.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and G. Barrett. 1990. Experiments on the influence of oysters on the distribution, abundance and sizes of the gastropod <i>Bembicium auratum</i> in a mangrove swamp in New South Wales, Australia. <i>Journal of Experimental Marine Biology and Ecology</i> 137:25-45.	Mangrove/saltmarsh	No threat considered	Peer-reviewed
Underwood, A., and G. Skilleter. 1996. Effects of patch-size on the structure of assemblages in rock pools. <i>Journal of Experimental Marine Biology and Ecology</i> 197:63-90.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and K. McFadyen. 1983. Ecology of the intertidal snail <i>Littorina acutispira</i> Smith. <i>Journal of Experimental Marine Biology and Ecology</i> 66:169-197.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and M. Anderson. 1994. Seasonal and temporal aspects of recruitment and succession in an intertidal estuarine fouling assemblage. <i>Journal of the Marine Biological Association of the United Kingdom</i> 74:563-584.	Artificial	Habitat modification	Peer-reviewed
Underwood, A., and M. Chapman. 1985. Multifactorial analyses of directions of movement of animals. <i>Journal of Experimental Marine Biology and Ecology</i> 91:17-43.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and M. Chapman. 1989. Experimental analyses of the influences of topography of the substratum on movements and density of an intertidal snail, <i>Littorina unifasciata</i> . <i>Journal of Experimental Marine Biology and Ecology</i> 134:175-196.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and M. Chapman. 1992. Experiments on topographic influences on density and dispersion of <i>Littorina unifasciata</i> in New South Wales. In: J. Grahame, P.J. Mill and R.G. Reid (eds). <i>Proceedings of the third international symposium on littorinid biology</i> . The Malacological Society of London, London.	Rocky shore	No threat considered	Other
Underwood, A., and M. Chapman. 1996. Scales of spatial patterns of distribution of intertidal invertebrates. <i>Oecologia</i> 107:212-224.	Rocky shore	No threat considered	Peer-reviewed

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Underwood, A., and M. Chapman. 1998. Variation in algal assemblages on wave-exposed rocky shores in New South Wales. <i>Marine and Freshwater Research</i> 49:241-254.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and M. Chapman. 2000. Variation in abundances of intertidal populations: consequences of extremities of environment. <i>Hydrobiologia</i> 426:25-36.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and P. Jernakoff. 1981. Effects of interactions between algae and grazing gastropods on the structure of a low-shore intertidal algal community. <i>Oecologia</i> 48:221-233.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and P. Jernakoff. 1984. The effects of tidal height, wave-exposure, seasonality and rock-pools on grazing and the distribution of intertidal macroalgae in New South Wales. <i>Journal of Experimental Marine Biology and Ecology</i> 75:7	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and P. Verstegen. 1988. Experiments on the association between the intertidal amphipod <i>Hyale media</i> Dana and the limpet <i>Cellana tramoserica</i> (Sowerby). <i>Journal of Experimental Marine Biology and Ecology</i> 119:83-98.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., and R. Creese. 1976. Observations on the biology of the trochid gastropod <i>Austrocochlea constricta</i> (Lamarck) (Prosobranchia). II. The effects of available food on shell-banding pattern. <i>Journal of Experimental Marine Biology and Ecology</i> 23:229-240.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., E. Denley, and M. Moran. 1983. Experimental analyses of the structure and dynamics of mid-shore rocky intertidal communities in New South Wales. <i>Oecologia</i> 56:202-219.	Rocky shore	No threat considered	Peer-reviewed
Underwood, A., M. Kingsford, and N. Andrew. 1991. Patterns in shallow subtidal marine assemblages along the coast of New South Wales. <i>Australian Journal of Ecology</i> 16:231-249.	Subtidal reef	No threat considered	Peer-reviewed
URS Australia. 2009a. Port Botany Expansion Environmental Impact Statement. Report by URS Australia for Sydney Ports Corporation.	Multiple	Habitat modification	Report/grey literature
URS Australia. 2009b. Port Botany Expansion ship turning area dredging section 96 (1A) modification. Report by URS Australia for Sydney Ports Corporation.	Multiple	Habitat modification	Report/grey literature
Van Der Velde, J., and R. King. 1984. The subtidal seaweed communities of Bare Island, Botany Bay. <i>Wetlands Australia</i> 4.	Subtidal reef	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Vergés, A., N. A. Paul, and P. D. Steinberg. 2008. Sex and life-history stage alter herbivore responses to a chemically defended red alga. <i>Ecology</i> 89:1334-1343.	Subtidal reef	No threat considered	Peer-reviewed
Verhoeven, M. P., B. P. Kelaher, M. J. Bishop, and P. J. Ralph. 2012. Epiphyte grazing enhances productivity of remnant seagrass patches. <i>Austral Ecology</i> 37:885-892.	Seagrass	No threat considered	Peer-reviewed
Vila-Concejo, A., S. L. Gallop, and J. L. Largier. 2020. Sandy beaches in estuaries and bays. In: D. Jackson and A. Short (eds). <i>Sandy Beach Morphodynamics</i> . Elsevier.	Beach	Disturbance	Book
Watford, F. A., and R. J. Williams. 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to change in the distribution of seagrass. Fisheries Final Report Series 11, NSW Department of Primary Industries.	Multiple	No threat considered	Report/grey literature
West, L., K. Stark, J. Murphy, J. Lyle, and F. Ochwada-Doyle. 2015. Survey of recreational fishing in New South Wales and the ACT, 2013/14. Fisheries Final Report Series 149, NSW Department of Primary Industries.	Multiple	No threat considered	Report/grey literature
West, R., and A. Larkum. 1979. Leaf productivity of the seagrass, <i>Posidonia australis</i> , in eastern Australian waters. <i>Aquatic Botany</i> 7:57-65.	Seagrass	No threat considered	Peer-reviewed
West, R., and A. Larkum. 1983. Seagrass primary production—a review. <i>Proceedings of the Linnean Society of NSW</i> 106:213-223	Seagrass	No threat considered	Peer-reviewed
West, R., C. Thorogood, T. Walford, and R. Williams. 1985. An estuarine inventory for New South Wales, Australia. Fisheries Bulletin 2, Department of Agriculture, New South Wales.	Multiple	No threat considered	Report/grey literature
West, R., N. Jacobs, and D. Roberts. 1990. Experimental transplanting of seagrasses in Botany Bay, Australia. <i>Marine Pollution Bulletin</i> 21:197-203.	Seagrass	No threat considered	Peer-reviewed
White, A. 2010. The natural history of western Botany Bay. In: D. Lunney, P. Hutchings and D. Hochuli (eds). <i>The Natural History of Sydney</i> . Royal Zoological Society of New South Wales, Mosman, Australia.	Non-habitat specific	No threat considered	Book
Whittington, R. J., I. Paul-Pont, O. Evans, P. Hick, and N. K. Dhand. 2018. Counting the dead to determine the source and transmission of the marine herpesvirus OsHV-1 in <i>Crassostrea gigas</i> . <i>Veterinary Research</i> 49:1-21.	Oyster reef	Pathogen/disease	Peer-reviewed
Whittington, R. J., N. K. Dhand, O. Evans, and I. Paul-Pont. 2015. Further observations on the influence of husbandry practices on OsHV-1 μ Var mortality in Pacific oysters <i>Crassostrea gigas</i> : age, cultivation structures and growing height. <i>Aquaculture</i> 438:82-97.	Oyster reef	Pathogen/disease	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Whittington, R. J., O. Liu, P. M. Hick, N. Dhand, and A. Rubio. 2019. Long-term temporal and spatial patterns of Ostreid herpesvirus 1 (OsHV-1) infection and mortality in sentinel Pacific oyster spat (<i>Crassostrea gigas</i>) inform farm management. <i>Aquaculture</i> 513:734395.	Oyster reef	Pathogen/disease	Peer-reviewed
Wilkie, E. M., A. C. Roach, T. Micevska, B. P. Kelaher, and M. J. Bishop. 2010. Effects of a chelating resin on metal bioavailability and toxicity to estuarine invertebrates: Divergent results of field and laboratory tests. <i>Environmental Pollution</i> 158:1261-1269.	Soft sediment	Contamination	Peer-reviewed
Williamson, J. E., and P. D. Steinberg. 2012. Fitness benefits of size-dependent diet switching in a marine herbivore. <i>Marine Biology</i> 159:1001-1010.	Subtidal reef	No threat considered	Peer-reviewed
Williamson, J. E., D. G. Carson, R. De Nys, and P. D. Steinberg. 2004. Demographic consequences of an ontogenetic shift by a sea urchin in response to host plant chemistry. <i>Ecology</i> 85:1355-1371.	Subtidal reef	No threat considered	Peer-reviewed
Williamson, J. E., R. De Nys, N. Kumar, D. G. Carson, and P. D. Steinberg. 2000. Induction of metamorphosis in the sea urchin <i>Holopneustes purpurascens</i> by a metabolite complex from the algal host <i>Delisea pulchra</i> . <i>The Biological Bulletin</i> 198:332-345.	Subtidal reef	No threat considered	Peer-reviewed
Williamson, J., and P. Steinberg. 2002. Reproductive cycle of the sea urchin <i>Holopneustes purpurascens</i> (Temnopleuridae: Echinodermata). <i>Marine Biology</i> 140:519-532.	Subtidal reef	No threat considered	Peer-reviewed
Wilson, G. 1998. A Post-impact Monitoring Study of Benthic Fauna in Areas Dredged for the Third Parallel Runway in Botany Bay. Report for the Federal Airports Corporation. Australian Museum Marine Invertebrates Section.	Soft sediment	Habitat modification	Report/grey literature
Worthington, D., D. Ferrell, S. McNeill, and J. Bell. 1992a. Effects of the shoot density of seagrass on fish and decapods: are correlation evident over larger spatial scales? <i>Marine Biology</i> 112:139-146.	Seagrass	No threat considered	Peer-reviewed
Worthington, D., D. Ferrell, S. McNeill, and J. Bell. 1992b. Growth of four species of juvenile fish associated with the Seagrass <i>Zostera capricorni</i> , in Botany Bay, NSW. <i>Marine and Freshwater Research</i> 43:1189-1198.	Seagrass	No threat considered	Peer-reviewed
Worthington, D.G., Westoby, M. and Bell, J.D. 1991. Fish larvae settling in seagrass: effects of leaf density and an epiphytic alga. <i>Australian Journal of Ecology</i> , 16:289-293.	Seagrass	No threat considered	Peer-reviewed
Wressnig, A., and D. J. Booth. 2008. Patterns of seagrass biomass removal by two temperate Australian fishes (Monacanthidae). <i>Marine and Freshwater Research</i> 59:408-417.	Seagrass	No threat considered	Peer-reviewed

CITATION	HABITAT TYPE	THREAT TYPE	LITERATURE TYPE
Wright, J. T., and P. D. Steinberg. 2001. Effect of variable recruitment and post-recruitment herbivory on local abundance of a marine alga. <i>Ecology</i> 82:2200-2215.	Subtidal reef	No threat considered	Peer-reviewed
Wright, J. T., S. A. Dworjanyn, C. N. Rogers, P. D. Steinberg, J. E. Williamson, and A. G. Poore. 2005. Density-dependent sea urchin grazing: differential removal of species, changes in community composition and alternative community states. <i>Marine Ecology Progress Series</i> 298:143-156.	Subtidal reef	Fisheries	Peer-reviewed
Wright, J., R. De Nys, A. Poore, and P. Steinberg. 2004. Chemical defence in a marine alga: heritability and the potential for selection by herbivores. <i>Ecology</i> 85:2946-2959.	Subtidal reef	No threat considered	Peer-reviewed
York, P., D. Booth, T. Glasby, and B. Pease. 2006. Fish assemblages in habitats dominated by <i>Caulerpa taxifolia</i> and native seagrasses in south-eastern Australia. <i>Marine Ecology Progress Series</i> 312:223-234.	Seagrass	NIS	Peer-reviewed
Zozaya-Valdés, E., A. J. Roth-Schulze, S. Egan, and T. Thomas. 2017. Microbial community function in the bleaching disease of the marine macroalgae <i>Delisea pulchra</i> . <i>Environmental Microbiology</i> 19:3012-3024.	Subtidal reef	Pathogen/disease	Peer-reviewed
Zozaya-Valdes, E., S. Egan, and T. Thomas. 2015. A comprehensive analysis of the microbial communities of healthy and diseased marine macroalgae and the detection of known and potential bacterial pathogens. <i>Frontiers in Microbiology</i> 6:146.	Subtidal reef	Pathogen/disease	Peer-reviewed

Science of Kamay Questionnaire

Botany Bay Project

Scoping and Planning Workshop - Expression of Interest

***Required**

1. Full name *

2. Organisation *

3. Dept/School/Unit *

4. Role/position *

5. Email address *

6. What is your area of expertise? If you are currently conducting research in Botany Bay, or have done so in the past, please briefly clarify the nature of this work. Please also included details of any peer-reviewed research that has been published on this work. *

7. Please share any thoughts you have on key research questions for Botany Bay that you'd like to see explored in this workshop.

8. We have been working to compile literature and data on Botany Bay ecosystems. However, if you know of any relevant data sources or publications and are able to share them easily please feel free to do so here (web link or citations are most welcome). Alternatively, if you have documents you wish to send you can email them to: tste5627@gmail.com.

9. The workshops will most likely take place at SIMS as a face-to-face event (if restrictions allow) but with the opportunity for virtual attendance as well. Please indicate which of the following best characterises your preference for the workshop format (assuming you are available). *

Mark only one oval.

- ☐ I would attend only if it was face-to-face
- ☐ I would attend only if it was virtual
- ☐ I would attend if it was either face-to-face or virtual

10. Do you know of any other non-SIMS scientists that we might like to send this questionnaire too? Please include their contact information if possible.

“ Through this comprehensive review we have synthesised current ecological knowledge from scientific peer-reviewed literature and a wide range of non-scientific sources and have identified major knowledge gaps that should be filled if we are to manage this iconic ecosystem for all its residents, including both the people that live on its shores and the biota that live within its aquatic habitats. ”

Location shot of Boat Harbour in Kurnell, on the oceanic side of Gamay's southern headland. Image: John Turnbull www.marineexplorer.org



