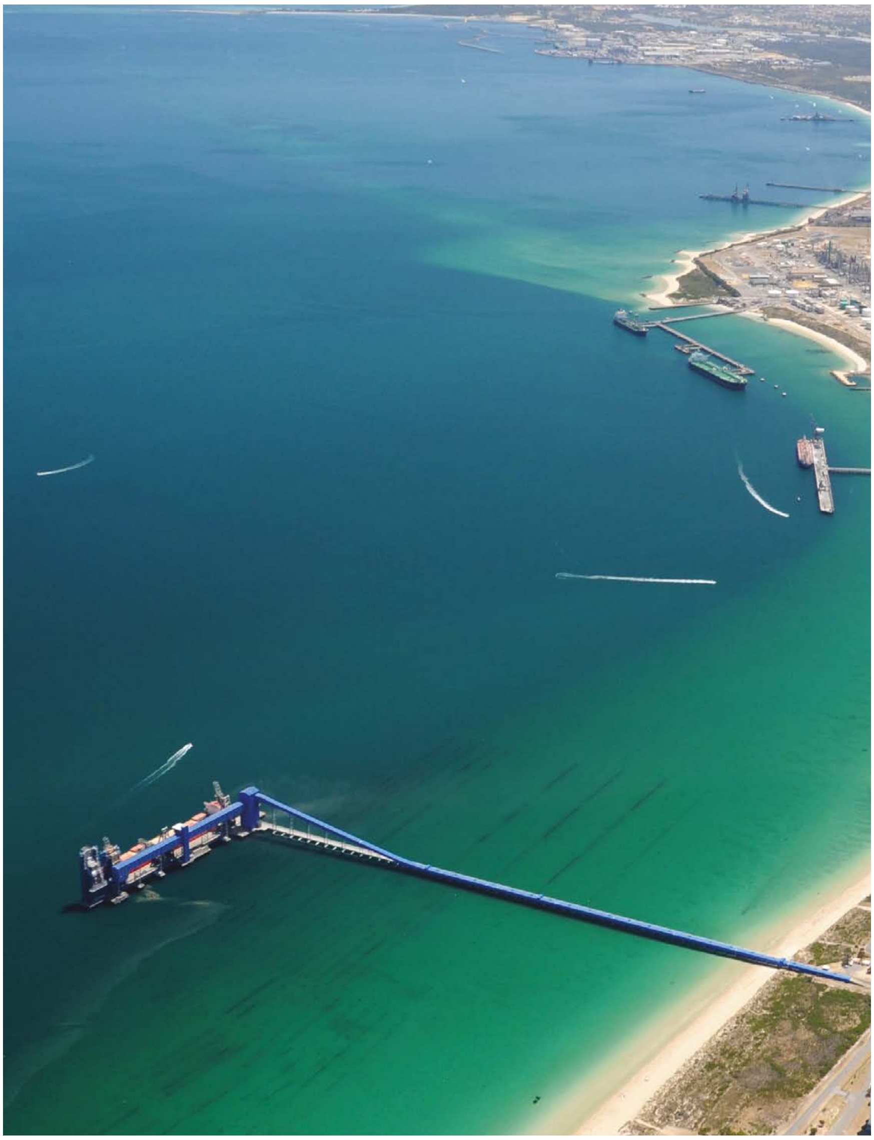

Cockburn Sound

Drivers, Pressures, State, Impacts, Responses Assessment 2017

Summary Report

February 2018

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Cockburn Sound
Drivers, Pressures, State, Impacts, Responses Assessment 2017:

Summary Report

Prepared by
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February 2018

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Executive summary

Cockburn Sound is one of the most intensively used marine areas in Western Australia and has had a history of nutrient pollution, which contributed to significant losses of seagrasses between the early 1960s and early 2000s. Following concerted effort by industry, government and the community, water quality in the Sound has now dramatically improved to an extent that environmental guidelines are only rarely exceeded.

While this outcome should be acknowledged as a true success, concerns remain about poor water quality in some areas of Cockburn Sound, the lag in seagrass recovery, development expansion and potential for cumulative impacts, declining commercial fish harvests and the potential emergence of new threats to Cockburn Sound, such as climate change. This report, which uses the Drivers-Pressures-State-Impacts-Response assessment framework, is intended to be used by stakeholders to help identify, plan for and respond to existing and emerging risks so that the environmental values of Cockburn Sound are protected and maintained now and into the future.

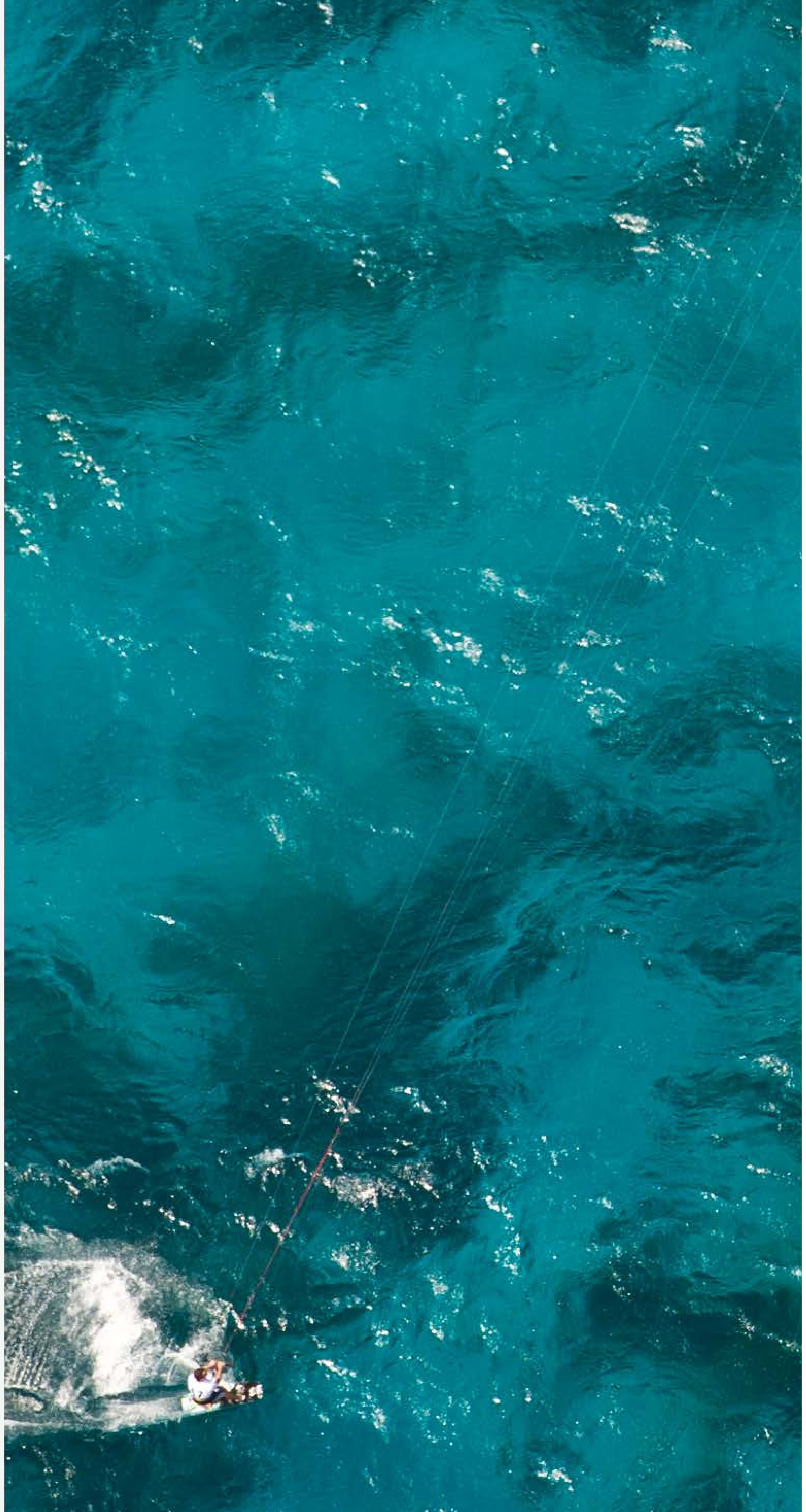
Driving forces

- Social drivers broadly capture the demography, cultural identity and governance of a community; and influence the structure and function of economic sectors.
- Economic sectors fulfil human needs for raw materials, food, water, health, shelter, infrastructure, security and culture.

Key pressures acting on Cockburn Sound

Pressures are human activities, derived from social and economic driving forces that induce changes in the environment, or human behaviours that can influence human health. The key pressures on Cockburn Sound are:

- Contaminated land and groundwater inputs, including nutrient loading and other toxicants.
- Marine vessel activities, including invasive marine species and biofouling controls.
- Commercial and recreational fishing.
- Climate change, including effects associated with elevated water temperatures, sea level rise, reduced rainfall and more frequent extreme weather.
- Cumulative impacts associated with future port, marina and industrial developments along the mainland coast.



Current state of Cockburn Sound

Key summary observations of the state of Cockburn Sound's natural and human-use built environment include:

- Coastal areas are highly modified, especially along the mainland coast of the Sound, the eastern shelf and eastern portion of Parmelia Bank.
- Water quality for recreational and industrial use is typically excellent.
- Sediment quality is generally considered acceptable, despite some evidence of localised sediment contamination by tributyltin (the active constituent in legacy antifoulant paints) in the vicinity of jetties and wharves.
- Seagrass extent has increased appreciably since 2008 (by ~130 hectares [ha]), although health indicators suggest a continued decline in some long-term monitoring sites, despite improved water quality.
- Some commercial and recreational fisheries are in decline (mussels, crabs, herring, garfish), while others are stable (e.g. squid, octopus, snapper).
- The populations of dolphins and little penguins resident in the Sound appear stable.

Effectiveness of management

The effectiveness of management in protecting the state of Cockburn Sound's marine environment can be summarised as:

- The *State Environmental (Cockburn Sound) Policy 2015 and Environmental Protection Act 1986* provide a robust management framework for:
  - establishment of the Cockburn Sound Management Council (CSMC) which includes stakeholders from government, industry and the community, providing an opportunity for regular engagement
  - the CSMC provides advice and recommendations to the Minister for Environment on the environmental management of Cockburn Sound
  - defining the environmental values of Cockburn Sound that are of importance to stakeholders and require protection
  - monitoring and managing exceedances of specific environmental quality criteria that are reported by CSMC to the Minister for Environment
  - environmental impact assessment of new projects
  - ongoing regulation of project-specific emissions, monitoring, management and offset conditions.
- Cockburn Sound is generally well managed due to implementation of this framework, other state government legislation and regulation, and a raft of initiatives undertaken by industry and other stakeholders operating in and around the Sound.
- This management has led to tangible improvements in water quality, stabilisation of seagrass loss, improved knowledge of hydrodynamics, coastal processes and habitat condition.

Long term outlook

Assuming the status quo of ongoing pressures and management measures, it is postulated that the future Cockburn Sound (10 to 20 years from now) is highly unlikely to return to pre-European conditions and will be characterised by:

- a catchment hinterland and coastline with high density urban and industrial development
- increased commercial shipping
- increased recreational use of the coast (beach visitation) and Sound (fishing, boating)
- cultural and spiritual values that do not have explicit criteria for monitoring and management
- non-eutrophic water quality, but primary production mainly from the water column (not seagrass)
- stable spatial extent of seagrass habitat
- shifts/changes in food-webs
- lack of recovery in historically-plentiful fisheries
- potential contamination and bioaccumulation of emerging contaminants
- water quality that is aesthetically pleasing and suitable for recreational use
- greater susceptibility to climate change induced stressors including coastal erosion and warmer waters
- overlapping residential, commercial and industrial development footprints leading to cumulative impacts and further declines in abundance and diversity of key biota, if not appropriately considered and managed.

Key gaps in knowledge and studies required to better manage key risks

Management areas requiring further effort of assessment to better understand risks to Cockburn Sound are listed below:

- Catchment-scale inputs of nutrients and contaminants to Cockburn Sound, such as the quality and volumes of stormwater and groundwater flows, and atmospheric deposition.
- Key marine processes, including direct measures of sediment nutrient recycling, pelagic primary productivity and other interlinking biogeochemical processes (encompassing spatial, seasonal and inter-annual variability).
- Effort is required to better understand the local parameters and regional factors influencing seagrass restoration success rates (including the confounding effects of climate change) and whether management targets for seagrass health protection are adequate to support restoration efforts.
- The sustainability of commercial and recreational fisheries, and aquaculture production. Further study is also required on the biodiversity of fish communities in Cockburn Sound from an ecological, and not fisheries, perspective.
- Impact of industrial seawater intakes on larval and juvenile fish and other biota.
- Specification of environmental quality criteria to measure whether cultural and spiritual values are being protected. Consultation with the Noongar people is warranted to develop and agree on appropriate criteria.
- Study is required to better characterise the contemporary visitation and usage of beaches in Cockburn Sound.
- Resilience of Cockburn Sound's coastal environment and key marine ecological components (e.g. communities of plankton, fish, seagrass, benthic macroinvertebrates), including in response to climate change pressures.
- Development of integrative models to better understand the interactions within and between ecological and social components of Cockburn Sound's marine environment. This would help decision-makers to more fully understand what are the key ecosystem levers and where future management action should be targeted.

Conclusion

- The Sound presently exists in a highly modified state, and over the coming decades is likely to experience further pressure from urbanisation, industrial and maritime infrastructure development and from effects associated with climate change.
- It is also clear, however, that the Sound can be managed to protect its environmental values by using the existing regulatory framework informed by a combination of regular monitoring of the status of key indicators and relevant research.
- There is no reason to doubt that the Sound's environmental values will continue to be maintained in a safe and healthy state whereby the water quality is safe to swim in, seagrass extent remains relatively stable, the recreational fish taken from it are safe to eat.
- However, given the existing pressures and management regime, the 'future' Cockburn Sound is unlikely to return to pre-European conditions and will be characterised by a lack of recovery of seagrass, some changes in food-webs and fish stocks, and cultural and spiritual values without specific criteria for monitoring and management.

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Recommended next steps

- Attain a better understanding of the interrelated physical, biological and human-use cause-effect pathways in Cockburn Sound.
- Direct management focus on aspects of Cockburn Sound's ecosystem that are highly valued by the community. Monitoring and management programs to-date have focused on water quality and seagrass habitat, with less attention to changes in fish stocks and other indicators of ecosystem stress. Efforts should be directed at reaching stakeholder consensus on the weighting of important environmental values to be preserved; and the best way to prioritise, monitor and manage those values.
- Review the flexibility of the existing regulatory framework to consider management effort versus "reward". The concept of managing impacts to "not be significant" versus impacts that are "as low as reasonably practicable" is worth consideration. Alternative conceptual tools such as ecosystem engineering or environmental accounting may be highly useful in helping to devise environmental management (or offset) measures that offer the best "bang for buck" in protecting stakeholder values of Cockburn Sound.

1. About this report

1.1 Assessment impetus

Cockburn Sound is one of the most intensively used marine areas in Western Australia. The Sound supports extensive recreational activity, tourism, aquaculture and commercial fishing, is home to the State's major heavy industry at Kwinana and supports the Australian Navy's HMAS Stirling Base on Garden Island. Cockburn Sound is of vital economic and social importance to the Western Australian community, as well as supporting significant environmental values.

The last formal pressure-state-response assessment of Cockburn Sound was undertaken in 2001 (DAL 2001). In light of ongoing concerns about poor water quality in some areas of Cockburn Sound, the lag in seagrass recovery, development expansion and potential for cumulative impacts, declining commercial fish harvests, and the potential emergence of new threats to Cockburn Sound, such as climate change, it is timely to undertake a contemporary assessment of: the current and emerging driving forces and pressures on the Cockburn Sound marine area; the Sound's current condition; trends and impacts to the Sound's condition; and management responses. It is intended that this information be used by stakeholders to help identify, plan for and respond to existing and emerging risks so that the environmental values of Cockburn Sound are protected and maintained now and into the future.

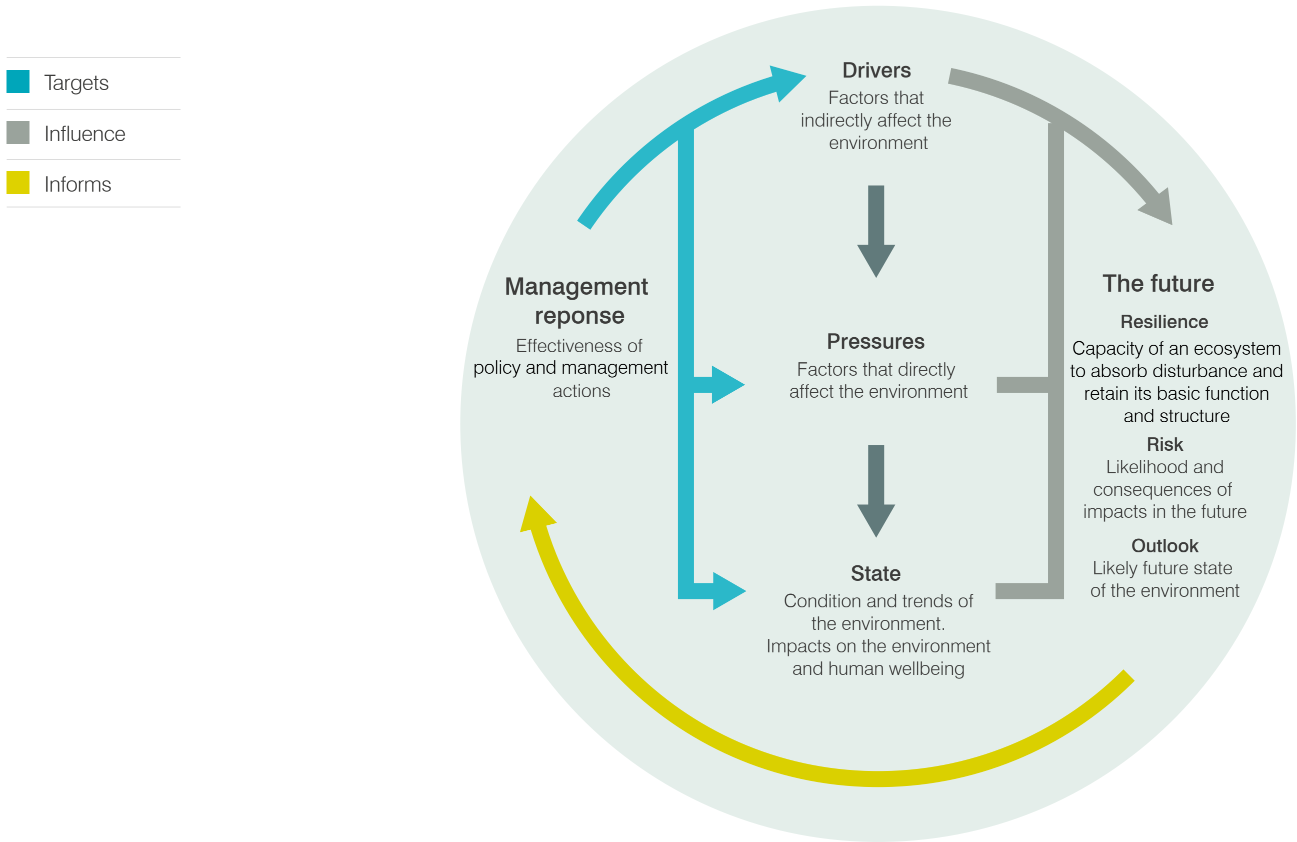
1.2 The DPSIR reporting framework

The Drivers-Pressures-State-Impacts-Responses (DPSIR) reporting framework (Figure 1.1) is used to assess cause-effect relationships between interacting components of social, economic and environmental systems (USEPA 2015). The framework expands upon the traditional Pressure-State-Response model, which was used to assess the state of Cockburn Sound in 2001 (DAL 2001). The DPSIR framework captures linkages between human activities and the environment that in turn enables more informed and targeted feedback to decision-makers and the community. The different categories in the DPSIR reporting framework are briefly described below.

- Driving forces: Driving forces are the factors that motivate human activities and fulfil basic human needs (which have been identified as the necessary conditions and materials for a good life, good health, good social relations, security and freedom); that is, they describe the social and economic developments in societies.
- Pressures: Pressures are defined as human activities, derived from the functioning of social and economic driving forces that induce changes in the environment, or human behaviours that can influence human health.
- State: State refers to the state of the natural and built environment (e.g. the quantity and quality of physical, chemical, and biological components) and human systems (e.g. health and well-being at either the population- or individual-level). Chemical, physical and biological processes interact to affect different system components (e.g. chemicals or biological species) that can be measured by their attributes (metrics of quantity or quality).
- Impacts: Impacts are the changes in the quality and functioning of the state of a system, i.e. either the ecosystem or the derived human uses (ecosystem services).
- Management Response: Responses are actions taken by groups or individuals in society and government to prevent, compensate, ameliorate or adapt to changes in the state of the environment; and to modify human behaviours that contribute to ecosystem health risks.
- Future: This DPSIR assessment also considers the likely long-term future for Cockburn Sound in terms of ecosystem resilience, risk and outlook. The intent is to stimulate discussion on what is the 'most-acceptable' state of the marine environment, and what actions are needed to facilitate that state.

Figure 1.1

DPSIR reporting framework and model



1.3 This report

This summary report provides a synthesis of the current and emerging driving forces and pressures on the Cockburn Sound marine area; the Sound's current condition; trends and impacts to the Sound's condition; and management responses. More detail on the justification and scientific assessment is provided in the full assessment report (BMT 2018).

The area covered by the assessment is the Cockburn Sound policy area as defined in the *State Environmental (Cockburn Sound) Policy 2015* (Cockburn Sound SEP) (Government of Western Australia 2015), with a specific focus on the Cockburn Sound marine area (Figure 1.2) and its environmental values (Table 1.1). The assessment has, where appropriate, also considered activities undertaken beyond the boundaries of the area covered by the Cockburn Sound SEP that have the potential to impact on the environmental values of the Cockburn Sound marine area.

Table 1.1

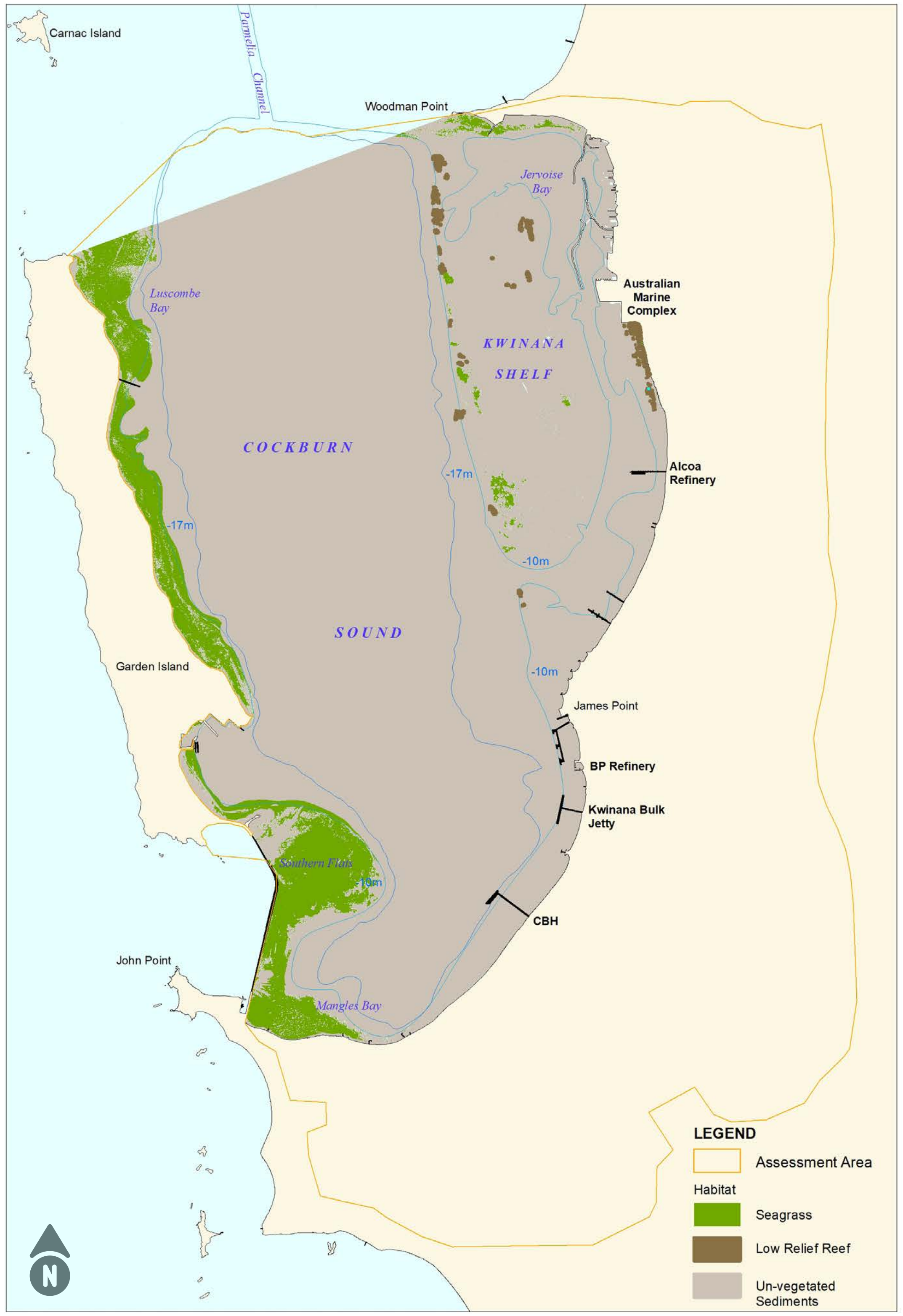
The Environmental Values and their corresponding Environmental Quality Objectives for Cockburn Sound

Environmental Values	Environmental Quality Objectives and their descriptions
Ecosystem Health	Maintenance of ecosystem integrity
Fishing and Aquaculture	Maintenance of seafood safe for human consumption Maintenance of aquaculture
Recreation and Aesthetics	Maintenance of primary contact recreation values Maintenance of secondary contact recreation values Maintenance of aesthetic values
Cultural and Spiritual	Cultural and spiritual values of the marine environment are protected
Industrial water supply	Maintenance of water quality for industrial use

Source: Government of Western Australia (2015).

Figure 1.2

Extent of benthic primary producer habitat across Cockburn Sound in 2017



Source: Seagrass data sourced from UWA (2018); low relief reef sourced from Oceanica (2009); the assessment area is the policy area defined in the Cockburn Sound SEP (Government of Western Australia 2015). Seagrass north of Garden Island has been clipped to only display meadows within the project area.

1.4 Stakeholder consultation

This assessment was informed by consultation with a range of stakeholders with an interest in the Cockburn Sound marine area, including, the community, industry and government.

Stakeholder comments were categorised into the following 'themes':

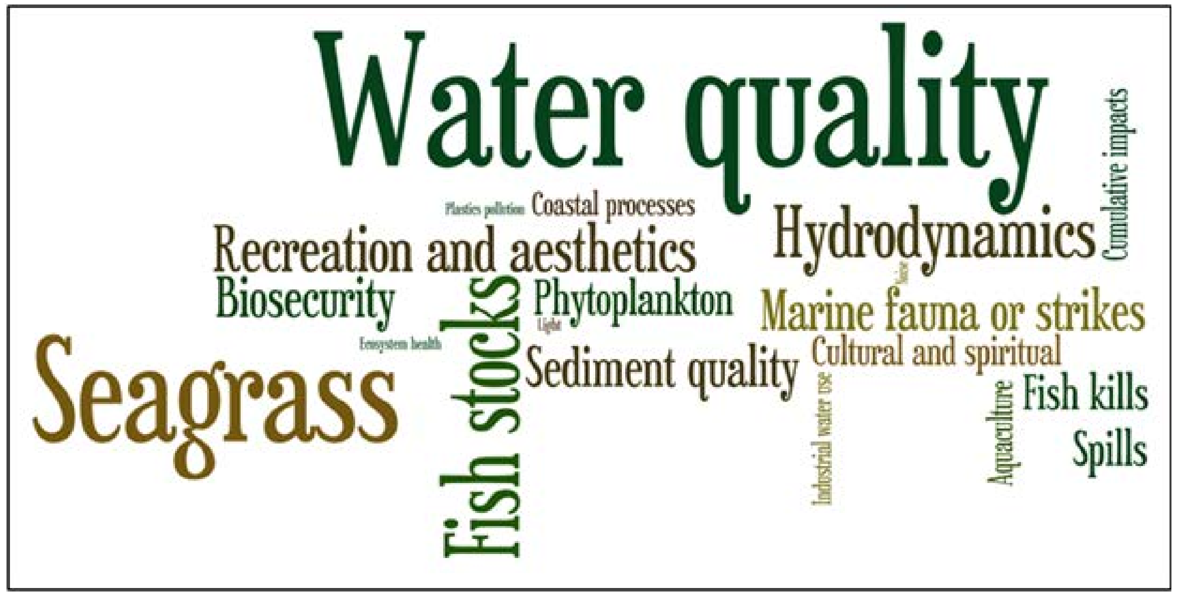
- Priority drivers and pressures (Figure 1.3[A]); and
- Priority issues for the state of Cockburn Sound (Figure 1.3[B]).

Figure 1.3

'Themes' of priority drivers and pressures [A] and issues for the state of Cockburn Sound [B] raised by stakeholders

[A] Drivers and pressures on Cockburn Sound

[B] Issues for the state of Cockburn Sound



Note: the size of the text is proportional to the number of times a certain theme was raised through consultation.

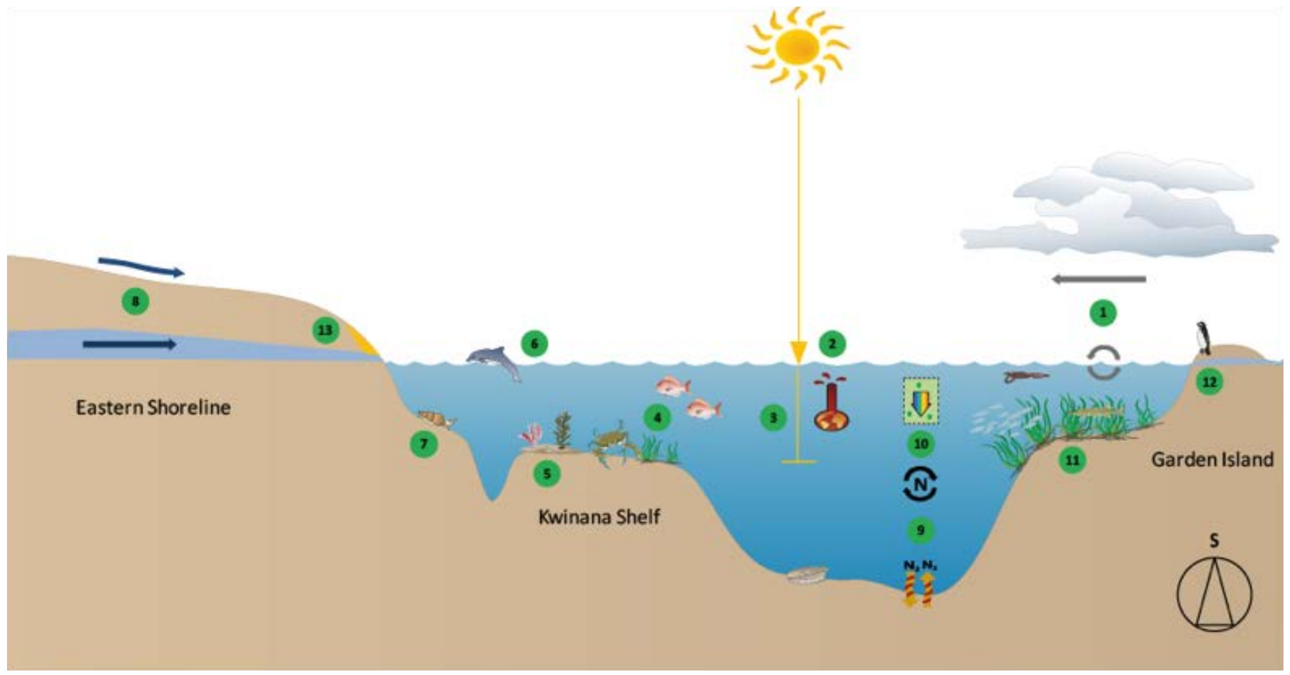
2. Background and historical context

2.1 Cockburn Sound's natural marine environment

Cockburn Sound's marine environment is naturally influenced by a complex interaction of physical and ecological processes. Physical features such as the Sound's protected embayment configuration, coastal sediment processes, marine water movements, groundwater and catchment runoff inputs are in turn responsible for its regional ecological significance. Key ecological features include extensive areas of seagrass species (e.g. Posidonia spp.) that prefer sheltered conditions, and organic-rich silts on the seabed of the deep basin that support food-webs and fisheries prominent on the central west coast of Western Australia (Figure 2.1).

Figure 2.1

Conceptual image of key marine environmental features of Cockburn Sound (image not to scale, southward facing)



1. Wind is the primary force responsible for mixing and moving the waters within Cockburn Sound
2. Climate change and heat wave events now appear a feature helping shape Cockburn Sound's marine ecosystems
3. Light is attenuated to about 90–95% of surface values within 8–10 m water depth, which is still enough light to allow seagrasses to grow at these depths
4. Cockburn Sound is a key spawning and nursery area for pink snapper and blue swimmer crabs
5. Historical dredge spoil disposal on the Kwinana Shelf created a 'Dredge spoil' reef habitat, which now supports a diverse habitat of mixed algae, seagrass and corals
6. Cockburn Sound is an important feeding ground and nursery for dolphins
7. Benthic macroinvertebrates provide a range of important ecological services to Cockburn Sound's marine environment and can be found across most areas of seafloor and among benthic primary producer habitats
8. Surface and groundwater flows into the intertidal zone along the eastern shoreline and along Garden Island after winter. There may also be areas of submarine (offshore) groundwater discharge into the Sound. Contaminated groundwater flows are the main source of human-induced nutrient loads to the Sound
9. Nutrient fluxes from marine sediments and water column recycling plays an important role in regulating nitrogen dynamics in Cockburn Sound
10. Phytoplankton concentrations in Cockburn Sound have historically been elevated and implicated in reducing available light to benthic primary producers; however, since mid-2000s phytoplankton concentrations have declined and available light has increased
11. Approximately 80% of the original seagrass meadow area in Cockburn Sound has been lost due to the effect of past human activities, with remnant seagrass areas of varying health remaining. Remaining seagrass assemblages provide important nursery areas for a variety of fish
12. Little penguins nest on Garden Island and feed in Cockburn Sound
13. Cockburn Sound's sandy shoreline is commonly used for recreational activities, but is now heavily modified and subject to coastal erosion in places

2.2 History of human use of the marine environment

Until 1954, Cockburn Sound was used mainly for recreational purposes, commercial fishing and – during both World Wars – for Commonwealth defence activities (particularly on Garden Island).

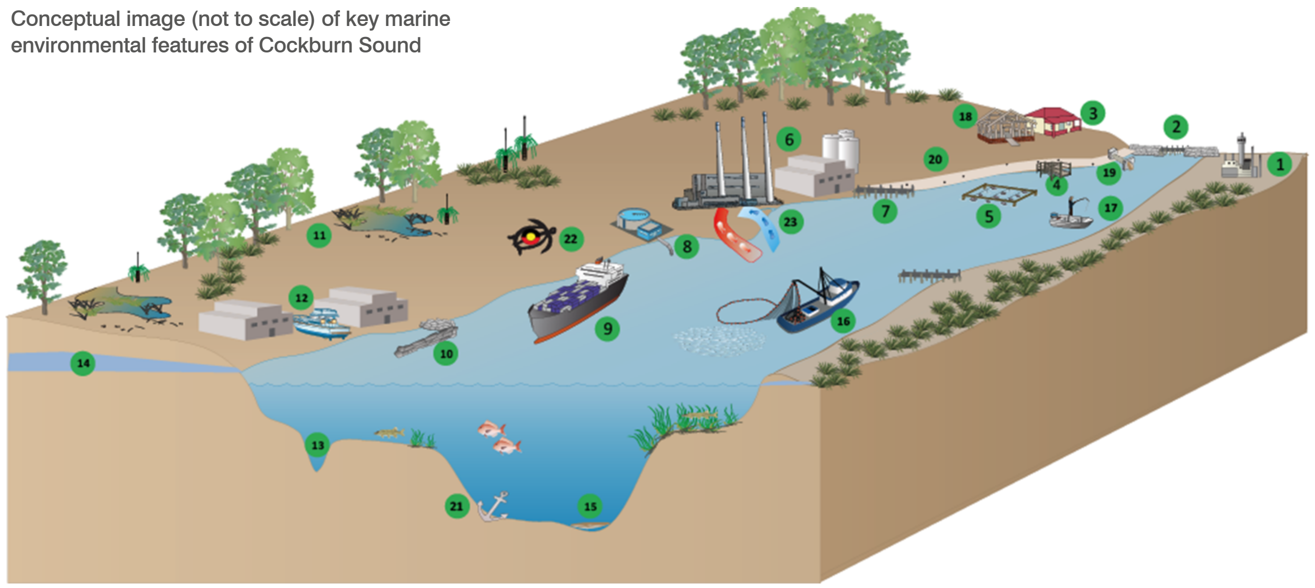
The following 25 years were characterised by industrial development, first with the building of an oil refinery at James Point, then the addition of iron, steel, alumina and nickel refining/processing plants, chemical and fertiliser production plants and a bulk grain terminal. With the successive development, there was an increasing amount of industrial effluent discharging into the waters, including wastewater contaminated with nutrients and hydrocarbons. At the northern end of the Sound, a sewage plant was also commissioned at Woodman Point in 1966, with discharge of wastewater into the Sound.

To service the growing industry, wharves and groynes were built and channels dredged for shipping access. At the southern end of the Sound, a rock-fill causeway connecting Garden Island with the mainland was built between 1971–1973, through which limited ocean exchange occurs. The causeway enabled land-based access to a naval base on Garden Island, which was constructed between 1973 and 1978. More recent capital-scale enterprises constructed in Cockburn Sound include the Australian Marine Complex in 2003 and the Perth Seawater Desalination Plant in 2006.

In 2017, Cockburn Sound remains highly valued by the community for recreational and commercial purposes such as swimming, sailing, fishing, aquaculture and tourism (Figure 2.2). The Sound also continues to support marine infrastructure vital to the operations of Fremantle Ports, major commercial enterprises and the Royal Australian Navy. The hinterland of Cockburn Sound supports a full range of land uses including urban, rural, industrial, defence and nature conservation. Among these, the Kwinana Industrial Area is one of Western Australia's premier industrial complexes for the import, processing and export of materials and also provides power and water infrastructure key to the functioning of the broader Perth metropolitan area.

Figure 2.2

Conceptual image (not to scale) of key marine environmental features of Cockburn Sound



1. Naval base and port
2. Causeway
3. Existing urban residential development
4. Coastal structures, jetties and groynes to support community recreational activates
5. Aquaculture activities
6. Kwinana Industrial activities
7. Commercially operated jetties and ports to support industry
8. Desalination discharge
9. Shipping activities
10. Breakwater/marina walls
11. Modified wetlands infiltrate the Sound via surface and groundwater flows
12. Australian Marine Complex
13. Dredging
14. Contaminated and managed groundwater inputs
15. Historical dredge disposal
16. Commercial fishing
17. Recreational boating and fishing
18. Expanding urban and population growth
19. Stormwater run-off
20. Recreational beaches
21. Shipwrecks and maritime history
22. Indigenous heritage
23. Cooling water discharges

2.3 Long-term changes in marine environmental quality

The developments that took place from 1954 onwards, resulted in deterioration of the marine environment, and in the 1970s the loss of natural amenity started to conflict with recreational uses of Cockburn Sound.

These events prompted several environmental investigations, most of which focused on:

- deteriorating water quality due to nutrient enrichment (eutrophication) of the Sound, predominantly high concentrations of nitrogen leading to 'blooms' of phytoplankton (microscopic algae floating in the water), and in turn,
- widespread loss of seagrass as a result of light reduction, due to shading caused by phytoplankton blooms and increased growth of epiphytes (algae that grow on seagrass leaves).

At its peak, the level of eutrophication observed was amongst the highest of all coastal embayments in Australia (Meagher & LeProvost 1975). The major nutrient contributions were from CSBP and Woodman Point outfalls. By the late 1970s, the annual load of nitrogen directly discharged into Cockburn Sound was ~1,820 tonnes nitrogen per year (N/yr).

Between 1967 and 1984, ~2,190 hectares (ha) or >75 per cent (%) of the seagrass meadows were lost from Cockburn Sound. The timeline of these historical losses is charted in Table 2.1, where it is possible to distinguish between what appears to have been localised events, and the extensive loss of seagrasses on the eastern shore coinciding with the introduction of industry and associated industrial effluents.

Since that time, reducing nutrient loading to the Sound and maintaining the health of the remaining seagrass beds have been priority management objectives of government and industry. Removing direct discharge streams from the fertiliser plant and significant upgrades of sewage treatment and outfall facilities provided the most gains in gradually reducing the total nitrogen input to Cockburn Sound to ~300 tonnes N/yr in 2000. However, legacy issues remain from agricultural and industrial contamination of groundwater, and groundwater discharge is now considered to be the main source of nitrogen to the Sound. The very slow flushing of Cockburn Sound (up to 47 days in spring) as a result of both the natural constraints of Garden Island and the Garden Island causeway, has also likely encouraged a legacy of nutrients remaining tied up in marine sediments.

While these issues have clearly left an imprint, a number of other significant environmental changes have occurred to Cockburn Sound, but remain less well studied. For example, since the 1970s and in-line with a drying climate, there have been considerable declines in surface and groundwater inputs to the Sound. Historically, outflow from the Swan River entered Cockburn Sound each winter, although from the mid 1980s the outflow has only occasionally been sufficient to reach Cockburn Sound.

Similarly, primary production in Cockburn Sound has shifted from seagrass dominated to phytoplankton dominated, which now contributes 73% (13,718 tonnes carbon/year [C/yr]) of the total primary production within the Sound. Despite this shift from benthic to pelagic production in a few decades, the flow-on effects and implications to food-webs remain poorly understood.

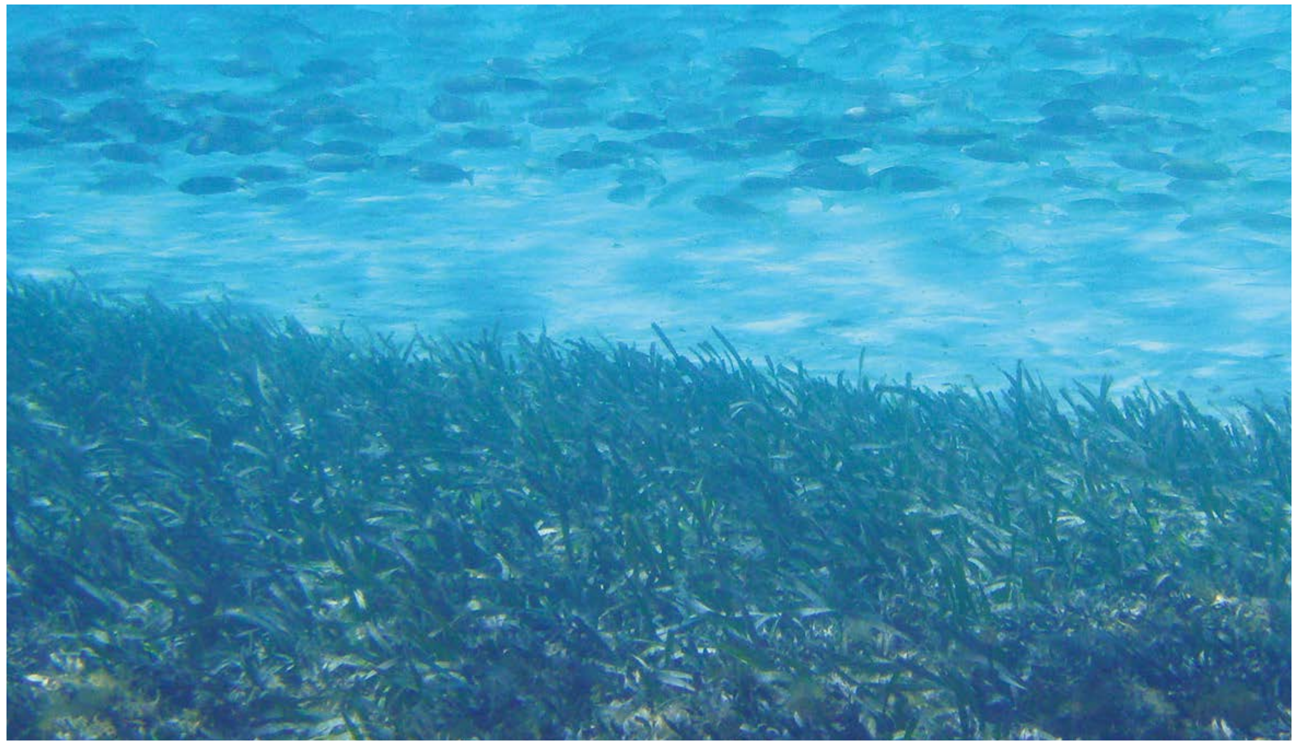
It is within this broad historical context that a comprehensive analysis of the state of Cockburn Sound has been undertaken by applying the DPSIR framework.

Table 2.1

Summary of dates of historical events in seagrass decline, and of industrial and port development between 1950 and 1981

Year	Seagrass meadows	Industrial and construction activites
1955	Seagrass meadows in undisturbed state	Oil refinery begins discharging cooling waters at James Point
1961–1962	Four hectares seagrasses lost on James Point near to oil-refinery outfall	
1966	No monitoring undertaken	Sewage-treatment plant begins discharging southwest of Woodman Point
1968	No monitoring undertaken	Blast furnace begins discharging cooling water coloured with black particulates
1969	First signs of main seagrass loss, later to become the major depletion along the eastern shore	Phosphate-fertiliser plant begins discharging
1970	No monitoring undertaken	Power station releases cooling water
1971–1973	Localised losses due to scouring beneath bridges and dredging; loss of seagrass south of Woodman Point; compounding effects of sea urchin grazing	Construction and dredging of a solid-fill limestone causeway across the southern entrance, with two bridges allowing access to open ocean; dredging associated with building and launching an oil-rig platform at Woodman Point
1974–1976	Loss of seagrass on Southern Flats in the lee of causeway	
1976–1977	Localised losses due to dredging and dumping of dredge spoil	Construction and dredging for access jetty at Sulphur Bay (now an armaments jetty), Garden Island
1981–onward	Large-scale seagrass loss stabilised	

Source: Cambridge and McComb (1984)



3. Drivers

Societal and economic developments within and around Cockburn Sound are the driving forces that create pressures on the state of its marine environment. Driving forces are typically categorised into "social drivers" and "economic sectors" (USEPA 2015). Social drivers influence the structure and function of economic sectors.

3.1 Social drivers

Social drivers broadly capture:

- Demography - the population neighbouring Cockburn Sound is approximately 300,000, which has increased by 150,000 people in the past 16 years and is expected to increase by a similar amount over the next 20 years.
- Cultural identity - the cultural attitudes of the people living around and using Cockburn Sound are important drivers affecting its marine environment, and are shaped by a blend of indigenous and non-indigenous senses of coastal identity. The landmark South West Native Title Settlement, which recognises the living cultural and spiritual relationship that the Noongar people have with the Noongar lands, including the Cockburn Sound area, is likely to be executed soon.
- Governance of a community - the democratic election of local, state and federal governments is an important driving force on marine and land use planning in and around Cockburn Sound; with an ability to affect pressures on the Sound, its state of environment and management.

3.2 Economic sectors

Economic sectors fulfil human needs for raw materials, food, water, health, shelter, infrastructure, security and culture. The marine, coastal and hinterland areas of Cockburn Sound support various uses and economic sectors. Land use in the area surrounding Cockburn Sound includes a mix of heavy and light industry, residential suburbs, agriculture, defence and conservation.

Coastal infrastructure provides access and services to many of these land uses; and interfaces with marine-based activities, such as fishing, aquaculture and recreation. Water from Cockburn Sound or its adjacent aquifers is also used for purposes of drinking, irrigation, industrial processes and sewage management. These uses of land and water act as driving forces that create pressures that potentially impact on the state of Cockburn Sound's marine environment.

4. Pressures affecting Cockburn Sound

Pressures are typically human activities or aspects of human activities derived from social and economic driving forces that can induce modifications to the environment, leading to changes in biotic and/ or human health. Historically, nutrient discharges, contaminated land and groundwater inputs, coastal modifications and fishing pressures have largely been responsible for shaping Cockburn Sound's marine environment. While these pressures remain influential, emerging pressures such as climate change, may potentially compound existing stressors. Further, because of the complex range and variety of uses of the marine environment in Cockburn Sound, it remains a challenge to disentangle and link observed impacts to individual pressures.

A summary of the pressures representing the greatest threat to Cockburn Sound and that have already influenced the marine environment, or show potential to re-shape it in the future, is provided in Table 4.1. The table includes an assessment of: trends; impact grades; confidence in presently available data; comparability of presently available data to 2001 data; and the risk of these pressures to Cockburn Sound's environmental values. For more detailed explanation and justification refer to the full assessment report (BMT 2018).

Explanatory notes:

1. The level of reporting on the current pressures acting on Cockburn Sound is highly variable and often inadequate for robust assessment, including consideration of interactive or cumulative effects. Reporting varies in terms of temporal coverage, parameters measured, methods used and key indicators. Further, due to the general management focus on pressures affecting water quality over the past two decades, there are few coordinated and sustained monitoring programs that address other pressures (i.e. that are not directly related to water quality). As a result, the level of certainty varies in understanding trends in pressures

2. Where sufficient data permits, analysis of trends for each pressure typically covers the period 2001–2017; this period follows the release of the previous Cockburn Sound pressure-state-response report (DAL 2001) and therefore provides an updated yardstick assessment of the pressures acting on the system in 2017.

3. The risk to the environment of each issue has been assessed using a qualitative approach. The reporting framework does not include a ranking system for prioritising the importance of issues and their order in Table 4.1 does not infer relative importance.

Table 4.1

Assessment summary of key pressures acting on Cockburn Sound

Key

Trend		Impact grade		Confidence in assessment		Comparability of data to 2001		Risk	
↗	Improving	■ (green)	Very low: There are few or negligible impacts from this pressure, and accepted projections indicate that future impacts on the marine environment are likely to be negligible	●	Adequate: Adequate high-quality evidence and high level of consensus	◆	Comparable: Grade and trend are comparable to the previous assessment	▲ (green)	Low: The likelihood that impacts associated with the pressure will erode one or more environmental values in Cockburn Sound is low and consequences are anticipated to be negligible
−	Stable	■ (yellow)	Low: There are minor localised impacts from this pressure in some areas, and accepted projections indicate that future impacts on the marine environment are likely to occur, but will be localised	◕	Somewhat adequate: Adequate high-quality evidence or high level of consensus	⬘	Somewhat comparable: Grade and trend are somewhat comparable to the previous assessment	▲ (yellow)	Medium: It is possible that impacts associated with the pressure may erode one or more environmental values in Cockburn Sound, although consequences are likely to be short-term and/or localised
↙	Deteriorating	■ (orange)	Moderate: Impacts from this pressure occur in many areas, but the extent of change is moderate and accepted projections indicate that future impacts on the marine environment are likely to occur.	◒	Limited: Limited evidence or limited consensus	◇	Not comparable: Grade and trend are not comparable to the previous assessment	▲ (orange)	High: It is probable that impacts associated with the pressure will erode one or more environmental values in Cockburn Sound, especially if not suitably managed
?	Unclear	■ (red)	High: The current environmental impacts from this pressure are significantly affecting the values of the region, and projections indicate serious environmental degradation in the marine environment within 50 years if the pressure is not addressed	◔	Very limited: Limited evidence and limited consensus	X	Not previously assessed: Grade and trend not previously assessed	▲ (red)	Severe: It is almost certain that impacts associated with the pressure will erode one or more environmental values in Cockburn Sound, with consequences anticipated to be long-term and/or acting at a whole of Sound scale
	-	■ (black)	Very high: The current environmental impacts from this pressure are widespread, irreversibly affecting the marine environment, and projections indicate widespread and serious environmental degradation in the marine environment	○	Low: Evidence and consensus too low to make an assessment		-		-

Notes: Assessment key derived from Evans et al. (2017). The 'impact grade' of a pressure pertains to the capacity of that pressure to cause impact/s on the state of the marine environment.

Table 4.1 (continued)

Assessment summary of key pressures acting on Cockburn Sound

Fundamental Pressure	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001	Risk to marine environmental values
Industrial point source discharges	Nitrogen loading	Nitrogen inputs from point source industrial discharges have been steadily reduced by improved management and diversion to the ocean via the Sepia Depression Ocean Outlet Line; such that point source nutrient and contaminant loads from industry are now estimated to be immaterial (see **Sources and trends in nitrogen inputs to Cockburn Sound**). The contribution of residual nitrogen bound in sediments to the Sound's nutrient budget remains uncertain.	↗			◆	▲
	Other contaminants	The improvements to the management of industrial discharges has resulted in large reductions in other contaminants loads (metals and hydrocarbons) entering the Sound from point sources.	−			◇	▲
	Cooling water discharges	Cooling water, used for industrial processes, is discharged into Cockburn Sound from three separate sources. Cooling water discharges are managed by licence limits for temperature and chlorine concentration (used as a biocide to prevent fouling). Seawater used for cooling is expected to result in minimal change in the environment after discharge and mixing.	−			◇	▲
	Desalination discharges	The Perth Seawater Desalination Plant began discharging brine to the eastern margin of Cockburn Sound in late 2006. Continuous real-time monitoring demonstrated that brine discharge and stratification did not generate low dissolved oxygen (DO) concentrations in the deep basin of Cockburn Sound, nor exacerbate naturally-occurring, low-DO events.	−			◇	▲
Contaminated land and groundwater inputs	Contaminated land inputs	The primary pathways for contaminants from terrestrial sources entering Cockburn Sound are in surface runoff via drains, and contamination of groundwater from land use practices in the catchment. A wide range of land uses exist along the Sound's coastline including heavy industry, light/supporting industry, transport infrastructure, agriculture, urban and commercial centres; each of these land uses has the potential to act as a source of contamination. There is no systematic monitoring of surface quality or flows discharging to the Sound, which makes determining contaminant loads difficult.	?			◇	▲
	Groundwater inputs	Large groundwater flows to Cockburn Sound have the potential to serve as a conduit for contamination. There is no systematic monitoring of groundwater flow or quality near the coast to assist assessment of contaminant loads in groundwater discharging to the Sound.	?			◆	▲
Coastal and seafloor modification	Coastal structures	The Cockburn Sound shoreline is the most heavily modified coastal system in Western Australia. Since the early-1900s, the development of the Sound as a major recreational, commercial, defence and industrial area has resulted in the creation of numerous coastal structures (Figure 4.1). At the regional level, the presence of large engineered structures (e.g. Woodman Point groyne, Jervoise Bay Boat Harbour northern breakwater and the Garden Island causeway) has effectively isolated Cockburn Sound from significant longshore feeds of sand from the north and south, with Cockburn Sound now considered as a single primary sediment cell. Within this cell, modifications have resulted in localised changes to sediment transport pathways, which in turn affect the position and stability of the shoreline. Renourishment activities (see below) and construction of groynes, seawalls and breakwaters are routinely required to rectify coastal stability. Due to the prevailing low energy conditions the coastal response to structural intervention within Cockburn Sound will be slow, with coastal response times in the order of many years to decades.	↙			◆	▲

Table 4.1 (continued)

Assessment summary of key pressures acting on Cockburn Sound

Fundamental Pressure	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001	Risk to marine environmental values
Coastal and seafloor modification	Dredging and nourishment	Since the 1950s, a large number of dredging and nourishment works have been undertaken within Cockburn Sound for the purposes of navigation and shoreline management (Figure 4.1). Future dredging works are expected for the maintenance of shipping channels, servicing of boat ramps, jetties and marinas and potential large-scale infrastructure projects. Impacts associated with dredging are typically well contained, however, they do have potential for broad-scale impacts if not well managed. The material from the majority of navigational dredging projects has been disposed to the seabed at locations within Cockburn Sound, which can change local hydrodynamic patterns and influence shoreline changes. To manage these effects, shoreline nourishment works are regularly conducted in Cockburn Sound to maintain recreational beach amenity, mostly on the southern beaches.					
Marine vessel activities -	Recreational boating	Recreational boating in Cockburn Sound is extremely popular and is set is to increase in-line with population increases. Key pressures on the marine environment associated with recreational boating include multi-user conflicts, vessel strikes on marine fauna and craft mooring. The long-term nature of fixed mooring locations means that vessels stationed at these locations pose a risk to marine sediment quality through long-term accumulation of toxic antifoulants and biocides; and may facilitate accumulation and translocation of invasive marine species in Cockburn Sound. The use of permanently fixed mooring chains has also led to loss of over 3.2 ha of seagrass in Mangles Bay due to chain drag.					
	Introduced marine species and pests	The main ways that foreign marine species can be introduced to Cockburn Sound are through vessel ballast water and biofouling. The higher risk vessels are generally those that are slow moving, have numerous spaces where marine species can gain purchase, and come into close contact with the seafloor. Current vessel usage patterns in Cockburn Sound have been identified as posing a high risk because of their average duration of stay, frequency of visits, the number of compatible pests and the socio-political status of arriving vessels. Of the 46 introduced marine species that are present in the Cockburn Sound and Fremantle Harbour area, four are considered pests: the Asian date/bag mussel (*Arcuatula senhousia*), the European fanworm (*Sabella spallanzanii*), a colonial ascidian (*Didemnum perlucidum*), and a toxic dinoflagellate (*Alexandrium catenella*) (Figure 4.2). The populations of these species are considered stable and not disturbing native populations of flora and fauna. Species belonging to the genus *Didemnum* remain a target for managers.					
	Bio-fouling controls	Until 1989, the antifoulant tributyltin (TBT) was the most commonly used biofouling control due to its extreme toxicity and therefore effectiveness. TBT can persist for up to 20 years in the soft sediment of harbours and remains consistently present in Cockburn Sound sediments. TBT and its degradation products (dibutyltin and monobutyltin) are often present in samples collected from areas where contamination is likely, such as port infrastructure, jetties and vessel mooring locations. Since the global ban on the use of TBT, there has been a shift to copper based antifoulants. Paints with copper often contain additional biocides such as zinc pyrithione or organic algaecides; and contamination by these TBT-replacement compounds may become an emerging issue.					
	Shipping activities	The level of commercial shipping activity in Cockburn Sound has been fairly stable, with the number of ships entering in any one year typically between 1,000–1,200, although the general size and tonnage of vessels is increasing. The main environmental pressures associated with shipping activities in Cockburn Sound include spillages during loading and unloading (e.g. grains, fertilisers and hydrocarbons), underwater noise, dredging activities and invasive marine species. While the handling of ‘dangerous cargo’ is heavily regulated and typically well managed in Cockburn Sound, chemical and biological toxicity can be a significant concern, especially if these types of spills occur.					

Table 4.1 (continued)

Assessment summary of key pressures acting on Cockburn Sound

Fundamental Pressure	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001	Risk to marine environmental values
Fishing pressures	Commercial fishing and aquaculture	Cockburn Sound supports substantial commercial fishing activities, as well as an aquaculture industry; however, since the early 1990s, there has been a progressive decline in the number of commercial licences operating in Cockburn Sound and nearly all commercial fishing catches have declined in recent years (refer to **Commercial fisheries in Cockburn Sound**). While breeding stock levels of many finfish species harvested in Cockburn Sound are presently considered 'sustainable-adequate', commercial catches of some indicator species pose a high ecological risk. Aquaculture activities in Cockburn Sound have also declined in recent years, with mussel farm operators claiming their annual tonnage has reduced by up to 60% in the past decade. It is believed by operators that reductions are the result of decreased nutrient concentrations, combined with snapper predation; although this has yet to be scientifically verified.					
	Recreational fishing	Boat-based and shore-based recreational fishing are popular activities in Cockburn Sound. It is presumed that participation rates in recreational fishing have increased steadily in-line with local population growth, but recent data are not available to verify this trend. Shore-based fishing takes a smaller proportion of the total recreational catch of popular fish species (~30%) and is focussed around jetties and the northern areas of Cockburn Sound. Boat-based fishing is relatively widespread throughout Cockburn Sound, although is more concentrated around Mangles Bay, Cape Peron and the northern entrance to the Sound. Recreational fishing comprises a significant proportion of the total catch compared to commercial fishing (~50%, excluding baitfish) from Cockburn Sound for many popular fish species. By volume (tonnes), the main species of finfish caught by recreational fishers in Cockburn Sound are Australian herring, squid and whiting. Recreational crabbing in Cockburn Sound has remained closed since 2014, due to low stock numbers.					
Climate change	Water temperature	In Cockburn Sound, water temperature has increased ~0.03°C per year since 1985; and if this trend continues, Cockburn Sound will be ~1.3°C warmer than present by 2060, with implications for biotic response and adaption. Increases in water temperature, including warm pulses of water associated with heatwave events, have been linked to possible declines in seagrass and other biota.					
	Sea level rise	Off south-western Australia, average sea level rising has been ~5 millimetres per year over the past two decades, which is anticipated to increase erosion and flooding risks in Cockburn Sound.					
-	Long-term reduction in rainfall	Since the mid-1970s, there has been a dramatic decline in rainfall in south-western Australia, which has further reduced since the early 2000s. The largest of terrestrial nitrogen loads into the Sound are now from groundwater discharge and future reduced loads are likely under a drier climate. There is also likely to be long-term reduction of flows from the Swan River and in turn, reduced nutrient discharges from this source.					
	Extreme and altered weather patterns	A weather or climate event is considered extreme if it is unusually intense or long, and may be beyond what has been experienced in recent history; examples relevant to the Cockburn Sound region include heatwaves, heavy rainfall, and coastal flooding. Extreme events (such as the flooding event observed in January/February 2017) are likely to become more common, although predicting their characteristics and frequency is an emerging area of climate science.					

Sources and trends in nitrogen inputs to Cockburn Sound

Nitrogen remains the chief contaminant of concern in runoff and groundwater, noting that insufficient information presently exists regarding emerging contaminant sources.

The reduction in nitrogen input from industrial point source discharges has increased the relative contribution of urban and agricultural land use as a nitrogen source (refer to the table below). It is estimated that the magnitude of nitrogen loads from groundwater sources have remained steady over the past few decades (~200-600 tonnes per year). While data are not available, over this time it is also postulated that nitrogen and other contaminant loads from surface run-off are unlikely to have increased (and perhaps decreased), due to substantial improvements in stormwater drainage infrastructure by local governments in the catchment.

Sources and trends in nitrogen inputs to Cockburn Sound

Source	1978	1990	2000	2015
Atmosphere	20	22	21	21
Point Source Discharge	1800	605	57	0
Groundwater	180	454	219-234	235-655
Urban catchment/ run-off	No Data	No Data	No Data	No Data
Other	No Data	No Data	9	9
Total	2000+	1081+	306-321+	265–685+

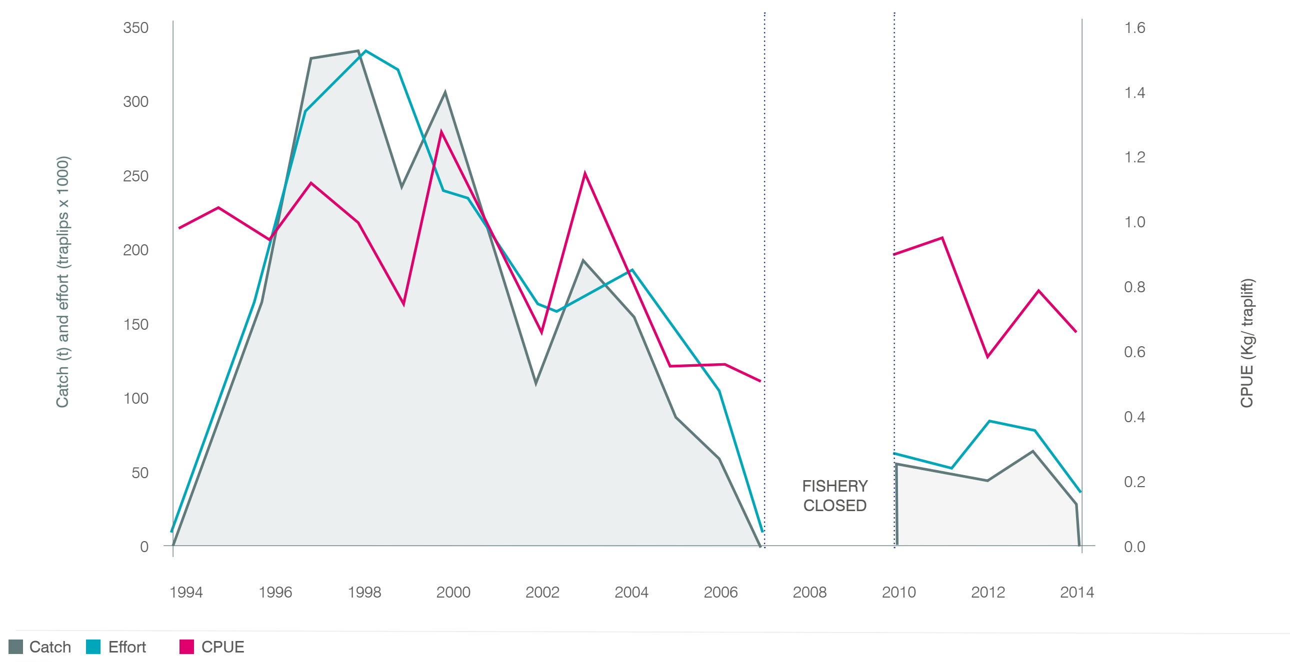
Note: Variation in estimates are partially due to differences in methods of calculation. Sources: DAL (2001), McFarlane (2015).

Commercial Fisheries in Cockburn Sound

Nearly all commercial fishing catches have declined in recent years, which may be due to a combination of reasons, including environmental factors, market pressure, changes in gear type and fishing effort, changes to fishery access rules and low recruitment (e.g. catches of blue swimmer crabs are shown in the figure below).

The blue swimmer crab fishery has been closed for several seasons in the past decade as stocks and recruitment capacity have been well below sustainable yields. It is presumed that recent blue swimmer crab declines are the combined result of reduced levels of primary productivity within Cockburn Sound, changes in water temperature, increased predation and the negative effects of density dependent growth, which appears to have had an effect on the proportion of berried females. Similar declines have been observed for the Australian herring fishery in Cockburn Sound. More recently, commercial and recreational harvesting of the southern garfish has also been banned. Conversely, the octopus catch in Cockburn Sound has steadily increased from two tonnes in 2000 to ~30 tonnes in 2015, and is believed to be operating well within the estimated sustainable harvest level.

Total commercial catches of Australian herring, 1976 to 2015



Source: Fletcher et al. 2017

Cumulative impacts

Cumulative impacts can occur when multiple pressures act together. There is a legacy of human modifications of Cockburn Sound and its catchment that together, have contributed to the Sound's non-pristine state and make the assessment of cumulative impacts a complex task. For example, Figure 4.1 illustrates the numerous major physical alterations to the coastline and seafloor.

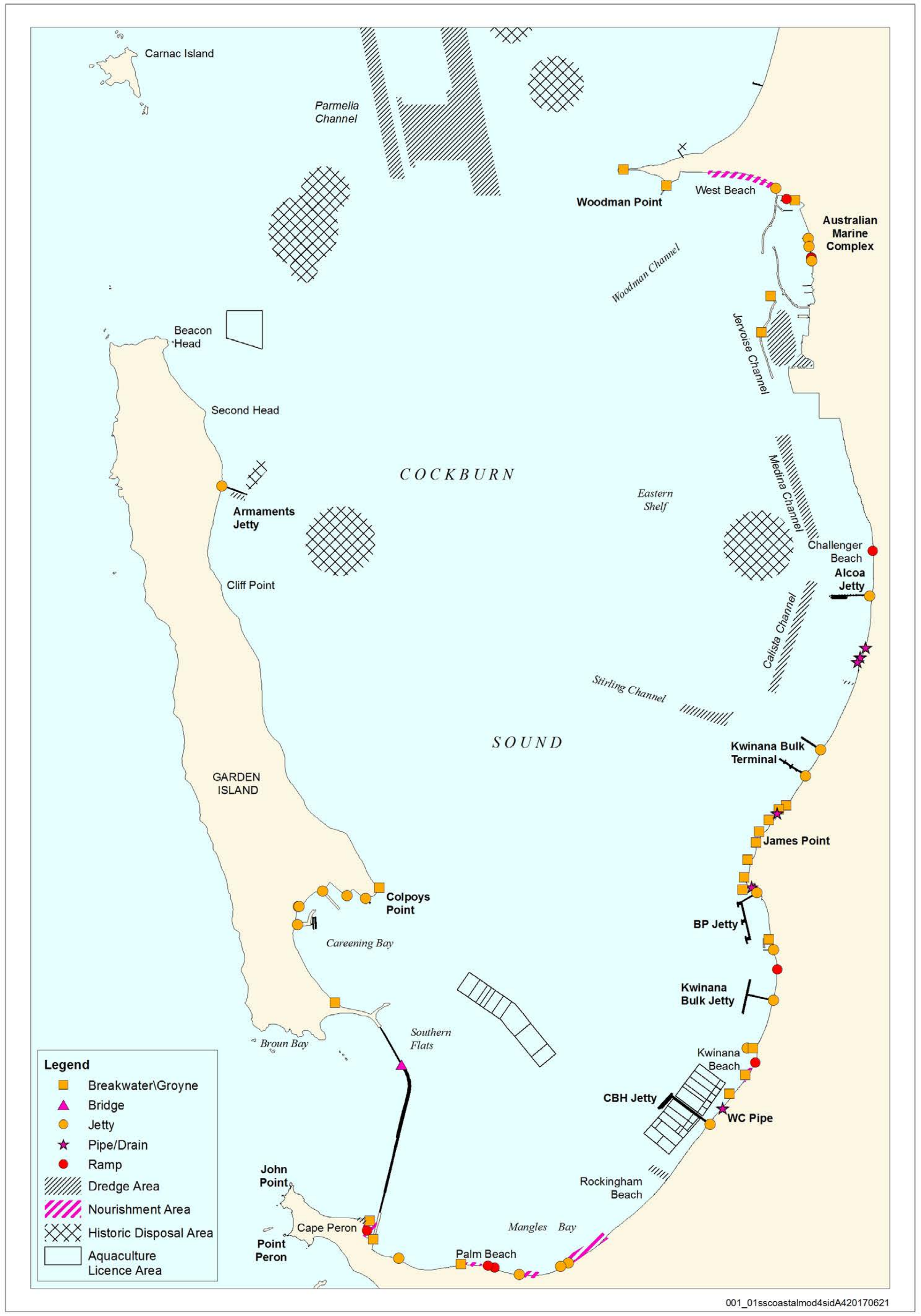
Since 1972, a number of studies have considered the effect of cumulative pressures and impacts on Cockburn Sound. The two general themes most often considered were:

1. What are the effects of multiple contaminants and contaminant sources on the Sound's benthic primary producers (seagrasses) and marine biota?
2. What are the potential effects of large-scale projects on hydrodynamics and marine quality, and in turn, upon the Sound's marine ecosystem?

Early investigations concluded that environmental degradation along the eastern foreshore was due to the cumulative impacts of industrial development and effluent discharge from the Kwinana Industrial Area. Investigations, which have sought to understand the cumulative impacts associated with large-scale projects, have typically incorporated hydrodynamic and biological modelling to predict and inform the design and layout of ports and harbours to ensure the Sound's marine environmental values would remain protected.

Figure 4.1

Introduced structures and physical alterations in Cockburn Sound



Climate change and other Emerging Pressures

Emerging pressures are those which are considered to pose a credible risk to the environmental values of Cockburn Sound, but for which data and information are insufficient to enable conclusions to be drawn about effects on the environmental quality of Cockburn Sound.

In the 16 years since the 2001 Cockburn Sound pressure-state-response assessment (DAL 2001), climate change has become recognised as a key issue for the south-west region of Australia. Coastal ecosystems such as Cockburn Sound are predicted to be significantly affected by climate change, with changes likely to include:

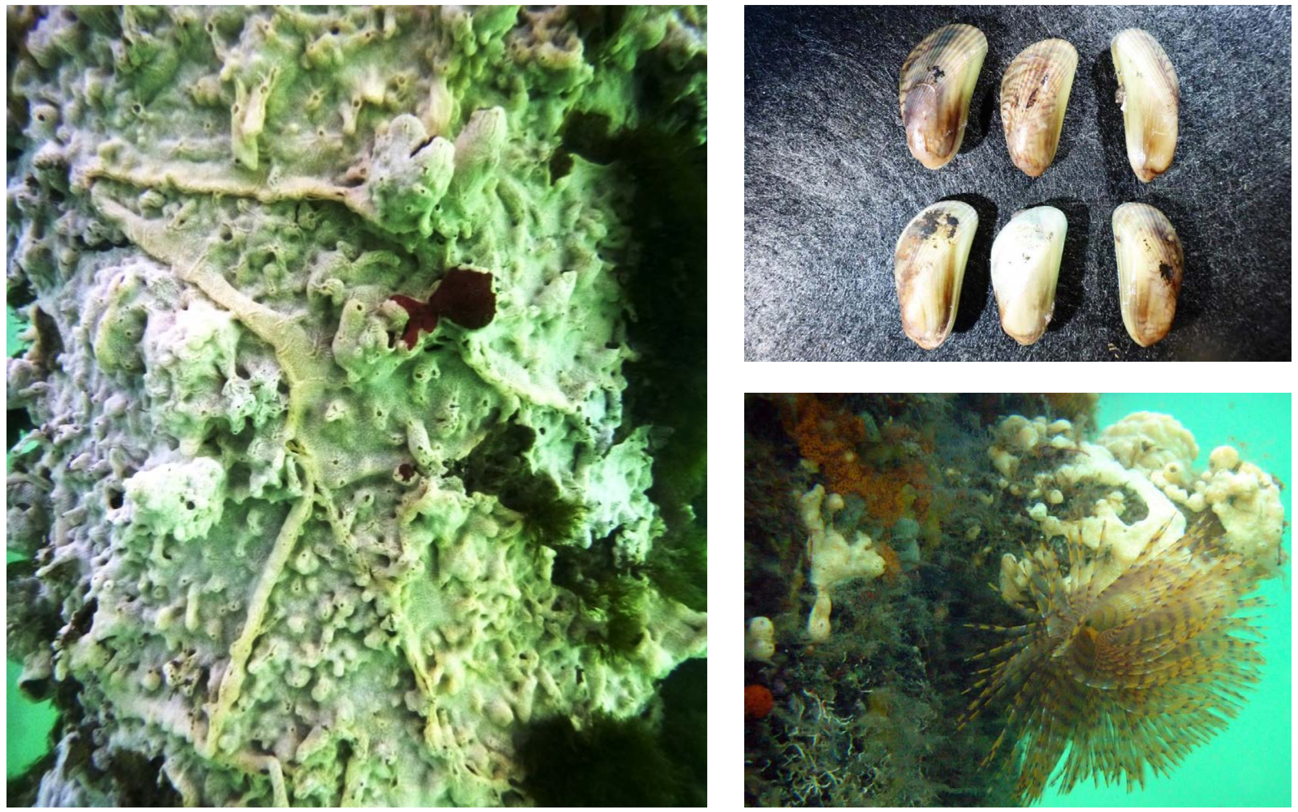
- increasing temperatures
- sea level rise
- altered rainfall patterns, and
- changes in frequency and intensity of extreme weather or climate events.

Other emerging pressures include:

- increased vessel size leading to enhanced underwater noise and turbidity
- contamination of marine sediments from dislodgement of cathodic protection
- uptake and biocide treatment of water used for industrial cooling and desalination purposes with subsequent entrapment and mortality of phytoplankton and zooplankton including larval fish and other fauna, and
- substances derived from fire-fighting chemical inputs (such as per- and poly-fluoroalkyl substances [PFAS]) contaminating land and groundwater with discharge to the Sound.

Figure 4.2

Marine pests in Cockburn Sound



Notes: From left to right - Asian date/bag mussel (Arcuatula senhousia), European fanworm (Sabella spallanzanii), colonial ascidian (Didemnum perlucidum). Source: images supplied by the Department of Primary Industries and Regional Development.

5. Current state of Cockburn Sound - impacts and trends

State refers to the general condition of Cockburn Sound's natural environment (biological, chemical and physical) in relation to its intrinsic/ecosystem value or human use (social value); including consideration of critical impacts and trends over time.

A summary of the state of Cockburn Sound, including trends in impacts and that have already influenced the marine environment, or show potential to re-shape it in the future is provided in Table 5.1. The table includes an assessment of trends; impact grades; confidence in presently available data; and comparability of presently available data to 2001 data. For more detailed explanation and justification refer to the full assessment report (BMT 2018).

Explanatory notes:

1. Where sufficient data permits, analysis of trends for each issue typically covers the period 2001–2017; this period follows the release of the previous Cockburn Sound pressure-state-response report (DAL 2001) and therefore provides an updated yardstick of the state of the environment for 2017.
2. The risk to the environment of each issue has been assessed using a qualitative approach. The reporting framework does not include a ranking system for prioritising the importance of issues and their order in Table 5.1 does not infer relative importance.

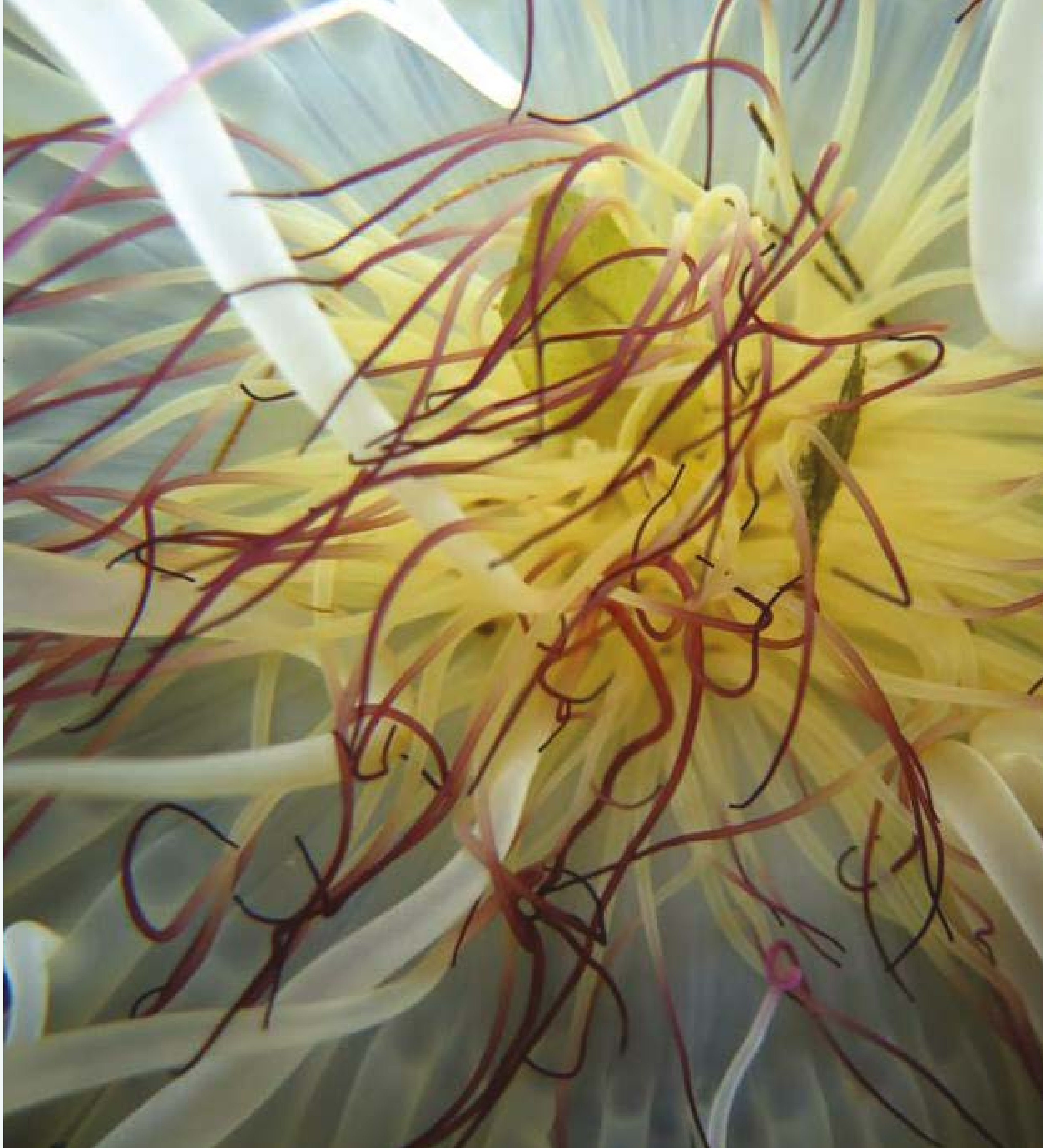


Table 5.1

Assessment summary of state of Cockburn Sound

Key

Recent trends	Impact Grade	Confidence in assessment	Comparability of data to 2001
↗ Improving	■ (green) Very good: Very few, if any, changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions	● Adequate: Adequate high-quality evidence and high level of consensus	◆ Comparable: Grade and trend are comparable to the previous assessment
– Stable	■ (yellow) Good: Some changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions in some areas, but these are not significantly affecting ecosystem functions	◕ Somewhat adequate: Adequate high-quality evidence or high level of consensus	⬘ Somewhat comparable: Grade and trend are somewhat comparable to the previous assessment
↙ Declining	■ (orange) Fair: Changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions across many areas of Cockburn Sound, but these are not significantly affecting ecosystem functions	◒ Limited: Limited evidence or limited consensus	◇ Not comparable: Grade and trend are not comparable to the previous assessment
? Unclear	■ (red) Poor: Substantial changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions, and these are significantly affecting ecosystem functions in some areas	◔ Very limited: Limited evidence and limited consensus	X Not previously assessed: Not previously assessed
-	■ (black) Very poor: Substantial changes in physical, chemical or biological processes have occurred as a result of human activities or declining environmental conditions, and these are significantly affecting ecosystem functions across widespread areas	○ Low: Evidence and consensus too low to make an assessment	-
-	□ Unknown: Changes in physical, chemical or biological processes that have occurred as a result of human activities or declining environmental conditions is currently unknown	-	-

Notes: Assessment key derived from Evans et al. (2017). The 'impact grade' upon a marine ecosystem component, pertains to the extent to which the state of that component has been impacted by pressures.

Table 5.1 (continued)

Assessment summary of state of Cockburn Sound

Ecosystem element	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001
Hydrodynamics	Marine water movements	Changes to circulation patterns are the result of the many large construction activities that commenced in the 1970s: • Construction of the Garden Island causeway in 1972 had a material impact on the hydrodynamics in Cockburn Sound within 1-2 km of the causeway. It is likely that the causeway has significantly reduced flushing in Mangles Bay and increased current velocities through the bridge openings. The causeway was not predicted to affect the northern basin or eastern margin of the Sound. • The shipping channels through Success and Parmelia Banks into the northern end of the Sound allow increased exchange with Owen Anchorage. • Construction of the Jervoise Bay Northern and Southern Harbours and the Australian Marine Complex has reduced flushing within harbour waters and changed currents in the local vicinity, but has not changed circulation in the broader Cockburn Sound. • Construction of the Naval Base, jetties, small groynes, dredging of channels on the eastern margin and discharges of cooling water and desalination brine have had localised impacts on currents and circulation patterns; however, there is no evidence that there has been any impact on the broader circulation of the Sound or in such a way as to change ecological processes.	⊟	■	●	◆
Coastal processes	Coastal processes	Coastal processes have been highly modified through the placement of shore structures and beach nourishment. In particular the changes in hydrodynamics due to the Garden Island causeway and other structures, have modified net sediment transport, accretion and erosion patterns. Present sediment transport patterns are illustrated in Figure 5.1, which demonstrates the potential for erosion along the eastern shoreline of the Sound and accretion adjacent to the causeway. The prevailing low-energy environment results in a significant lag in coastal response following structural interventions, which has led to several areas of present and future erosion and inundation risk.	↙	■	●	◆
Ecosystem health	Phytoplankton primary production, composition and toxicity	Pelagic primary production has never been directly measured within Cockburn Sound and it is therefore difficult to characterise the present state of the phytoplankton community. Estimates based on phytoplankton biomass (chlorophyll-a concentrations) indicate that phytoplankton are the dominant contributor (73%) to primary production within the Sound; similarly, nitrogen budget calculations attribute 90% of the biological nitrogen demand in Cockburn Sound to phytoplankton. A depth-integrated model of primary productivity (Figure 5.2) shows that rates of pelagic phytoplankton production are highest in the south-east of the Sound and in the vicinity of Jervoise Bay Northern Harbour where chlorophyll-a biomass is reportedly much higher than elsewhere in the Sound. Information from a long-term phytoplankton community composition dataset (1999–2012) indicates there was a step-change in phytoplankton cell density in early 2005, which may be associated with shifts in community composition, including a decline in silicoflagellates and increase in diatoms. There has been no research conducted on the ecological implications of this shift and flow-on effects are therefore unknown. There are few contemporary studies of the zooplankton community and pelagic secondary production within Cockburn Sound.	?	■	◒	◆

Table 5.1 (continued)

Assessment summary of state of Cockburn Sound

Ecosystem element	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001
Ecosystem health	Benthic primary producers	Seagrass extent has increased appreciably since 2008 (by ~130 ha), although health indicators (shoot density) suggest a continued decline at some long-term monitoring sites, despite improved water quality (see **Seagrass extent and health**).	[?]	■	●	◆
	Water quality	Management of nutrient inputs has reduced the in-water total nitrogen concentrations over time. Despite the large reduction in nitrogen availability, average phytoplankton biomass (measured as chlorophyll-a concentration) has been variable over the same period (Figure 5.3), and remains elevated in locations such as Jervoise Bay Northern Harbour. Nutrient concentrations have also tended to remain spatially variable and sometimes elevated in the southern waters of Cockburn Sound. The reasons for the spatial and temporal variations in chlorophyll-a concentration have not been resolved, and internal stores and recycling from sediments are not well enough understood to determine if slow phytoplankton (chlorophyll-a concentration) response is a legacy of historical nutrient stress. Brine discharge from the Perth Seawater Desalination Plant has the potential to increase stratification of the water column. Median bottom salinities at sites in close proximity to the discharge outlet have regularly exceeded the environmental quality guideline (EQG) for salinity, but the impact on salinity is localised and does not generate stratification sufficient to deplete oxygen in the deep basin of Cockburn Sound. Dissolved oxygen (DO) concentrations are typically high in Cockburn Sound, but seasonal cycles occur related to water column stratification. In general, natural stratification events are not sufficient to cause exceedance of the EQG for DO. Abnormal heat-wave conditions (e.g. in the summer of 2011) and other extreme events (e.g. 2017 summer rainfall deluge) can reduce DO concentrations.	↗	■	●	◆
	Sediment quality	Nutrient release from organic-rich sediments may be a significant contributor to the maintenance and variability of phytoplankton biomass in Cockburn Sound. Determining whether nutrient release from organic-rich sediments is a significant contributor to the maintenance of phytoplankton biomass (chlorophyll-a concentration) and productivity is limited by the current understanding of nutrient cycling in the Sound. While sediment monitoring demonstrates environmental protection requirements are typically being met, toxicants are regularly detected, albeit in localised areas such as ports. The most common toxicants in sediments are associated with biofouling controls. Tributyltin (TBT) and its degradation products (dibutyltin and monobutyltin) are often present in samples collected from areas where contamination is likely, such as port infrastructure, jetties and vessel mooring locations. Concentrations of copper are occasionally elevated at individual sites around shipping related infrastructure, but like TBT are spatially variable between sites. Per- and poly-fluoroalkyl substances (PFAS) have also been detected in localised areas of soil and groundwater on Garden Island (associated with Department of Defence fire-fighting activities). PFAS compounds have not yet been detected in the marine environment of Cockburn Sound.	[?]	■	◒	⬘
	Ecosystem integrity	The overall ecosystem integrity of Cockburn Sound may generally be characterised as a marine ecosystem modified in both structure and function by historic nutrient enrichment (eutrophication) and seagrass loss (**see Ecosystem integrity**).	[?]	■	◒	X
Marine fauna	Benthic macrofauna	There have been marked changes in the benthic macrofauna communities between 1978 and 2008 (the most recent information), including declines in species abundances and distribution, as well as shifts in community indices such as species diversity. There are also spatial variations in benthic macrofauna diversity and abundance around the Sound (Figure 5.4). It is likely that anthropogenic modifications to the benthic marine environment are the leading cause of shifts in macroinvertebrate abundances and community composition. However, it is not clear if the functional and ecological roles of marine macroinvertebrate communities have experienced a similar shift; examination of the 2008 macrofauna data indicates most taxa are not characteristic of disturbed communities.	[?]	■	◒	⬘

Table 5.1 (continued)

Assessment summary of state of Cockburn Sound

Ecosystem element	Component	Summary	Recent trend	Impact grade	Confidence	Comparability of data to 2001
Marine fauna	Fish and fish communities	The ecological health of non-commercial and non-recreational fish populations and communities in Cockburn Sound is unknown. Surveys in 2008 suggest that fish diversity decreases southwards into the Sound, with the lowest diversity recorded 'offshore' of Mangles Bay. Habitat loss, particularly of seagrasses, is likely to have led to long-term changes in fish assemblages of Cockburn Sound, although the link has never been quantified or documented. Fish kill events associated with reduced water quality have also been known to occur.	?	■ (orange)	◒	◇
	Little penguins	Garden Island supports an estimated colony of 180–200 little penguins (*Eudyptula minor*). In this colony, the population abundance appears stable primarily due to strong success with nesting behaviours. This is important as breeding penguins from Cockburn Sound play an important role in the long-term maintenance of little penguins in the Perth region. Water craft strikes and starvation were the leading causes of mortality between 2003 and 2013. It is probable that deaths driven by starvation were linked to oceanic conditions and increased water temperatures, rather than trophic implications associated with habitat loss of little penguin prey.	–	■ (yellow)	◕	◇
	Dolphins	The bottlenose dolphin (*Tursiops* spp.) community of Cockburn Sound is resident year-round. The dolphins typically forage in a dispersed mode, meaning they are distributed individually around the Sound or in small groups. The size of the dolphin community appears to have remained stable for the past two decades.	–	■ (yellow)	●	◆
	Protected marine fauna	While several species of protected marine fauna occasionally occur in Cockburn Sound (e.g. sea lions, whales and turtles), they are infrequent visitors and do not have habitat affiliations with Cockburn Sound	–	■ (yellow)	●	◆
Recreation and aesthetics	Recreational use of the coastal environment	A 2005 survey of Perth's metropolitan beaches, including Rockingham Beach and Challenger Beach, found that: • Visitation to Rockingham Beach was similar to other popular beaches south of Swan River (e.g. South Beach and Secret Harbour); but not as high as the central metropolitan beaches of Cottesloe, City Beach and Scarborough. • Usage of Challenger Beach was an order of magnitude less than Rockingham Beach. • The main activities pursued were swimming (35-42% of respondents), visiting cafes at Rockingham Beach (21%), walking/running (14-17%) and fishing at Challenger Beach (15%). Further study is required to characterise whether the coastal environment is of sufficient quality to maintain or enhance contemporary visitation uses of coastal areas.	?	■ (orange)	◒	◇
	Recreational use of the marine environment	Since 2009, monitoring has consistently found that Cockburn Sound waters are safe for swimming and other water sports, with no broad-scale exceedances of relevant water quality guidelines.	–	■ (yellow)	●	◇
	Aesthetic values of Cockburn Sound	Annual monitoring in summer occasionally reports localised algal blooms, surface films and objectionable odours; but rarely to the extent that the overall aesthetic value of Cockburn Sound is considered compromised.	–	■ (yellow)	◒	◇
Cultural and spiritual values	Indigenous culture and heritage	It is difficult to determine the present state of indigenous cultural and spiritual values, which default to assessment of ecosystem health, recreational values and aesthetics of Cockburn Sound. Without tangible environmental quality criteria to assess the maintenance of indigenous cultural and spiritual values it is difficult to assess whether these values are being protected.	?	□	◒	◇
	Non-indigenous culture and maritime heritage	Similar to Indigenous Australians, many non-indigenous Australians consider the coastal and marine environment to hold significant cultural and spiritual value; and their way of life on the coastal fringe helps define their identity. The Western Australian Museum's Shipwreck Database presently lists 31 protected maritime heritage sites within and around Cockburn Sound. Despite their value, very little information is available on the state or effectiveness of protection of cultural heritage sites.	?	□	◒	◇
Industrial water supply	Industrial water supply	Seawater remains of an acceptable quality for existing industrial needs (including desalination for potable supply).	–	■ (yellow)	●	◆

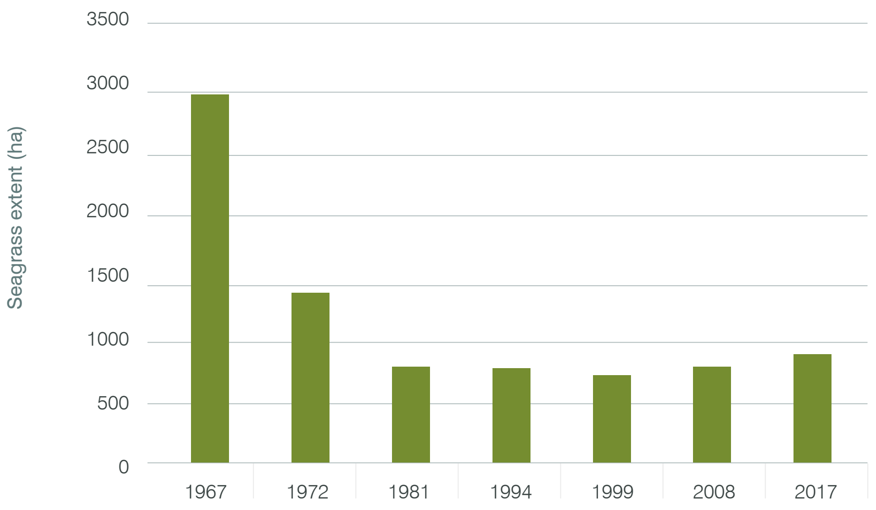
Seagrass extent and health

The extent of seagrass meadows in Cockburn Sound declined severely during the late 1960s and early 1970s due to poor water quality; and by 1978 it was estimated that only 872 ha remained from a pre-disturbance extant of ~4000 ha.

The main cause of seagrass loss was identified as poor water quality arising primarily from highly enriched nutrient discharges from local industry and municipal sewage outfalls. Since 2000, water quality conditions have improved considerably and there has been a recent appreciable increase in seagrass extent (132 ha gained between 2008 and 2017; refer to the figure below), most noticeably in the meadows immediately adjacent to Woodman Point.

However, there also remains a persistent decline in seagrass health at some sites within Cockburn Sound (i.e. a long-term trend of declining seagrass shoot density in some meadows). While it is evident that seagrass health can no longer be regarded solely as a nitrogen related water quality issue, the reasons for these declines remain speculative; recent research suggests physical (temperature) and biogeochemical variables in the water column and sediment processes may help explain ongoing stress to some seagrass meadows.

Change in seagrass extent across Cockburn Sound between 1967 and 2017



Source: Kendrick et al. (2002); Oceanica (2009); Hovey and Fraser (2018).

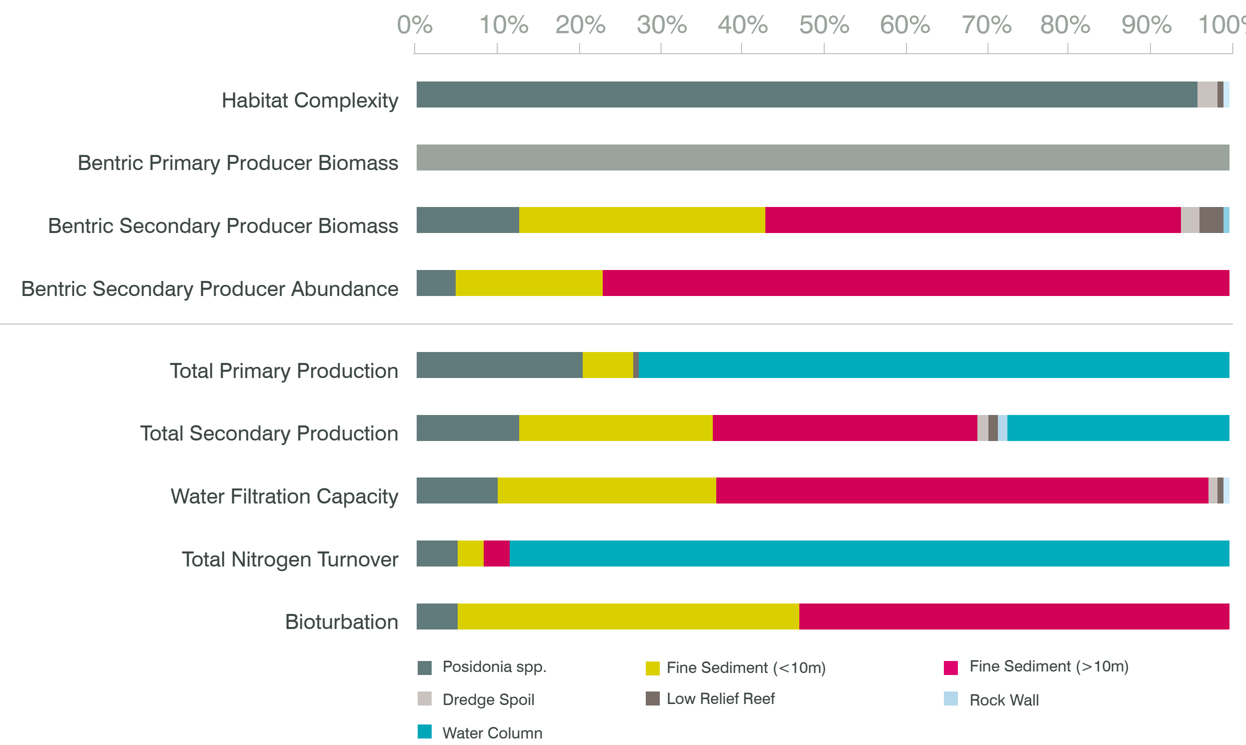
Ecosystem integrity

Ecosystem integrity is a term that considers both the structure (in terms of the biodiversity, biomass and abundance of biota) and functioning (biogeochemical cycling and primary and secondary production) of a marine ecosystem.

Semi-quantitative modelling termed ecosystem component characterisation was undertaken by Oceanica (2009, refer to the figure below) to better understand and characterise these ecosystem attributes for Cockburn Sound, with key conclusions being:

- The overall primary production rate across the Sound, including phytoplankton, was estimated at 18,973 tonnes of carbon per year (C/yr).
- Seagrass remains the dominant habitat across Cockburn Sound (overall extent and biomass); however, phytoplankton primary production exceeded that of all benthic habitats, due to fast growth rates, contributing 73% (13,718 tonnes C/yr) of the total primary production within the Sound.
- The total water filtering capacity of benthic invertebrate fauna within Cockburn Sound was estimated to be 25 billion litres/day (230 megalitres/square kilometre [ML/km^2]). 'Fine sediment (>10 m water depth)' habitat dominated the overall filtering capacity (60%) of the Sound due to large areas comprising filter feeders.
- Overall nitrogen turn-over rate of primary producers across Cockburn Sound is estimated as 1,560 tonnes N/yr. Phytoplankton dominated the total nitrogen turn-over (89% or 1,384 tonnes N/yr) due to fast growth rates and relatively high nitrogen content of phytoplankton.
- The overall sediment turn-over rate across Cockburn Sound was estimated at 4,455 tonnes sediment/day, with fine sediment being the dominant habitat of bioturbating fauna.

Contemporary estimate of the contribution of various components to ecosystem integrity in Cockburn Sound



Source: Oceanica (2009)

Figure 5.1

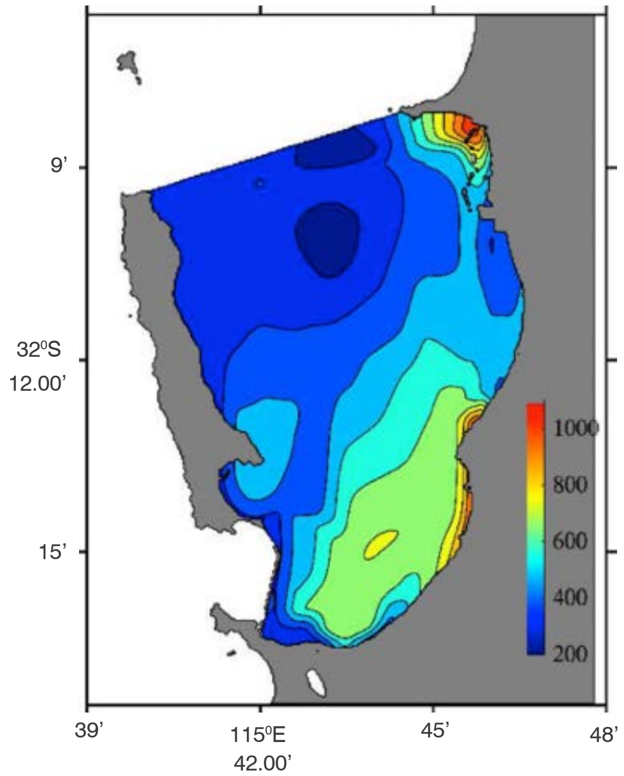
Cockburn Sound indicative sediment pathways

Notes:

'Subject to Reversal' refers to direction of sediment movements; sediment transport direction may reverse for seasonal changes in wind/wave/current regime, but the dominant or net direction is shown. 'Supply Controlled' refers to sediment availability; i.e. sediment transport is limited and controlled by supply of sediment. Red blocks are sediment sources, with potential for erosion. Green blocks are locations of sediment accretion. Source: CZM et al. (2013)

Figure 5.2

Estimated distribution of depth-integrated pelagic productivity in Cockburn Sound based on mean chlorophyll-a measurements (2008–2014)

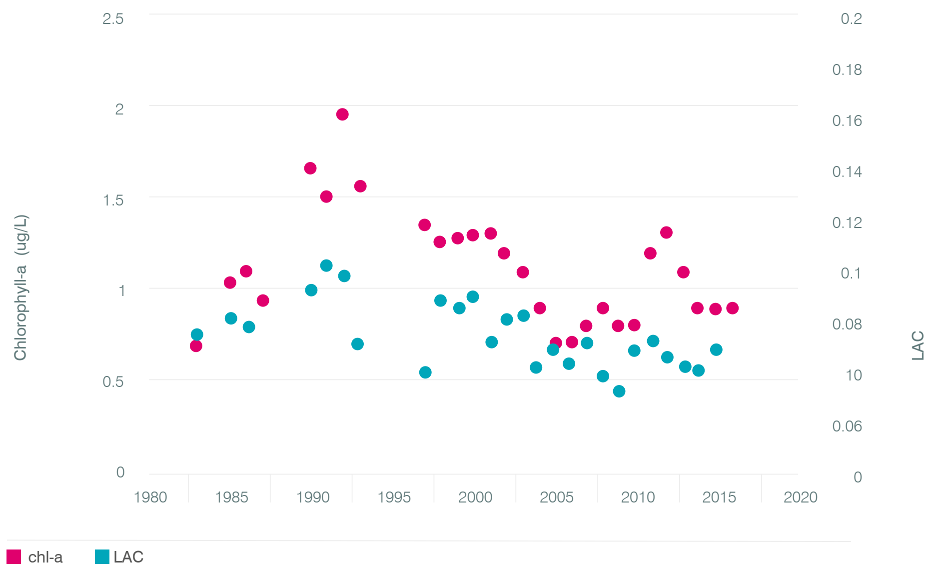


Note:

Contours represent depth-integrated pelagic productivity in units of milligrams of carbon per milligrams of chlorophyll-a/square metre/day (mg C mg chl a^{-1} m^{-2} d^{-1}). Source: Greenwood et al. (2016)

Figure 5.3

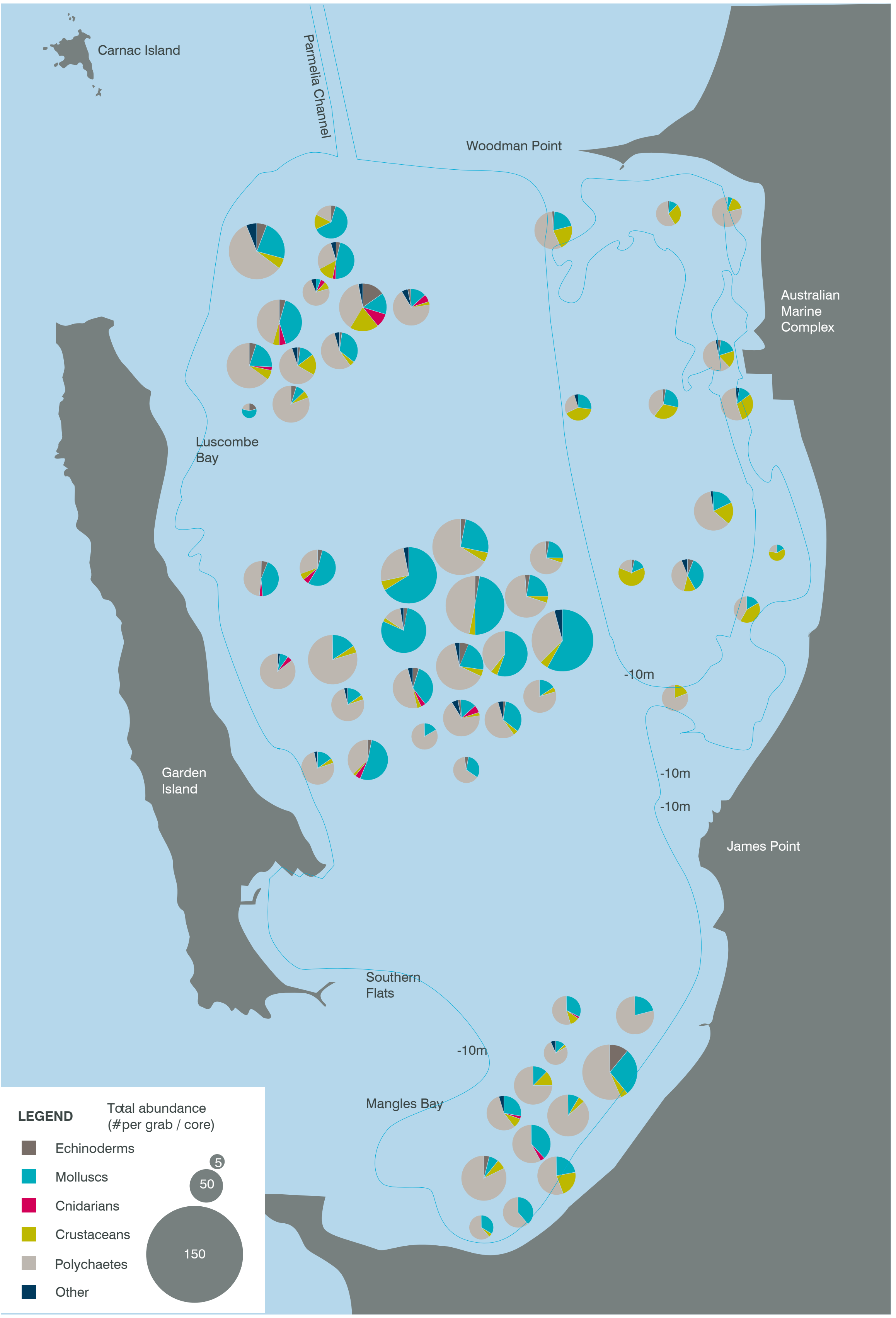
Median chlorophyll-a (chl-a) concentration and light attenuation coefficient (LAC) in Cockburn Sound



Data source: (MAFRL 2017)

Figure 5.4

Benthic macrofauna abundance and contribution made by taxonomic groups



Source: Deep basin data (collected February 2008) courtesy of the Water Corporation

6. Management responses

6.1 Current management responses and monitoring efforts

Western Australian government measures

The Western Australian (WA) government's commitment to Cockburn Sound's environmental health was established with the capital infrastructure project to divert the outfall of Woodman Point Wastewater Treatment Plant out of Cockburn Sound via the Sepia Depression Ocean Outlet Line. The WA government's ongoing support in establishing the Kwinana Water Recycling Plant, combined with industries' commitment to diverting wastewater discharges to the plant, has been pivotal in further reducing nutrient and other contaminant loads to Cockburn Sound.

Establishment of the Cockburn Sound Management Council (CSMC) in 2000 to assist in the management of Cockburn Sound and its catchment and the release in 2005 of the first Cockburn Sound SEP and the implementation documents for the protection of the Sound, consolidated the WA government's commitment to protecting the environmental values of Cockburn Sound. Together with the provisions for environmental impact assessment (EIA) and regulation of discharges under the *Environmental Protection Act 1986*, these measures ensure that a robust management framework specific to Cockburn Sound, exists for:

- defining environmental values that are of importance to stakeholders and require protection;
- regular engagement between stakeholders from government, industry and the community through the CSMC;
- the provision by the CSMC of advice and recommendations to the Minister for Environment on the environmental management of Cockburn Sound, particularly in relation to the protection and maintenance of water quality and associated environmental values;
- public authorities undertaking environmental monitoring and providing the results to CSMC which compiles and reports on the results;
- monitoring and managing exceedances of specific environmental quality criteria that are reported by the CSMC to the Minister for Environment;
- EIA of new projects, with specific environmental quality criteria to protect the environmental values of Cockburn Sound – many developments within the Sound are now subject to Ministerial Implementation Statements defining environmental monitoring, management and offset conditions; and
- ongoing regulation of project-specific emissions, monitoring and management.

Other WA government measures relevant to the effective monitoring and management of Cockburn Sound's marine environment include:

- Establishment of the *Contaminated Sites Act 2003* for the identification and management of contaminated sites, which has allowed better definition of potential contaminant sources.
- The management of fish stocks for commercial and recreational fishing by the Department of Primary Industries and Regional Development.
- The Department of Planning, Lands and Heritage has responsibility to conduct land use planning in Cockburn Sound's catchment in an environmentally sustainable manner that is protective of both indigenous and non-indigenous heritage values.

Industry measures

Since the 1970s, industry within the industrial areas of Cockburn Sound's hinterland have been proactive in working with government to reduce industrial emissions and improve environmental quality of the region. Establishment of the Kwinana Industries Council (KIC) in 1991, including an active environmental management committee, and representation on the CSMC; has provided avenues for industries to engage with other stakeholders to improve the environmental management of their operations. The Kwinana Industrial Area has been globally recognised for its pollutant emission reduction initiatives and its unique level of evolved connectivity between industries. Active industry participation has been key to the success of reducing point source discharges of nutrients and other contaminants and improving the water quality of Cockburn Sound over the past few decades.

While some of the environmental monitoring and management measures undertaken by industry are derived from regulatory requirements, many are also instigated due to good corporate citizenship and for purposes of attaining a 'social licence' to operate. Many industries voluntarily adopt environmental management systems, often certified to international standards (such as ISO14001). Furthermore, the EIAs and ongoing monitoring and management measures undertaken by many proponents has significantly contributed to the knowledge-base of Cockburn Sound's marine environment, e.g. the development of Cockburn Sound scale hydrodynamic models.

Local government measures

Local government measures relevant to the effective management of the Cockburn Sound marine environment include:

- Improvement of stormwater drainage that has significantly contributed to improvement of water quality in Cockburn Sound.
- Local governments can mandate and effect environmental change at a community level (e.g. in developing dune rehabilitation programs).
- The Cockburn Sound Coastal Alliance (CSCA) a partnership between the Cities of Cockburn, Fremantle, Kwinana and Rockingham and Perth Region NRM, which was formed in recognition that coastal erosion and inundation are common problems across Cockburn Sound and an integrated and collaborative approach to planning, monitoring and management is advantageous.

6.2 Effectiveness of management responses

The effectiveness of management measures has been assessed by examining the recent trends in key pressures upon (Table 4.1) and current state of ecosystem elements (Table 5.1).

A summary of the assessment is presented in this report, for more detailed explanation and justification refer to the full assessment report (BMT 2018):

1. The management of industrial point source discharges has been effective.
2. Monitoring and management of groundwater intrusion and surface water run-off into Cockburn Sound is piece-meal (both spatially and temporally) and requires greater coordination and focus.
3. The construction of the Garden Island causeway had a material impact on the hydrodynamics of the southern portion of the Sound; however, management of further developments has resulted in only localised changes in water movement and not Cockburn Sound scale impacts. Overall, management has been effective.
4. The overall deteriorating trend in coastal stability indicates that ongoing impacts from coastal modifications continue to occur in many areas, but the extent of change is not significantly affecting ecosystem function. Accepted projections indicate that future impacts on the coastal environment are likely to occur. While current coastal management is likely adequate in mitigating short-term impacts, it is difficult to assess the confounding impact of climate change and the effectiveness of long-term management measures.
5. The number of commercial vessels using Cockburn Sound has been stable for several years, however recreational boating activity is increasing. Management of associated risks such as the introduction of marine pests and contamination by biofouling paints has been sufficient to maintain only localised impacts.
6. Nearly all commercial fishing catches and aquaculture activities have declined in recent years; available data on recreational fishing catches are limited. In some instances, further studies are required to better understand the causes of decline and effectiveness of management of fish stocks; in others, present catch limits pose a high ecological risk. Continued scrutiny of management of commercial and recreational fisheries and aquaculture production in Cockburn Sound is warranted to ensure that yields are sustainable, and in some instances recoverable.
7. Overall, management has been effective in meeting the environmental objectives for marine ecosystem health components of the Sound (water quality, sediment quality, pelagic and benthic primary production and 'ecosystem integrity'). However, given the shift in primary productivity from a benthic to pelagic driven system, further studies are required to better understand sediment-water biogeochemistry in driving Cockburn Sound's ecology and productivity to be able to determine the ongoing effectiveness of management.
8. The status of benthic macrofauna and fish communities indicates that overall management has been somewhat effective, however the trend of change in these communities is unclear. Further studies are required to determine the ongoing effectiveness of management.
9. The population status of little penguins, dolphins and protected marine fauna indicates that overall management has been effective.
10. The status of marine recreational use and aesthetic values of Cockburn Sound indicates that overall management has been effective. Further data and studies are required to determine the trends in recreational use of the coastal environment and beaches; and also to understand the effectiveness of management in protecting coastal recreational values.
11. The effectiveness of management of indigenous and non-indigenous cultural and heritage values is unclear. Further work is required to assess the state of these values and trends in how well they are being protected.
12. Industrial water supply is presently effectively managed.

Cumulatively, the monitoring and management measures described in Section 6.1 are robust, but are often disparate and not well coordinated. Fostering further interaction between all stakeholders responsible for monitoring and management activities in Cockburn Sound – with centralisation of all environmental and social data – would lead to more efficient and effective management outcomes.

Management focus should be directed at aspects of Cockburn Sound's ecosystem that are highly valued by the community. Monitoring and management programs to date have focussed on water quality and seagrass habitat, with less attention to changes in fish stocks and other indicators of ecosystem stress. Given the improvements in water quality realised over the past few decades, it may be that the seagrass beds on the Eastern Shelf cannot be substantively improved without disproportionate effort. Efforts should be directed at reaching stakeholder consensus on the weighting of important values to be preserved; and the best way to prioritise, monitor and manage those values. The question that needs to be asked of stakeholders is:

What would be considered a realistically 'acceptable' condition of the Sound's priority values?

Finally, while the environmental quality management framework which is given effect through the Cockburn Sound SEP has been effective in addressing water quality issues and protecting the extent of existing seagrass habitat, opportunities for implementing alternative conceptual tools such as "as low as reasonably practicable" (ALARP), ecosystem engineering, and/or environmental accounting may be useful in helping to devise environmental management (or offset) measures that offer the best "bang for buck" in protecting the environmental values of Cockburn Sound in the future.

7. Long-term outlook

This DPSIR assessment has highlighted the historical, contemporary and future drivers of pressures on Cockburn Sound's marine environment, and characterised its current state as a marine system modified by historic eutrophication and seagrass loss.

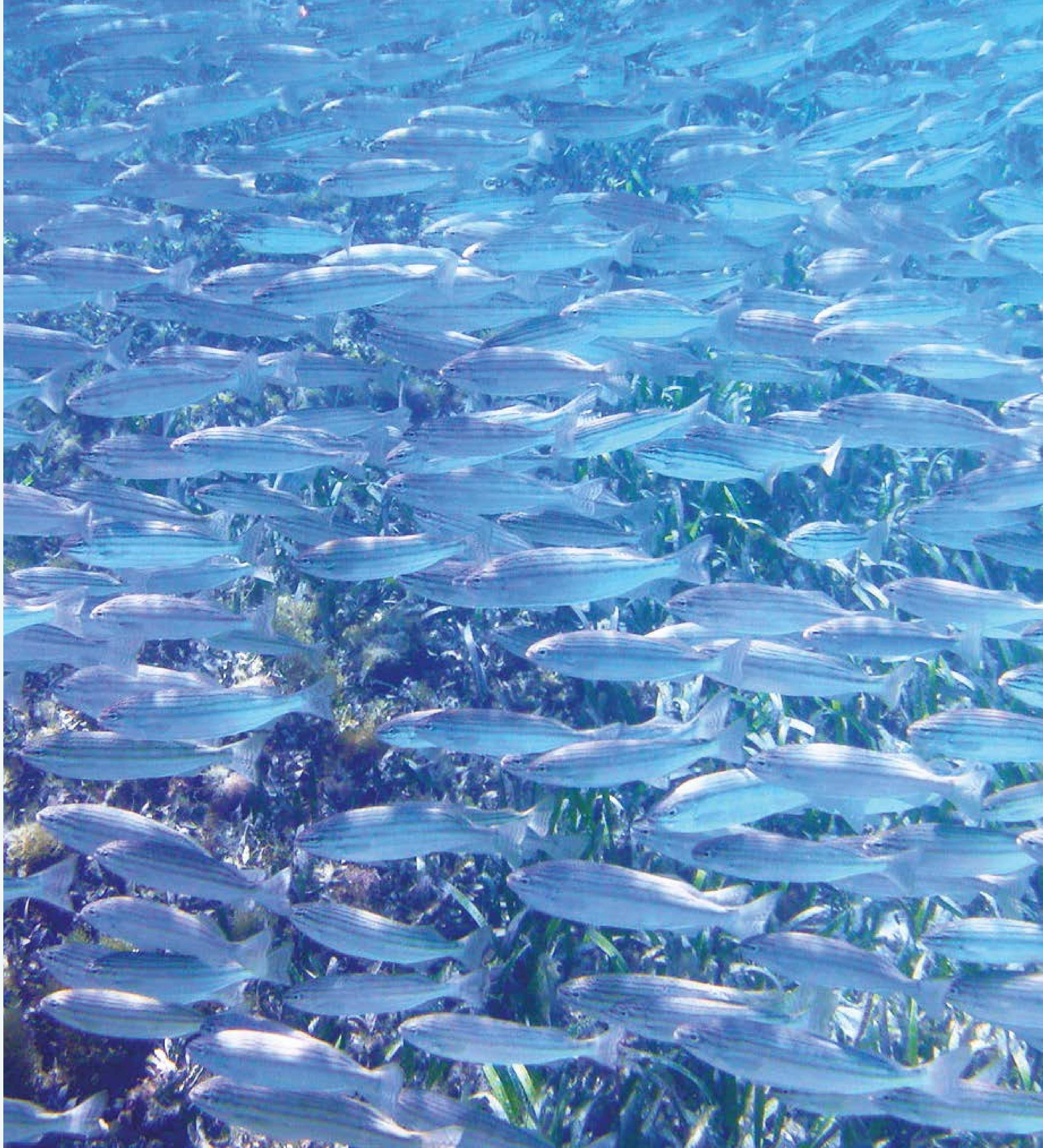
The water quality of Cockburn Sound has broadly improved in response to the efforts of government and industry to reduce nutrient loads, however questions remain about the desired 'end-state' of the system (and its capability to adapt to this state), such as:

- *Do the community and stakeholders want marine ecosystem quality and seagrass extent in Cockburn Sound to be rehabilitated to a pre-disturbed state – and is it possible? If not, then what state is acceptable?*
- *Will further nutrient reductions lead to lower phytoplankton productivity and what are the implications of further changes in Cockburn Sound? Is this what the community and stakeholders want?*
- *How will climate change compound the pressures on Cockburn Sound's marine environment and its ability to adapt?*

Given that the broad-scale seagrass loss in Cockburn Sound has significantly – and likely irreversibly – altered the diversity and integrity of the marine ecosystem (EPA 2016); further work is required to determine:

1. Community and stakeholder consensus on what is the 'most-acceptable' state of the marine environment in Cockburn Sound that both facilitates its multiple human uses and protects its environmental values?
2. The resilience and adaptability of Cockburn Sound's marine ecosystem - what state/s can be achieved?

Answers to these questions will be assisted by filling gaps in existing knowledge and developing integrative models that provide a better understanding of the interactions within and between ecological and social components of Cockburn Sound's marine environment. The key challenge will be to balance environmental pressures associated with existing use and ongoing development in Cockburn Sound and its catchment, against the ecosystem's capacity and resilience to cope with existing and emerging issues.



7.1 Potential influence of future cumulative development

Approved proposals

Future proposals that have received approval under the *Environmental Protection Act 1986* include:

- Port Rockingham Marina (Ministerial Implementation Statements No. 826 [February 2010] and No. 1041 [November 2016]).
- Mangles Bay Marina Based Tourist Precinct (Ministerial Implementation Statement No. 974, June 2014).

Both of these project proposals are located along the southern coastline of Cockburn Sound. While environmental approval does not necessarily infer commercial development, these projects have been assessed as capable of meeting the existing environmental quality management framework requirements in Cockburn Sound, if implemented and managed in compliance with applicable conditions. The efficacy of compliance with management measures will require a future assessment of the state of environment in Cockburn Sound.

Future proposals

Major developments that have been proposed (and may or may not occur in the future), but not yet assessed, include:

- An outer harbour (e.g. the Westport Project, Fremantle Ports 'Kwinana Quay' Outer Harbour Development, the Indian Ocean Gateway Outer Harbour Proposal)
- Expansion in the defence industries at Kwinana
- Kwinana Managed Aquifer Recharge concept, and
- Potential for future expansion of Perth Seawater Desalination Plant's production capacity and brine discharge.

There is no doubt that the construction of one or more of these large-scale projects (or multiple smaller projects) will have some level of cumulative impact on the Sound's already modified environment. While management and offset measures can likely be developed to mitigate these cumulative impacts – and future state of Cockburn Sound assessments can evaluate how successful these mitigation measures have been – with persistent population growth, pressures and development, the main question becomes how resilient is Cockburn Sound's marine ecosystem?

7.2 Ecosystem resilience

Ecosystem resilience refers to the capacity of an ecosystem to absorb disturbance and still retain its basic function and structure.

This section provides a discussion around the potential resilience of Cockburn Sound's marine ecosystem to a selection of key historic and emerging pressures acting on the system; acknowledging that the available information is sparse and requires considerable maturation to enable these concepts to evolve beyond general speculation.

Deteriorating water quality and seagrasses

While there has been an increase in the extent of seagrass in Cockburn Sound between 2008 and 2017, it appears from trends in ongoing declines in seagrass health (as measured by shoot density) that seagrass meadows in Cockburn Sound presently remain stressed. Seagrass meadows are unlikely to have any further residual capacity to tolerate significant declines in water quality for any sustained periods of time regardless of the agent of change.

Development and coastal processes

It is almost certain that any additional coastal structures or construction will lead to further changes in coastal processes and rates of erosion and/or accretion, which in turn may cause changes to the biotic environment.

Climate change and primary production

Heatwave events and spikes in water temperature may possibly result in reduced seagrass growth rates and potential mortality when exposed to extreme conditions. Longer-term increases in average water temperature, sea-level rise and ocean acidification may also be adding chronic stress to seagrasses in Cockburn Sound. For phytoplankton, the long-term consequences of climate change in Cockburn Sound remain unclear.

Climate change and fish

Nearly all commercial fishing catches have declined in recent years, which may be due to a combination of reasons, including environmental factors. The Cockburn Sound blue swimmer crab fishery also succumbed to reduced growth followed by poor recruitment in the year following the 2011 marine heat wave event.

7.3 Characterising the future of Cockburn Sound

This report will provide a platform to assist stakeholders to better plan for future management of Cockburn Sound's marine environment. As illustrated in Figure 7.1, there have been a number of key turning points in the state of Cockburn Sound, and it is not unreasonable to suggest that it is again transitioning towards a new state.

The historical change from a pre-European 'natural state' (Figure 7.1[A]) to a 'disturbed state' of poor water quality and declining ecosystem health (Figure 7.1[B]) has been summarised in Section 2 of this DPSIR assessment. The 'present state' of improved water quality yet limited biotic recovery (described in Section 5), is depicted in Figure 7.1[C].

While it is possible to speculate what the future may look like based on the available information (see Figure 7.1[D]), it is also acknowledged that the picture presented remains at best an educated guess – especially when taking into account the limited understanding of cumulative impacts and ecosystem resilience. Notwithstanding, and assuming the status quo of ongoing pressures and management measures, it can be postulated that the future Cockburn Sound (10 to 20 years from now) is highly unlikely to return to pre-European conditions and will be characterised by (Figure 7.1[D]):

- a catchment hinterland and coastline with high density urban and industrial development and potentially canal developments
- increased commercial shipping
- increased recreational use of the coast (beach visitation) and the Sound (fishing, boating)
- cultural and spiritual values that do not have explicit criteria for monitoring and management
- non-eutrophic water quality, but major primary production from the water column rather than seagrass, which in turn could lead to shifts in food-webs
- the return of seagrass habitat in some areas
- lack of recovery in historically-plentiful fisheries
- potential contamination and bioaccumulation of emerging contaminants
- water quality that is aesthetically pleasing and suitable for recreational use
- greater susceptibility to climate change induced stressors including:
    - reduced groundwater inputs
    - increased storm activity and coastal erosion
    - warmer waters and heat waves, which in turn could induce more frequent low dissolved oxygen events
    - more frequent unseasonal rainfall events, which in turn could stimulate algal blooms
    - emergence of marine species more typically associated with tropical regions
- overlapping urban, commercial and industrial development footprints leading to cumulative impacts and further declines in abundance and diversity of key biota, if not appropriately considered and managed.

As the foundation for any future 'whole of Sound' investigations, Table 7.1 provides a distillation from this report of all the key pressures and environmental issues that should be considered for future management. This DPSIR assessment's grading of risks from key pressures to environmental values (see Table 4.1), has also been flagged in Table 7.1 (colour of warning symbols) to provide an indication of which pressures are likely to require most focus when attempting to understand cause-effect pathways. This conceptualisation of Cockburn Sound's marine ecosystem is intended as a first step towards better understanding ecosystem dynamics at a whole of Cockburn Sound scale, and provides a precursor to formal qualitative and quantitative modelling approaches that could be used to inform management decisions, including gap-analyses of where further information or studies on key processes are required.

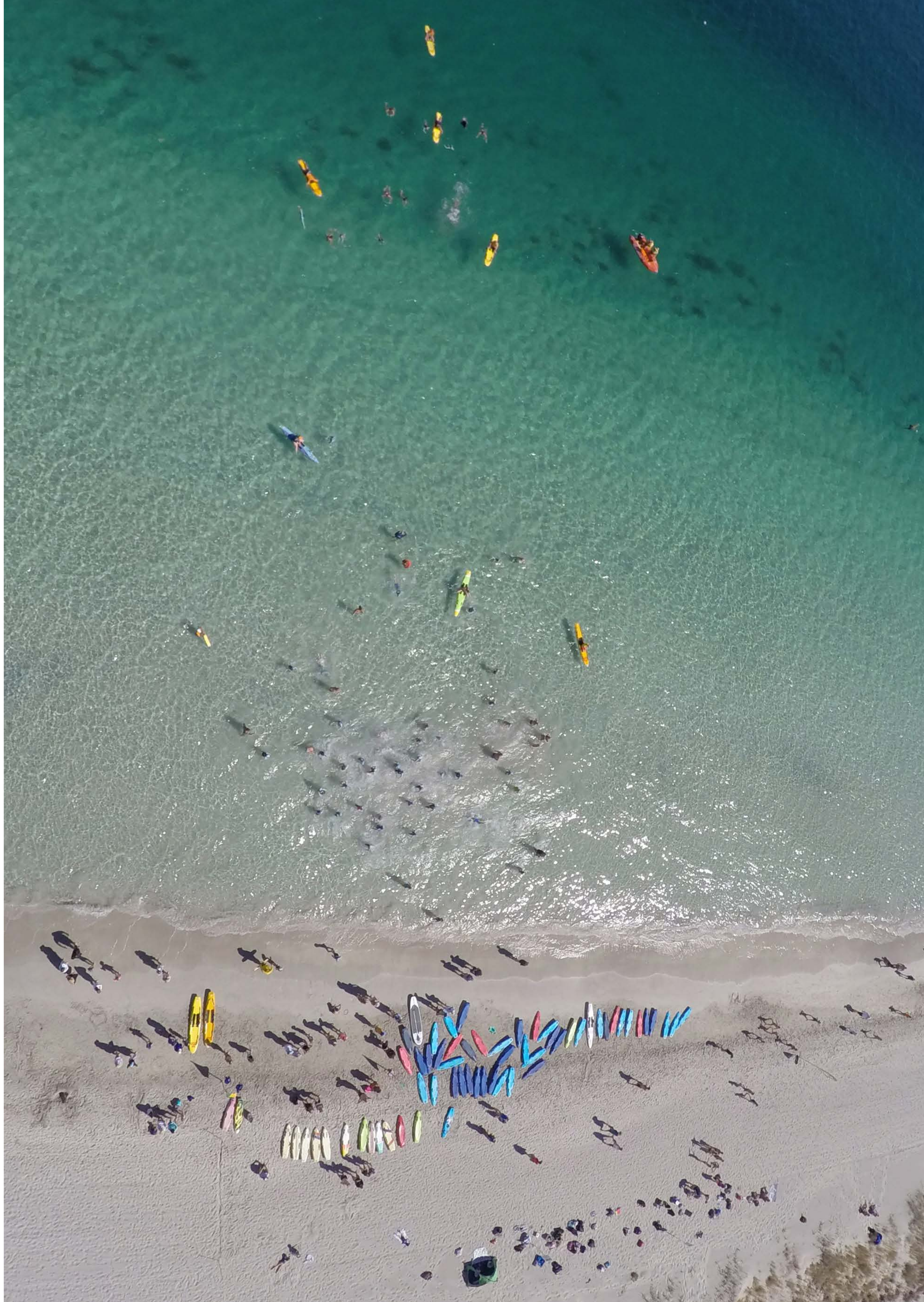
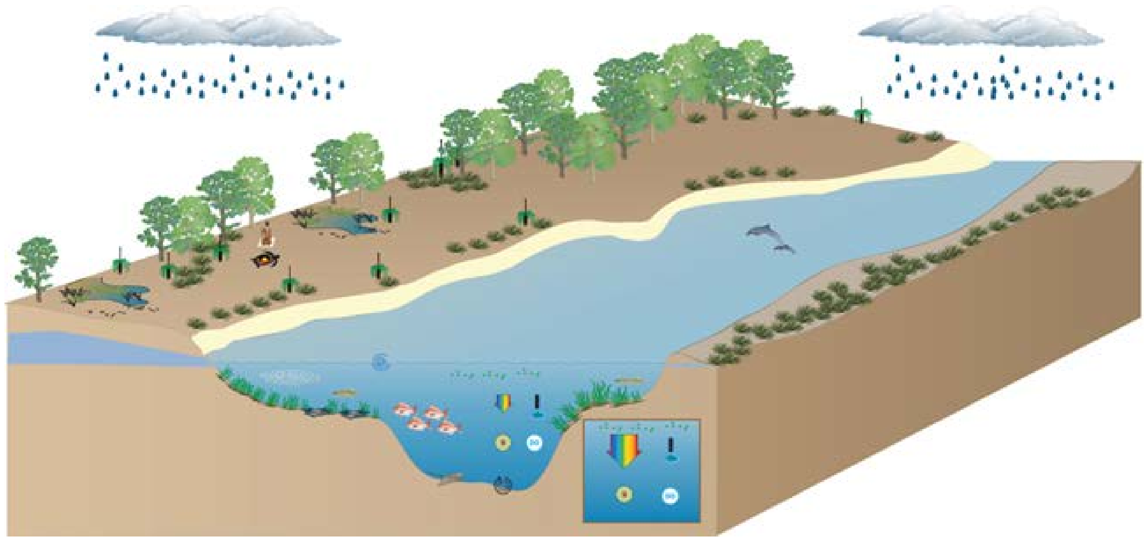
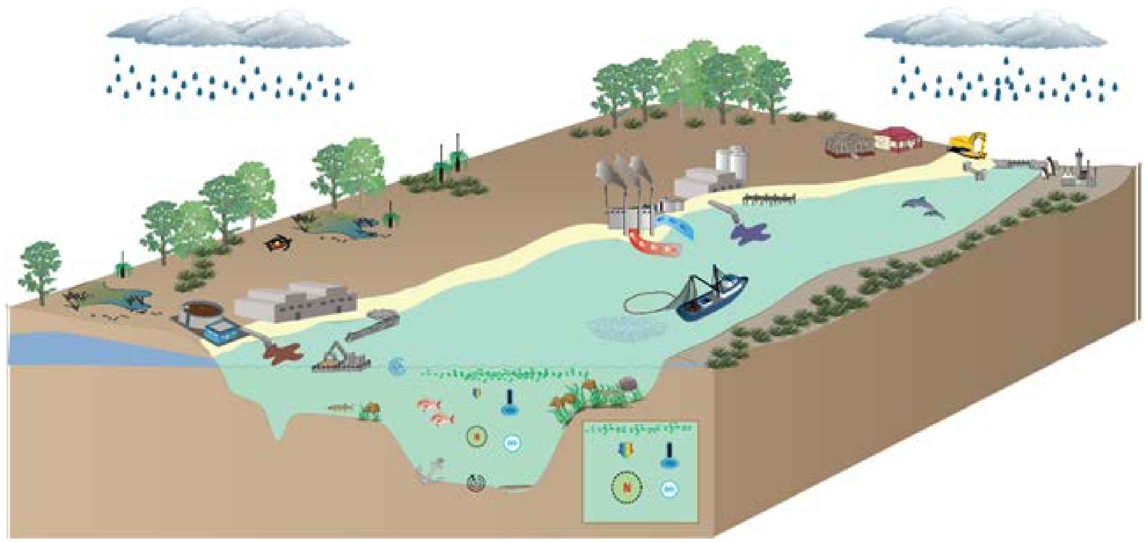


Figure 7.1

Identified and predicted key turning points in the state of Cockburn Sound

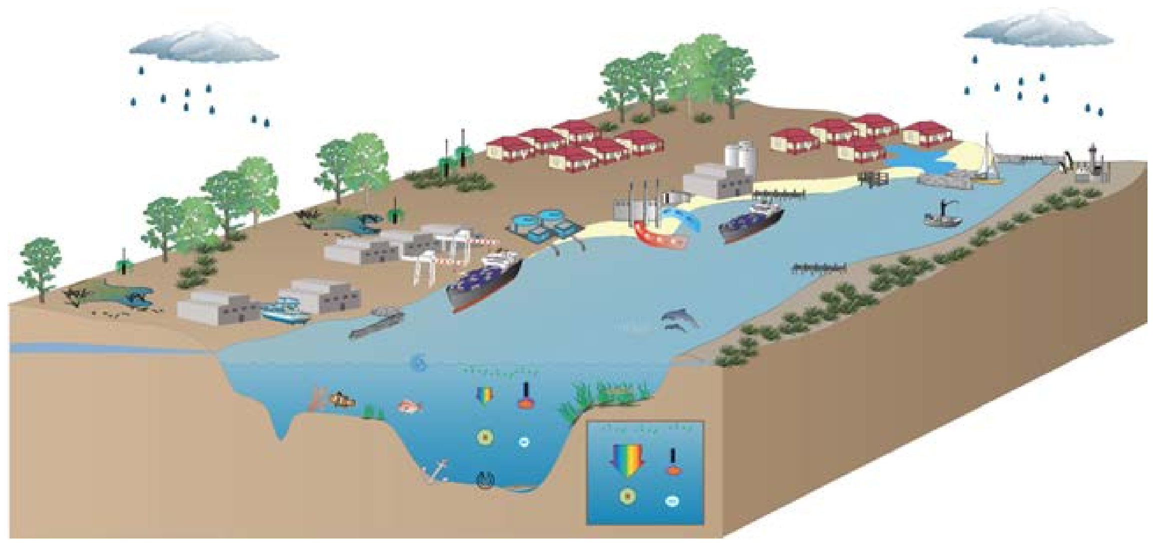


[A] Pre-European settlement - earlier than 1950 - natural



[B] 1950s-1980s - disturbance, poor water quality and severe decline in ecosystem

[C] 1980s-2018 - intense management, improved water quality, limited biotic recovery



[D] Future state?

Note: Refer to Section 7.3 for additional explanatory text.

Table 7.1

Key pressures and environmental cause-effect pathways in Cockburn Sound

Pressures/Stressors

Climate change
Increased sea surface temperatures
Sea level rise
Altered rainfall
Increased number of extreme weather events

Surface and groundwater flows
Contaminated land inputs
Contaminated groundwater flows

Industrial point source discharges
Nitrogen
Other contaminants
Cooling water
Desalination

Atmospheric deposition
Nitrogen inputs

Coastal and seafloor modifications
Coastal structures
Dredging & beachnourishment

Recreational boating
Interactions with fauna and humans
Introduced marine species
Mooring
Biofouling controls

Shipping
Introduced marine species
Biofouling controls
Spillages

Fishing pressures
Commercial
Aquaculture
Recreational

1st Order Effect (and cause)

Modified physico-chemical profile
Water temperature, DO, salinity, pH (climate change, industrial point source discharges)

Eutrophication & water Clarity
Nutrients (run-off, groundwater, atmosphere)
Turbidity (dredging)
Water temp. elevation (climate change)

Toxicity - sediments & water column
Nutrients (run-off, groundwater)

Modified hydrodynamics & wave energy
Circulation patterns
Stratification
Flushing rates

Direct loss of habitat
Seagrass (dredging)
Benthic invertebrates (dredging)

Fauna strikes
Injury/mortality (rec. boating)

Decline in fish stocks
Over fishing

2nd Order Effect (and cause)

Phytoplankton blooms Resulting from
Eutrophication
Elevated Sea surface temperatures

Growth of epiphytes Resulting from
Eutrophication
Elevated Sea surface temperatures

Blooms of toxic algae and dinoflagellates Reulting from
Eutrophication
Elevated Sea surface temperatures

Erosion & accretion Resulting from
Altered water circulation
Increased wave energy

Marine fauna population impacts Resulting from
Fauna strikes
Loss of benthic habitat
Over fishing
Climate change
Oxygen stress

3rd Order Effect (and cause)

Oxygen stress Resulting from
Eutrophication
Increased Increased biological oxygen demand
Elevated Sea surface temperatures

Shading Resulting from
Phytoplankton blooms
Algal epiphyte growth

Smothering of blots Resulting from
Sediment accretion

Shifts in community composition & ecological function Resulting from
IMS
Loss of benthic habitat
Over fishing
Climate change
Oxygen stress

Receptor & reponses

Benthic primary producers Indicators of stress
Reduced extent
Reduced density
Reduced reproductive capability
Reduced resilience

Plankton Indicators of stress
Shift in community composition
Reduced productivity
Lower concentration

Target fish stocks Indicators of stress
Reduced catches (tonnes)
Reduced licences
Reduced fishing effort
Increased environmental stress

Other marine fauna Indicators of stress
Nesting success (penguins)
Mortality rates

Ecological communities Indicators of stress
Reduced biodiversity
Increased presence of opportunistic taxa
Increased IMS

Aesthetics Indicators of stress
Water clarity
Phytoplankton blooms
Spillages
Fish tainting
Fauna mortality

Recreation and human health Indicators of stress
Coastal/beach access
Toxicants in water
Faecal bacteria
Toxic algae
Water clarity

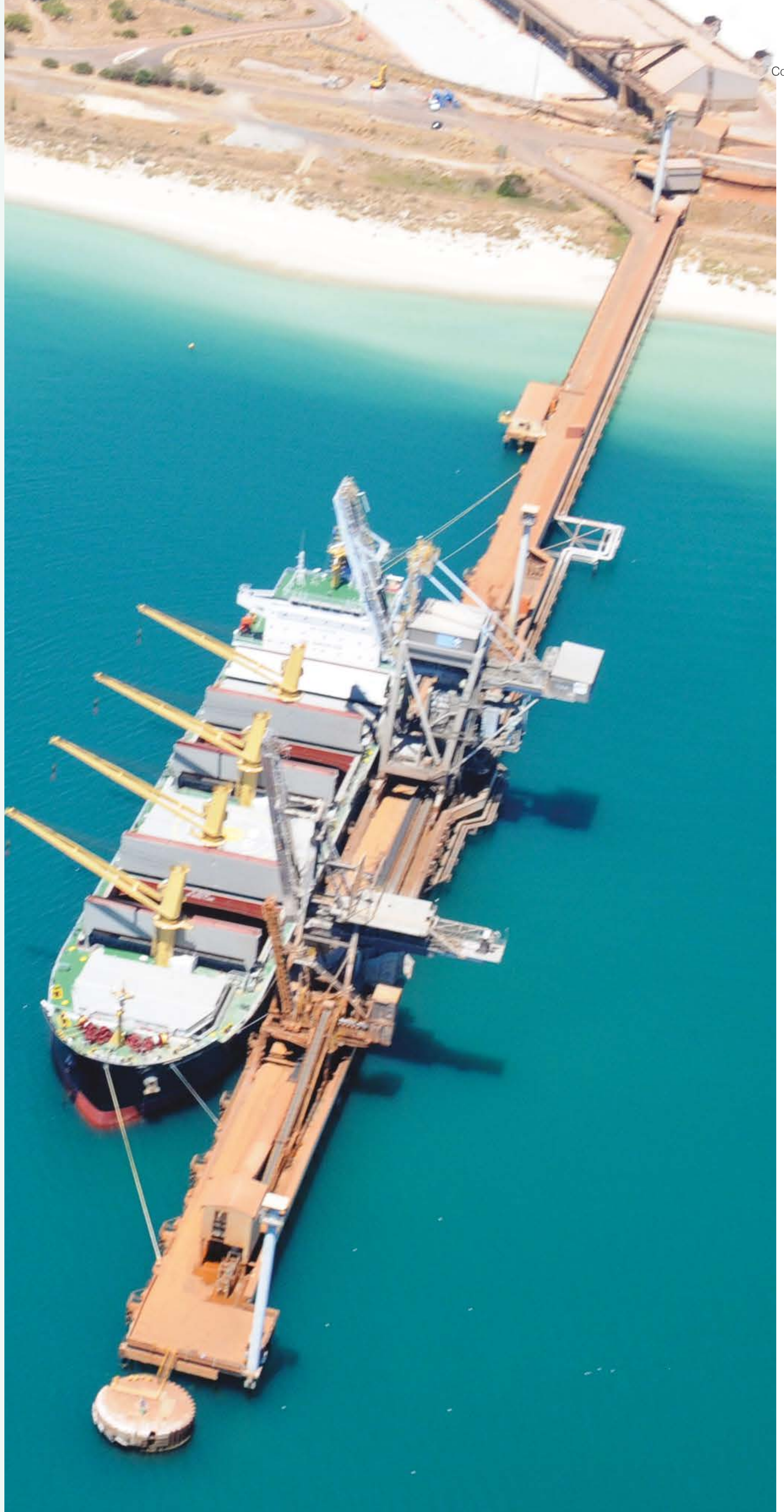
Cultural & Spiritual values Indicators of stress
To be determined
Default - marine environmental quality and ecological indicators

Note: the colour of triangle symbols under each pressure equates to the risk that impacts associated with the pressure may erode one or more environmental values in Cockburn Sound (as defined in Table 4.1)

8. Gaps in monitoring and knowledge

Gaps in monitoring and knowledge that have been identified through this DPSIR assessment and represent a challenge to the effective management of Cockburn Sound are described below.

1. Quantitative data on catchment-scale inputs of nutrients and contaminants to Cockburn Sound, such as the quality and volumes of stormwater and groundwater flows, and atmospheric deposition.
2. Rationalisation of the current list of contaminants of concern to Cockburn Sound's marine environment against likely contemporary contaminant sources and pathways. Particular consideration should be given to emerging potential contaminant risks and derivation of appropriate environmental quality criteria.
3. Quantification of key marine processes, including direct measures of sediment nutrient recycling, pelagic primary productivity and other interlinking biogeochemical processes and encompassing spatial, seasonal and inter-annual variability.
4. The long-term phytoplankton dataset provided by the Western Australian Shellfish Quality Assurance Program sampling adjacent to mussel aquaculture locations, provides an opportunity for further evaluation of temporal dynamics and potential shifts in phytoplankton abundance and composition.
5. Studies of the zooplankton community and pelagic secondary production within Cockburn Sound.
6. Assessment of the broad-scale efficacy of seagrass restoration efforts across Cockburn Sound. Particular effort is required to better understand the local parameters and regional factors influencing seagrass restoration success rates (including the confounding effects of climate change) and whether management targets for seagrass health protection are adequate to support restoration efforts.
7. Data to determine the sustainability of aquaculture production, and the level of commercial and recreational fishing pressure are not publically available. The most recent comprehensive study on recreational fishing is over ten years old. Further study is also required on the biodiversity of fish communities in Cockburn Sound from an ecological, not fisheries, perspective.
8. Assessment of the impact of seawater intakes and outlets on larval and juvenile fish and other biota.



9. Assessment of the potential impacts on marine fauna from the emerging pressure of underwater noise from vessels and other activities in and around the Sound.
10. The *State Environmental (Cockburn Sound) Policy 2015* includes cultural and spiritual values of Cockburn Sound. Environmental quality criteria to measure whether these values are being protected have not been established, and consultation with the Noongar people is warranted to develop and agree on appropriate, specific criteria.
11. Further study is required to better characterise the contemporary visitation and usage of beaches in Cockburn Sound.
12. Further investigations of the resilience of Cockburn Sound's coastal environment and key marine ecological components (e.g. communities of plankton, fish, seagrass and benthic macroinvertebrates), including in response to climate change pressures.
13. Development of integrative models to better understand the interactions within and between ecological and social components of Cockburn Sound's marine environment. Advancements in modelling capabilities mean it is possible to test the effects of complex interactions and determine how changes in some ecosystem components could potentially affect others. In turn, this would help decision makers to more fully understand what are the key ecosystem levers and where future management action should be targeted.

9. Conclusion

This DPSIR assessment describes the current and emerging driving forces and pressures on Cockburn Sound, the Sound's current state of environment (including trends and key impacts) and management responses. The intent is to assist stakeholders to identify, plan for and respond to existing and emerging risks to the Sound's environmental values.

Historically, nutrient discharges, contaminated land and groundwater inputs, coastal modifications and fishing pressures have largely influenced Cockburn Sound's marine environment. The Sound is likely to experience further pressure over the coming decades, particularly arising along its mainland coastline from urbanisation, industrial and infrastructure development, and likely from effects associated with climate change.

In response to these pressures, Cockburn Sound's marine ecosystem has changed considerably over the past half century, and it presently exists in a highly modified state relative to pre-European development. Perhaps the most fundamental shift in terms of ecosystem dynamics, the consequences of which have yet to be fully understood, is the loss of seagrass from the eastern shelf and bulk transfer of primary productivity from seagrass to the water column. There is limited understanding of the ecological resilience of Cockburn Sound's marine environment to these pressures.

Notwithstanding, under the present environmental quality management framework it is clear that the Sound can be managed to protect the defined environmental values, by using the existing regulatory framework informed by a combination of stakeholder engagement, regular monitoring of the status of key indicators and relevant research.

There is no reason to doubt that the Sound's environmental values can continue to be maintained in a healthy state whereby the seagrass extent remains relatively stable, water is safe to swim in and the fish taken from it are safe to eat. However, given the existing pressures and management regime, it is considered that the 'future' Cockburn Sound is unlikely to return to pre-European conditions and will be characterised by a lack of recovery of seagrass, some changes in food-webs and fish stocks, and cultural and spiritual values that do not have explicit criteria for monitoring and management.

It is recommended that the key next steps involve:

1. Gaining a better understanding of the interrelated physical, biological and human-use cause-effect pathways in Cockburn Sound.
2. Directing management focus on aspects of Cockburn Sound's ecosystem that are highly valued by the community. Monitoring and management programs to date have focused on water quality and seagrass habitat, with less attention to changes in fish stocks and other indicators of ecosystem stress. Efforts should be directed at reaching stakeholder consensus on the weighting of important environmental values to be preserved; and the best way to prioritise, monitor and manage these values.
3. Reviewing the flexibility of the existing regulatory framework to consider management effort versus "reward". The concept of managing impacts to be insignificant versus impacts that are "as low as reasonably practicable" is worth consideration. Alternative conceptual tools such as ecosystem engineering or environmental accounting may be highly useful in helping to devise environmental management (or offset) measures that offer the best "bang for buck" in protecting stakeholder values of Cockburn Sound.

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