Cockburn Sound-Drivers-Pressures-State-Impacts-Responses Assessment 2017 Final Report

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July 2018

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Final Report

Prepared for

Department of Water and Environmental Regulation, the Kwinana Industries Council, the City of Rockingham and the City of Kwinana on behalf of the Cockburn Sound Management Council

Prepared by

BMT Western Australia Pty Ltd

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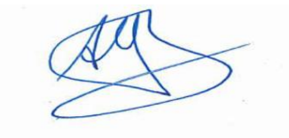

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Executive Summary

Cockburn Sound is one of the most intensively used marine areas in Western Australia and has 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, further development 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–Responses (DPSIR) 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 temperature, 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 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 the 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 (e.g. 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* (Cockburn Sound SEP) and *Environmental Protection Act 1986* (EP Act) 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 stressors induced by climate change 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 risks

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:

- A better understanding of catchment-scale inputs of nutrients and contaminants to Cockburn Sound is required, such as the quality and volumes of stormwater and groundwater flows, and atmospheric deposition.
- Several key marine processes are yet to be fully understood, including direct measures of sediment nutrient recycling, pelagic primary productivity and other interlinking biogeochemical processes (encompassing spatial, seasonal and inter-annual variability and understanding of intermittent occurrence of stratification and oxygen depletion).
- 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 requires further investigation. Further study is also required on the biodiversity of fish communities in Cockburn Sound from an ecological (not a fisheries) perspective.
- Understanding of the impact of industrial seawater intakes on larval and juvenile fish and other biota is required.
- Environmental quality criteria to measure whether cultural and spiritual values are being protected are yet to be specified. Consultation with the Noongar people is warranted to develop and agree on appropriate criteria.
- Study is required to better characterise the contemporary visitation and use of beaches in Cockburn Sound.
- The level of resilience of Cockburn Sound's coastal environment and key marine ecological components is yet to be fully understood (e.g. communities of plankton, fish, seagrass, benthic macroinvertebrates), including responses to climate change.
- Integrative models need to be developed 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 the key ecosystem levers are 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 and 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.

Recommended next steps

- Attain a better understanding of the interrelated physical, biological and human-use cause–effect pathways in Cockburn Sound.
- A direct management focus is required 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.

- There is a need to 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 considering. 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 value for money in protecting stakeholder values of Cockburn Sound.

Acronyms and Measurement Units

Acronyms	
AMC	Australian Marine Complex
ALARP	as low as reasonably practicable
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BOM	Australian Bureau of Meteorology
BP	British Petroleum
Cockburn Sound SEP	*State Environmental (Cockburn Sound) Policy 2015*
CS Act	*Contaminated Sites Act 2003*
CSBP	Cumming Smith British Petroleum
CSCA	Cockburn Sound Coastal Alliance
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSMC	Cockburn Sound Management Council
DMIRS	Department of Mines, Industry Regulation and Safety
DO	dissolved oxygen
DOEE	Department of the Environment and Energy (Commonwealth)
DOH	Department of Health
DOT	Department of Transport
DPI	Department for Planning and Infrastructure (now Department of Planning, Lands and Heritage)
DPIRD	Department of Primary Industries and Regional Development
DPSIR	Drivers–Pressures–State–Impacts–Responses
DWER	Department of Water and Environmental Regulation
EIA	environmental impact assessment
EP Act	*Environmental Protection Act 1986*
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EQC	environmental quality criteria
EQMF	environmental quality management framework
EQG	environmental quality guideline
FRDC	Fisheries Research and Development Corporation
HMAS	Her Majesty's Australian Ship
KBJ	Kwinana Bulk Jetty
KBT	Kwinana Bulk Terminal
KIC	Kwinana Industries Council
KIA	Kwinana Industrial Area
LAC	light attenuation coefficient
MARPOL	*International Convention for the Prevention of Pollution from Ships 1973* (International)
MIS	Ministerial Implementation Statement
MNES	Matters of National Environmental Significance
MPB	microphytobenthos
PFAS	per- and poly-fluoroalkyl substances
SDOOL	Sepia Depression Ocean Outlet Line
SWALSC	South West Aboriginal Land and Sea Council
TBT	tributyltin
TN	total nitrogen

TP	total phosphorous
WA	Western Australian
WAPC	Western Australian Planning Commission
WASQAP	Western Australia Shellfish Quality Assurance Program
WWTP	wastewater treatment plant
Measurement units	
°C	degrees Celsius
GL	gigalitres
GL/yr	gigalitres per year
h	hour
ha	hectares
km	kilometres
km^2	square kilometres
kL/d/m	kilolitres per day per metre
L	litres
m	metres
m^3	cubic metres
m/d	metres per day
m^3/s	cubic metres per second
mg/L	milligrams per litre
mL	millilitres
ML/d	megalitres per day
ML/km^2	megalitres per square kilometre
mm/yr	millimetres per year
%	per cent
pH	potential of hydrogen (acidity or alkalinity)
t	tonnes
t/yr	tonnes per year
t C/yr	tonnes of carbon per year
t N/yr	tonnes of nitrogen per year
t P/yr	tonnes of phosphorous per year
µg/L	micrograms per litre

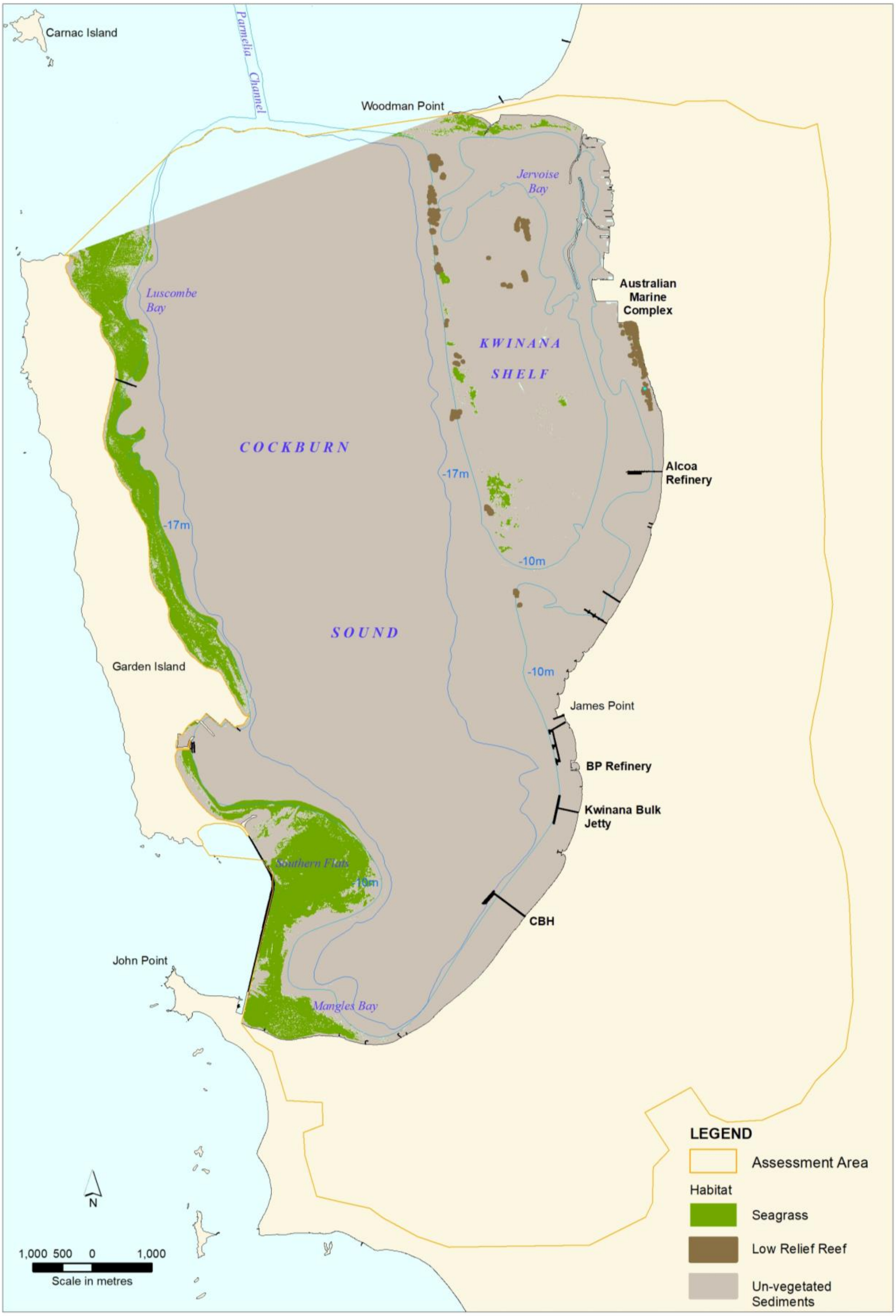
About this Report

This report

This report was commissioned by the Department of Water and Environmental Regulation (DWER; formerly Department of Environment Regulation) and Cockburn Sound Management Council (CSMC). The intent of the report is to provide a comprehensive critical assessment of the current and emerging driving forces and pressures on the Cockburn Sound marine area, the Sound's current condition and trends, impacts and management responses. This report aims are to:

- Identify and evaluate the environmental, social, cultural and economic driving forces and pressures affecting the environmental values of the Cockburn Sound marine area.
- Describe and assess the actual and potential impacts and their effects on the environmental values of the Cockburn Sound marine area.
- Describe and assess the current condition and trend in the environmental values of the Cockburn Sound marine area.
- Evaluate the effectiveness of existing management arrangements to manage impacts to protect and maintain the environmental values of the Cockburn Sound marine area.
- Assess the risks to the environmental values of the Cockburn Sound marine area, based on an evaluation of trends in driving forces and pressures, the effects of identified impacts, current condition and trends, the effectiveness of current management and the resilience of the Cockburn Sound ecosystem.
- Describe the likely long-term outlook for the environmental values of the Cockburn Sound marine area, based on an evaluation of actual and potential impacts, current condition and trends, the effectiveness of management arrangements, the resilience of the Cockburn Sound ecosystem and the overall risk assessment.
- Identify key knowledge gaps and priorities for research, modelling and monitoring to address critical information needs.

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) with a specific focus on the Cockburn Sound marine area (Figure ES.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.



Note:

1. Seagrass data, collected in 2017, was supplied by the University of Western Australia. Low relief reef date was sourced from Oceanica (2009a). Seagrass north of Garden Island has been clipped to enable comparisons with previous years (see Section 4.8).

Figure ES.1 Area covered by the Cockburn Sound SEP

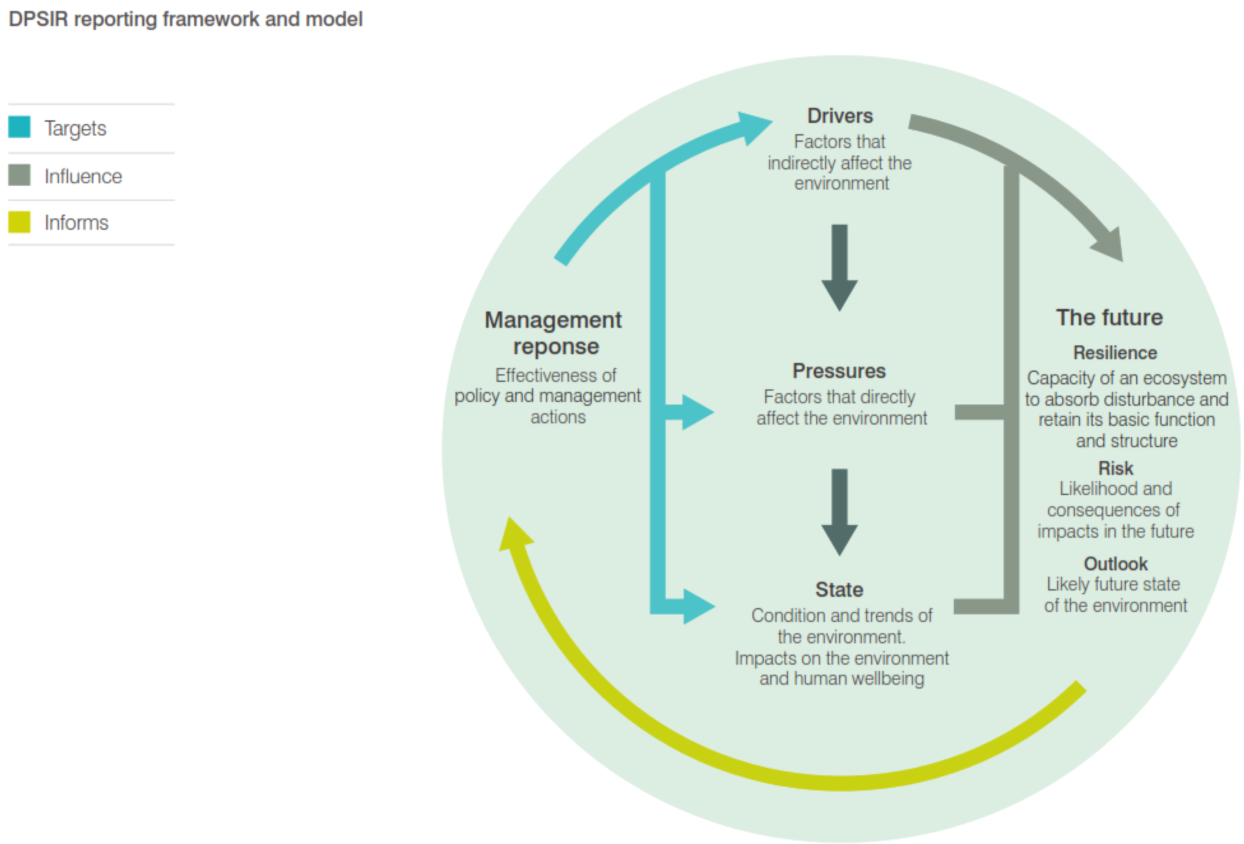
Drivers–Pressures–State–Impacts–Responses reporting framework

A 'state-of-environment' report is intended to communicate credible information about the condition of an environment in a relatively simple format that is easily interpreted by the community and relevant stakeholders. Yet understanding and describing the state of an environment and the complex series of interactions that define a marine ecosystem can be a difficult task. Scientific research and decision-making is often limited to a particular component of the system, economic concern, level of authority or scientific field. Therefore, relevant environmental literature or knowledge tends to be compartmentalised, addressing a single aspect of an issue without providing understanding of linkages or consideration of short- and long-term consequences to the system as a whole (USEPA 2015).

While not a new concept, 'systems thinking' is an approach to problem-solving that assists with state-of-environment reporting by considering different components in the context of their relationships and interactions with one another and with other systems (Von Bertalanffy 1972). Conceptual models, which consist of diagrams and accompanying narratives, can be developed to capture, visualise and organise connections to better understand the links between anthropogenic and environmental stressors, and in turn, ecosystem condition (Yee et al. 2012). This assessment of Cockburn Sound's marine environment has adopted the Drivers–Pressures–State–Impacts–Responses (DPSIR) conceptual framework (Figure ES.2).

The DPSIR 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***: These 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***: These 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***: This 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 wellbeing 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***: These 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.



Source: Modified from Evans et al. (2017)

Figure ES.2 The DPSIR framework and conceptual relationships among DPSIR categories

Identification and assessment of relevant pressures, issues and impacts for this report

This report's structure aligns with the traditional DPSIR model and the assessment is centred around general environmental and social themes, issues and indicators. Fundamentally, this assessment has been informed by:

1. a review of existing relevant environmental management frameworks and contemporary technical literature pertaining to Cockburn Sound's marine environment
2. consultation with stakeholders who have an interest in the marine environment of Cockburn Sound.

The DPSIR reporting process is underpinned by the environmental quality management framework (EQMF) defined by the Cockburn Sound SEP and subsidiary documents (EPA 2017). The Cockburn Sound EQMF sets clear environmental values and environmental quality objectives, which in turn provides direction for setting environmental themes and issues relevant to the Cockburn Sound DPSIR assessment. Further, the environmental quality criteria developed for the Cockburn Sound EQMF (EPA 2017) provide well considered benchmarks and indicators for assessing the key stressor–response pathways potentially impacting on the defined environmental values; providing primary foci of assessment in this DPSIR report.

The Cockburn Sound EQMF is derived from the *National Water Quality Management Strategy* (ANZECC & ARMCANZ 2000) and its scope is centred on the assessment of water quality condition and interactions. While robust, the EQMF does not cover the entirety of environmental and social issues relevant to the state of Cockburn Sound, particularly those that are not tightly coupled to water quality, such as the status of fish stocks or establishment of invasive marine species (which are managed via separate frameworks).

To ensure that relevant driving forces, pressures, potential environmental issues and impacts were considered in this DPSIR assessment, a comprehensive program of technical literature review and stakeholder consultation was undertaken, which involved:

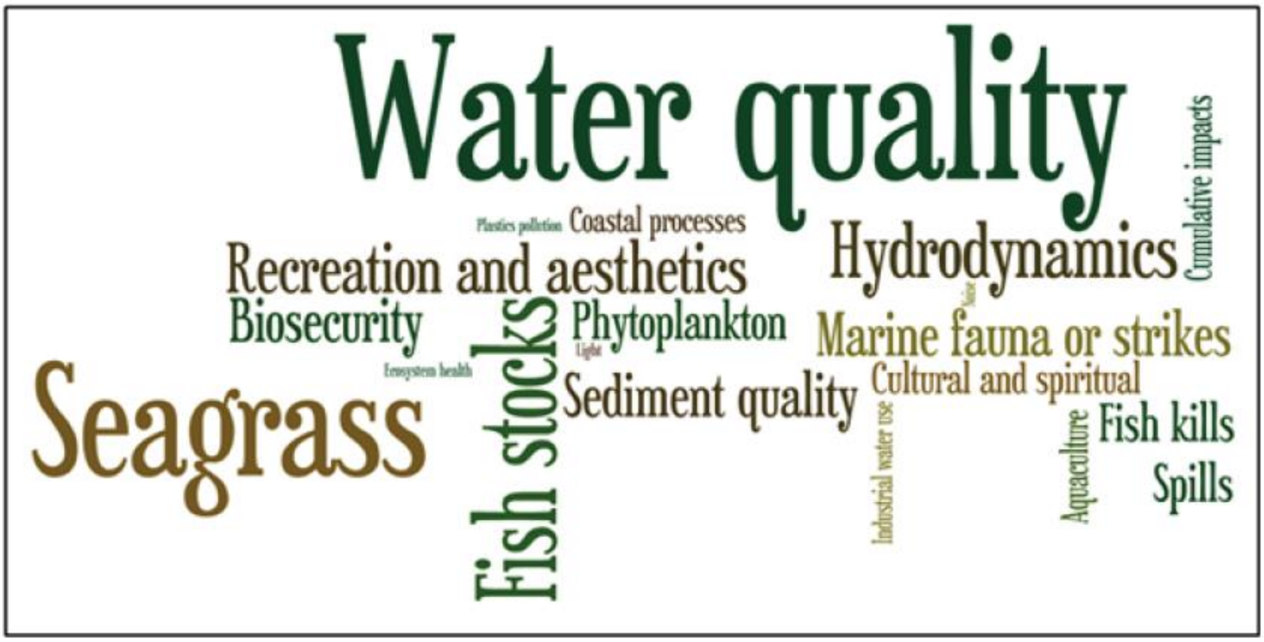
i. scoping via preliminary review of technical literature
ii. internal workshopping of relevant issues and cause–effect pathways with scientific experts
iii. explicitly requesting stakeholder comment and feedback on relevant pressures, issues and data that should be used to inform the DPSIR assessment, via:
    - project presentation and submission of briefing note to a full sitting of the CSMC
    - submission of briefing note to other stakeholder representatives (i.e. stakeholders that are not members of the CSMC)
iv. reviewing and summarising stakeholder comments and feedback for inputting to the DPSIR assessment (further see Appendix A).

Stakeholder comments were categorised into the following themes:

- priority drivers and pressures (Figure ES.3[A])
- priority issues for the state of Cockburn Sound (Figure ES.3[B]).

[A] Drivers and pressures on Cockburn Sound

[B] Issues for the state of Cockburn Sound



Note:

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

Figure ES.3 Themes of priority drivers and pressures [A] and issues for the state of Cockburn Sound [B] raised by stakeholders

Summary assessment of pressures and state

The approach used to summarise DPSIR findings in Sections 3.1 and 4.1 (synopsis of pressures and synopsis of state, respectively) follows the approach used by Evans et al. (2017). Qualitative summary descriptions have been provided of recent trends, assessment grades, confidence in the data/information and comparability of data to 2001 (the previous Cockburn Sound Pressure-State-Response report; DAL 2001), drawing on evidence provided in the main body of the report.

1. Introduction and Background

1.1 Background

1.1.1 Cockburn Sound

Cockburn Sound is one of the most intensively used marine areas in Western Australia (WA). 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 WA community, as well as supporting significant environmental values.

Cockburn Sound has a history of significant nutrient pollution. Nutrient pollution has been identified as the primary cause of the loss of more than three-quarters of the seagrass meadows in the Sound between the early 1960s and early 2000s. In response to actions by industry, government and the community, water quality in the Sound has improved, although concerns remain about the decline and lack of recovery of seagrass.

The diversity and sometimes competing nature of activities in Cockburn Sound keeps it under ongoing environmental pressure. Given Cockburn Sound's important and multiple values and uses, the Government of Western Australia strongly supports the development and management of the Sound in an ecologically sustainable manner.

1.1.2 Cockburn Sound Management Council

Since the 1970s, the Government of Western Australia, in partnership with industry, local government and the community, has worked to improve the environmental health of Cockburn Sound. These partnerships, combined with strong community support and concern for the state of the marine environment, resulted in the formation of the CSMC in 2000.

The CSMC is an advisory council to the Minister for Environment established under Section 25 of the *Environmental Protection Act 1986* (EP Act). Its comprised of members representing government, industry, recreational users, conservation interests and the community. Under the CSMC's Terms of Reference (CSMC 2015), the council is responsible for:

i. providing advice to the Minister for Environment on the environmental management of Cockburn Sound, particularly on the protection and maintenance of water quality and associated environmental values for the Cockburn Sound marine area
ii. reporting to the minister and the community on the state of the environment of the Sound, particularly on the protection and maintenance of water quality and associated environmental values for the Cockburn Sound marine area.

1.1.3 2001 Pressure-State-Response Assessment

The last formal Pressure-State-Response assessment of Cockburn Sound was undertaken in 2001 (DAL 2001). The 2001 Pressure-State-Response report:

- provided an up-to-date assessment of the state of Cockburn Sound, pressures on its natural resources base and management responses
- identified the gaps in management responses and indicated management strategies to address these gaps
- outlined a research and investigation program to improve the information and knowledge base for future decision-making.

At the time (DAL 2001), two pressures were identified as having the greatest impact on Cockburn Sound over time (especially when acting in concert):

- physical alterations to the environment which cause direct or indirect habitat loss, effects on water quality or alterations to coastal processes
- nutrient enrichment (which can also cause habitat loss through algal blooms, shading and deoxygenation).

1.1.4 Western Australian Auditor General's report of 2010

In his report on the environmental management of Cockburn Sound, the Western Australian Auditor General (2010) noted there had been no formal environmental risk assessment of Cockburn Sound since 2001. The Auditor General noted that over the preceding ten years, new environmental pressures on Cockburn Sound had emerged, including increasing urbanisation, recreational boating and fishing, and encroaching contaminated groundwater plumes. The Auditor General recommended that a contemporary environmental risk assessment of Cockburn Sound should be undertaken.

1.1.5 Current situation

There are a number of current and emerging issues which have led to questions about the pressures and impacts on Cockburn Sound and the state of the Sound. Examples include:

- Decreasing nutrient concentrations in Cockburn Sound as a whole are not resulting in improvements in water column algal biomass at some sites, especially in the southern area of the Sound.
- There is a general lag in recovery of seagrass extent and continuing decline of seagrass shoot density despite reported improvements in water quality.
- Climate change and associated effects include the potential for a rise in sea level, coastal inundation and warmer waters.
- There is an environmentally limited status of blue swimmer crab stocks in Cockburn Sound (the fishery is presently closed in Cockburn Sound) despite significant management changes.
- The November–December 2015 fish kill, which affected ~2000 fish and invertebrates representing over 15 species, including more than 250 large spawning pink snapper.
- There have been detections of per- and poly-fluoroalkyl substances (PFAS) in groundwater samples collected at HMAS Stirling (Garden Island).

There is also the potential for future pressures to impact on the state of Cockburn Sound, such as the development of an outer harbour for Fremantle Port, a marina at Rockingham and managed aquifer recharge in the catchment of Cockburn Sound.

Since the time of the initial 2001 Pressure-State-Response report (DAL 2001), a substantive body of monitoring, scientific data and information relating to the Cockburn Sound marine area has been produced. This information has been prepared in response to a variety of interests and needs. While the CSMC have collated much of this information—including details of recent monitoring programs, research and investigative studies—to date, there has been no critical analysis and synthesis of this information.

It is timely to undertake a comprehensive critical 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
- present management responses

This assessment is intended to help identify, plan for and manage existing and emerging risks so that the environmental values of Cockburn Sound are protected and maintained in the future.

1.2 Cockburn Sound's natural marine ecosystem

Cockburn Sound's marine environment is naturally influenced by a complex interaction of physical and ecological processes as illustrated in Figure 1.1. Physical features such as the Sound's protected embayment configuration, coastal sediment processes, marine water movements, groundwater and catchment run-off inputs are responsible for its regional ecological significance. Key ecological features include extensive areas of seagrass species that prefer sheltered conditions, and organic-rich silts on the seabed of the deep basin that support animals that are unique to the central west coast of WA.

Cockburn Sound's coastal waters are influenced by the regional climatic pattern of hot, dry summers and cool, wet winters and the changing flow of the Leeuwin Current, which brings warm, tropical waters down the WA coast from Indonesia. Classified as a temperate extra-tropical region, there is a prevailing influence from diffuse high pressure systems, an occasional influence from mid-latitude low pressure cells or fronts and the rare influence of tropical systems (Gentilli 1971). These synoptic conditions provide a distinct seasonal shift between a strong diurnal land–sea breeze cycle in summer (December–March) and more variable conditions in winter (July–September), but typically swinging from mild north-east winds[1] to intense westerlies associated with storms (Steedman & Craig 1979, Masselink & Pattiaratchi 2001). Storms can occur at any time of year but are most prevalent during winter.

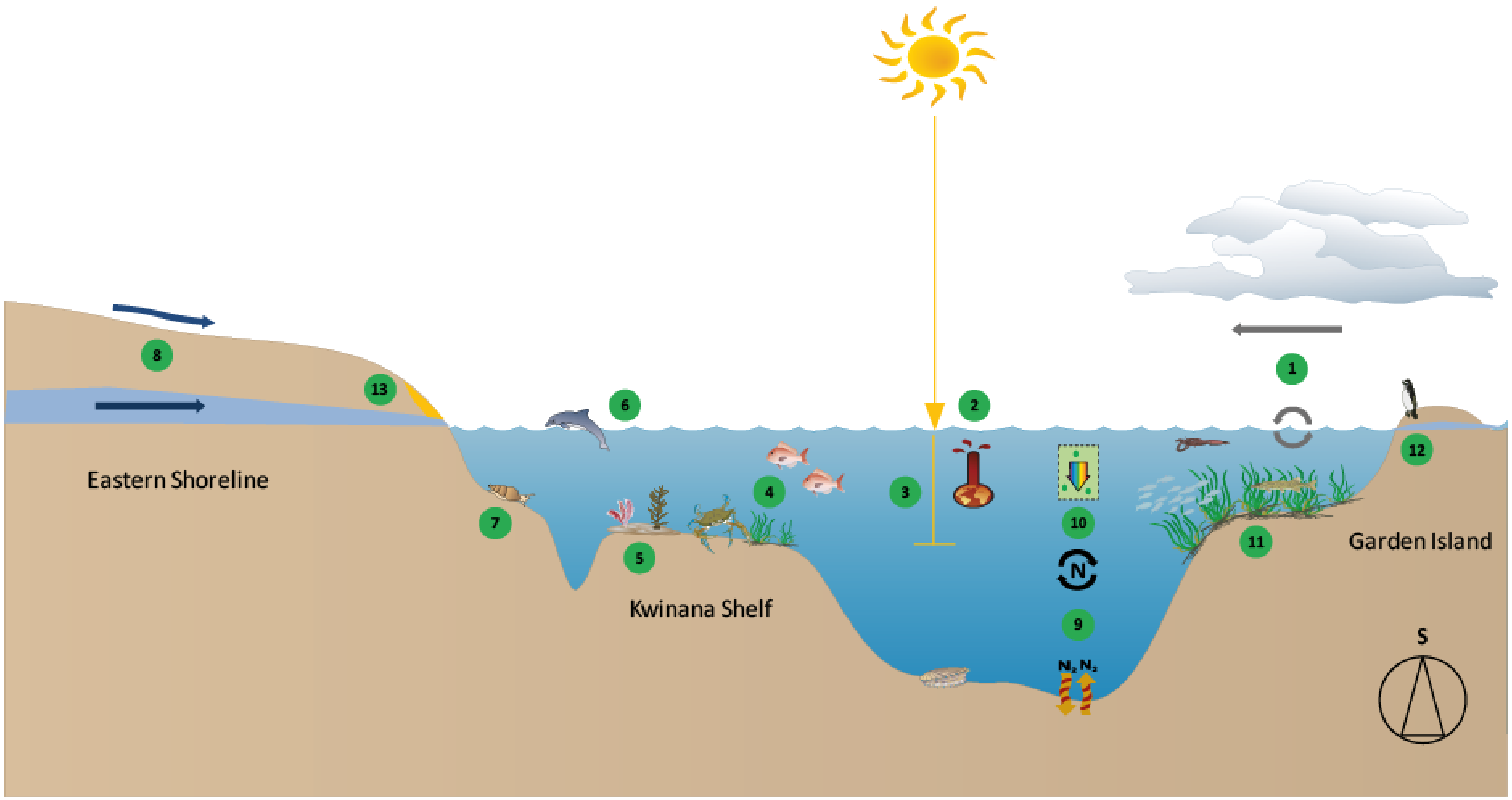
Cockburn Sound is a shallow, elongated, partially-enclosed coastal basin located between two Pleistocene limestone dune ridges; the Garden Island Ridge to the west and the Spearwood Dunes to the east (Skene et al. 2005). The broad central basin has a maximum depth of 22 m which rises steeply to sandbanks to the north and south, the shoreline of Garden Island to the west and the Eastern Shelf to the east. The Eastern Shelf is a relatively flat shoal ~8 m deep that extends from James Point to Woodman Point.

While marine water movements play a pivotal role in shaping Cockburn Sound's ecosystem, groundwater discharges also contribute significantly to the functioning of biotic processes. CSIRO (2006) described the local groundwater body as being predominantly within the Superficial aquifer, typically extending ~40 m below the ground surface. Groundwater flows though the Superficial aquifer from east to west, with flows entering Cockburn Sound along the shoreline and from the floor of the Sound. There are virtually no natural surface drains to the ocean because the coastal sands are permeable enough to prevent significant surface run-off (CSIRO 2006).

Cockburn Sound is within a region of marine ‘biogeographical overlap’ that extends from Cape Leeuwin to North West Cape. Perth’s coastal waters essentially comprise a temperate environment for inhabitant marine flora and fauna, but tropical species are also found due to the influence of the Leeuwin Current which brings water from the north. Endemic species (i.e. species only found in WA) typically make up 10–25% of the species in Perth’s coastal waters, depending on the type of organism (e.g. crustaceans, shellfish, worms) (DAL 2001). The diversity of seagrass species in Perth's coastal waters is high. There are less than 60 species of

[1] *Note that the standard oceanographic and meteorological conventions are used throughout when referring to current and/or wind direction. For wind direction, the direction given indicates the direction from which the wind is blowing. For current direction, the direction given indicates the direction to which the current is flowing.*

seagrass worldwide, 13 of which are found in the local region. The six main meadow-forming seagrass species are *Amphibolis griffithii*, *A. antarctica*, *Posidonia australis*, *P. sinuosa*, *P. angustifolia* and *P. coriacea*. In Cockburn Sound, the most dense stands of seagrass occur in shallow sheltered areas and consist of meadows of *P. sinuosa* or *P. australis*. Cockburn Sound had extensive areas of these species before massive seagrass loss occurred in the late 1960s to early 1970s, although most species remain present in the remaining stands of seagrass. Microphytobenthos (MPB; microscopic algae that resides on the surficial layer of sediments) also plays an important role in the provision of primary production to Cockburn Sound, but remains poorly studied and understood.



Note:

1. Wind is the primary force responsible for mixing and moving the waters within Cockburn Sound.
2. Climate change and heat waves now appear to be 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.
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 sea floor 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. Groundwater flows are the main source of 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 the 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 effects 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.

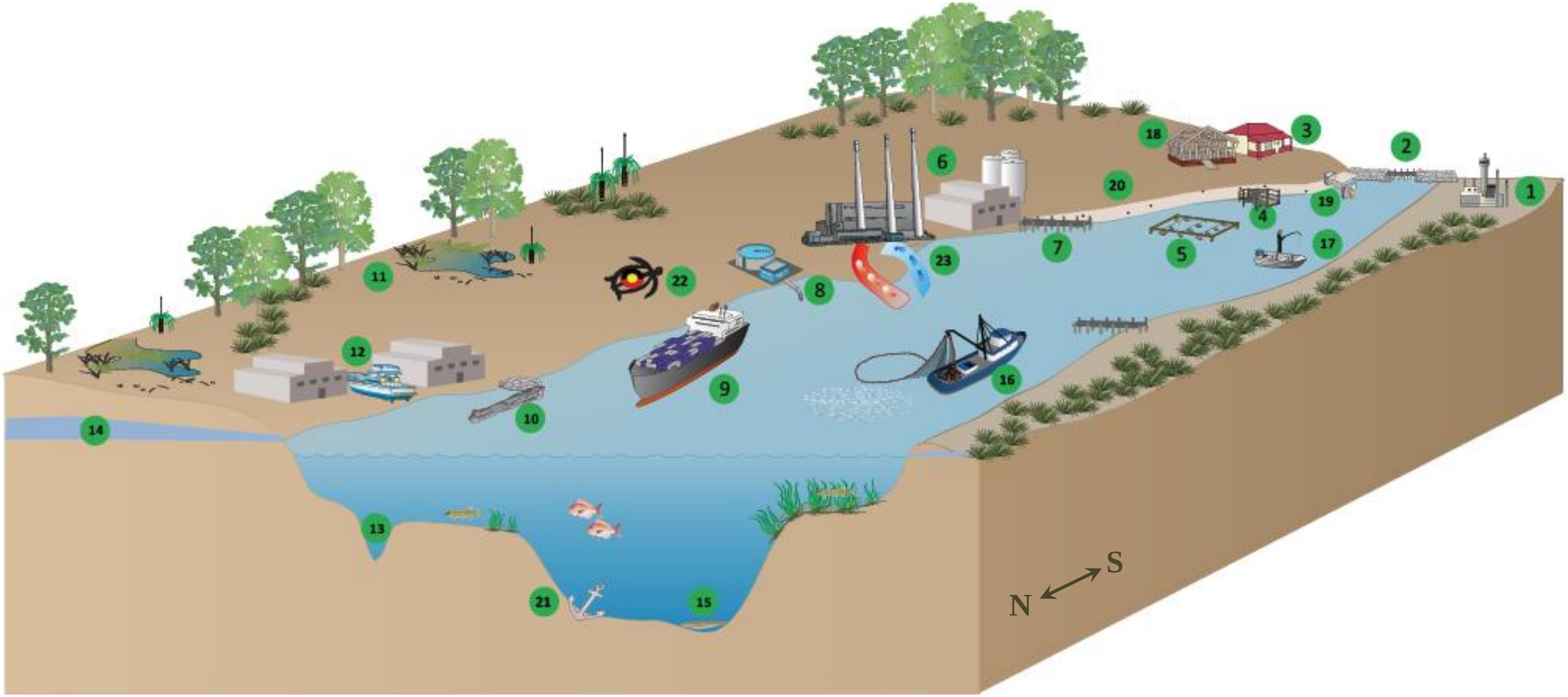
Figure 1.1 Key marine environmental features of Cockburn Sound (image is south-facing)

1.3 History of human use and the environment

Cockburn Sound is a key distinguishing feature of Perth's metropolitan coastal waters and has two attributes that are regionally unique: its degree of shelter from ocean swells and its water depth. These attributes, combined with Cockburn Sound's close proximity to the metropolitan area (~20 km south of Fremantle), make it the most intensively used marine embayment in WA (Botting et al. 2009). The main contemporary human uses of Cockburn Sound are illustrated in Figure 1.2.

Until 1954, Cockburn Sound was used mainly for recreational purposes, commercial fishing and for Commonwealth defence activities (particularly on Garden Island) during both World Wars. 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 wastewater treatment plant (WWTP) 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 were 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 and 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. Currently, Cockburn Sound remains highly valued by the community for recreational and commercial purposes such as swimming, sailing, fishing, aquaculture and tourism (Figure 1.2). 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 WA's premier industrial complexes for the import, processing and export of materials and also provides power and water infrastructure which are key to the functioning of the broader Perth metropolitan area.



Notes:

1. Naval base and port
2. Causeway
3. Existing urban residential development
4. Coastal structures, jetties and groynes to support community recreational activities
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

Figure 1.2 Key human-use features of Cockburn Sound (image is south-facing)

1.4 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)
- 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 among the highest of all coastal embayments in Australia (Meagher & LeProvost 1975). The major nutrient contributions were from Cumming Smith British Petroleum (CSBP) Limited and Woodman Point outfalls. By the late 1970s, the annual load of nitrogen directly discharged into Cockburn Sound was ~1820 tonnes of nitrogen per year (t N/yr).

Between 1967 and 1984, ~2190 hectares (ha) or 77% of the seagrass meadows were lost from Cockburn Sound. The timeline of these historical losses is charted in Table 1.1, 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 ~300 t 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; DAL 2001) 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 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 of carbon per year (t C/yr)—of the total primary production within the Sound (see Section 4.10). 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 1.1 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 activities
1955	Seagrass meadows in an undisturbed state	Oil refinery begins discharging cooling waters and primary treated effluent at James Point
1961–1962	4ha of seagrasses lost on James Point near to oil refinery outfall	
1966	No monitoring undertaken	WWTP begins discharging south-west of Woodman Point
1968	No monitoring undertaken	Blast furnace begins discharging cooling water coloured with black particulates
1969	First signs of seagrass loss which became 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 the causeway	
1976–1977	Localised losses due to dredging and dumping of dredge spoil	Construction and dredging for an access jetty at Sulphur Bay (now an armaments jetty), Garden Island
1981 onward	Large-scale seagrass loss stabilised	

Source: Cambridge and McComb (1984)

1.5 Cockburn Sound's regulatory management framework

1.5.1 *Environmental Protection Act 1986*

The EP Act is WA's primary piece of environmental legislation, providing the basis for:

- establishing advisory panels such as the CSMC (under Part II of the EP Act) (see Section 1.1.2)
- creating environmental policy for whole-of-government adoption (under Part III of the EP Act), including the Cockburn Sound SEP; Government of Western Australia 2015
- environmental impact assessment of proposed projects and land development (under Part IV of the EP Act)
- regulation of pollution and emissions (under Part V of the EP Act).

State Environmental (Cockburn Sound) Policy 2015

An important priority for the state government is to ensure that Cockburn Sound continues to support the multiple values for which it is renowned. The Cockburn Sound SEP was first introduced by government in 2005 (updated in 2015) as a mechanism to ensure that the values and uses of Cockburn Sound are protected and fully considered in decision-making about ongoing and new uses of the Sound. The area covered by the Cockburn Sound SEP is shown in Figure ES.1.

The overall objective of the policy is to ensure that the water quality of the Sound is maintained and, where possible, improved so that there is no further net loss and preferably a net gain in seagrass areas, and that other environmental values and uses are maintained. The management framework established by the policy is based on that recommended by the *National Water Quality Management Strategy* (ANZECC & ARMCANZ 2000), representing an agreed, Australia-wide approach to protecting water quality and associated environmental values.

The Cockburn Sound SEP establishes five environmental values for Cockburn Sound (Table 1.2):
1. ecosystem health
3. fishing and aquaculture
4. recreation and aesthetics
5. cultural and spiritual
6. industrial water supply.

As the basis for protecting these values, the Cockburn Sound SEP also establishes environmental quality objectives (Table 1.2) and environmental quality criteria, and a framework for monitoring and reporting against the objectives and criteria. Environmental quality criteria are further detailed in *Environmental Quality Criteria Reference Document for Cockburn Sound – A supporting document to the State Environmental (Cockburn Sound) Policy 2015* (EPA 2017) and environmental monitoring protocols are defined in the *Manual of Standard Operating Procedures for Environmental Monitoring against the Cockburn Sound Environmental Quality Criteria* (EPA 2005).

Table 1.2 The environmental values and corresponding environmental quality objectives for Cockburn Sound

Environmental value	Environmental quality objectives and their descriptions
Ecosystem health	*Maintenance of ecosystem integrity* Ecosystem integrity is considered in terms of structure (e.g. the biodiversity, biomass and abundance of biota) and function (e.g. food chains and nutrient cycles).
Fishing and aquaculture	*Maintenance of seafood safe for human consumption* Seafood is safe for human consumption when collected or grown. *Maintenance of aquaculture* Water is of a suitable quality for aquaculture purposes.
Recreation and aesthetics	*Maintenance of primary contact recreation values* Primary contact recreation (e.g. swimming) is safe to undertake. *Maintenance of secondary contact recreation values* Secondary contact recreation (e.g. boating) is safe to undertake. *Maintenance of aesthetic values* The aesthetic values are protected.
Cultural and spiritual	*Cultural and spiritual values of the marine environment are protected* Indigenous cultural and spiritual values are not compromised.
Industrial water supply	*Maintenance of water quality for industrial use* Water is of suitable quality for industrial use.

Environmental impact assessment

Project proposals including marine infrastructure and coastal development that may significantly impact upon the environment are required to be referred to the Environmental Protection Authority (EPA; an independent board providing advice to the Minister for Environment), for a decision as to whether the potential environmental impacts require formal assessment under Part IV of the EP Act. The framework for environmental impact assessment (EIA) of project proposals in WA is provided by the EP Act's subsidiary *Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2016*.

EPA (2016a) considers environmental factors to be parts of the environment that may be impacted by an aspect of a project proposal. The EPA (2016a) defines 14 environmental factors each with an objective for its protection, organised into five themes: sea, land, water, air and people. The themes, environmental factors and objectives that are relevant to the marine environment and human use of Cockburn Sound are listed in Table 1.3.

Table 1.3 Environmental factors, themes and objectives relevant to EIA in Cockburn Sound

Theme	Factor	Objective
Sea	Benthic communities and habitats	To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained.
	Coastal processes	To maintain the geophysical processes that shape coastal morphology so that the environmental values of the coast are protected.
	Marine environmental quality	To maintain the quality of water, sediment and biota so that environmental values are protected.
	Marine fauna	To protect marine fauna so that biological diversity and ecological integrity are maintained.
People	Social surroundings	To protect social surroundings from significant harm.
	Human health	To protect human health from significant harm.

Source: EPA (2016a)

If the EPA determines that a referred proposal may significantly impact on one or more environmental factors, the project is required to be formally assessed under the EP Act. The intent of formal assessment by the EPA is to decide whether a project may be implemented in a manner that meets the objectives for relevant environmental factors and is consistent with the environmental principles of the EP Act. Depending on the complexity and severity of potential environmental impacts and/or level of public interest in a proposed project, the EPA's formal assessment may include input from the public, other stakeholders and technical specialists.

Following formal assessment, the EPA publishes a report of findings concluding whether the proposed project may be implemented in an environmentally acceptable manner, consistent with the requirements of the EP Act. Informed by the EPA's report, the Minister for the Environment (WA) then ultimately decides whether the project may be implemented, by way of a Ministerial Implementation Statement (MIS). The MIS typically imposes conditions on a project, such as environmental monitoring and management requirements that must legally be adopted by the proponent, with ongoing compliance against those requirements assessed by the EPA.

Many existing developments within and surrounding Cockburn Sound are subject to MIS conditions and ongoing environmental compliance assessment. Some proposed developments (such as Rockingham Marina) have not yet commenced but have been formally assessed with MIS conditions imposed. Significant development proposals in the future will be subject to this regulatory EIA process.

Regulation of emissions

Certain industrial premises with the potential to cause emissions and discharges to water, land or air are known as ‘prescribed premises’ and trigger regulation under Part V of the EP Act. DWER is responsible for regulating industrial emissions and discharges to the environment through a works approval and licensing process. To control emissions to the environment from prescribed premises, DWER issues and administers works approvals for construction and commissioning activities and environmental licences for ongoing operations.

Works approvals and licences generally define regulatory conditions for the composition and maximum allowable quantity of emissions from industrial operations, such as the salinity and volume of brine discharged to marine waters from desalination plants. Many of the industries adjacent to Cockburn Sound are prescribed premises and subject to environmental licences and ongoing environmental compliance assessment by DWER.

1.5.2 Contaminated Sites Act 2003

The *Contaminated Sites Act 2003* (CS Act) was introduced by the state government to identify, record, manage and clean up contamination of land, sediments and/or groundwater. Under the CS Act, known or suspected contaminated sites must be reported to DWER, investigated, and if necessary, cleaned up and remediated. DWER administers and enforces the CS Act which includes classifying sites (in consultation with the Department of Health) and making information on contaminated sites available to the public. Investigating and cleaning up the soil, sediments and/or groundwater of contaminated sites is, in most cases, the responsibility of the polluter or current site owner. DWER's *Contaminated Sites Database* (2017) is publicly accessible and lists many locations along the coastline and hinterland of Cockburn Sound with contemporary or remediated contamination.

1.5.3 *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Commonwealth Department of the Environment and Energy (DOEE) and provides a legal framework to protect and manage nationally and internationally important fauna, flora, ecological communities and heritage places, defined in the EPBC Act as matters of national environmental significance (MNES). The specific MNESs relevant to Cockburn Sound are:

- nationally threatened species and ecological communities
- migratory species (such as various marine and shore birds, sharks and sea lions).

In addition, the EPBC Act has jurisdiction and procedures for EIA of proposed actions or projects that may have a significant impact on the environment where carried out on Commonwealth land (such as Garden Island) or are carried out by a Commonwealth agency (such as the Department of Defence), even if the significant impact does not relate to an MNES.

Finally, the EPBC Act also provides Australia's key heritage law administered at a national level by DOEE, including the registration, maintenance and protection of sites on the Australian Heritage Database (DOEE 2017). The DOEE also administers the following Commonwealth heritage legislation:

- *Historic Shipwrecks Act 1976*
- *Aboriginal Torres Strait Islander Heritage Protection Act 1984*
- *Australian Heritage Council Act 2003*.

1.5.4 Other relevant legislation

Other legislative instruments relevant to the environmental management of Cockburn Sound are listed in Table 1.4

Table 1.4 Other legislation relevant to environmental management of Cockburn Sound

Legislation	Administrative body	Relevance to Cockburn Sound
Wildlife Conservation Act 1950 and *Biodiversity Conservation Act 2016*	Department of Biodiversity, Conservation and Attractions	The *Wildlife Conservation Act 1950* provides a legal framework to protect and manage native fauna and flora that are threatened, rare or otherwise significant to WA (including many species within Cockburn Sound). The *Biodiversity Conservation Act 2016* will soon modernise and completely repeal the *Wildlife Conservation Act 1950*, having an expanded remit to protect habitats, ecological communities and the biodiversity of WA (in addition to individual species).
Conservation and Land Management Act 1984	Department of Biodiversity, Conservation and Attractions	This act provides for the establishment of marine and terrestrial parks and reserves and implementation of management plans. While there are no marine parks or reserves in Cockburn Sound, the Shoalwater Islands Nature Reserve and Marine Park adjoins the Sound to the south, while Carnac Island Nature Reserve has been established slightly north of the Sound. These areas protect many species of marine fauna that utilise Cockburn Sound.
Fish Resources Management Act 1994 (soon to be replaced by the *Aquatic Resources Management Bill 2015*)	Department of Primary Industries and Regional Development (DPIRD)	This act provides for the sustainable development and management of fisheries (fish, crustacean and shellfish stocks) and aquaculture, including within Cockburn Sound. DPIRD is also WA's lead agency for the management of marine pests and diseases under this act and various other state, Commonwealth and international legislation (see DPIRD's *Aquatic Biosecurity Policy, January 2017*).
Biosecurity Act 2015 (Commonwealth)	Department of Agriculture and Water Resources (Commonwealth)	The introduction of non-native marine pests may generally occur via ballast water exchange or transfer of organisms adhered to vessels or vessel equipment (i.e. 'biofouling'). Vessel ballast water exchange is managed under the *Biosecurity Act 2015* in state waters out to 12 nautical miles. In addition to the general biosecurity risk assessment provisions for vessels specified in this act, relevant guidance documents encouraging voluntary best practice for biofouling management of vessels operating in Australia include: • *National Biofouling Management Guidance for Non-trading Vessels* (Commonwealth of Australia 2009a) • *National Biofouling Management Guidance for Commercial Vessels* (Commonwealth of Australia 2009b).
Port Authorities Act 1999	Fremantle Ports	This act establishes Fremantle Port Authority, the areas it controls and manages, and the way in which it operates including navigation, safety and environmental matters.

Legislation	Administrative body	Relevance to Cockburn Sound
Marine and Harbours Act 1981 *Western Australian Marine Act 1982* *Western Australian Marine (Sea Dumping) Act 1981* *Marine Navigational Aids Act 1973* *Harbours and Jetties Act 1928* *Jetties Act 1926* *Pollution of Waters by Oil and Noxious Substances Act 1987*	Department of Transport (DOT)	These acts regulate recreational and commercial vessel activities including navigation, safety and environmental protection. The purpose of the *Pollution of Waters by Oil and Noxious Substances Act 1987* is to protect the sea and specific waters from degradation by the pollution of oil and other noxious substances. Generally, this act makes the discharge of the following substances into state waters an offence: oil (Sections 8–9), oily residues (Section 10) and noxious substances (Section 20). In Cockburn Sound, DOT manages and administers boat launching facilities in the Woodman Point Regional Park.
International Convention for the Prevention of Pollution from Ships 1973 (MARPOL) (International)	Various	MARPOL includes regulations aimed at preventing accidental pollution and pollution from routine operations. Special areas with strict controls on operational discharges are included in most annexes. MARPOL includes six technical annexes: • Annex I: Regulations for the Prevention of Pollution by Oil • Annex II: Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk • Annex III: Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form • Annex IV: Prevention of Pollution by Sewage from Ships • Annex V: Prevention of Pollution by Garbage from Ships • Annex VI: Prevention of Air Pollution from Ships. All vessels are required to adhere to relevant MARPOL regulations.
Mining Act 1978	Department of Mines, Industry Regulation and Safety (DMIRS)	Under the *Mining Act 1978*, DMIRS requires the management of exploration and mining activities to minimise environmental impacts and to be left as safe, stable, non-polluting and as self-sustaining ecosystems unless there is an agreed end land use. There is currently one exploration licence area within Cockburn Sound (Mr I Briggs 2017, DMIRS, pers. comm., 28 June).
Metropolitan Water Supply, Sewerage, and Drainage Act 1909 *Metropolitan Arterial Drainage Act 1982* *Rights in Water and Irrigation Act 1914* *Waterways Conservation Act 1976* *Water Agencies (Powers) Act 1984* *Water Corporations Act 1995* *Water Services Act 2012*	DWER and Water Corporation	These acts regulate the take and use of water (including groundwater abstraction), protect waterways, manage drainage and protect public drinking water sources and supply in the hinterland of Cockburn Sound. It is proposed that these acts will soon be repealed and consolidated into one modern comprehensive *Water Resources Management Act.*

Legislation	Administrative body	Relevance to Cockburn Sound
Health Act 1911 and *Public Health Act 2016* (and *Food Act 2008,* which adopts the Australia New Zealand Food Standards Code)	Department of Health (DOH) and local governments	These acts provide for DOH's local governments' environmental health powers (and officers), providing guidance, management and enforcement of environmental health issues such as recreational water quality (e.g. polluted waters and toxic algae) and seafood consumption. The *Health Act 1911* will soon be repealed and replaced by by the *Public Health Act 2016*.
Aboriginal Heritage Act 1972	Department of Planning, Lands and Heritage (previously Department of Aboriginal Affairs)	This act provides for the identification, protection and management of Aboriginal sites and artefacts. Disturbance to such sites must be avoided or an application required to be made to the Department of Planning, Lands and Heritage for consent for disturbance of the site under Section 18 of the act.
Native Title Act 1993 (Commonwealth)	National Native Title Tribunal (Commonwealth) and Land, Approvals and Native Title Unit (WA)	This act provides for native title rights to be recognised across Australia. Native title claims have been made across south-west WA, including over the waters of Cockburn Sound and adjacent lands (see section 2.2.2).
Heritage of Western Australia Act 1990 (soon to be replaced by the *Heritage Bill 2016*)	Department of Planning, Lands and Heritage (previously State Heritage Office) and Heritage Council of Western Australia	This act provides for the State Register of Heritage Places, established to ensure that places are recognised for their value and importance to the state, and to promote their conservation into the future. Disturbance to such sites must be avoided and preserved with management advice sought from the Heritage Council of Western Australia.
Planning and Development Act 2005	Department of Planning, Lands and Heritage and Western Australian Planning Commission (WAPC)	The *Planning and Development Act 2005* establishes the WAPC and provides for an efficient and effective land-use planning system which promotes the sustainable use and development of land in WA.
Defence Act 1903; Control of Naval Waters Act 1918; Naval Defence Act 1910 (Commonwealth)	Department of Defence (Commonwealth)	These acts provide for the establishment and operation of naval bases on Commonwealth land including HMAS Stirling on Garden Island, and management of activities on naval bases and in naval waters.

2. Driving Forces acting on Cockburn Sound

2.1 Synopsis

Societal and economic developments within and around Cockburn Sound (introduced in Section 1.3 and Figure 1.2) 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 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.

The population neighbouring Cockburn Sound is ~300 000 people, which has increased by 150 000 in the past 16 years and is expected to increase by a similar amount over the next 20 years, with likely consequential increase in pressure on the adjacent marine environment. 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 sense of coastal identity. The landmark *South West Native Title Settlement* represents the largest native title settlement in Australian history. The Settlement recognises:

> The living cultural, spiritual, familial and social relationship that the Noongar people have with the Noongar lands, and the significant and unique contribution that the Noongar people have made, are making, and will continue to make, to the heritage, cultural identity, community and economy of the state.

Cockburn Sound also has a rich history of maritime heritage that has influenced the identity of people living in and visiting the area. This history is considered important to conserve and protect. In terms of governance, 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 the ability to affect pressures on the Sound, its state-of-environment and management.

The marine, coastal and hinterland areas of Cockburn Sound support various uses and economic sectors. Land uses in the area surrounding Cockburn Sound include 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 the 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.

2.2 Social drivers

2.2.1 Demography

The change in size and composition of the population living and working around Cockburn Sound over time is the consequence of many complex and interrelated socio-economic factors. While this section does not investigate the reasons behind the changing demographics of the area, the resultant population growth is fundamental to the pressures acting on the Cockburn Sound marine environment[2].

In 2001, the combined population of the City of Cockburn, City of Kwinana and City of Rockingham was ~150 000. This has since doubled to around 300 000 in 2017 (IDPE 2017a,b,c). Expected population growth for this region over the next 20 years is in the order of 40-50% (IDPE 2017a,b,c). The introduction of 150 000 people to the area surrounding Cockburn Sound over the past 16 years and a predicted similar amount over the next 20 years instils myriad pressures on the adjacent marine environment (see Section 3). Further, use of the marine and coastal environment of Cockburn Sound is not limited to neighbouring residents, and while it is difficult to quantify non-resident use of the area, a similar order of magnitude of growth of the non-resident population may be expected.

2.2.2 Cultural identity

The cultural attitudes of the people living around and using Cockburn Sound are important drivers affecting its marine environment. Community values of Cockburn Sound are shaped by both indigenous and non-indigenous culture and heritage, and a sense of coastal identity.

Indigenous culture and heritage

The descriptions of indigenous culture and heritage pertinent to the Cockburn Sound area are mainly sourced from South West Aboriginal Land and Sea Council (SWALSC 2017), the state government's Land, Approvals and Native Title Unit (LANTU 2017) and the Commonwealth Government's National Native Title Tribunal (NNTT 2017). Noongar people are the traditional owners of the south-west of WA, with archaeological evidence establishing continuous inhabitation for at least 45 000 years. Noongar people share an ancient culture strongly attached to their landscape and governed by customary laws. Strong spiritual beliefs govern their views of the world, and mythical creatures, stories and obligations are associated with many geographical features of their landscape.

Before European arrival, the Noongar population was estimated to be between 6000 and 10 000 people, divided into 14 language groups. Noongar people living on the coastal plain adjacent to Cockburn Sound sourced their food largely from the sea, the now Swan-Canning river system and the extensive system of freshwater lakes that once lay between the coast and the Darling Scarp.

The number of people in WA with Noongar ancestry is ~30 000, most of whom can trace their lineage back to the early 1800s. The Noongar population continues to have a unique, strong and identifiable culture—indeed it is one of the largest Aboriginal cultural blocs in Australia—and the Noongar people continue to assert their rights and identity. Native title claims have been made across south-west WA, providing a vehicle through which Noongar people may seek formal recognition of their ongoing connection to land and sea.

There are presently four overlapping native title claims over the sea and adjacent land of Cockburn Sound (Figure 2.1):

- Gnaala Karla Booja: registered on the Register of Native Title Claims from September 1998 (National Native Tribunal File Number WC1998/058)
- Whadjuk People: registered on the Register of Native Title Claims from October 2011 (National Native Tribunal File Number WC2011/009)

[2] *Population growth is not itself a social driver, but rather a result of social drivers acting on the human population (USEPA 2015).*

- Swan River People 2: not registered on the Register of Native Title Claims (National Native Tribunal File Number WC2011/002)
- Single Noongar Claim (Area 1): not registered on the Register of Native Title Claims (National Native Tribunal File Number WC2003/006).

In an attempt to resolve these claims, in June 2015, a group of Noongar and Government of Western Australia leaders gathered at Parliament House for the signing of agreements comprising the *South West Native Title Settlement* (the Settlement). The Settlement is the largest native title settlement in Australian history and, if executed, will resolve the Noongar native title claims in the south-west of WA in exchange for a package of benefits. At the heart of the Settlement is an acknowledgment honouring the Noongar people as the traditional owners of the land, recognising:

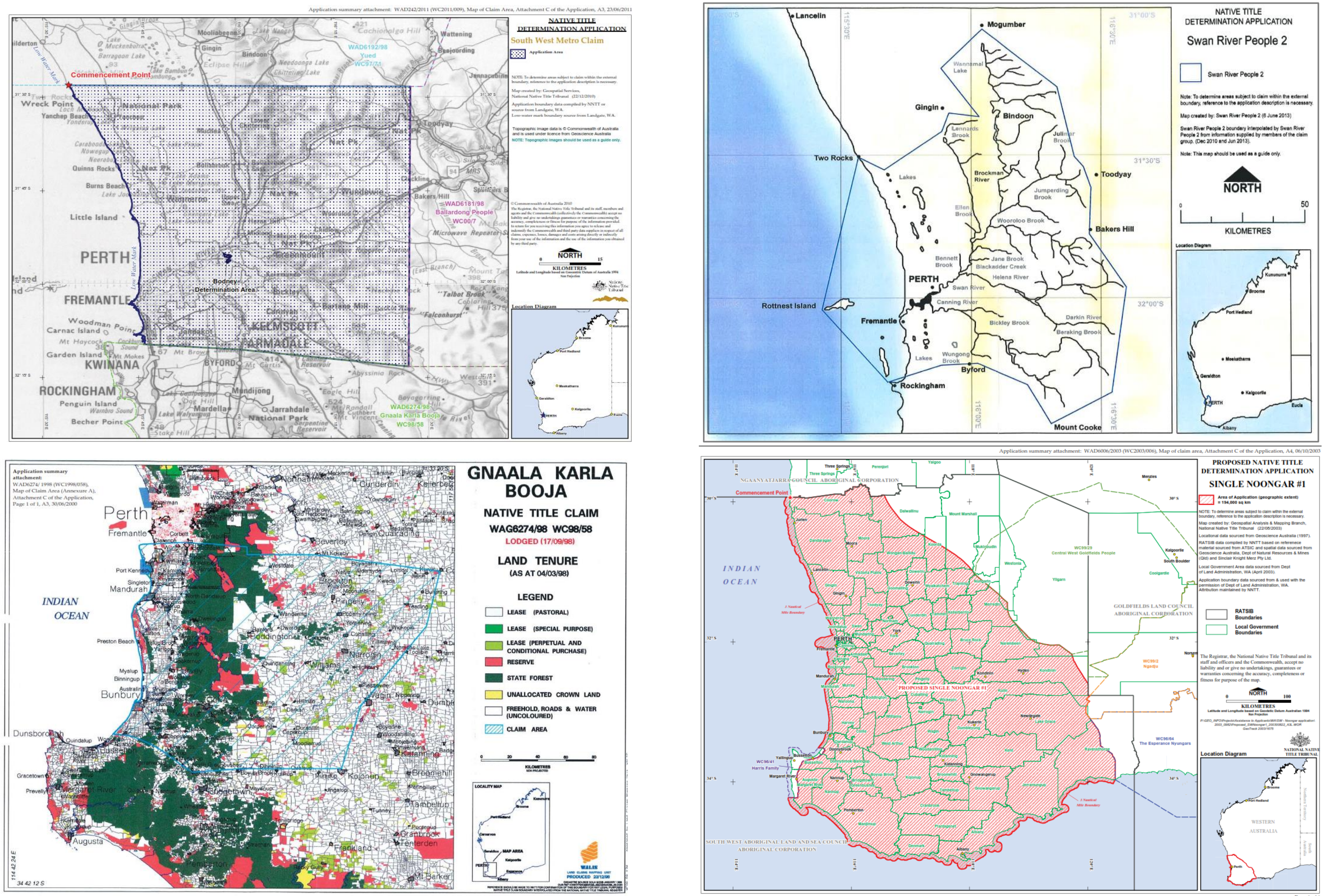
> The living cultural, spiritual, familial and social relationship that the Noongar people have with the Noongar lands, and the significant and unique contribution that the Noongar people have made, are making, and will continue to make, to the heritage, cultural identity, community and economy of the state.

The Settlement is made up of six individual Indigenous Land Use Agreements, including the above-mentioned registered native title areas of Gnaala Karla Booja (which encompasses most of Cockburn Sound and its adjacent land) and the Whadjuk People (incorporating land adjacent to the northern coastline of Cockburn Sound; Figure 2.1). All six agreements have been authorised by the native title holders of each area, meaning the Noongar people have effectively resolved to enter into the Settlement. The commitment to the Settlement represents an act of self-determination by the Noongar people, and binds the Government of Western Australia and the Noongar people to work together towards a new level of partnership and shared responsibility for the future.

The agreements are currently lodged with the Commonwealth Government National Native Title Tribunal to be entered onto the Register of Indigenous Land Use Agreements. The Native Title Registrar must now make a decision on whether or not to register the six agreements, after first considering any objections from Noongar people.

While SWALSC is optimistic that a decision on whether or not to register the agreements will be made in the near term (months to years), until that time, the Commonwealth *Native Title Act 1993* still applies to all land-use planning activities in the Cockburn Sound area. Furthermore, and regardless of the commencement of the Settlement, the WA *Aboriginal Heritage Act 1972* will continue to apply at all times—if a proposed activity or planned land use may affect Aboriginal heritage, the Department of Planning, Lands and Heritage must be contacted for approval.

The current state of the cultural, spiritual and heritage values of Cockburn Sound is discussed in Section 4.12.1.



Source: Commonwealth Government National Native Title Tribunal 2017

Figure 2.1 Native title claims over the sea and adjacent land of Cockburn Sound

Non-indigenous culture and heritage

The natural harbour and safe anchorage provided by Cockburn Sound and its close proximity to the Swan River were key features in determining the location of European settlement in the Perth region (Botting et al. 2009). Cockburn Sound was named in 1827 by the first Governor of WA, Captain James Stirling (Botting et al. 2009). Since European settlement, the Sound has provided an increasingly important harbour, anchorage and land access point that continues to be critical to the strategic development of the metropolitan area and more broadly, WA. Accordingly, Cockburn Sound has a rich history of maritime heritage that has influenced the identity of people living in and visiting the area. This is considered important to conserve and protect.

The way that the local and visiting population feel about Cockburn Sound and its hinterland (their 'sense of place') is a very important driver of local community action and governance in and around the Sound (see Section 2.2.3). Most people residing in the Sound's fringing areas of the City of Cockburn, City of Kwinana, City of Rockingham and Garden Island, or that frequent the area, are drawn to the region's:

- employment opportunities in various industries and defence (see Sections 2.3.1 and 2.3.2)
- coastal lifestyle and enjoyment of recreational activities (see Section 2.3.3).

These cultural values of the regional population are deterministic of the type and extent of pressures on Cockburn Sound, for example whether particular areas should be reserved for recreational amenity, conservation, industry, housing or marinas.

The current state of non-indigenous cultural and heritage values of Cockburn Sound is discussed in Section 4.12.2.

2.2.3 Governance

The democratic right of an individual in Australia to elect members representing local, state and federal governments is an important driving force on marine and land-use planning in and around Cockburn Sound, with the ability to affect pressures on the Sound, its state-of-environment and management. Government policies can influence the marine environment of Cockburn Sound either directly such as the implementation of the Cockburn Sound SEP (see Section 1.5.1) or an election platform for a particular marine development (such as an outer harbour); or indirectly, such as through zonation of land-use planning in its hinterland. Ultimately, in a democracy, a majority of votes can decide outcomes affecting Cockburn Sound (however, electoral results and decisions of government may not always please all parties).

2.3 Economic sectors

2.3.1 Use of Cockburn Sound's hinterland

The land surrounding Cockburn Sound is used to support various economic sectors including heavy industry, urban, agriculture, defence and conservation. Land-use zoning in the Sound's hinterland is presented in Figure 2.2.

Heavy industry

To the east of Cockburn Sound, the largest fraction of coastal land use is occupied by heavy industry, comprised of the Kwinana Industrial Area (KIA) adjoined to the Rockingham Industry Zone[3] along the central and southern coasts of the Sound, separated from the Australian Marine

[3] *The combined Kwinana Industrial Area and Rockingham Industry Zone are hereafter referred to solely as KIA.*

Complex (AMC) and its satellite industries in the north (see purple shading in Figure 2.2). Commencing with British Petroleum's (BP's) oil refinery, the state government has supported development of the KIA since the 1950s, strategically established as an industrial base for the state's economy (KIC 2017). The KIA is now WA's primary area of industrial development and supports a highly diverse range of industries including:

- very large heavy process industries such as alumina, nickel and oil refineries
- smaller service industries such as fabrication and construction facilities
- multiple power plants
- a large-scale wastewater treatment and recycling plant
- the Perth Seawater Desalination Plant.

Of note, the KIA (and broader industrial area) has been globally recognised for its pollutant emission reduction initiatives (since the 1970s) and its unique level of evolved connectivity between industries, many of which use the end- or by-products of adjacent operations for source materials (ENVIRON 2005, SKM & REU 2014).

The AMC is a world-class centre for excellence in manufacturing, fabrication, assembly, maintenance and technology. It services the marine, defence, oil and gas, and resource industries (AMC 2017). The AMC has been developed to enhance the opportunities created by the clustering of industries and is home to the largest marine industry in Australia (AMC 2017).

The Latitude 32 industrial area is presently being developed and zoned to the east of the AMC and the northern section of the KIA (see white shading in Figure 2.2). While land-use zoning has not yet been finalised in this area, which will include some mixed use, the principal zoning will be for light to heavy industry.

Urbanisation

As described in Section 2.2.1, the hinterland of Cockburn Sound has been populated by an additional 150 000 residents since 2001, with the population expected to increase by a similar amount over the next 20 years. Areas zoned for residential and urban use are shown in Figure 2.2 (peach and light blue shading), within the:

- Rockingham urban and city area to the south of the Sound
- Medina, Calista, Orelia, Parmelia area to the east of the KIA
- Coogee, Beeliar, Yangebup, Success and Hammond Park to the north-east of the Sound.

It is anticipated that housing density will increase concurrent with the expected population growth in these areas.

Agriculture

Agricultural land use has generally ceded to industrial and urban development over the past 70 years (most recently including to the development of Latitude 32 in the Hope Valley Area, see above). Pockets of rural land remain in areas of Wattleup, Mandogalup and Hope Valley (see the light green shading in Figure 2.2). It is expected that rural areas will be most at risk of rezoning in the future as the trends of urbanisation and industrialisation continue.

Defence

The entirety of Garden Island is Commonwealth land reserved for defence (Figure 2.2). The Naval Base HMAS Stirling is principally located on the south-east coast of Garden Island around Careening Bay. Most of the land on Garden Island remains undeveloped and is registered as an important Bush Forever site (see Parks and Conservation section).

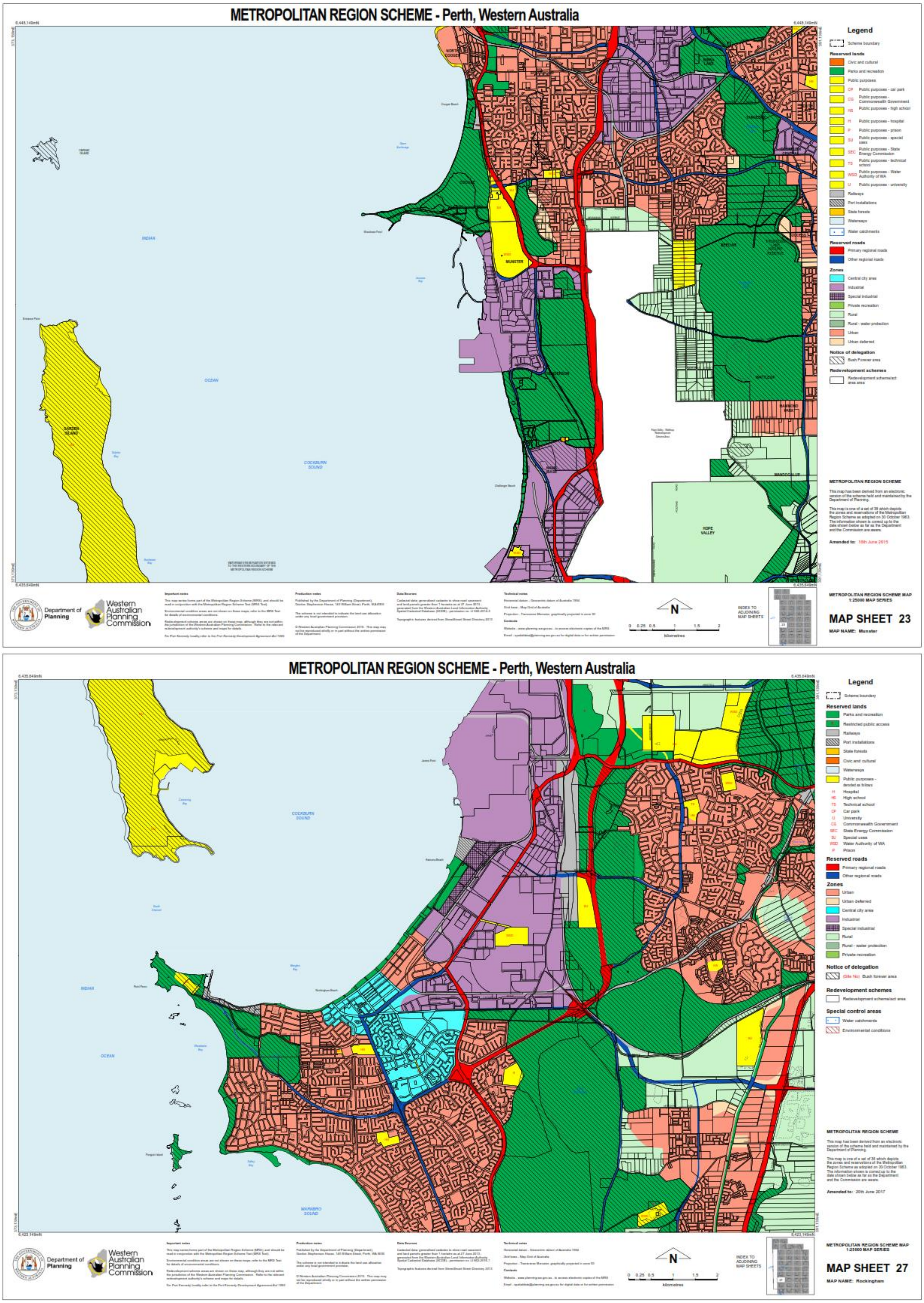
Parks and conservation

Bush Forever zoning is part of the state government's strategic plan for the conservation of bushland on the Swan Coastal Plain, a global biodiversity hotspot. The aim of the Bush Forever zoning is to provide a policy and implementation framework to ensure bushland protection and management issues in the Perth metropolitan region are appropriately addressed and integrated with broader land-use planning and decision-making.

Large areas of land surrounding Cockburn Sound have been reserved as Bush Forever sites (see crosshatching in Figure 2.2), including:

- Woodman Point Regional Park
- Beeliar Regional Park
- Rockingham Lakes Regional Park
- Point Peron area
- Garden Island.

The long coastal strip of the Rockingham foreshore reserve on the south-eastern shoreline of Cockburn Sound is zoned for parks and recreation, but it is not a Bush Forever site (see dark green shading (no crosshatching) in Figure 2.2).



Source: Department of Planning, Lands and Heritage and WAPC (2017)

Figure 2.2 Land-use zoning in Cockburn Sound's hinterland

2.3.2 Use of water

The use of water for purposes of drinking, irrigation, industrial processes and sewage management are driving forces that create pressures potentially affecting the state of Cockburn Sound's marine environment.

Water for drinking, irrigation and industry

Coincident with the drying climate of south-western WA (see Section 3.8), the Perth metropolitan area has become less reliant on dam water and new sources of water for domestic and industrial uses have been developed including desalination, wastewater recycling and groundwater replenishment.

The Perth Seawater Desalination Plant began supplying potable water to the Perth metropolitan water scheme in late 2006 and now contributes ~18% of water supply (Water Corporation 2016). The plant extracts saline marine water from Cockburn Sound, has a capacity to produce 45 gigalitresof water per year (GL/yr) and is approved to discharge 180 megalitres per day (ML/d) of desalination reject brine to the Sound via an ocean outlet diffuser (EPA 2009). The desalination plant and its water intake and outlet pipes are located on the central eastern coastline of Cockburn Sound (between Alcoa's Kwinana Refinery and Fremantle Port's Kwinana Bulk Terminal). Potential pressures imposed on Cockburn Sound by the plant are discussed in Section 3.2.4.

Many industrial processes require large amounts of water and while the Perth metropolitan scheme provides 15–20% of these requirements, the majority is sourced from groundwater and recycled wastewater. Groundwater supplies ~46% of metropolitan Perth's water requirements but is reliant on rainwater recharge which has been decreasing as the climate dries (Section 3.8; Water Corporation 2016). To supplement natural recharge, the concept of managed aquifer recharge is presently being considered to replenish the Superficial aquifer in Cockburn Sound's hinterland using treated wastewater from the Woodman Point WWTP. Potential pressures on Cockburn Sound associated with extraction and recharge of groundwater are considered in Section 3.3.

Wastewater management

Woodman Point WWTP was commissioned in 1966 and primary treated effluent was discharged directly to Cockburn Sound for nearly 20 years. In 1984, a 23 km pipeline was built to divert the discharge to Cape Peron, away from Cockburn Sound. The marine component of this pipeline, referred to as the Sepia Depression Ocean Outlet Line (SDOOL), is 4.3 km long and discharges into the Sepia Depression, a 20 m deep depression behind Garden Island. An emergency outfall pipe from the Woodman Point WWTP still remains in Cockburn Sound, but discharge very rarely occurs.

Establishment of the Kwinana Water Recycling Plant in 2004 has also been a major development in terms of wastewater management affecting Cockburn Sound. The plant was built to accept, process and re-use wastewater from Woodman Point WWTP for supply to industry (up to 6 GL/yr). As part of the project, industrial wastewater is diverted to the SDOOL, which has been instrumental in further reducing industrial discharges to Cockburn Sound (see Section 3.2).

2.3.3 Use of marine and coastal environment

The use of the marine body of water and shoreline comprising Cockburn Sound itself supports various economic sectors including marine and coastal infrastructure, fishing, aquaculture and recreation.

Marine and coastal infrastructure

Marine and coastal infrastructure in Cockburn Sound is important for the functioning of WA's trade and economy. The Sound supports Fremantle Ports' outer harbour facilities in the KIA, the AMC and various jetties and harbours supporting industrial and recreational activity. While the central basin of Cockburn Sound is naturally deep, many shipping channels have been dredged and maintained in shallower areas to facilitate safe access to the Sound and its nearshore facilities. The potential pressures on Cockburn Sound associated with coastal and sea floor modifications are further described in Section 3.5.

Fishing and aquaculture

Cockburn Sound supports significant commercial and recreational fisheries, as well as commercial aquaculture production of mussels. These activities are described in Section 3.7, while the current ecological state of fish communities in Cockburn Sound is detailed in Section 4.9.2.

Recreation and tourism

Recreational uses of Cockburn Sound's coastline and marine environment that are highly valued by both residents and visitors/tourists to the area include:

- recreational boating (power boats and sailing)
- recreational fishing
- swimming and beach-going
- kitesurfing and windsurfing
- scuba diving and snorkelling
- guided tours including fishing and wildlife watching.

Loss of foreshore areas and coastal access for recreational use due to development of the KIA and AMC has meant that the remaining recreational beaches (see Figure 3.1) are both highly valued and subject to increased pressures from visitation. Pressures on Cockburn Sound associated with recreational boating and fishing are described in Sections 3.6.1 and 3.7.2, and the current state of the recreational and aesthetic values of Cockburn Sound are presented in Section 4.11.

3. Pressures on the Marine Environment

3.1 Synopsis of key pressures acting on 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 threats to Cockburn Sound that have already influenced the marine environment, or have the potential to reshape it in the future, is provided in Table 3.1. The table includes an assessment of trends, impact grades, confidence in the presently available data, comparability of presently available data to 2001 data, and the risk of these pressures to Cockburn Sound's environmental values.

Explanatory notes:

- 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 the trends in pressures.
- 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.
- The risk to Cockburn Sound's environmental values (Table 1.2) 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 3.1 does not infer relative importance.

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 presently insufficient to enable conclusions to be drawn about effects on the environmental quality of Cockburn Sound. To avoid excessive speculation, emerging issues have not been investigated in this report. Notwithstanding, these issues (listed below), should not be dismissed and may likely require dedicated evaluation and potential monitoring in the future:

- 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

- substances derived from firefighting chemical inputs (such as PFAS) contaminating land and groundwater with discharge to the Sound.

Assessment key for Table 3.1

Trend	Impact grade	Confidence in assessment	Comparability of data to 2001	Risk
Improving	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 a high level of consensus	Comparable: Grade and trend are comparable to the previous assessment	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	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 a high level of consensus	Somewhat comparable: Grade and trend are somewhat comparable to the previous assessment	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	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	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	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	Not previously assessed: Grade and trend not previously assessed	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.
	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		

Source: Assessment key derived from Evans et al. (2017)

Table 3.1 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	Point source nutrient and contaminant loads to the Sound are now estimated to be immaterial. The contribution of residual nitrogen bound in sediments to the Sound's nutrient budget remains uncertain.	↗	🟨	◕	◆	▲ (green)
	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.	⊟	🟨	◒	◇	▲ (green)
	Cooling water discharges	Seawater used for cooling is expected to result in a minimal change to the environment after discharge and mixing.	⊟	🟨	◒	◇	▲ (green)
	Desalination discharges	Continuous real-time monitoring conducted since commencement of the Perth Seawater Desalination Plant operation has demonstrated that brine discharge and stratification does not generate low dissolved oxygen (DO) in the deep basin of Cockburn Sound or exacerbate naturally occurring, low-DO events.	⊟	🟨	◕	◇	▲ (green)
Contaminated land and groundwater inputs	Contaminated land inputs	The primary pathways for contaminants from terrestrial sources entering Cockburn Sound are in surface run-off via drains and contamination of groundwater from land-use practices in the catchment. There is no systematic monitoring of surface quality or flows discharging to the Sound, which makes determining contaminant loads difficult.	?	🟨	◒	◇	▲ (yellow)
	Groundwater inputs	Large groundwater flows to Cockburn Sound have the potential to serve as a conduit for contamination. However, 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.	?	🟧	◒	◆	▲ (yellow)
Coastal and sea floor modification	Coastal structures	The large number of coastal structures within Cockburn Sound has resulted in a highly modified coastline. 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.	↙	🟥	●	◆	▲ (orange)
	Dredging and nourishment	Ongoing future dredging works are expected from 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, have potential for broadscale impacts if not well managed.	⊟	🟥	●	⬘	▲ (orange)
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 multiple-user conflicts, vessel strikes on marine fauna and craft mooring.	↙	🟨	◕	◇	▲ (orange)
	Introduced marine species and pests	While four pest species are known to occur in Cockburn Sound, their populations are considered stable and are not disturbing native populations of flora and fauna.	⊟	🟨	◕	⬘	▲ (yellow)
	Biofouling controls	While there is evidence of some localised sediment contamination by tributyltin (TBT; the active constituent in legacy antifoulant paints) in the vicinity of jetties and wharves, sediment quality is generally considered acceptable.	⊟	🟨	◒	⬘	▲ (green)
	Shipping activities	The level of commercial shipping activity in Cockburn Sound is fairly stable, although the size of vessels is increasing. The environmental effects associated with vessel activities are presently well managed.	⊟	🟨	●	◆	▲ (green)

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	Although for many species harvested in Cockburn Sound are presently considered 'sustainable–adequate', commercial catches of several indicator species pose a high ecological risk, and nearly all commercial fishing catches and aquaculture activities have declined in recent years.	↙	■	◒	◆	▲
	Recreational fishing	Recreational fishing comprises a significant proportion of the total catch from the Sound for many popular fish species and is likely to increase in line with the increase in the use of recreational vessels.	↙	■	◒	◆	▲
Climate change	Water temperature	Trends suggest that by 2060, water temperature will be ~1.3 degrees Celcius (°C) warmer in Cockburn Sound than present. Increases in water temperature, including warm pulses of water associated with heatwaves, have been linked to possible declines in seagrass and other biota.	↙	■	●	◆	▲
	Sea level rise	Off south-western WA, average sea level has been rising ~5 millimetres per year (mm/yr) 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 WA, which has further reduced since the early 2000s. The largest terrestrial nitrogen load into the Sound is 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. The 2011 heatwave in particular has been well documented.	↙	■	●	◆	▲

3.2 Industrial point source discharges

There are a range of industrial discharges into Cockburn Sound. Nitrogen inputs from point source industrial discharges have been steadily reduced by improved management and diversion to the ocean via the SDOOL, such that point source nutrient (Table 3.2) and contaminant loads from industry are now estimated to be immaterial. Cooling water, used for industrial processes, is discharged into Cockburn Sound from three separate sources. Cooling water discharges are presently managed by licence limits for temperature and chlorine concentration (used as a biocide to prevent fouling). Finally, the Perth Seawater Desalination Plant began discharging brine to the eastern margin of Cockburn Sound in late 2006.

Table 3.2 Sources and trends in nitrogen inputs to Cockburn Sound

Source	Nitrogen (tonnes/year)			
	1978	1990	2000	2015
Atmosphere	20	22	21	21
Point source discharge	1800	605	57	0
Groundwater[1]	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+**

Sources: DAL (2001), McFarlane (2015)

Note:

1. Ranges in estimates are provided where there have been differences in calculation methods

3.2.1 Nitrogen from industrial point sources and spills

Nitrogen limits algal growth in WA marine waters and is the nutrient of concern for the historical deterioration of water quality in Cockburn Sound. The nitrogen-related impact on water quality was initially addressed by reducing loads from point source industrial discharges, the largest contributor to nitrogen loads at the time (DAL 2001). In 1978, ~90% of total nitrogen loading to the Sound came from these point source discharges (i.e. ~1800 t N/yr of 2000 t N/yr total load; Table 3.2) (DAL 2001).

Point source discharges are easily identified, are typically licensed and can be effectively managed through regulation by requiring diversion and/or treatment. Improved wastewater management by industry and diversion of the discharge from the Woodman Point WWTP to offshore disposal via the SDOOL had reduced point source nitrogen discharges to ~57 t N/yr by around 2000—just 20% of the estimated 300 t N/yr total nitrogen flux to the Sound (DAL 2001). Since 2005, the key industries discharging nitrogen into the Sound in 2000 (DAL 2001) have predominantly directed their treated wastewater to the SDOOL for offshore disposal. As a result, the remaining industrial point source discharges to the Sound represent a very small proportion of what remained in 2000 and are no longer considered significant enough for inclusion in nitrogen budgets (Greenwood et al. 2016).

The infrastructure that previously discharged wastewater to the Sound for the Water Corporation (the Woodman Point and Jervoise Bay outlets), CSBP and BP are now used by those organisations as emergency outlets for times that the discharge cannot be directed to and/or accepted by the SDOOL. CSBP's beach outfall is intended for the emergency discharge of stormwater only. Discharge from emergency outlets is typically rare, episodic and brief and any potential impacts are therefore not material to the broader health of the Sound as they are expected to be temporary and limited in extent.

In 2001, ship loading spills were estimated to contribute 5.6 t of nitrogen to the Sound each year, a marked reduction from the 27.9 t/yr estimated for the early 1990s (DAL 2001). While shipping volumes through all Perth ports have increased dramatically since 2001 (DOT 2016), spillage is likely unchanged or reduced due to continual improvements in dust mitigation and spill management practices. It is conservatively estimated that spillages contribute 5.6 t N/yr to the Sound.

3.2.2 Other contaminants from industrial point sources and spills

The improvements to the management of industrial discharges to reduce nutrient loads also resulted in large reductions in the loads of other contaminants (metals and hydrocarbons) entering Cockburn Sound from point sources (DAL 2001). Subsequent diversion of Cockburn Sound point source discharges to the SDOOL further reduced contaminant loads to the Sound (GHD 2013). With the exception of chlorine, used as a biocide in cooling water discharge (see Section 3.2.3), contaminant loads to Cockburn Sound from point sources are now very small.

In relation to loading of other contaminants in Cockburn Sound as a result of spills of materials, the import and export of bulk products from vessels is centred on facilities in the Kwinana area, with facilities owned by Fremantle Ports (the Kwinana Bulk Terminal and the Kwinana Bulk Jetty), Alcoa, BP and Cooperative Bulk Handling. These facilities ship and move iron ore, cement clinker, gypsum, granulated slag, grain, petroleum, liquid petroleum gas, alumina, fertilisers and sulfur (DOT 2016). The reported volumes of spills from these sources are negligible.

3.2.3 Cooling water discharges

Two power stations (Synergy's Cockburn Power Station and Bluewaters' Kwinana Gas-Fired Power Station) and BP's Kwinana refinery are licensed to discharge cooling water into Cockburn Sound. Seawater used for cooling—4.74 cubic metres per second (m^3/s) by Synergy, 5 m^3/s by Bluewaters and 5.4 m^3/s by BP—is subject to licence conditions that typically allow a differential between inlet and outlet temperatures that will result in minimal change in the environment after discharge and mixing.

The power station discharges also have licence limits—0.5 parts per million in each case—applied for chlorine (a biocide added to the cooling water stream to prevent fouling of pipes by marine organisms). There are no formal guidelines (ANZECC & ARMCANZ 2000) to assess chlorine toxicity, but it is assumed that the prevailing licence limits are sufficiently protective of the marine environment outside the mixing zones mandated for each facility.

3.2.4 Desalination discharges

A 45 GL/yr capacity desalination plant (the Perth Seawater Desalination Plant) began supplying potable water to the Perth metropolitan water scheme in late 2006. The plant is approved to discharge 180 ML/d desalination reject brine to Cockburn Sound via a 40 port ocean outlet diffuser (EPA 2009). Following discharge and subsequent mixing and dilution, the desalination brine eventually sinks to the bottom, forming a discrete layer underneath the lower density seawater and spreads along the depth contours of the Sound, tending to gravitate towards the deeper shipping channels of the eastern Sound (Okely et al. 2007a,b,c). Stratification of the bottom layer of diluted brine and microbial respiration in the sediments can potentially deplete DO near the seabed. Despite the potential, modelling undertaken during the initial EIA (Yeates et al. 2006) suggested that the risk of adverse effects on the environment from brine discharges are low (the outcomes of monitoring are described in Section 4.4):

- The discharge of brine from the desalination plant should have no impact on the intensity and duration of stratification in the deeper waters (>15 m) of Cockburn Sound.

- The brine should be of insufficient volume and salinity to impede the natural de-stratifying forces (wind and tides) and horizontal mixing processes in the deeper waters.
- Any impact of discharged brine on stratification in Cockburn Sound should only be apparent on the shallow eastern bank within 2 km of the diffuser.
- Brine should be diluted by natural mixing processes in Cockburn Sound by more than suggested by the diffuser design (45 times). Median dilution in the deeper waters was predicted to be greater than 600-fold (Yeates et al. 2006).

3.3 Contaminated land and groundwater inputs

3.3.1 Contaminated land inputs

The primary pathways for contaminants from contaminated land to enter Cockburn Sound are as surface run-off that enters drains or direct recharge to groundwater from the various land uses in the catchment (GHD 2013). As described in Section 2, 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.

The principal causes of environmental contamination are generally poor or inadequate operational practices associated with the manufacture, use and disposal of chemicals by past or current industrial, agricultural or commercial land uses. Contamination may result from sources such as accidental spillage of chemicals, leakage of chemicals from storage containers, drains, leaching of contaminants from landfills or regional contamination of groundwater by pesticide and fertiliser application. The extent and degree of contamination at a location is dependent on physical site characteristics such as soil type, depth to groundwater and proximity to drains.

The contaminant load assessment undertaken by GHD (2013) reviewed historical land and groundwater contamination data and assessed the nutrient and contaminant loads entering Cockburn Sound based on estimates for different land-use categories (urban, agriculture, heavy industry, light industry and natural areas). However, the availability and extent of historical baseline information was found to be inconsistent and represented poor temporal and spatial distribution (GHD 2013).

Urban and agricultural land uses were postulated to be the largest contributors of nitrogen in the catchment at 21–51 t/yr and 6–53 t/yr respectively (GHD 2013). Urban and agricultural land uses were also the largest sources of phosphorous at 3–6 t/yr and 1–11 t/yr respectively.

Based on GHD's (2013) contaminant load review, additional desktop evaluation of DWER's *Contaminated Sites Database* (refer to Appendix B for methods) and the National Pollutant Inventory website, multiple land-use areas on the coast and their associated contaminants were identified to pose a tangible risk as potential sources of contaminants to Cockburn Sound. A total of 694 land parcels (Appendix B) were identified as known contaminated sites within the Cockburn Sound policy boundary:

- 35 land parcels identified as 'contaminated–remediation required'
- 19 land parcels identified as 'contaminated–restricted use'
- 640 land parcels identified as 'remediated for restricted use'.

Land parcels classified as 'contaminated–remediation required' and 'contaminated–restricted use' were identified to be potential contemporary sources of contamination into Cockburn Sound. The following high-risk areas were identified, associated with various land uses along the Cockburn Sound coastline:

- Henderson
- Hope Valley
- Kwinana Beach
- Munster
- Rockingham
- Naval Base
- Garden Island.

A summary of risk areas surrounding Cockburn Sound, potentially contaminating land uses and contaminants of concern is provided in Table 3.3. A full analysis of all potentially contaminated areas within the Cockburn Sound policy boundary, and the reasoning for the classifications is provided in Appendix B.

Table 3.3 Summary of risk areas surrounding Cockburn Sound, potential land uses and contaminants of concern

Risk area	Current/historic land uses	Contaminants of concern
Henderson	• boat building and maintenance • historical land uses of market garden activities between 1965–1974.	• heavy metals (including copper, zinc and nickel) • organotin compounds (such as tributyltin) • organochlorine pesticides (e.g. dieldrin).
Hope Valley	• alumina refining operation • disposal of mineral processing waste from bauxite/aluminium processing facility • limestone quarry • fly-ash disposal facility.	• heavy metals (including barium, manganese, arsenic, aluminium, molybdenum) • fluoride • chloride • elevated alkalinity.
Kwinana Beach	• fertiliser production and storage • storage, manufacture and distribution of chemicals since 1978 • disposal of mineral processing waste from the adjacent bauxite/aluminium processing facility • nickel refinery • railway yard • bulk fuel terminal.	• heavy metals (including arsenic, aluminium, molybdenum) • petroleum hydrocarbons • pesticides • ammonia • fluoride • elevated alkalinity • nutrients • ammonium sulfate • chlorophenols.
Munster	• boat building and maintenance activities.	• heavy metals (including copper, zinc, lead, nickel, arsenic) • organotin compounds (such as tributyltin) • polycyclic aromatic hydrocarbons • nutrients.
Rockingham	• service station that has been in use since the 1980s.	• free-phase and dissolved-phase hydrocarbons.

Risk area	Current/historic land uses	Contaminants of concern
Naval Base	• coal-fired power station and ancillary uses such as coal storage, bottom ash storage, bulk fuel storage, electrical transformers, workshops and offices • commercial yard and fuel storage and distribution facility • bulk storage of petroleum fuels and as a natural gas metering station • former service station comprising underground storage tanks, fuel bowsers and associated infrastructure • electricity generation and fuel storage facilities.	• hydrocarbons • chromium.
Garden Island	• fire training • ordnance destruction and disposal • vehicle/vessel/weapons maintenance • WWTP • landfill • bulk fuel storage • distribution of above-ground and underground storage tanks.	• hydrocarbons • PFAS • heavy metals • nitrogen compounds, phosphorous and bacteria.

3.3.2 Groundwater inputs

Groundwater flow

With no rivers or creeks flowing directly into Cockburn Sound, groundwater has been identified as the major pathway for contaminant loads into Cockburn Sound (although it is noted that contaminant load data from stormwater drains is limited). Large groundwater flows to Cockburn Sound have the potential to serve as a conduit for contamination, with between 13.6 and 27.5 GL of groundwater discharged each year through permeable soils (GHD 2013). Groundwater in the Superficial aquifer is recharged by rainfall on the Jandakot Mound and discharges to Cockburn Sound from north of Woodman Point to the southern end of Kwinana Beach (Davidson & Yu 2008). Further to the south and west (Rockingham), groundwater flows to Cockburn Sound from a small mound south-east of Rockingham (Safety Bay Mound). Groundwater flow from Garden Island contributes minor volumes to Cockburn Sound.

The aquifer at the coast consists of two main units: fine- to medium-grained, shelly sand of the Safety Bay Sand, overlying medium- to coarse-grained sand and limestone of the Tamala Limestone. There is commonly a thin, clayey layer between these units that restricts the vertical movement of groundwater between them (Nield 1999). The Safety Bay Sand has moderate hydraulic conductivity and 15 m/d is generally adopted for calibrating numerical groundwater models of the area (Davidson & Yu 2008). However, analysis of tidal fluctuations in bores near Woodman Point suggest a higher hydraulic conductivity of the Safety Bay Sand (a range of 53–174 m/d) which was evidently strongly influenced by the high tidal efficiency of the underlying Tamala Limestone (Smith & Hick 2001). A range of hydraulic conductivities from 100–1000 m/d are suggested for the Tamala Limestone (Davidson & Yu 2008). Hydraulic conductivities close to the coast of 400–1000 m/d were adopted for calibrating numerical groundwater models that extend from Woodman Point to Rockingham (e.g. Nield Consulting 2004, Rockwater 2008).

The high hydraulic conductivity means that most of the groundwater flow to Cockburn Sound is from the Tamala Limestone formation. Average flows (in September–October 1992) calculated using flow-net analysis were 51.4 ML/d from Fremantle to Kwinana, 15 ML/d from Kwinana to northern Rockingham and 2 ML/d from the Safety Bay Mound discharging along the coast at

Rockingham, with an overall total of 68.4 ML/d (Davidson 1995). These flows are equivalent to 2 kilolitres per day per metre (kL/d/m) to 3.1 kL/d/m (Davidson 1995), similar to:

- submarine groundwater discharge rates of 2.0–3.7 kL/d/m calculated using seepage meters, radium isotopes and radon (Burnett et al. 2006)
- rates of 2.5–4.8 kL/d/m determined by numerical groundwater modelling (Smith & Nield 2003).

There is no systematic monitoring of groundwater flows near the coast, but they are typically lowest at the end of summer, and have probably reduced over time due to a long period of below-average rainfall and the extraction of groundwater for industries in the KIA. However, urbanisation and industrial development tends to increase groundwater recharge rates and has potentially served to offset these long-term reductions in groundwater flow (GHD 2013).

Garden Island is about 12.9 km^2 in area. Assuming groundwater recharge averages 30% of the average annual rainfall of 598 mm/yr, and that half of the groundwater discharges along the east coast, then groundwater flows to Cockburn Sound from Garden Island would average about 3.2 ML/d. Again, short-term flows will be strongly seasonal and affected by tides and ocean levels.

Groundwater quality

While Section 3.3.1 has documented the potential risk and types of contaminants in groundwater surrounding Cockburn Sound, there is no systematic monitoring of groundwater quality near the coast to assist assessment of contaminant loads in groundwater discharging to the Sound. The DWER's Water Information Reporting database contains few measurements of metal or nutrient concentrations in DWER monitoring bores and no recent data. For example, there have been no measurements of nitrogen concentrations in DWER bores since 1997 and no measurement of phosphorus concentrations since 1992.

<u>Nutrients</u>
Historically, high loads of groundwater nitrogen were discharged into Jervoise Bay due to contamination from the Love Starches facility (now Nagata) and leachate from sludge drying beds at the Woodman Point WWTP. Injection of wastewater to the aquifer at the Love Starches site stopped in 2002 and the Woodman Point WWTP sludge beds were removed in 1999. A groundwater recovery scheme operated from December 2000 to at least October 2011 to capture and divert the contaminated groundwater away from the Sound (PB 2011). As a result, nitrogen loads in groundwater discharging to the bay from these sources decreased from 69 t in 1997 to 9.7 t in 2010 (CSMC & DEC 2012) and will have continued to decrease since then.

Generalised groundwater contours of total nitrogen (TN) concentration based on more than 500 bores in the Perth region suggest that TN concentrations increase from around 2 milligrams per litre (mg/L) in the south to about 8 mg/L near Woodman Point (Sarukkalige 2011). TN concentrations in porewater from Cockburn Sound in nearshore holes measured by Smith et al. (2003) ranged from <1 to 739 mg/L, and were generally <3 mg/L. The highest concentrations were centred north and south of James Point, down-gradient of industries in that area. In 2003, TN loads in groundwater discharging to the Sound were estimated at 234 ±88 t N/yr, depending on groundwater recharge rates, and were dominated by ammonium (Smith et al. 2003). A more recent estimate suggests that the total groundwater nitrogen supply could be higher (655 t N/yr) depending on annual rainfall (McFarlane 2015). Both estimates relied on the same groundwater concentration data (Smith et al. 2003) and the difference between the two estimates appears to result from upgrades to the model (Greenwood et al. 2016). Since large differences between estimates over time can be due to technical differences, it makes it very difficult to determine temporal variations in groundwater nitrogen fluxes. However, it is unlikely that the groundwater nitrogen load has significantly increased between the 2003 and 2016 studies.

Phosphorus is readily absorbed by calcareous sand and limestone, and the Superficial aquifer adjacent to Cockburn Sound is likely to naturally attenuate phosphorus concentrations. Total phosphorous (TP) concentrations in porewater from the nearshore holes measured by Smith et al. (2003) ranged from 0.02 to 2 mg/L and were generally <0.5 mg/L, with elevated concentrations again in the areas down-gradient of industry north and south of James Point. TP loads in groundwater discharging to the Sound were estimated to be 1.3–2.5 tonnes of phosphorous per year (t P/yr), depending on groundwater recharge rates (Smith et al. 2003).

Managed aquifer recharge using secondary-treated wastewater is an option presently being examined for recharge of the Superficial aquifer in the KIA, to increase the quantity of non-potable water available for industries in the area and to counter coastal saltwater intrusion into the aquifer (McFarlane 2015, GHD 2016). Managed aquifer recharge increases nutrient loads to groundwater but the cumulative impact on loads to Cockburn Sound is uncertain, due to the potential offset of reduced submarine groundwater discharge as a result of the drying climate. Notwithstanding, the possible addition of nitrogen up to a maximum of ~185 t N/yr would only increase the groundwater contribution by between ~20% and 34%, a minor addition, relative to other sources in the overall budget of nitrogen entering Cockburn Sound (Greenwood et al. 2016).

Petroleum hydrocarbons

Contamination from petroleum hydrocarbons in groundwater is considered a low risk for Cockburn Sound because hydrocarbons are readily degraded in the aquifer. Known groundwater plumes contaminated with hydrocarbons are localised and the fluxes to the Sound are likely modest (Trefry et al. 2006).

Metals

Generalised contour maps of groundwater metal concentrations suggest arsenic concentrations range from around 0.01 to 0.02 mg/L and zinc concentrations range from about 0.1 to 0.24 mg/L in the catchment (Sarukkalige 2011). Nevertheless, metals have limited mobility in groundwater systems and are therefore likely to be of low risk to Cockburn Sound.

Pesticides/herbicides

Pesticides/herbicides (chlorophenols) in a groundwater plume sourced from the former Chemical Industries Kwinana site may pose a risk to Cockburn Sound. However, in 2006 the plume had not reached the Sound, and if it does/has, the effects are expected to be localised (Trefry et al. 2006). Monitoring has not been carried out around other pesticide/herbicide manufacturing sites (such as Bayer Crop Science).

Caustic groundwater

High pH groundwater containing metals and fluoride in the vicinity of the Alcoa alumina refinery may potentially be discharged to the Sound (Trefry et al. 2006). The fate of these contaminants and impact on the Sound is uncertain.

PFAS

PFAS compounds have been detected in monitoring bores in three areas of Garden Island (GHD 2016). Some groundwater flows towards Cockburn Sound and has the potential to transport these emerging contaminants of concern. Whether this has occurred and the potential impact on the marine environment is the subject of ongoing study.

3.4 Atmospheric deposition to Cockburn Sound

Nitrogen can enter Cockburn Sound's marine environment from the atmosphere via several processes including biological nitrogen fixation, dust deposition and rainfall. Atmospheric deposition of nitrogen to Cockburn Sound between 1978 and 2001 was estimated to be relatively stable at 20–21 t N/yr (DAL 2001). More recently, Greenwood et al. (2016) estimated nitrogen fixation at 7.4 t N/yr, rainfall sourced nitrogen input at 2.1 t N/yr and a small contribution from nitrogen in dust at 0.4 t N/yr; providing a total estimated atmospheric input of ~10 t N/yr. Due to the differences in estimation technique and assumptions, it is not possible to comment on or be confident that the apparent halving of atmospheric nitrogen input since 2001 is real or due to scientific error, but the order of magnitude of deposition is likely to be correct.

3.5 Coastal modification and change in sea floor

The Cockburn Sound shoreline is the most modified coastal system in WA. The development of the Sound as a major recreational, commercial, defence and industrial area has resulted in the construction of numerous coastal structures and dredging/nourishment activities since the early 1900s (Figure 3.1). Each of these activities has resulted in direct and indirect pressures on the coastal system. Recent increases in the rate of sea level rise places pressure on the stability and function of the structures and will affect the shoreline (see Section 3.8).

3.5.1 Coastal structures

The majority of structures are found on the eastern shore of Cockburn Sound, while the western shore (Garden Island) is relatively undeveloped, where coastal structures are only present in the south (Garden Island Causeway and Careening Bay) and north (Armaments Jetty) (Figure 3.1). The coastal structures within Cockburn Sound include breakwaters, groynes, jetties, revetment walls, pipelines and ramps (Figure 3.1). Much of this infrastructure has been constructed to facilitate industrial development and some was specifically intended to modify coastal processes. The presence of these structures at the coastline modifies the longshore sediment transport pathways and consequently shoreline position. In response, structures such as groynes, seawalls and breakwaters have been placed to improve coastal stability. The presence of large, engineered structures (Woodman Point groyne, Jervoise Bay Boat Harbour northern breakwater and the Garden Island Causeway) have effectively isolated Cockburn Sound from significant longshore feeds from the north and south, hence Cockburn Sound has been identified as a single, primary sediment cell[4] (Stul et al. 2015). Wave reflection and modification of nearshore currents by coastal structures can also cause seabed scour and local changes to the benthic habitat.

The largest changes in shoreline position within Cockburn Sound may generally be attributed to the influence of coastal structures. 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 (DAL 2001, Stul et al. 2007, BMT Oceanica 2014).

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[4] *A sediment cell is a spatially discrete area of the coast, within which sediment transport processes are interrelated, and there is little or no sediment movement across cell boundaries. A primary sediment cell is the largest (most broadscale) type of sediment cell, in a hierarchy of three.*

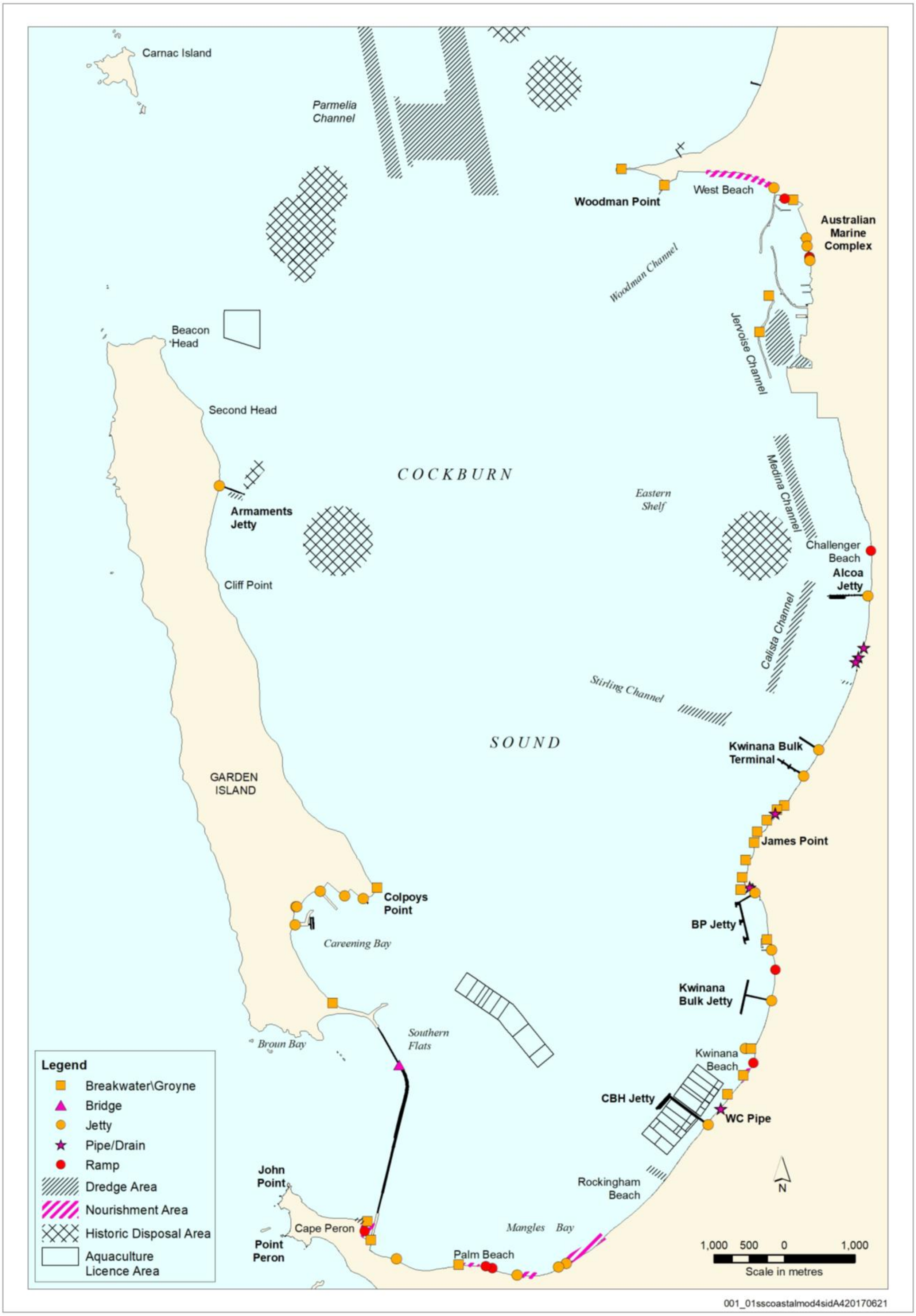


Figure 3.1 Coastal modifications in Cockburn Sound

3.5.2 Dredging and nourishment

Since the 1950s, a number of dredging and nourishment works have been undertaken within Cockburn Sound for the purposes of navigation and shoreline management. Commercial shipping access to the Sound occurs to the north via Parmelia Channel (dredged to -14.8 m chart datum; Figure 3.1). In addition, Cockburn Cement has been dredging for shellsand resource on Parmelia and Success Banks (to the north of Cockburn Sound) since 1972 under a State Agreement Act. Within Cockburn Sound, there are five designated shipping navigation channels: The Woodman and Jervoise channels are naturally deep waterways (Figure 3.1). The Stirling and Calista channels and their associated basins have been dredged to depths of ~11.7 m to enable access to the Alcoa and Kwinana Bulk Terminal jetties (FP & DoP 2012). The Medina Channel has been dredged to -10 m chart datum to enable access to the AMC. Dredging has also been undertaken in the Jervoise Bay Southern Harbour and at the Armaments Jetty on Garden Island (Figure 3.1). Occasional maintenance dredging of these channels will continue to be required to ensure safe navigation.

The material from the majority of these navigational dredging projects has been disposed to the seabed at locations within Cockburn Sound. The dredged sediment from the Jervoise Bay Southern Harbour was used to fill the harbour reclamation area. The removal or placement of material on the seabed can affect the energy of the waves as they pass over the area. Deepening of the seabed will reduce wave attenuation causing larger wave energy to propagate shoreward. Conversely, the placement of material on the seabed causes shallowing and an increase in the attenuation of wave energy. Changes in wave energy are dependent on the relative water depth and wave heights, and the effects are dependent on the proximity of the dredging/disposal area to the shoreline. It is typically difficult to distinguish the coastal impact of these wave energy effects unless the dredging/disposal is located very close to the shore. Further, the shoreline effect from the modification of wave energies is often obscured by direct shoreline changes arising from the installation of coastal structures.

Shoreline nourishment (the artificial delivery of sediment from an external source) has been used to manage shoreline erosion at a number of sites within Cockburn Sound. This process helps to mitigate erosion effects and can provide a recreational beach resource, but it does not change the underlying physical forces causing the erosion. Several of the southern beaches have been nourished regularly (including Palm Beach, Mangles Bay and Kwinana Beach; Figure 3.1), with volumes of sand from 500 to 30 000 m^3, using sand excavated from the shoreline to the west of the Point Peron boat ramp (DOT 2009).

3.6 Marine vessel activities

3.6.1 Recreational boating

Recreational boating is very common in Cockburn Sound, but can add pressures on the marine environment and users of the marine environment. While recreational boating occurs across the whole of Cockburn Sound, the majority of vessels typically concentrate in southern areas such as Mangles Bay, where many of the boat launching and mooring facilities are located (Table 3.4). The likelihood that recreational boating pressures will increase in the future, if not well managed, is high. The population of major suburbs immediately adjacent to Cockburn Sound are expected to increase by 150 000 or 40–50% over the next 20 years (see Section 2.2.1) and it is anticipated that recreational boating will rise at a similar rate. For example, a study by Department for Planning and Infrastructure (DPI) released in 2009 predicted that the number of recreational boats would have increased by 77% from 2006 to 2025 (DPI 2009). Similarly, DOT (2009) predicted for the suburbs immediately adjacent to Cockburn Sound that:

- The number of trailerable boats will increase by 1500–3900 over the medium-term (2011–2018) to long-term (2011–2025), and about three-quarters of this increase will be in the Rockingham region.
- The number of non-trailerable boats will increase by 112–258 vessels over the medium-term (2011–2018) to long-term (2011–2025) and about two-thirds of this increase will be in the Rockingham region.

Key pressures on the marine environment associated with recreational boating include multiple-user conflicts, interactions with marine fauna (vessel strikes and provisioning), mooring of non-trailerable craft and potentially hydrocarbon pollution and littering. Fishing is a pressure that is also commonly associated with recreational vessel use and is discussed in detail in Section 3.7.2. Interactions between recreational vessels and other marine users, or marine fauna, are recognised as a major challenge (CSMC 2005). According to CSMC (2005), the issue of potential conflict between users is greatest in the summer months when there are more people using the water. Swimmers are particularly noted as being affected by people using boats and/or jet skis, interfering with their recreational use of the area (CSMC 2005).

Table 3.4 Potential sources of recreational boat pressure within Mangles Bay

Source of recreational boating pressure	Potential boat numbers during peak times at present	Potential boat numbers at peak times in the marina by 2025
Swing moorings in Mangles Bay	600 moorings, a large proportion with boats.	600 moorings, a large proportion with boats. Level of use continues.
Cruising Yacht Club ramp	Unknown	Level of use continues; club members use marina boat ramp.
Mangles Bay Fishing Club ramp	Unknown	Level of use continues; club members use marina boat ramp.
Cape Peron public boat ramp	100–175 boats launched at peak times of each day. Proportion entering Mangles Bay unknown, but area is popular for trailerable boats.	118–254 boats launched at peak times of each day. Proportion entering Mangles Bay unknown, but area is popular for trailerable boats.
Palm Beach public boat ramp	100 boats launched at peak times of each day. Proportion entering Mangles Bay unknown, but area popular for trailerable boats.	118–145 boats launched at peak times of each day. Proportion entering Mangles Bay unknown, but area is popular for trailerable boats.

Source: Strategen (2012)

Recreational vessel use is also a major contributor to collisions with little penguins in Cockburn Sound (reports of collisions with other marine fauna are extremely rare). Cannell et al. (2016) recently reported that trauma, most likely from watercraft, was the main cause of mortality of little penguins in Cockburn Sound (see also Section 4.9.3). Little penguins are often very difficult to observe at sea because they swim low in the water when at the surface and also swim much slower than most boats (Bethge et al. 1997), making it difficult for penguins to get out of the way of vessels. It has also been suggested that increased vessel movements could cause an interruption of a penguin's resting period on the surface, or make it move away from feeding areas, potentially causing long-term impacts on the penguin's energetic costs and lowering the carrying capacity of penguins in Cockburn Sound (Strategen 2012). Provisioning by watercraft users can also potentially harm some marine fauna, in particular dolphins, by increasing the risk of injury and disease (Christiansen et al. 2017; further discussed in Section 4.9.4).

While moving vessels can be an issue, mooring and anchoring of recreational vessels can also lead to marine impacts. Results of analysis of aerial imagery reported from 1967, 1972, 1981, 1999, 2002 and 2008 demonstrate the increase in the number of mooring scars and subsequent increase in the area of seagrass loss in Mangles Bay (Table 3.5 and Figure 3.2; Oceanica 2012). Although the contribution to overall loss of seagrass in Cockburn Sound is small (3.2 ha) relative to historic losses associated with poor water quality (see Section 4.8), Mangles Bay is recognised as an important habitat area for crabs, fish and other marine fauna, so any form of seagrass loss and habitat fragmentation is generally considered undesirable. Anchor damage is also likely to contribute to seagrass scarring, especially around popular recreational fishing spots (see Section 3.7.2); although monitoring this type of disturbance is labour-intensive and relative contributions to impacts across Cockburn Sound would be difficult to assess.

Table 3.5 Historical changes in number of mooring scars and associated seagrass loss in Mangles Bay, Cockburn Sound

Characteristic	Year					
	1967	1972	1981	1999	2002	2008
No. of mooring scars	93	93	114	199	249	312
Area of seagrass loss (ha)	1.06	1.60	2.14	2.71	3.04	3.20

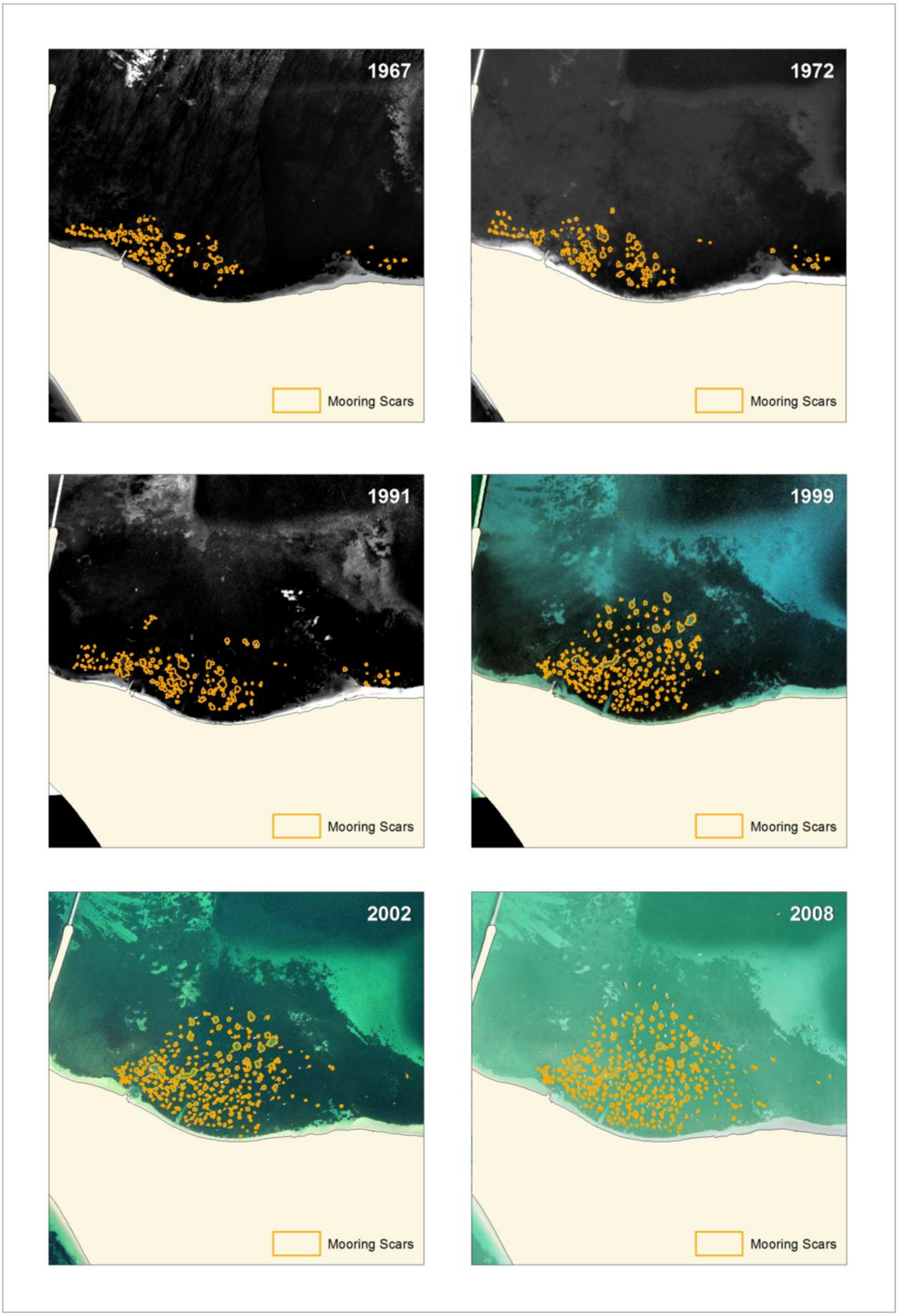


Figure 3.2 Mangles Bay aerial imagery from 1967 to 2008 with digitised mooring scars

The long-term nature of fixed mooring locations also means that vessels stationed at these locations pose a risk to marine sediment quality, through potential long-term accumulation of toxic antifoulants (e.g. tributyltin- and copper-based paints) and translocation and accumulation of invasive marine species (Brine et al. 2013; further see Sections 3.6.2 and 3.6.3). A large area of Cockburn Sound was gazetted as a Mooring Control Area in late 2007. This allowed the then DPI to manage mooring introductions to the Sound and establish regulations that restrict the type of mooring used and where those moorings can be placed.

The release of hydrocarbons and other toxic substances into the environment by the engines of recreational and commercial small crafts is thought to only represent a small share (2%) of the overall hydrocarbon releases into the marine environment (European Commission 2007). This includes hydrocarbons associated with oily bilge or deck water, which if spilled as unburnt or incompletely burnt fuel, can be released into the environment and often result in an oil film on the surrounding water. Despite the potential, there is limited evidence that hydrocarbon contamination from recreational boating poses a high risk to Cockburn Sound, as monitoring of both marine water and marine sediments in areas frequented by recreational vessels (e.g. Mangles Bay) demonstrate hydrocarbon concentrations well below environmental protection guidelines (CSMC 2013).

3.6.2 Introduced marine species and pests

Vessels are known to transport non-native species as either hull fouling or in their ballast water. Different types of vessels provide very different risks for the introduction of marine species (Wells et al. 2009). According to Wells et al. (2009), the high-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 sea floor. Vessels that are stationed in a single area for months enhance the opportunity for species to settle at the source and then be introduced to new regions (Wells et al. 2009). Once introduced, many non-native species remain inconspicuous and innocuous. However, a small portion of those can drastically alter marine environments, becoming the dominant flora or fauna of an area to the detriment of native species. These species are referred to as introduced marine pests (Bax et al. 2003).

Bridgwood and McDonald (2014) acknowledge that vessel traffic entering Cockburn Sound contributes a high risk of the introduction of marine pests. The reasons for this risk rating were identified as:

- number of vessels
- the overall vessel risk rating
- the average duration of stay
- the visit frequency
- the number of compatible pests
- the origin of the vessels arriving at Fremantle Port (Bridgwood & McDonald 2014).

While Bridgwood and McDonald (2014) determined that the majority of entering vessels had a low risk rating, the vessels with a moderate and high risk rating tended to stay the longest. Approximately half of the vessels visiting Fremantle Port (including the outer harbour in Cockburn Sound) were registered from countries considered to be a 'flag of convenience' (i.e. the vessel is registered in a country other than that of its owners) and about two-thirds were from flag states that had not ratified the International Maritime Organization's Ballast Water Management convention. They also found a high compatibility (79%) between the potential incoming marine pests and the environment of Fremantle Ports, meaning environmental conditions were suitable to support the majority of invasive species. The international locations that posed the greatest risk to Fremantle Port were Singapore and Indonesia, with the invasive algal strain *Caulerpa taxifolia* identified as a particularly concerning threat (Bridgwood & McDonald 2014). Port

Adelaide posed the greatest domestic risk to Fremantle Port based on the number of vessels arriving from there and the number of potentially compatible pests (Bridgwood & McDonald 2014).

In WA, DPIRD is the primary agency responsible for marine biosecurity, including the surveillance of introduced marine pests in Cockburn Sound. To facilitate this monitoring, Fremantle Ports and the Department of Defence conduct a voluntary marine pest surveillance program in cooperation with DPIRD. Monitoring involves early warning surveillance (e.g. passive arrays, crab traps and shoreline surveys) which typically occur seasonally, and more targeted monitoring for introduced marine pest (e.g. beam trawls, phytoplankton and zooplankton trawls and infrastructure surveys) which occur once annually (CSMC 2016a). From this monitoring, over 60 species have been recorded as being introduced into WA waters (Enzer 2008, Wells et al. 2009) including 46 that are known non-indigenous species in the Cockburn Sound and Fremantle Harbour area (McDonald & Wells 2009). Of the 46 introduced marine species in Cockburn Sound, four are now considered to be pests according to the National Introduced Marine Pest Information System (CA 2017; Figure 3.3):

- Asian date mussel/bag (*Arcuatula senhousia*)
- European fanworm (*Sabella spallanzanii*)
- colonial ascidian (*Didemnum pellucidum*)
- toxic dinoflagellate (*Alexandrium catenella*).

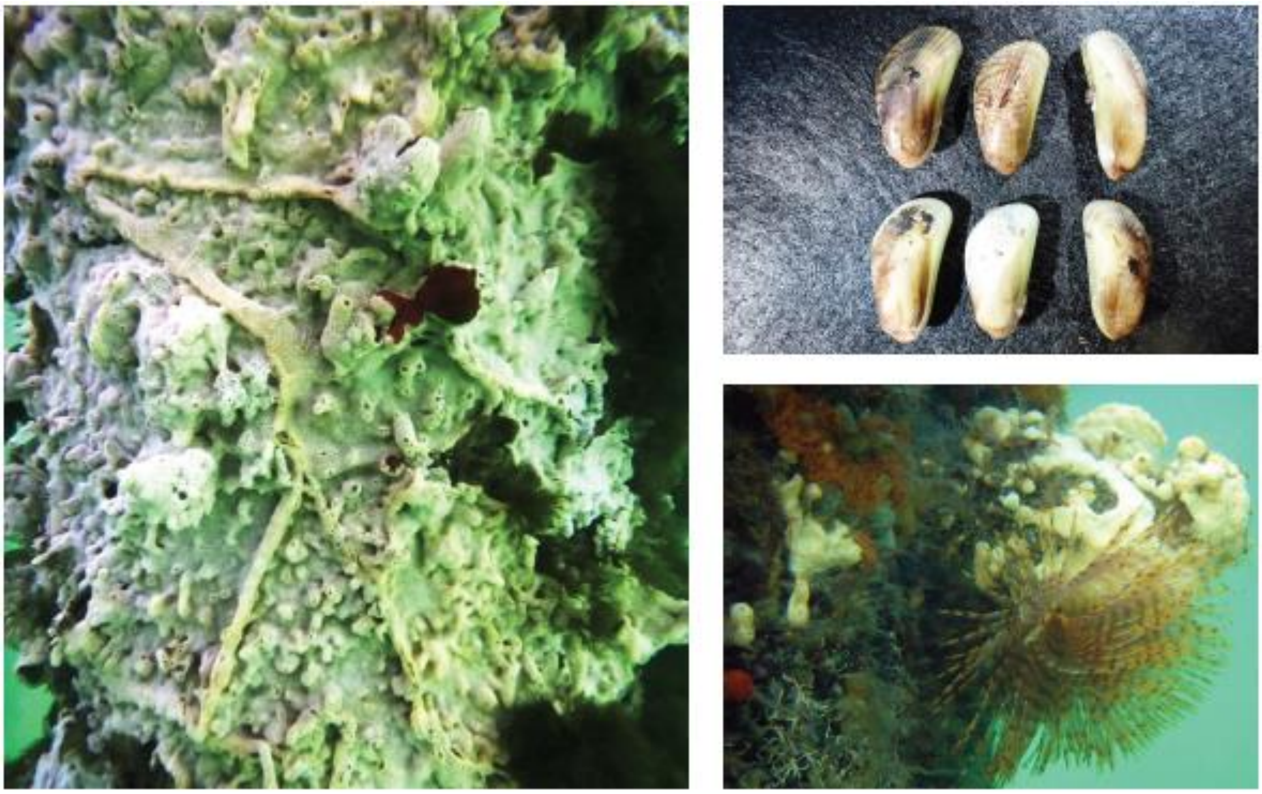
The Asian date mussel was first discovered in the Swan River in the early 1980s, and within a few years was one of the most common shells washed up on the beach (Wells et al. 2009). Interestingly, Swan River populations appear to have been decimated by an intense summer rainfall event in 2000 (Wells et al. 2009). Recent surveys in Cockburn Sound by Wellington (2016) and Simpson (2017) have noted the presence of this species along the Garden Island Causeway and in the Fremantle Ports inner harbour. However, in both cases the species was not determined to represent a new risk.

The European fanworm also remains present in Cockburn Sound (Wellington 2016, Simpson 2017; Figure 3.4). The species appears highly resilient to many forms of disturbance and has a high tolerance to wounding (Furlani 1996), to the extent of being capable of regenerating from fragments (Hewitt et al. 2002). Further, the species is not known to be predated by native fish due to a naturally high arsenic and/or vanadium content (Notti et al. 2007). According to McDonald and Wells (2009), surveys conducted in the early 2000s speculated that the population of the European fanworm in Cockburn Sound had died out and it became accepted locally that this species was no longer present in the region. However, McDonald and Wells (2009) reported its widespread presence in Cockburn Sound following sampling undertaken in 2008 (Figure 3.4) and it is now known to be widespread across WA (Wellington 2016, Simpson 2017). However, there have been no reports of this species causing adverse consequences in the Cockburn Sound area (Wellington 2016, Simpson 2017).

The colonial ascidian *D. pellucidum* has only recently been introduced to Cockburn Sound and is now known to be present at Careening Bay and the Armaments Jetty as fouling on artificial substrates (Wellington 2016), and in the past, attached to the Kwinana Bulk Jetty pylon structures (Figure 3.1; Muñoz & Bridgwood 2013). Exotic species belonging to the *Didemnum* genus are targeted by the National System for the Prevention and Management of Marine Pest Incursions and remain listed as a target marine pest. However, due to its extensive distribution in the state, DPIRD advice regarding the management of this species is for reporting purposes only (Simpson 2017).

There have been no recent reported outbreaks of paralytic shellfish poisoning by the toxic dinoflagellate *A. minutum* (Enzer 2008), and it is particularly noted that this species was not implicated by the then Department of Fisheries (now DPIRD) in the 2015 fish kill in Cockburn Sound (DOF 2015; see Section 4.6).

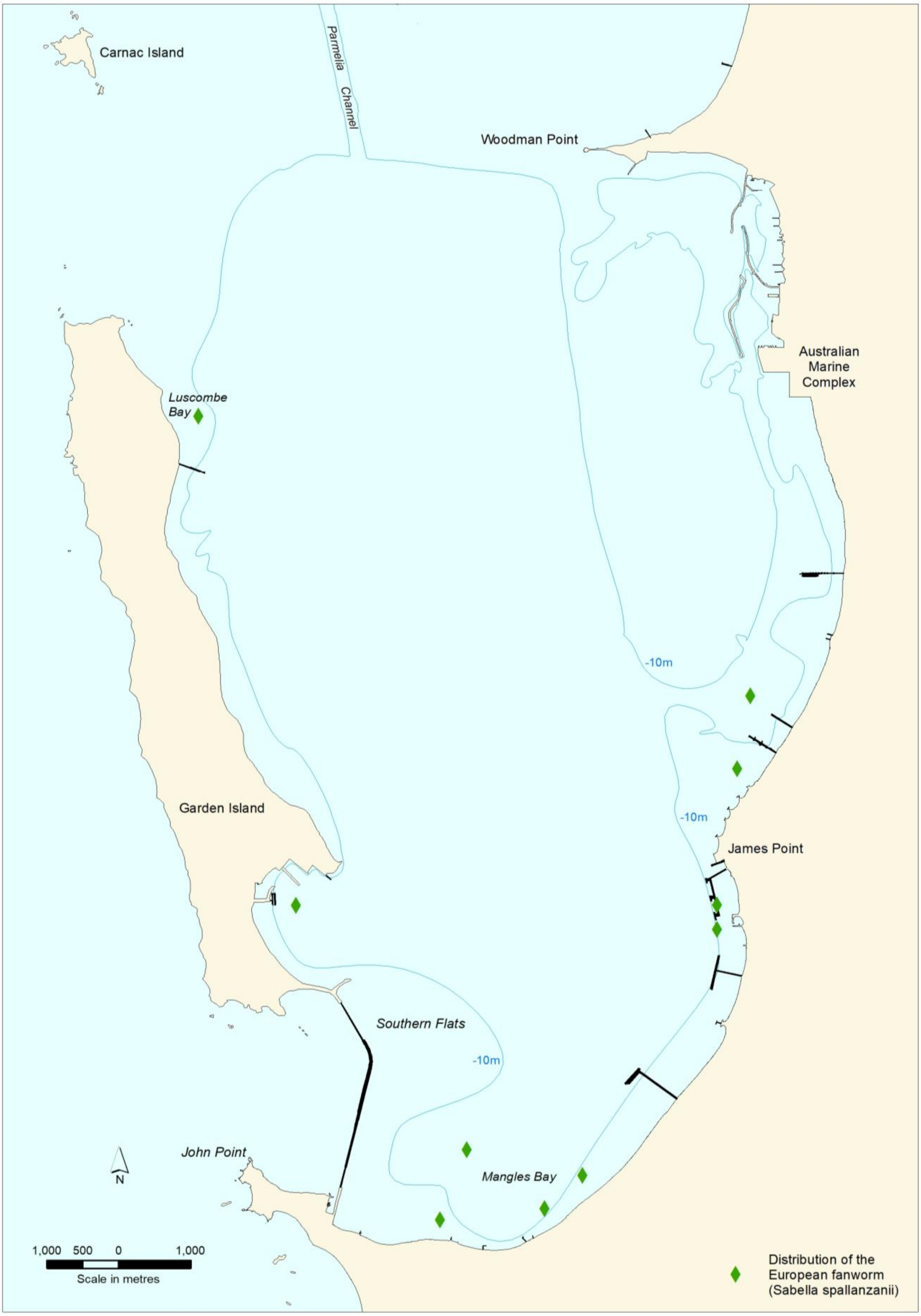
While not presently listed as a marine pest according to the National Introduced Marine Pest Information System (CA 2017), it is noteworthy to mention that the scallop *Scaeochlamys livida* has well-established populations in Cockburn Sound and the Swan River (McDonald & Wells 2009). This species is unusual since it is an introduction from eastern Australia rather than from overseas (Wells et al. 2009) and there is some speculation that this species may have displaced the native scallop (*Mimachlamys asperrima*) in Cockburn Sound (McDonald & Wells 2009). According to McDonald and Wells (2009), *M. asperrima* previously occupied much of the range now occupied by populations of *S. livida*, although it is unclear whether the populations of *M. asperrima* declined independently at about the same time as *S. livida* bloomed, or whether *S. livida* outcompeted *M. asperrima*. The two species are taxonomically related, feed and reproduce in the same way, and live in similar habitats (McDonald & Wells 2009) although the mechanism by which *S. livida* would outcompete *M. asperrima* is not known (McDonald & Wells 2009). The potential impacts of *S. livida* in WA marine systems are uncertain and require further investigation. This is particularly so given the apparent spread of this species and the possible displacement of local species (McDonald & Wells 2009).



Source: DPIRD
Note:

1. Images, clockwise from left to right: colonial ascidian (*Didemnum pellucidum*), Asian date/bag mussel (*Musculista senhousia*), European fanworm (*Sabella spallanzanii*)

Figure 3.3 Marine pests in Cockburn Sound



Source: Reproduced from McDonald and Wells (2009)

Figure 3.4 Locations where the European fanworm *(Sabella spallanzanii)* has been detected within Cockburn Sound (2008)

3.6.3 Biofouling controls

Biofouling, or biological fouling, is the accumulation of microorganisms, plants, algae or animals on vessel hull surfaces. There are two major mechanisms for combating biofouling: regular cleaning, or the use of antifoulant hull coatings (typically toxic paints). Hull cleaning is simple and can be done whenever a vessel is in dry dock or removed from the water, and is not considered a major issue in Cockburn Sound. However, antifoulants can be harmful to the environment and have the potential to accumulate in sediments and biota. Until 1989, TBT was the most commonly used antifoulant because of its extreme toxicity and therefore effectiveness. Due to TBT's toxic adverse environmental consequences, it has since been banned and replaced by copper-based antifoulants.

However, TBT can persist for up to 20 years in the soft sediment of harbours and remain consistently present in sediments (see Section 4.5). 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 (Oceanica 2006). High concentrations are typical around the enclosed harbour structures in Jervoise Bay and the naval facility at Careening Bay (Figure 3.1; Oceanica 2006). Australian use of TBT on small vessels (<25 m) and structures was banned in 1989, with international treaties also banning the use of TBT antifouling products on larger commercial vessels coming into force between 2003 and 2008. These restrictions effectively eliminated the source of ongoing contamination, but TBT compounds are resilient in the environment and hotspots of TBT contamination around relevant infrastructure are expected to persist for some time.

High incidence and severity of imposex (male characteristics exhibited by female gastropods; used as an indictor of the potential effects of TBT contamination in Cockburn Sound) have been found in *Thais orbita* collected throughout Cockburn Sound (Oceanica 2006). While reductions in imposex are expected after recovery from TBT contamination (Reitsema et al. 2003), it appears that even very low concentrations can potentially lead to imposex (Wells et al. 2009). Imposex of gastropods determined in the Sound on a site-by-site basis is of potential ongoing concern (i.e. determined as an exceedance of the sediment TBT environmental quality guidelines; CSMC 2015). However, broadscale surveys have not been completed since 2006 when all locations sampled exhibited high occurrence (Oceanica 2006) and the overall effectiveness of the mid-2000s ban on reducing the effects of TBT contamination cannot be fully determined.

Use of copper-based antifoulant coatings has increased and effectively replaced the use of TBT-based paints in WA and abroad. Current antifouling technologies for ship hulls are mostly based on metals such as cuprous oxide. Paints require a high cuprous oxideconcentration to give effective protection against fouling. Concerns regarding the impact of copper-based coatings (and others) have resulted in bans on their use for recreational boats in the ports of San Diego and Washington (Rei & Ye 2014). Paints with lower copper concentration, or with less effective forms (e.g. copper thiocyanate) may contain additional biocides such as zinc pyrithione or organic algaecides. However, a baseline describing these TBT-replacement concentrations in Cockburn Sound does not presently exist and this may become an emerging issue in port, fixed mooring and/or regular recreational vessel-launching locations.

3.6.4 Shipping activities

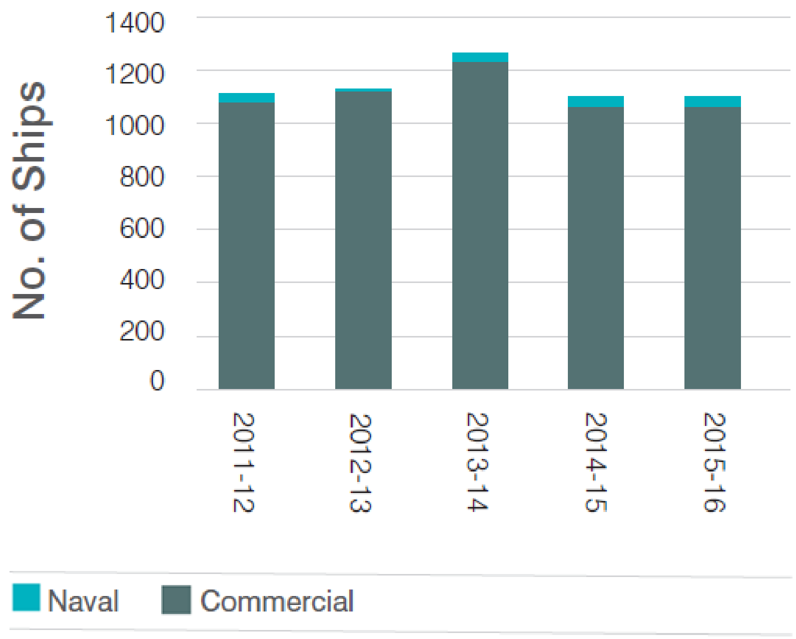
Shipping activities in Cockburn Sound are centred around commercial jetties (Alumina Refinery Jetty, Kwinana Bulk Terminal, BP Oil Refinery Jetty, Kwinana Bulk Jetty and Kwinana Grain Jetty), the Naval Base at Garden Island and the AMC shipbuilding area (Figure 3.1). Parmelia Channel provides the main shipping entrance into Cockburn Sound and a series of secondary channels allows access and navigation across the Kwinana Shelf. The number of ships entering in any one year is typically between 1000 and 1200, remaining relatively stable since 2012 (Figure 3.5). The classes of ships entering Cockburn Sound include bulk carriers, tankers, dry bulk, naval, bunkering and other trade vessels (FP 2016), which range in size from ~5000 to 33 000 t. While the number of ships has remained stable, the proportion of large vessels entering Cockburn Sound has steadily increased over the past few decades, the environmental consequences of which have not been fully investigated.

The main environmental pressures associated with shipping activities relevant to Cockburn Sound include spillages during loading and unloading (e.g. grains, fertilisers and hydrocarbons), dredging activities (see Section 3.5.2), propeller wash reducing water clarity and invasive marine species (see Section 3.6.2). The possibility of vessel collisions with marine fauna is also often cited as a risk associated with heavy vessel use of marine areas. However, the maximum speed of commercial cargo vessels in Cockburn Sound is 8 knots and there are rarely fauna of an at-risk size class present in Cockburn Sound (e.g. whales), so the probability of vessel strike is considered to be extremely low (Vanderlaan & Taggart 2007).

Without appropriate management, there is a tangible risk of spillages of liquids or materials into Cockburn Sound as a result of ship loading and fuelling activities. Such spillages could include toxic or non-toxic liquids and solids. The main factors implicated in marine spillages or discharge include a ship striking the wharf when mooring, a moored ship being struck by a passing ship, and the failure of pipelines, loading arms and mooring systems. The potential impact on fisheries and aquaculture species (BMT Oceanica 2016a), benthic habitats (BMT Oceanica 2016b) and overall ecosystem integrity (BMT Oceanica 2016c) as a result of a hydrocarbon or chemical spill include:

- chemical and biological effects, including toxicity and bioavailability that may affect feeding, reproduction and growth
- physical effects through smothering of benthic habitats that can disrupt functional ecological processes, for example, primary and secondary productivity and nutrient cycling.

While the handling of dangerous cargo is heavily regulated in Cockburn Sound, chemical and biological toxicity arising from a major spill remains a significant concern. Smothering of benthic habitats arising from a spill is considered a relatively low risk in Cockburn Sound, since the areas surrounding commercial jetties are largely devoid of benthic primary producers (see Section 4.8).



Source: FP (2016)

Figure 3.5 Number of commercial and naval ships docked in Cockburn Sound (2011–2016)

3.7 Fishing pressures

3.7.1 Commercial fishing and aquaculture

Commercial fishing

Cockburn Sound supports substantial commercial fishing activities and an aquaculture industry (DOF 2008). Some of the commercially important species known to frequent different habitats within Cockburn Sound include:

- open (deep) water: pink snapper, pilchards and bonito
- shallow water with sandy seabed: whiting, juvenile king prawns, pilchards, blue sprat and whitebait
- seagrass meadows: octopus, leatherjackets, wrasse, crabs and herring
- jetties and groynes: herring, yellowtail scad, trevally, samson fish and mussels.

Commercially managed fisheries presently operating within Cockburn Sound are listed in Table 3.6, and can be categorised as operating either partly (i.e. part of the West Coast Bioregion), or wholly within the Sound. Since the early 1990s, there has been a progressive decline in the number commercial licences operating in Cockburn Sound. In the Cockburn Sound fish net fishery, for example, the number of licences fell from six in the early 1990s to one in 2003 and subsequent years and the total number of days fished declined from 474 in 2000 to 117 in 2009 (Fletcher & Santoro 2011).

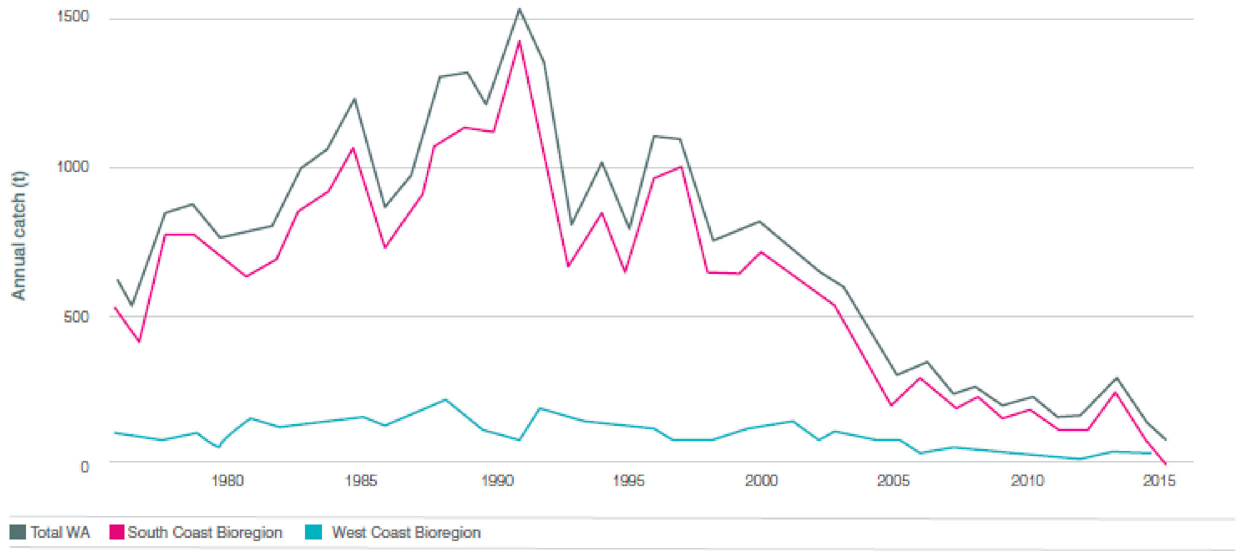
With the exception of octopus, nearly all commercial fishing catches have declined in recent years, which may be due to a combination of reasons, including environmental factors, market pressure, changes in gear type and fishing effort, changes to fishery access rules and low recruitment (Fletcher et al. 2017). Despite declines, many fish stocks in the West Coast Bioregion are still considered 'sustainable–adequate' by the DPIRD (Table 3.6). However, Fletcher et al. (2017) contend that commercial catches of some indicator species pose a high ecological risk. For example, in 2015 the total WA commercial catch for Australian herring was the lowest since the 1940s (72 t; Figure 3.6) (Fletcher et al. 2017). Similarly, total commercial landings in the West Coast Bioregion for southern garfish peaked at 44 t in 1999 and then steadily declined, reaching a historical low of 2 t in 2015 (Fletcher et al. 2017). At the time of writing, southern garfish stock closure was effective immediately in Cockburn Sound (Mr T Nicholas 2017, DPIRD, pers. comm., 28 August). Breeding stocks of pink snapper in Cockburn Sound are also considered to be low. Catches are dependent on the preservation of the spawning area which is defined by water circulation patterns from October to December (Wakefield et al. 2009), noting that much of the commercial catch of pink snapper in the West Coast Bioregion occurs outside of Cockburn Sound. To reduce fishing mortality during the vulnerable spawning period in Cockburn Sound, a seasonal commercial and recreational closure was introduced in 2000 (currently October to January). With increasing concerns for tailor and whiting stocks in the nearshore regions (Fletcher et al. 2017), DPIRD are investigating and implementing management actions to better measure fishing catch and effort and assess stocks (Fletcher et al. 2017).

Conversely, the gloomy octopus (*Octopus tetricus*) catch in Cockburn Sound has steadily increased from 2 t in 2000 to ~30 t 2015 (Figure 3.7; Fletcher et al. 2017). *O. tetricus* was subject to a recent comprehensive stock assessment which investigated biology, fishing efficiency, stock abundance and distribution (Hart et al. 2016). Hart et al. (2016) concluded that the stock is highly productive, and abundant and widely distributed along the western and southern coasts of WA. The estimated area of fished habitat was found to be only a minor percentage (~2%) of the total estimated habitat area it occupies (Hart et al. 2016). The current catch of 274 t is considerably lower than the estimate of the sustainable harvest derived by Hart et al. (2016), which was in the range of 800–2200 t. Consequently, the breeding stock is presently considered to be adequate (Fletcher et al. 2017).

Table 3.6 Managed fisheries in Cockburn Sound and stock status in the West Coast Bioregion

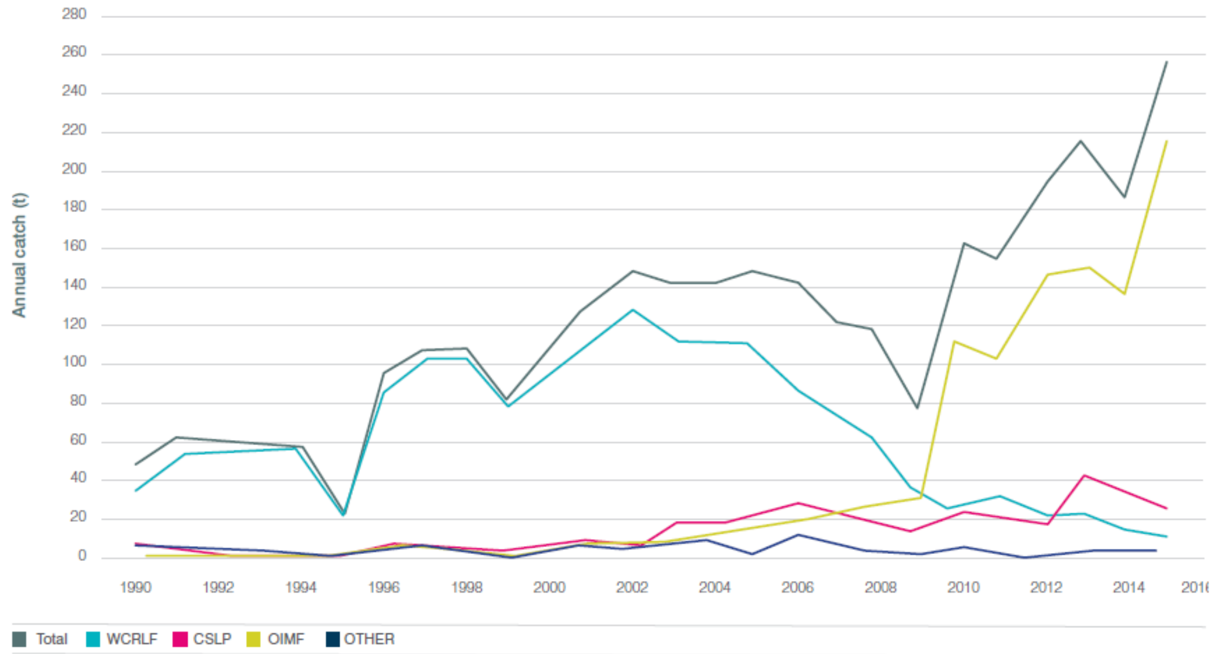
Managed fishery	Primary species targeted	Stock status in 2016
Operating wholly within Cockburn Sound		
Cockburn Sound line and pot	Pink snapper	Sustainable–recovering
	Octopus	Sustainable–adequate
Cockburn Sound fish net	Australian herring	Sustainable–recovering
	Southern garfish	Inadequate (closed)
	King George whiting	Sustainable–adequate
	Taylor	Adequate
Cockburn Sound crab	Blue swimmer crab	Environmentally limited (closed)
Cockburn Sound mussel	Mussels	n/a
Operating partly within Cockburn Sound		
West Coast beach bait	Whitebait	Sustainable–adequate
West Coast purse seine	Pilchards, tropical sardines	Sustainable–adequate

Source: Fletcher et al. (2017)



Source: Fletcher et al. (2017)

Figure 3.6 Total commercial catches of Australian herring, 1976 to 2015



Source: Fletcher et al. (2017)

Note:

1. West Coast rock lobster fishery = WCRLF; Cockburn Sound line and pot = CSLP; Octopus interim managed fishery = OIMF

Figure 3.7 Commercial catch of *Octopus tetricus* in WA since 1990

Blue swimmer crabs are also a highly valued species to commercial (and recreational) fishers in Cockburn Sound, but stocks and stock recruitment capacity has been below sustainable yields for several years. Historically, commercial blue swimmer crab catches in Cockburn Sound have shown large fluctuations. For example, 92 t were caught during the 2001/2002 season, versus 362 t in 1996/1997 (Figure 3.8). These fluctuations have previously been attributed to changes in commercial fishing practices and normal variations in recruitment strength. However, in the mid-2000s, commercial catches declined significantly from 231 t in 2003 to 42 t in 2006 (Johnston et al. 2017). Subsequent recruitment surveys in 2006 revealed the relative abundance of crabs in Cockburn Sound was the lowest on record, with numbers in 2007 only marginally higher (Johnston et al. 2017). It was concluded that high levels of fishing pressure, coupled with three years of reduced recruitment due to unfavourable and lower than average water temperatures, resulted in significantly reduced levels of relative egg production during the 2004/2005 season and the fishery was closed in 2007 (Fletcher et al. 2017).

The blue swimmer crab fishery reopened for a short period between December 2009 and April 2014, although it has remained closed since (Figure 3.8). Reasons for the most recent stock decline have been related to the combined effects of changes in primary production and dietary limitation, water temperature, increased predation and the negative effects of density-dependent growth, which in turn, appear to have had an effect on the proportion of berried females (Johnston et al. 2017). How these factors are affecting stock numbers in Cockburn Sound remains unclear and is subject to investigation by DPIRD. So far, the declines in blue swimmer crab stock abundance have been substantially attributed to environmental changes rather than fishing pressure, and the stock is currently classified as 'environmentally limited' (Fletcher et al. 2017, Johnston et al. 2017).

Source: Fletcher and Santoro (2015)

Figure 3.8 Blue swimmer crab catch, effort and catch per unit in the Cockburn Sound Managed Fishery using crab traps since 1993/94 season

Aquaculture

Three lease areas for mussel aquaculture (*Mytilus edulis*) exist within Cockburn Sound:

- north Garden Island (currently not active)
- Kwinana Grain Jetty
- Southern Flats.

The main mussel farming area is in southern Cockburn Sound (east of Southern Flats), where conditions are sheltered and the nutrient and planktonic food levels are sufficient to promote good growth rates. Owing to the generally low productivity of the WA coastline under the influence of the Leeuwin Current, areas outside of embayments are unsuitable for bivalve aquaculture. The industry in Cockburn Sound is limited by the availability of protected and productive waters, and increased use of the Sound by proposed developments may increase resource-sharing issues (Lawrence & How 2007).

Commercial mussel production in Cockburn Sound varied between 650 t and 950 t in the period between 1998/1999 and 2005/2006 (Lawrence & How 2007). Since 2006, mussel farm operators have claimed that their annual tonnage has declined by up to 60% and believe that the reductions are the result of decreased nutrient concentrations combined with pink snapper predation (ABC Rural 2017).

3.7.2 Recreational fishing

Boat-based and shore-based recreational fishing are popular activities in Cockburn Sound, forming part of the West Coast Nearshore and Estuarine Finfish Fishery (Fletcher et al. 2017). According to the most recent data available from DPIRD (Sumner and Lai 2012), shore-based fishing took a smaller proportion of the total recreational catch of popular fish species (~30%; Table 3.7) in 2001/2002 and was focused around jetties and the northern areas of Cockburn Sound (Fletcher & Santoro 2007). Recreational boat-based fishing is relatively widespread throughout Cockburn Sound, but is more concentrated around Mangles Bay, Cape Peron and the northern entrance to the Sound (Figure 3.9 and Figure 3.10; (based on 2005/2006 data from Sumner & Lai 2012). Differences in landings from boat-based and shore-based fishing methods likely reflect the different habitats preferred by the targeted species. Shore-based catches of Australian herring, yellowtail scad, trumpeter and scaly mackerel were greater than boat-based catches during 2001/2002 (Sumner & Lai 2012). During the same period, King George whiting, tailor and pink snapper catches were predominantly boat-based, while other finfish were landed in similar amounts from both fishing methods (Sumner & Lai 2012). Squid are generally only caught from boats (Sumner & Lai 2012).

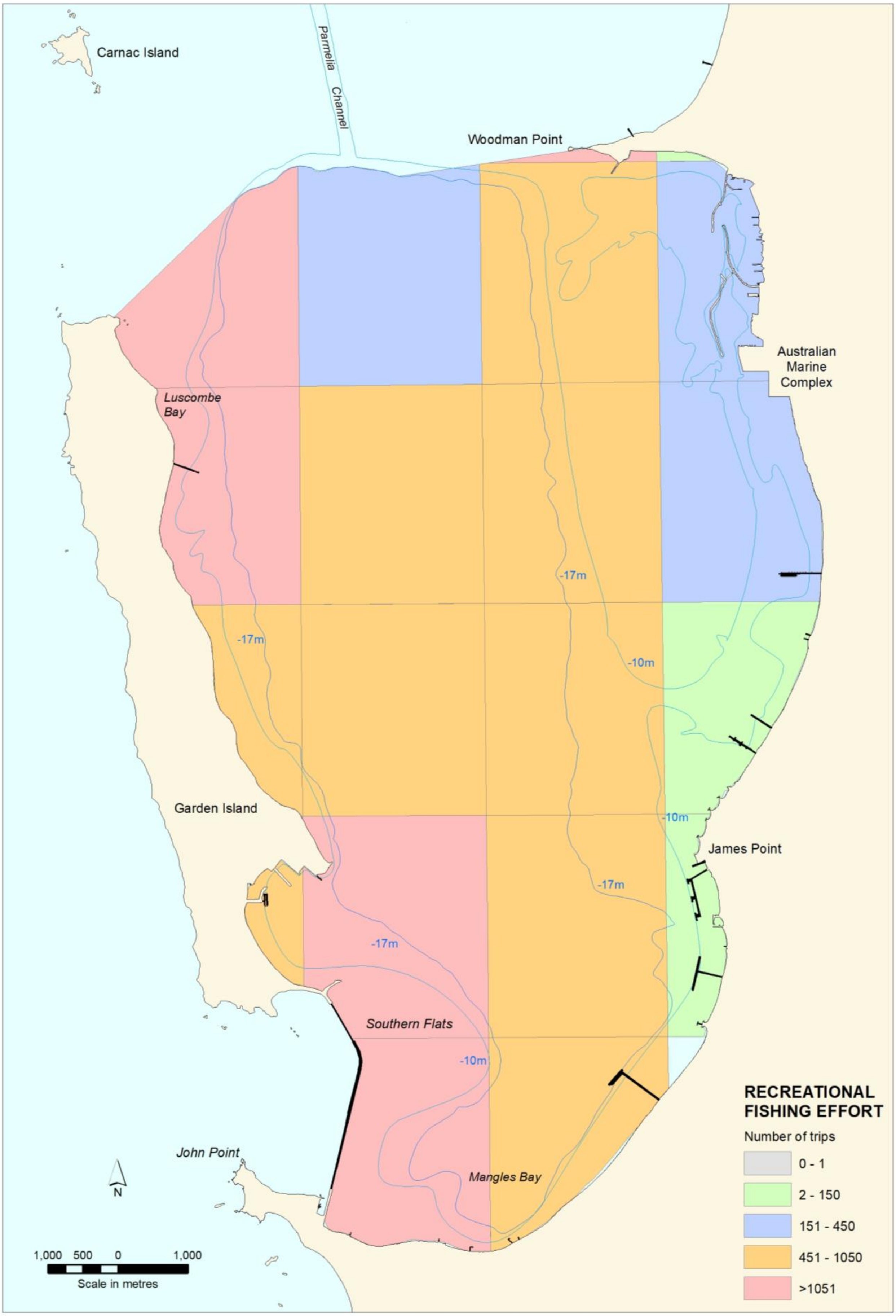
Recreational fishing in general comprises a significant proportion of the total catch (recreational and commercial) from Cockburn Sound for many popular fish species. Around half of the total catch of finfish (excluding baitfish) is caught by recreational fishers (Lenanton & Brown 2007). Similarly, the recreational catch of blue swimmer crabs accounts for ~60% of the total catch when the seasons have been open (Johnston et al. 2008). By volume (t), the main species of finfish caught by recreational fishers in Cockburn Sound are Australian herring, squid and whiting, including King George whiting (Table 3.7, noting data is over ten years old and trends may have since varied).

Blue swimmer crabs are the most important recreationally fished species in terms of community participation rates in WA. The total recreational catch of blue swimmer crabs in WA during the 2011/2012 season was 97 t, with 92% coming from the West Coast Bioregion (Caputi et al. 2015a). Crabbing has also long been a very popular recreational fishery in Cockburn Sound. Most crab fishing during the 2005/2006 season was concentrated around Mangles Bay, Southern Flats, Woodman Point and the shallow margins of the Sound (Figure 3.10). However, concern about low stocks led to a complete closure of Cockburn Sound from 2006 to 2009 and 2014 to the present (the reasons for the stock closure are described in Section 3.7.1).

Table 3.7 Estimated boat-based recreational weights of fish species and crabs caught and retained from Cockburn Sound

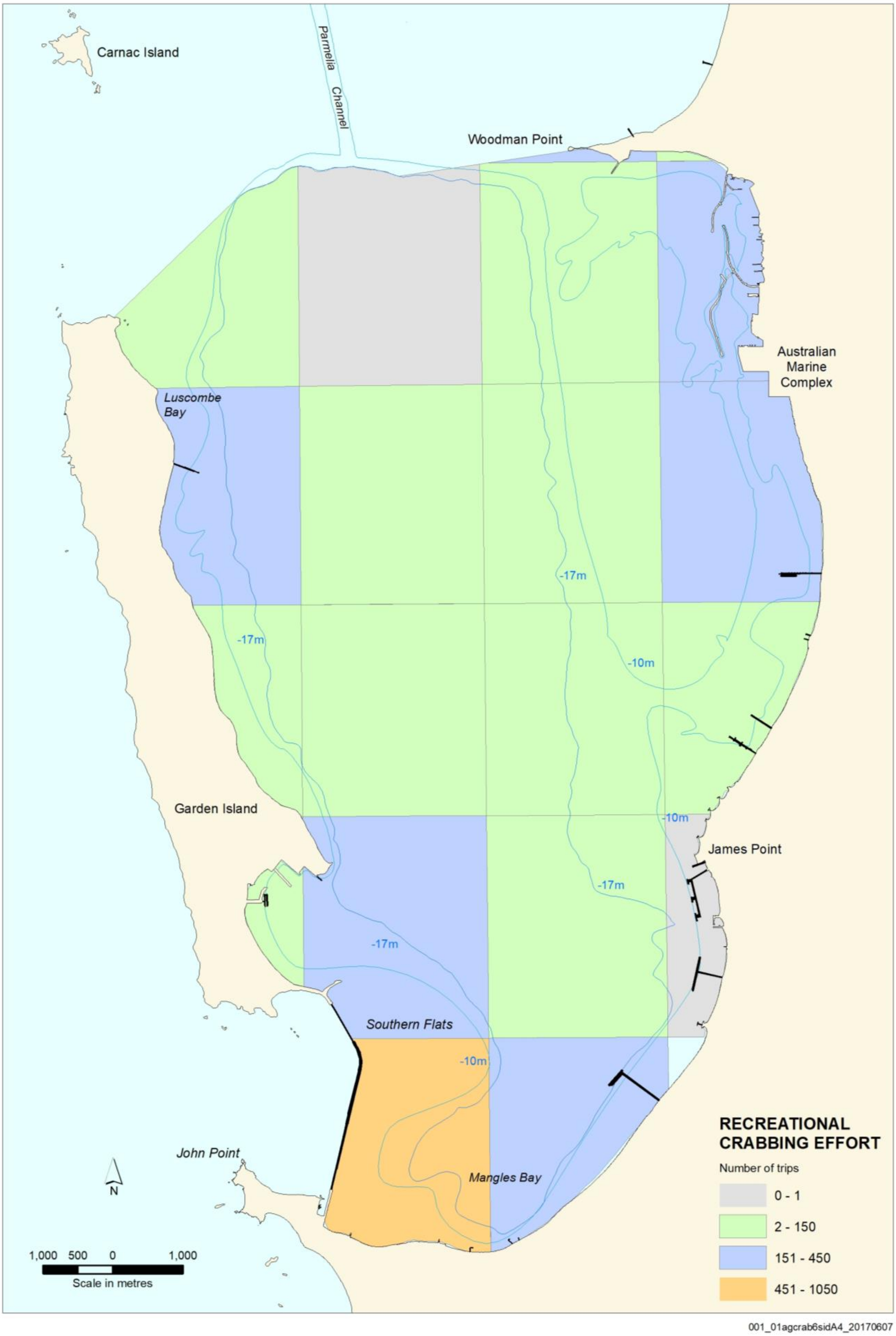
Species	Boat-based catch (t)			Shore-based catch (t)
	1996/1997	2001/2002	2005/2006	2001/2002
Australian herring[1]	8	17	16	15
Whiting other than King George whiting[1]	2	5	5	4
King George whiting[1]	4	9	4	0
Skipjack trevally[1]	n/a	2	5	1
Blue swimmer crab[1]	24	25	4	0
Squid[2]	15	14	21	1
Yellowtail scad[2]	<1	<1	<1	5
Tailor[2]	3	5	<1	<1
Pink snapper[2]	<1	4	1.4	0
Garfish[2]	2	2	<1	2
Trumpeter[2]	<1	1	<1	3
Scaly mackerel[2]	0	0	0	3
Tarwhine[2]	<1	1	<1	1

Sources: Sumner and Lai (2012), DOF (2008)



Source: Reproduced from Sumner and Lai (2012)

Figure 3.9 Recreational fishing effort in Cockburn Sound during 2005–2006



Source: Reproduced from Sumner and Lai (2012)

Figure 3.10 Recreational crabbing effort in Cockburn Sound during 2005–2006

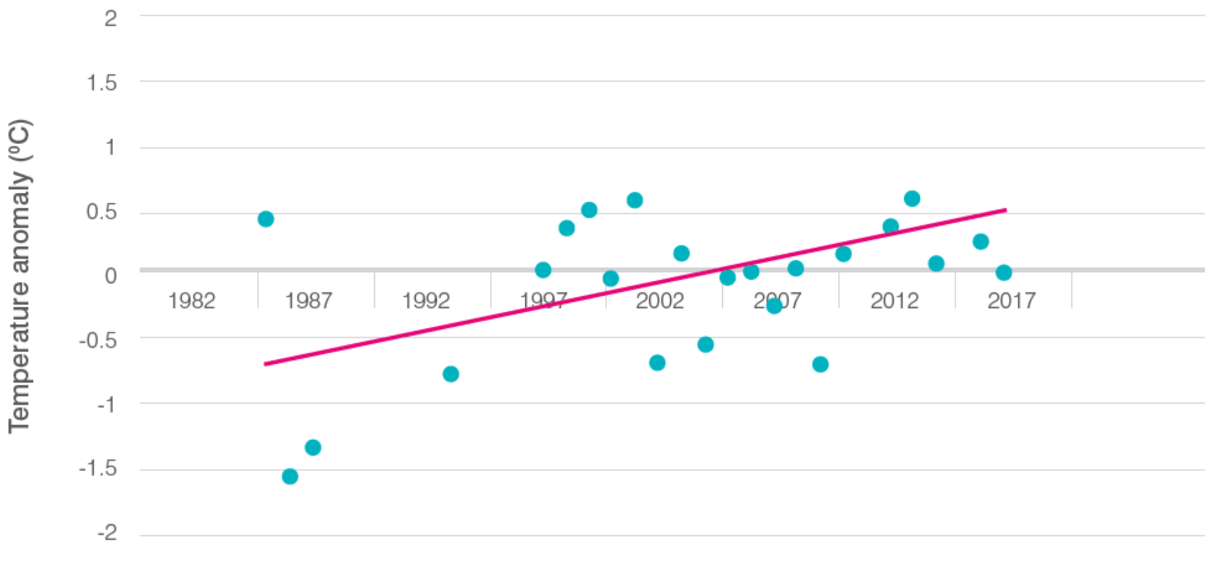
3.8 Climate change

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 WA (IOCI 2012). Coastal ecosystems such as Cockburn Sound are predicted to be significantly affected by climate change (Paice & Chambers 2016), with general impacts related to:

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

Increasing temperatures

The waters off south-western WA are one of three hotspots in the Indian Ocean where sea surface temperature increases since the 1950s have been greater than the Indian Ocean basin average (Pearce & Feng 2007). Ocean temperatures off Perth have risen by ~0.6°C over five decades (1951–2002; Pearce & Feng 2007) and recent modelling efforts[5] predict a further increase of at least 1.8°C–2.2°C over the period 1990–2060 (Caputi et al. 2015b). Long-term records of surface water temperature in Cockburn Sound (1985–2017; Figure 3.11) suggest a statistically significant increase of 0.03°C per year (Keesing et al. 2016). This rate of increase is similar to other measurements from the south-western WA coastal region (Pearce & Feng 2007, Caputi et al. 2009), and if this trend continues at the same rate, Cockburn Sound water temperature will be ~1.3°C warmer than present by 2060.



Note:

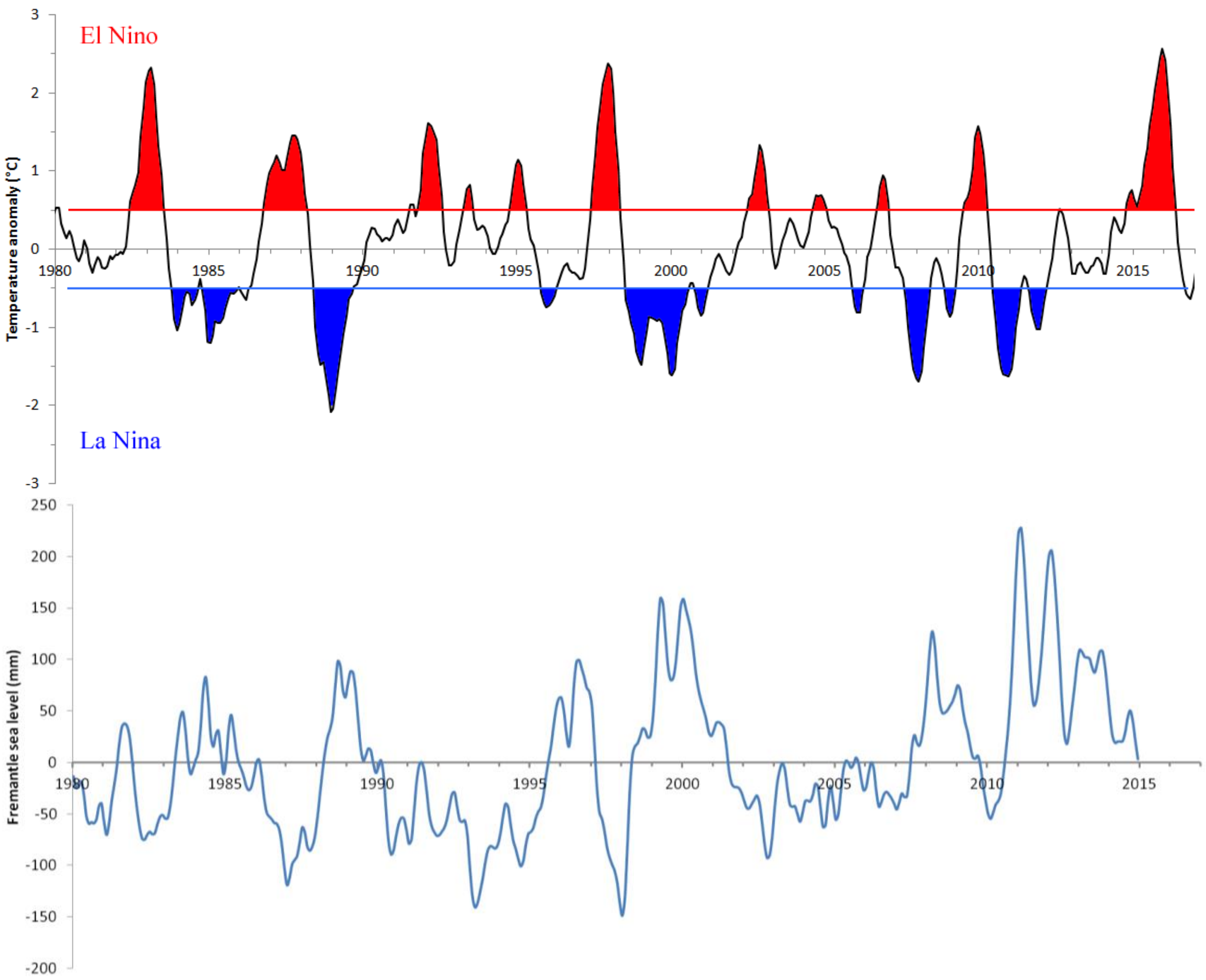
1. In line with Keesing et al. (2016), data is the monthly average anomaly for March from central northern Cockburn Sound.

Figure 3.11 Surface temperature anomaly in Cockburn Sound (1985–2017)

[5] *These predictions are based on a climate downscale product (10 km resolution) using the Ocean Forecasting Australia Model (Oke et al. 2008), a global ocean model that is eddy-resolving in the Australian region (Schiller et al. 2008). The downscaling was carried out for the 2060s decade, which is considered consistent with the present social and economic development in the world (Caputi et al. 2009).*

Superimposed on this long-term warming trend, inter-annual variation in ocean temperature off south-western WA is closely linked to the changing frequency and intensity of El Niño-Southern Oscillation events, which in turn influences the strength and volume of the Leeuwin Current. Higher coastal sea levels correspond to stronger Leeuwin Current flow during La Niña years, while lower sea levels correspond to weaker flow during El Niño years (Feng et al. 2003, 2004). During La Niña years, the strengthened Leeuwin Current transports warmer-than-normal water further south along the WA coast, resulting in higher ocean temperatures. During El Niño years, the weaker current is associated with lower ocean temperatures (Feng et al. 2013).

While observed El Niño-Southern Oscillation variability over the past few decades (Figure 3.12) is within the broad range of natural variability, the possibility that anthropogenic forcing has influenced this has not been ruled out (Poloczanska et al. 2012). Of concern for south-western WA coastal waters, recent modelling experiments project an increased frequency of extreme La Niña events under simulated future greenhouse warming, from an average of once every 23 years to once every 13 years (Cai et al. 2015). In the summer of 2011, WA coastal waters were affected by a marine heatwave, with temperatures rising up to 5ºC above average, causing mass death of marine life. This heatwave was primarily the result of the intense 2010–2011 La Niña event, which led to an unseasonable summer surge of the Leeuwin Current (Figure 3.12; Feng et al. 2013). In Cockburn Sound, the average March 2011 temperature anomaly was ~1.5ºC, the highest recorded value in the dataset (Figure 3.11). Summer temperatures in Cockburn Sound have since returned to background levels, particularly in conjunction with the El Niño conditions observed in 2015 and 2016 (Figure 3.11, Figure 3.12).



Sources: Top graph: NOAA (2017), Bottom graph: updated from Feng et al. (2013)
Notes:

1. Anomaly refers to a departure from a reference value or long-term average.
2. El Niño (La Niña) is a phenomenon in the equatorial Pacific Ocean characterised by five consecutive three-month running mean anomalies of sea surface temperature in the Niño 3.4 region that are above (below) the threshold of +0.5°C (-0.5°C). This standard of measure is known as the Oceanic Niño Index.
3. Fremantle sea level height (an indicator of the strength of the Leeuwin Current) tends to follow the Niño 3.4 sea surface temperature index, but with a delay of a few months—the time taken for the sea level change in the western Pacific to influence the strength of the Leeuwin Current near Fremantle.

Figure 3.12 Records from 1980 to present of a) sea surface temperature anomaly in the Niño 3.4 Region, and b) Fremantle sea level anomaly

Sea level rise

The rate of global sea level rise has significantly increased since the start of the 19th century and has been rising at the rate of ~3 mm/yr since the early 1990s (Church et al. 2013). Off south-western WA, the average sea level rising trend has been ~1.5 mm/yr over the past century, although there has been an acceleration in the past two decades, to ~5 mm/yr (Caputi et al. 2015b). This local increase is due to the overall global trend (a function of thermal expansion[6] and additional water flows into the oceans from melting ice; Rhein et al. 2013) and an increase in the strength of the Leeuwin Current over the past two decades (Figure 3.12; Feng et al. 2013, Caputi et al. 2015b).

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[6] *Ocean water expanding as it heats up due to a warming climate.*

A projected sea level increase of 0.9 m by 2110 has been adopted for planning purposes in WA (Bicknell 2010), and the potential impact of this increase on the Cockburn Sound region has been examined via recent coastal hazard modelling and mapping commissioned by the Cockburn Sound Coastal Alliance[7] (CSCA 2017). The CSCA was formed to develop and distribute knowledge pertaining to the vulnerability of the coastal zone and develop coastal management strategies to respond to climate change.

The CSCA study analysed existing coastal processes and dynamics within Cockburn Sound and assessed potential changes arising from sea level rises of 0.5 m (2070), 0.9 m (2110) and 1.5 m (2110+) and 1 year, 10 year, 100 year and 500 year average recurrence interval storm events (BMT Oceanica 2014). The maps of estimated areas of coastal erosion and inundation under these scenarios (see example of the Rockingham coastline at 2070; Figure 3.13) provide a critical tool for subsequent coastal adaptation planning that is currently underway by the CSCA.

Analysis of Cockburn Sound coastal processes with future sea level rise by Coastal Zone Management (CZM) et al. (2013) identified that sediment transport pathways (see Figure 4.3) are unlikely to change significantly with water levels up to 1 m above present level. However, it is expected that rising sea level may cause a decrease in onshore sand supply (e.g. Woodman Point and through South Channel) and a reduction in supply to downdrift coastal compartments (e.g. James Point and Rockingham Beach). With an increased sea level, the following three areas are anticipated to experience increased erosion: Woodman Point, the coast between James Point and the Kwinana Industrial strip, and Careening Bay (south of the naval facilities; CZM et al. 2013).

An examination of the existing and future risk of inundation (flooding) identified the Rockingham shore as having a high level of present inundation hazard (CZM et al. 2013). However, the potential increase in inundation zones due to sea level rise is generally small, because the height of coastal dunes is generally higher than the projected inundation levels (CZM et al. 2013). Notwithstanding this, the low back beach elevation at the Verve Energy flume canals, James Point and the facilities of BP Australia is likely to increase the inundation hazard with sea level rise (CZM et al. 2013).

The CSCA are continuing their Coastal Vulnerability and Flexible Adaptation Pathways project, aiming to further describe climate change – induced coastal hazards and develop adaptation strategies. Stage four of this project implements coastal adaptation actions and a comprehensive coastal monitoring framework. The results of this program will be a key indicator of the state of the Cockburn Sound coastal system.

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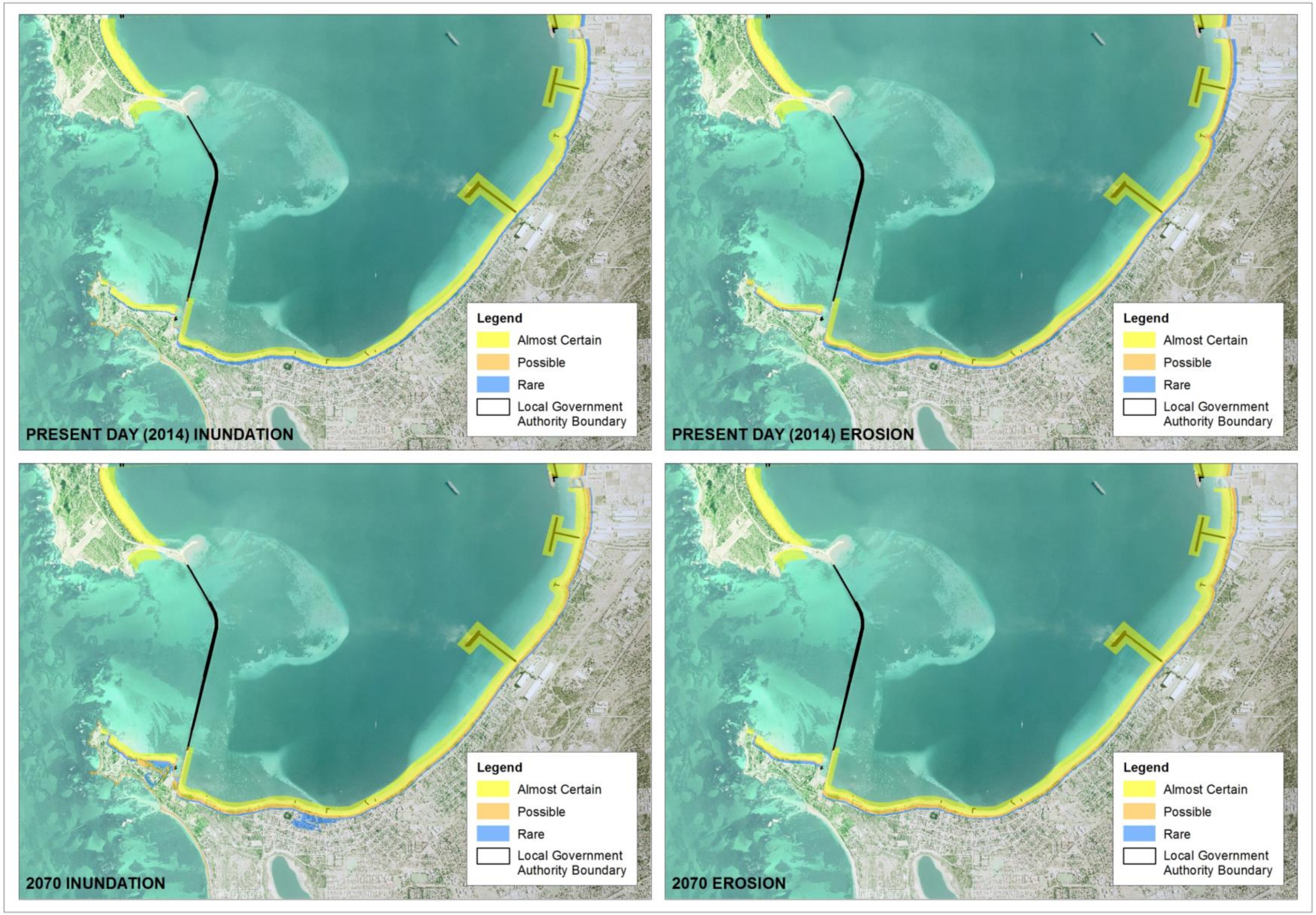
[7] *A partnership between the Cities of Cockburn, Fremantle, Kwinana and Rockingham, and Perth Region Natural Resource Management with support from the Departments of Transport, Planning, Lands and Heritage, Water and Environmental Regulation, the Cockburn Sound Management Council and the Department of Defence.*



Source: BMT Oceanica (2014)

Figure 3.13 Estimates of coastal inundation and erosion along the Rockingham coastline following a sea level rise of 0.5 m by 2070

Altered rainfall patterns

Since the mid-1970s, there has been a dramatic decline in rainfall in south-western WA, most notably during autumn and early winter (Li et al. 2005). Since the early 2000s, the reduction in early winter rainfall has intensified and expanded over a wide area (IOCI 2012). Autumn rainfall has also declined by 15% since 2000, with May now typically being a dry month over much of south-western WA (IOCI 2012). These declines have been driven by major changes in global atmospheric circulation and temperature, including reduced strength in the subtropical jet stream, a reduced temperature gradient between the equator and the South Pole, and an increased incidence of high pressure systems associated with dry winds blowing from the Australian interior (IOCI 2012).

Rainfall projections, downscaled from global climate models, suggest continued reductions this century for south-western WA. Modelling suggests there will be a 7% decrease in mean annual rainfall and a 14% reduction in surface water run-off in the period 2021–2050, relative to 1961–1990 (CSIRO & BOM 2015). As noted in Section 3.3.2, there are large groundwater flows into Cockburn Sound from aquifers that are recharged by rainfall and these flows would continue to fall as rainfall declines. The largest terrestrial nitrogen load into the Sound is now from groundwater discharge (Greenwood et al. 2016) and future reduced nutrient loads are likely under a drier climate.

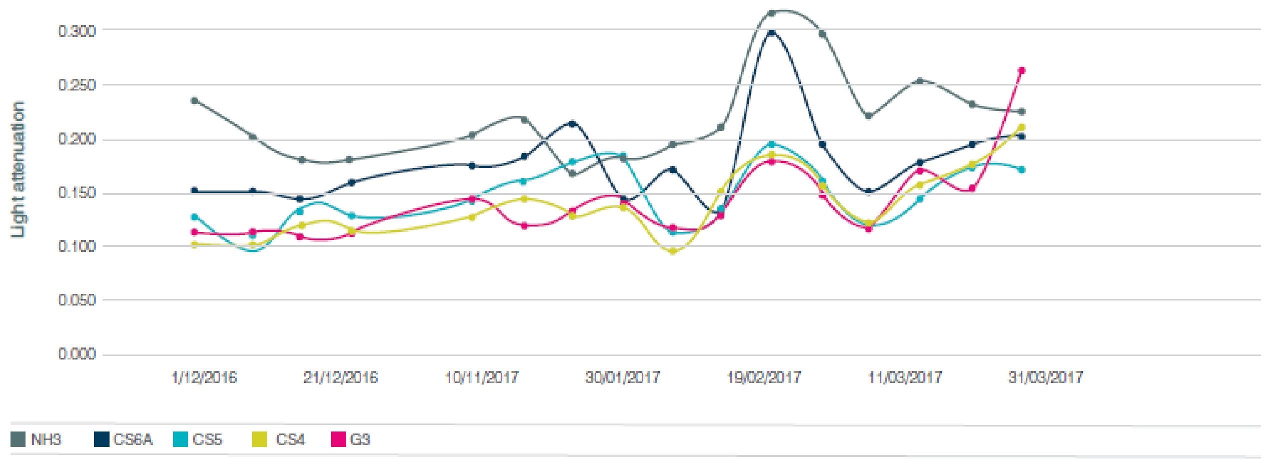
Changes in frequency and intensity of extreme weather or climate events

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 (IPCC 2012). Examples relevant to the Cockburn Sound region include heatwaves, heavy rainfall and coastal flooding. Extreme events are likely to be more common under a changing climate. For example, under a sea level rise scenario of 0.5 m, coastal flooding that is currently considered a 1 in 100 year event would occur every year in most parts of WA, and even more frequently in Perth (ACE CRC 2008, Steffen & Hughes 2013). Other weather events known to cause extreme water levels in south-western WA include extra-tropical or mid-latitude storms (Haigh et al. 2010), tropical cyclones (Fandry et al. 1984) and meteotsunamis (Pattiaratchi & Wijeratne 2015).

The most recent extreme weather event to affect Cockburn Sound occurred in January and February 2017, when unusually heavy rainfall flooded large parts of south-west WA (declared a natural disaster for the region by the Government of Western Australia; BOM 2017). Flooding in both the Avon and Swan River catchments resulted in a large plume of turbid fresh water extending well into Cockburn Sound (Figure 3.14). The discharge reduced surface salinities (~34.5–36.0 parts per thousand) and increased light attenuation (Figure 3.15). It is not possible to determine if this (or any) individual event was caused or exacerbated by a changing climate and projecting future changes in the characteristics and frequency of extreme events is an emerging area of climate science.

Source: Image reproduced by permission of the Western Australian Land Information Authority (Landgate) 2017

Figure 3.14 Swan River flooding event in February 2017



Source – Cockburn Sound Management Council

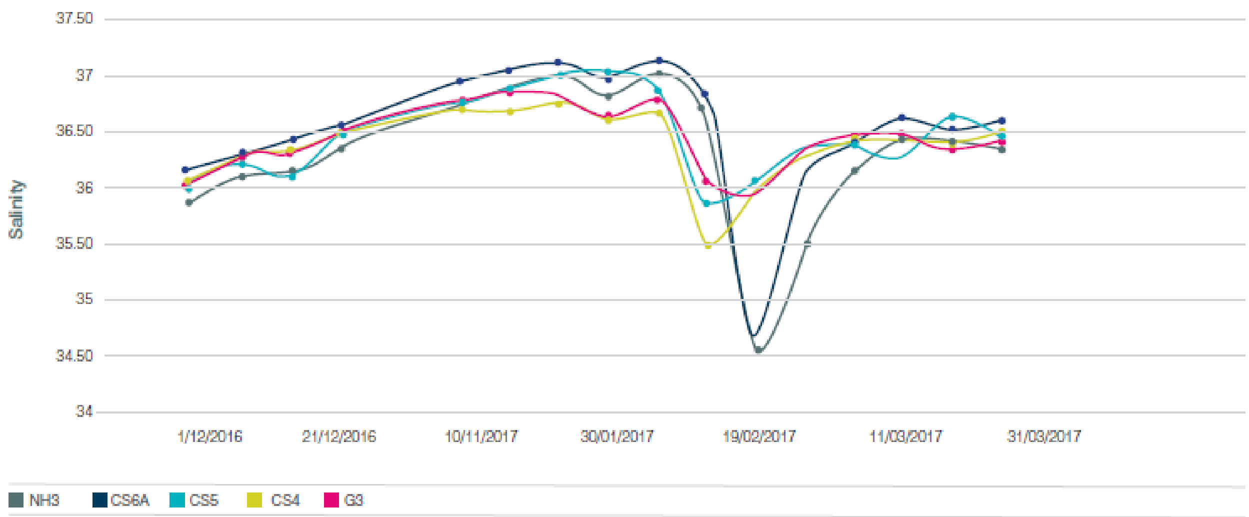


Figure 3.15 Salinity (parts per thousand) and light attenuation across the northern boundary of Cockburn Sound during the summer of 2016/2017

Ocean acidification

The ocean is becoming more acidic (measured as declining pH) as an increasing amount of atmospheric carbon dioxide is absorbed by surface waters. Acidity of surface waters has increased by ~30% (0.1 pH units) since 1950 (Dore et al. 2009), and is affecting the growth of corals and other marine organisms because it reduces the concentration of carbonate ions available to build their skeletons. In Cockburn Sound, measurements of pH have been recorded since 2005 and range from 8.10 to 8.31 in surface waters. However, these records are of insufficient duration and accuracy to allow for an evaluation of climate-induced pH changes in Cockburn Sound waters.

3.9 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 3.1 illustrates the numerous major physical alterations to the coastline and sea floor.

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 KIA. 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 remain protected.

4. Current State of Cockburn Sound – Impacts and Trends

4.1 Synopsis

'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 that have already influenced the marine environment, or show potential to reshape it in the future, is provided in Table 4.1. The table includes an assessment of trends, impact grades, confidence in presently available data and comparability of presently available data to 2001 data.

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 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.

Assessment key for Table 4.1

Recent Trend	Impact grade	Confidence in assessment	Comparability of data to 2001
Improving	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	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 a high level of consensus	Somewhat comparable: Grade and trend are somewhat comparable to the previous assessment
Declining	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	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	Not previously assessed: Grade and trend not previously assessed
	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.		

Source: Assessment key derived from Evans et al. (2017)

Table 4.1 Assessment summary of state of Cockburn Sound

Ecosystem element	Component	Summary	Recent trend	Assessment grade	Confidence	Comparability of data to 2001
Hydrodynamics	Marine water movements	The construction of the Garden Island Causeway had a material impact on the hydrodynamics of the southern portion of the Sound, while the construction of Northern and Southern Harbours and the AMC complex has changed currents at the northern end of the eastern margin. Other structures (jetties and small groynes) and discharges of cooling water and desalination brine have created localised changes in water movement, but not whole-of-Sound scale impacts.	⊟	🟧	●	◆
Coastal processes	Coastal processes	Because of the causeway and other significant structures, coastal processes which lead to net sediment transport remain in a modified state of long-term flux. Several areas of present and future erosion and inundation have been identified.	↙	🟧	●	◆
Ecosystem health	Phytoplankton primary production, composition and toxicity	Very little is known of phytoplankton production rates or local ecological value across the Sound, although cell density and species composition have shifted since the mid-2000s.	?	🟧	◒	◆
	Benthic primary producers	The lack of conformity among lead indicator trends means it is not possible to provide a confident conclusion on the overarching state of seagrasses in Cockburn Sound, although it is reasonable to assume that seagrass losses in Cockburn Sound have stabilised and may have reached a new equilibrium which is being expressed as dynamic fluctuations in natural growth patterns.	?	🟧	●	◆
	Water quality	Management of nutrient inputs has reduced the in-water TN 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.	↗	🟨	●	◆
	Sediment quality	Nutrient release from organic-rich sediments may be a significant contributor to the maintenance and variability of pelagic phytoplankton biomass in Cockburn Sound. While sediment monitoring demonstrates environmental protection requirements are typically being met, toxicants are regularly detected, albeit in localised areas such as ports.	?	🟧	◒	⬘
	Ecosystem integrity	The overall ecosystem integrity of Cockburn Sound may generally be characterised as a marine system modified by historic nutrient enrichment (eutrophication) and seagrass loss.	?	🟧	◒	X
Marine fauna	Benthic macrofauna	It is evident that there have been marked decadal changes in the benthic macrofauna communities of the Sound, however, it is not clear if their functional and ecological role has experienced a similar shift.	?	🟧	◒	⬘
	Fish and fish communities	Habitat loss is likely to have led to long-term changes in fish assemblages of Cockburn Sound, however, the link has never been quantified or appropriately documented. Fish kills associated with reduced water quality have also been known to occur.	?	🟧	◒	◇
	Little penguins	Garden Island supports an estimated colony of 180–200 penguins. In this colony, the population abundance appears stable, primarily due to strong success with nesting behaviours.	⊟	🟨	◕	◇
	Dolphins	The size of the dolphin community in Cockburn Sound appears to have remained stable for the past two decades.	⊟	🟨	●	◆
	Protected marine fauna	While several species of protected marine fauna occasionally occur in Cockburn Sound, they are infrequent visitors and do not have habitat affiliations with Cockburn Sound.	⊟	🟨	●	◆
Recreation and aesthetics	Recreational use of the coastal environment	Further study is required to characterise whether the coastal environment is of sufficient quality to maintain or enhance contemporary visitation uses of coastal areas.	?	🟧	◒	◇
	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 broadscale exceedances of relevant water quality guidelines.	⊟	🟨	●	◇
	Aesthetic values of Cockburn Sound	Annual monitoring occasionally detects localised algal blooms, surface films and objectionable odours, but rarely to the extent that the overall aesthetic value of Cockburn Sound is considered compromised.	⊟	🟨	◒	◇
Cultural and spiritual values	Indigenous culture and heritage	Without tangible 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	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).	⊟	🟨	●	◆

4.2 Wave climate and circulation

Cockburn Sound is located in a microtidal region with a spring tide range of ~60 centimetres (DEP 1996, NTF 2000). The influence of non-tidal sea level processes can be comparable in scale to tidal effects, including seasonal and inter-annual mean sea level variations, storm surge, continental shelf waves, seiching, meteotsunami and inter-annual tidal modulations (Pattiaratchi & Eliot 2008). The Sound typically experiences a strong diurnal land–sea breeze cycle during summer and more variable conditions over winter including storm events, in which mild north-easterly winds swing towards intense westerly winds.

4.2.1 Wave climate

The prevailing offshore waves are dominated by a south-westerly swell with a median significant wave height of 1–2 m during summer and 2–3 m during winter (Lemm et al. 1999). The swell wave energy decreases southward into the Sound with a concomitant change in the direction of wave approach at the shoreline from westerly to northerly. Wind waves within Cockburn Sound may be generated by storms (resulting in westerly and north-westerly waves), sea breezes (south to south-westerly waves) and land breezes (resulting in easterly waves). The energy of wind waves in the Sound is also a function of the fetch (amount of open water) the wind acts upon.

Wave conditions along the broader south-west coast are indirectly related to the observed wind patterns, with predominant waves generated by mid-latitude systems propagating from the south-west, resulting in a prevailing south-west swell offshore. Wave height outside the Garden Island ridge has been recorded since 1994, and wave direction since 2004 using a permanent wave-rider buoy offshore from Rottnest Island (Lemm et al. 1999, Li et al. 2009). Offshore waves typically have a 1–2 m median significant wave height during summer, and 2–3 m during winter, with larger waves during westerly (south-west through north-west) storm events (Roncevich et al. 2009).

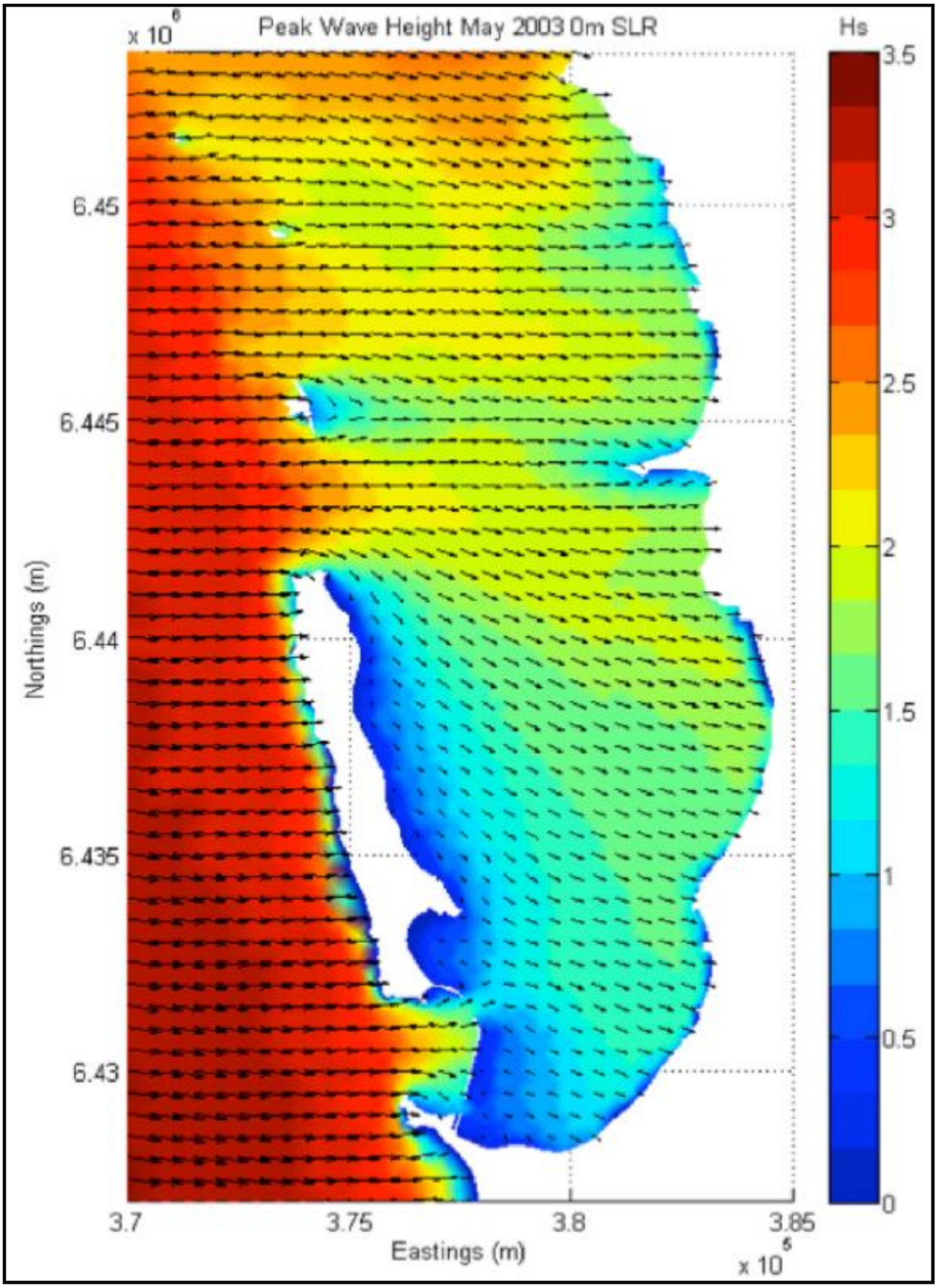
The offshore waves are modified by diffraction around islands and breaking across the extensive limestone reef chains and platforms before they reach the shore (e.g. Figure 4.1). Additional wave energy is added by local winds; the most distinct are produced by strong south-westerly sea breezes (Pattiaratchi et al. 1995). The Cockburn Sound coastline has a variable wave climate as a result of sheltering by Garden Island and the outer reefs. Variable wave fetches within Cockburn Sound provide local changes in prevailing and dominant wave conditions, resulting in local divergences in the mean direction of incoming waves (Travers 2007).

4.2.2 Circulation

Cockburn Sound circulation and exchange processes are driven at timescales ranging from diurnal to annual by winds (including storm events), coastal currents, estuarine discharges and differential heating and cooling. Natural hydrodynamics within the Sound have also been heavily influenced by development, in particular the presence of the Garden Island Causeway. Three distinct hydrodynamic regimes have previously been identified in Cockburn Sound based on the relative importance of wind and pressure gradients in determining circulation patterns and flushing (DEP 1996):

- 'summer' (~December–March)
- 'autumn' (~April–July)
- 'winter–spring' (~August–October.

Additional insight into these seasonal patterns has been gained through updated three-dimensional hydrodynamic modelling of Cockburn Sound (validated for temperature, salinity and velocity; Okely et al. 2007a,b, Antenucci et al. 2009, Harris & Antenucci 2009; e.g. Figure 4.2).



Source: CZM et al. (2013)

Figure 4.1 Example of attenuation of wave energy by reefs and islands during storm conditions (May 2013)

During summer, wind dominates the circulation within Cockburn Sound, and generates net northward flow in the upper ~10 m of the water column. Strong and persistent sea breezes ensure that waters are vertically mixed every ~1–2 days (DEP 1996). Wind-driven flows along the eastern margin of the Sound return southward along the east coast of Garden Island, creating an anticlockwise gyre in the northern portion of the Sound (Figure 4.2). Smaller clockwise gyres are also predicted in the southern end of the Sound and on the northern section of the Eastern Shelf (Figure 4.2; Harris & Antenucci 2009). During summer, much of the water exchange between Cockburn Sound and coastal waters to the north is driven by transient, two-layer exchange flows forced primarily by local wind stresses (Ruiz-Montoya & Lowe 2014).

In autumn, depth-averaged currents are typically weaker and more variable than in summer (Figure 4.2), with less frequent vertical mixing due to the reduced wind energy. Basin waters have a higher density due to higher salinities following summer evaporation, and lower water temperatures following differential cooling (DEP 1996). On the Eastern Shelf, flows are generally northwards, but with a clockwise gyre still persistent on the north of the shelf. Smaller-scale circulation cells may form during the autumn, including an anticlockwise gyre in the southern half of the Sound, driven by the residual currents through the Garden Island Causeway (Figure 4.2; Harris & Antenucci 2009).

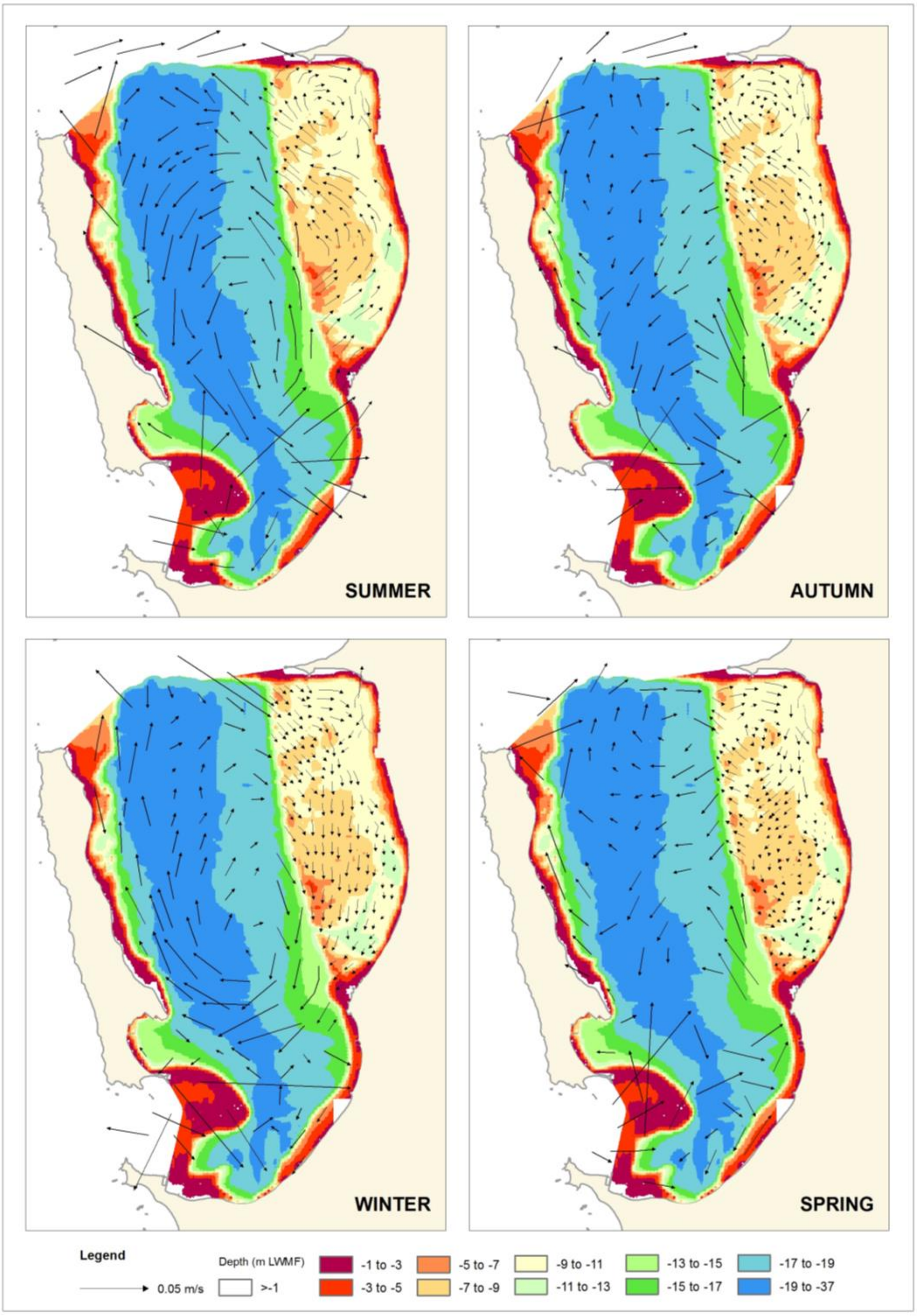
During the winter–spring period, the dynamics of the Sound are typically influenced by the passage of storm systems at 7–10 day intervals (with wind magnitudes sufficient to fully mix the water column) and an increase in the buoyant discharge from the Swan River. During winter, a reversal of circulation occurs due to northerly winds, setting up a clockwise-rotating gyre in the main basin of the Sound and a strong southward flow on the Eastern Shelf (Figure 4.2). In spring, the wind is less dominant and horizontal pressure gradients have a greater influence on circulation, resulting in reduced and more variable currents throughout the Sound (Figure 4.2; Harris & Antenucci 2009). Relatively low residual velocities and a complex flow pattern are observed on the Eastern Shelf, with a clockwise gyre in the northern region and a lower-velocity anticlockwise gyre in the central region (Figure 4.2). Between storm events, Cockburn Sound's surface mixed layer is typically 5–10 m deep, with intermittent weak vertical stratification during periods of light winds (DEP 1996).

Flushing times for Cockburn Sound calculated from hydrodynamic modelling undertaken for Fremantle Ports and Water Corporation are estimated at 24 days in summer, 31 days in autumn, 26 days in winter and 47 days in spring (Antenucci et al. 2009, Harris & Antenucci 2009). The long flushing times in spring coincide with low residual velocities throughout the Sound during this season (Harris & Antenucci 2009). Regional-scale fluctuations of the alongshore pressure gradient, such as the propagation of coastally trapped waves down the WA coast, can also affect the local exchange and flushing of Cockburn Sound (Ruiz-Montoya & Lowe 2014).

Changes to Cockburn Sound circulation have been caused by:

- A modelling study found that the Garden Island Causeway (constructed in 1972) was likely to have significantly affected currents in the Sound within 1–2 km of the causeway (DALSE 2003). The predicted impacts were significantly reduced flushing in Mangles Bay and increased current velocities through the bridge openings. The causeway was not predicted to affect the northern basin of the Sound or the eastern margin.
- During World War II, the shipping channel through Success and Parmelia Banks into the north end of the Sound was first dredged to allow naval vessels and submarines to access the Sound. Although the effects of the current channel have never been studied, the effects of widening this channel as part of the Cockburn Cement shellsand dredging program were investigated (DAL & PHC 2000). It can be inferred from the results that the existing channel allows increased exchange between the northern end of the Sound and Owen Anchorage.
- Modelling for this region has found that the Jervoise Bay Northern and Southern Harbours and the AMC complex have reduced flushing within harbour waters and changed currents in the vicinity. However, they have not changed circulation in the broader part of Cockburn Sound (e.g. HGM 1997, Wright 2000, APASA 2004).
- Relatively small-scale changes to shorelines and bathymetry, through construction of the Naval Base, jetties, small groynes and dredging of channels on the eastern margin will have

had very 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.



Source: modified from Harris and Antenucci (2009)

Notes:

1. LWMF = low water mark Fremantle
2. These residual currents represent the net movement of water over all depths of the water column for 90-day periods. They are an accurate representation of the overall average circulation of the Sound.
3. A twofold, nested grid set-up was used for the model—a 100 m by 100 m grid resolution within the main Cockburn Sound basin, and a 50 m by 50 m grid resolution on the Eastern Shelf.

Figure 4.2 Modelled seasonal residual current velocities within Cockburn Sound

4.3 Coastal processes

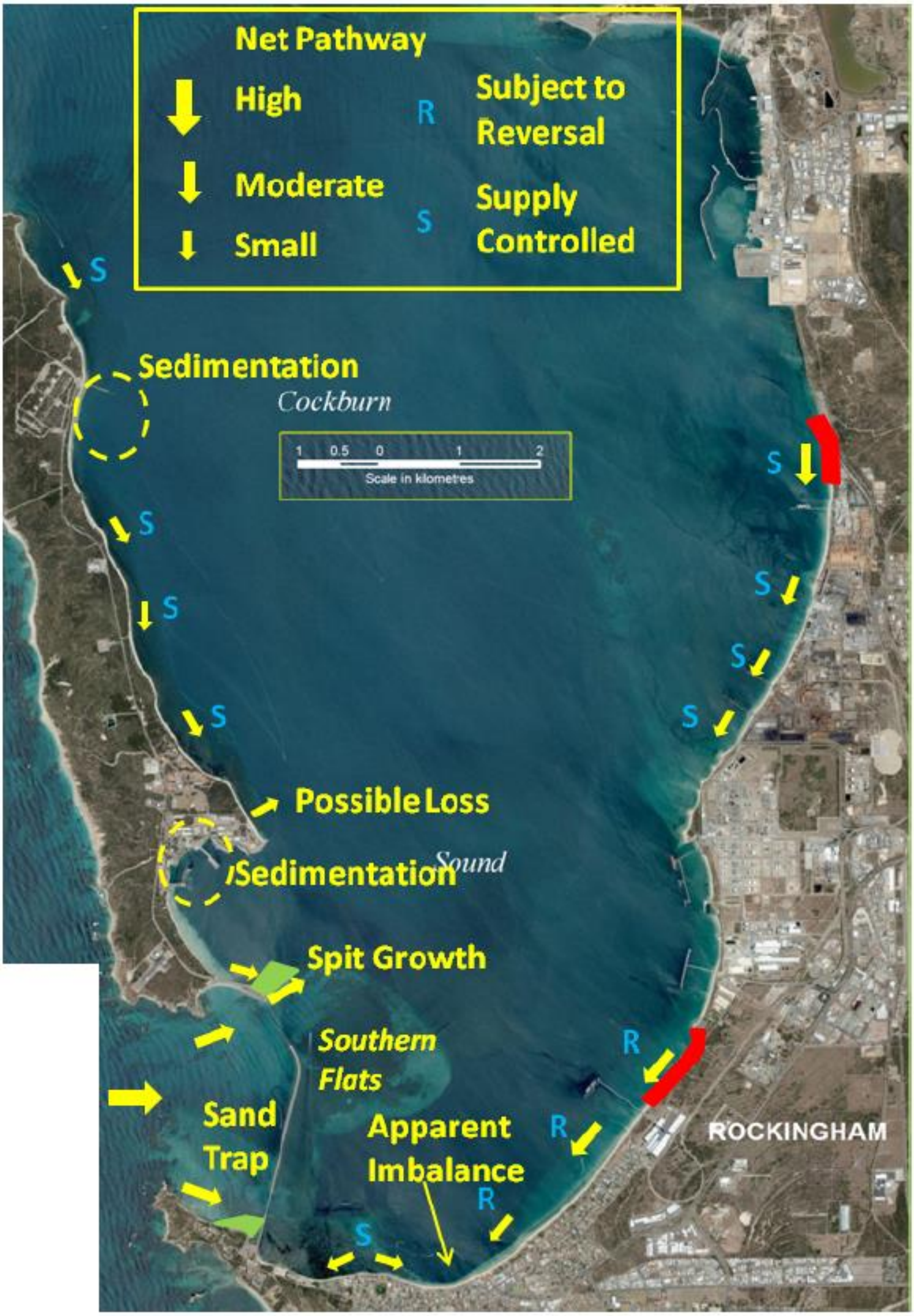
The complex geology and geomorphology of Cockburn Sound play an important role in controlling coastal processes and long-term sediment transport pathways (CZM et al. 2013). These broadscale controls have been highly modified at a local level, through the placement of coastal structures and dredging/nourishment activities which can cause significant local shoreline changes within the Sound (Section 3.6). Due to the low-energy environment, there can be a significant lag in the coastal response to these interventions (DAL 2001, Stul et al. 2007, BMT Oceanica 2014).

The interplay between the energy of the swell and wind waves determines the dominant sediment transport direction at the shoreline such that net sediment transport is generally southward in the north of the Sound and northward in the south, with a small net southerly trend resulting in accretion on the northern flank of James Point (Figure 4.3; DOT 2009). Along the east coast of Garden Island sediment net transport is generally southward driven by the penetration of swell wave energy.

The major sediment transport pathways into Cockburn Sound are onshore sediment feed across Parmelia Bank and through the northern and southern gaps in the Garden Island Causeway (Figure 4.3). The sediment feed from the south of Garden Island has caused significant coastal changes. Westward sediment transport has depleted sand from Broun Bay and resulted in the accumulation of a sandbank at the northern end of the Southern Flats (see Figure 3.1 and Figure 4.3) (MP Rogers and Associates 2011a,b). The westward sediment transport in the vicinity of the causeway has caused significant accretion along the Point Peron shoreline, which has been managed through the placement of groynes and regular excavation as a source for shoreline nourishment within the Sound (see Section 3.5.2).

The installation of the Garden Island Causeway in 1972 also changed the relative balance between swell and sea wave energy and caused significant changes to the shoreline at James Point. Since 1979, a series of seven offshore breakwaters have been placed at James Point to provide shoreline stabilisation and minimise the southward transport of sediment (CZM et al. 2013). Other shoreline changes within Cockburn Sound (east of the causeway) have generally been of a smaller scale and are associated with a localised response to adjacent coastal structures or nourishment works (BMT Oceanica 2016d). Recent analysis of shoreline position in Cockburn Sound using available aerial photography (1942–2015), indicates that the shoreline has had some incidences of notable erosion and accretion, but overall has been relatively stable (BMT Oceanica 2016d). The greatest changes over this period were observed in the vicinity of the causeway and Point Peron groynes, where considerable accretion has occurred. Other areas of relatively active shoreline change include Verve Energy flume canals, BP Flume, Small Boat Harbour and Kwinana Beach.

An analysis of coastal hazards (CZM et al. 2013) identified three areas of existing acute erosion hazard in Cockburn Sound: Garden Island north of Colpoys Point, Palm Beach and the Kwinana Bulk Terminal. Two areas with anticipated severe long-term erosion were identified: Woodman Point and KIA. The historic shoreline erosion along the Kwinana Industrial strip and at Kwinana Beach has also been recognised by DOT and these areas have been identified in a register of WA coastal erosion hotspots (Stead 2016).



Source: CZM et al. (2013)

Notes:

1. '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.
2. 'Supply controlled' refers to sediment availability. This occurs where there is only a limited quantity of sediment available to be transported i.e. sediment transport is controlled by supply of sediment.
3. Red blocks are sediment sources, with potential for erosion.
4. Green blocks are locations of sediment accretion.

Figure 4.3 Cockburn Sound indicative sediment pathways

4.4 Water quality

Physico-chemical properties of the water column

DO concentrations are typically high in Cockburn Sound waters, but there is a seasonal reduction as seawater temperature increases, with the lowest DO concentrations occurring in February (Keesing et al. 2016). In general, this is not sufficient to exceed the environmental quality guidelines for DO in Cockburn Sound (CSMC 2013). However, elevated water temperatures associated with an abnormal heat wave (see Section 3.8) for >8 weeks in the summer of 2011 (February to mid-March) reduced DO concentrations across the Sound to as low as 3.12 mg/L in the deep southern basin (Rose et al. 2012). No instances of dead fish or other biota were reported during this event, but low DO could increase susceptibility of seagrass to stressors and enhance the release of nutrients/contaminants from the sediments. Therefore, temperature-related effect on DO concentration requires careful consideration in the development of management strategies related to climate change (see Section 3.8).

Stratification within the Sound is naturally driven by both salinity and temperature gradients which are, in turn, created by local and regional seasonal meteorological and oceanographic (met-ocean) events (D'Adamo 2002). Stratification is generally weak and regularly eroded by strong winds, which occur most often as summer sea breezes (DEP 1996). Because discharges from the Perth Seawater Desalination Plant also have the potential to influence stratification events, discharge from the plant has been subject to extensive post-commissioning monitoring (according to DWER Licence L8108/2004/4 and MIS conditions in Ministerial Statements 655 and 832). This monitoring has demonstrated that brine discharge and stratification does not reduce oxygen concentrations in the deep basin of Cockburn Sound. While median bottom salinities at two sites (CS9 and CS12) in close proximity to the discharge outlet have exceeded the salinity environmental quality guideline (EQG; defined as no significant change beyond natural variation) regularly since the 2006–2007 monitoring period (following plant commissioning in 2006; CSMC 2016b), these salinity exceedances appear to be localised. During the same period, the DO EQG was only exceeded on one occasion, which was at CS9 over the 2015–2016 non-river-flow period. However, there were no reports of marine organism deaths during the periods of low DO concentrations that may have been attributable to deoxygenation, or, anthropogenically-sourced salinity stress (CSMC 2016a). Basin-scale surveys completed prior to construction and repeated in 2009 and 2013, have been unable to identify any change in the distribution or abundance of benthic infauna over the period the plant has been operating (Oceanica 2013). The Office of the EPA (now DWER) concluded that the monitoring had adequately demonstrated that the risk of low-DO events was low and that the real-time monitoring required under condition 8-1 of Statement 832 was no longer required.

Biological indicators of water quality

Productivity in WA coastal waters is strongly limited by the availability of nitrogen (e.g. Lourey et al. 2006) and measures to improve water quality in Cockburn Sound have centred on the reduction of nitrogen inputs (e.g. DEP 1996). Point source industrial discharges, once the predominant source of anthropogenic nitrogen to the Sound, have been reduced from around 1800 t N/yr in 1978 to a negligible amount in 2017 (Section 3.1). Load reductions have resulted in the in-water TN concentrations in the Sound falling from a median concentration of ~500 micrograms per litre (µg/L) in 1985 to ~100 µg/L in 2016 (Figure 4.4; MAFRL 2017). Over the same time, concentrations of the total dissolved inorganic nitrogen fraction (ammonia, nitrate and nitrite)[8] have fallen from around 20 µg/L to concentrations that are typically below the analytical limit of reporting (3 µg/L; Figure 4.4; MAFRL 2017). The stepwise reductions in 1990–1993 and

[8] *The fractions of nitrogen used by phytoplankton and algae for growth.*

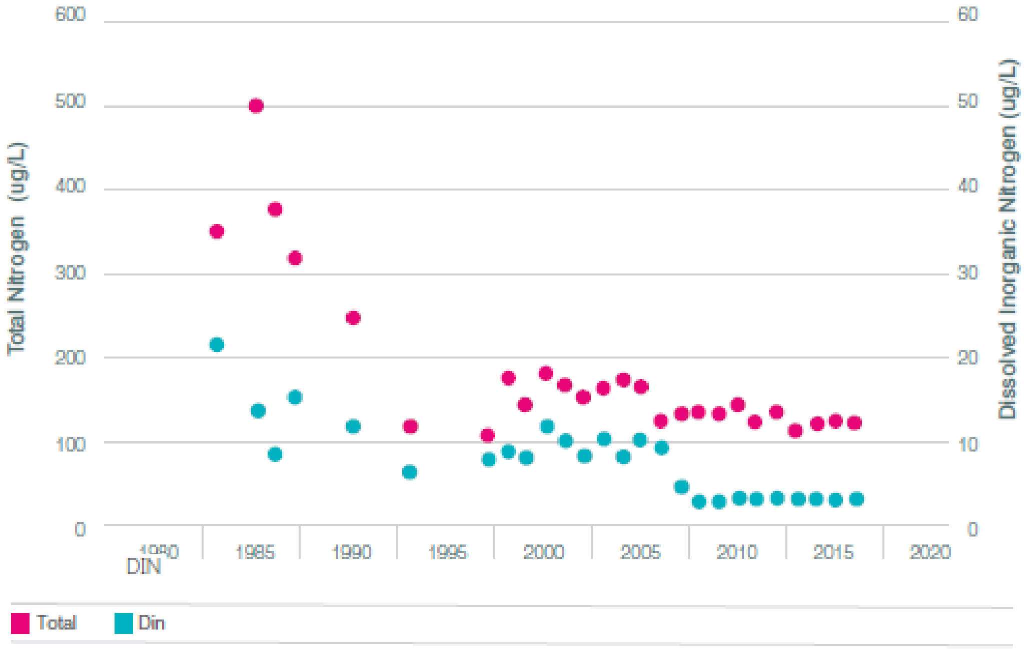
2006–2008 (Keesing et al. 2016) coincide with the diversion of Woodman Point treated wastewater and select industrial discharges to offshore ocean disposal. It has been suggested that the Sound switched from having nitrogen inputs that were surplus to overall water-column demand (by 160 t N/yr) in 1978 to an apparent deficit between supply and demand (of at least 550 t N yr) in 2000 (Greenwood et al. 2016).

On average, the highest nutrient concentrations in Cockburn Sound are found in Northern Harbour and Mangles Bay, due to poor flushing and exchange (Keesing et al. 2016). Northern Harbour has a long history of poor water quality arising due to close proximity to sources of contaminated groundwater, in addition to the poor mixing due to the breakwaters.

Despite the large reductions in nitrogen availability, phytoplankton biomass has not responded in an obvious or predictable manner (Mohring & Rule 2013, Keesing et al. 2016). In the late 1970s to early 1980s, median chlorophyll-a concentrations exceeded 2 µg/L (Cary et al. 1995). Chlorophyll-a concentrations dropped to ~1 µg/L in the mid-1980s, before again increasing to ~2 µg/L in the mid-1990s (Figure 4.5). Since then, chlorophyll-a concentration has generally decreased to ~1 µg/L. Phytoplankton cells in the water column contribute to the attenuation of light by particles in the water column (a key requirement for seagrass health) so the light attenuation coefficient has mostly followed variations in chlorophyll-a concentrations over time (Cary et al. 1995; Figure 4.5).

Significant historical water column nutrient stress (i.e. eutrophication) can lead to significant legacy nutrient concentrations held in sediments. Nutrient recycling could maintain phytoplankton growth long after the external pressures have been relieved. Nutrient resupply from sediments and rapid uptake by the pelagic algal community could sustain phytoplankton biomass (chlorophyll-a concentration) in the absence of measurable dissolved nutrient concentrations. Evidence of this is already cited in Keesing et al. (2016) where bottom waters in deep sections of Cockburn Sound had elevated concentrations of nitrogen and phosphorus compared to the surface, as would be expected from sediment nutrient resupply at depth (Keesing et al. 2016).

While the temporal relationship between nutrient load and overall pelagic chlorophyll-a concentration is not straightforward, there does appear to have been a general reduction in the spatial variability of chlorophyll-a concentration over time (Figure 4.5). The deviation around the mean in each sampling year has reduced over time, suggesting that there has been a reduction in the variability between sampling sites. The reduced spatial variability may be due to changes in the spatial distribution of nitrogen inpus as diffuse groundwater sources increased in relative importance over point source industrial outlets.

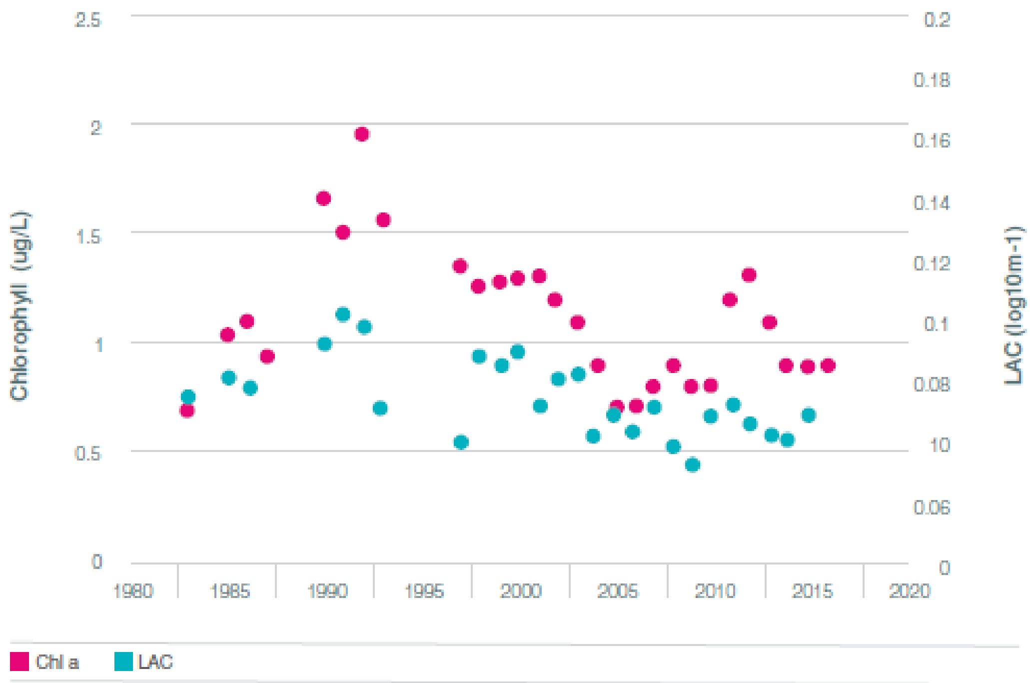


Source: MAFRL (2017)

Note:

1. DIN = Dissolved inorganic nitrogen

Figure 4.4 Median TN and dissolved inorganic nitrogen concentrations in Cockburn Sound



Source: MAFRL (2017)

Note:

1. Chl a = Chlorophyll-a; LAC = Light attenuation coefficient

Figure 4.5 Median chlorophyll-a concentration and light attenuation coefficient in Cockburn Sound

Toxicants in marine waters

Concentrations of potential toxicants in Cockburn Sound were last comprehensively assessed in 2008 (PB 2009). Concentrations of potential contaminants were below their environmental quality criteria (EQC) values (where available) for both moderate and high ecological protection areas. A further 70 potential toxicants without guidelines were mostly below their respective detection limits or limits of reporting, or present at low concentrations. Contaminants with concentrations above the limit of reporting but with no EQC were within accepted international standards where available (PB 2009).

4.5 Sediment quality

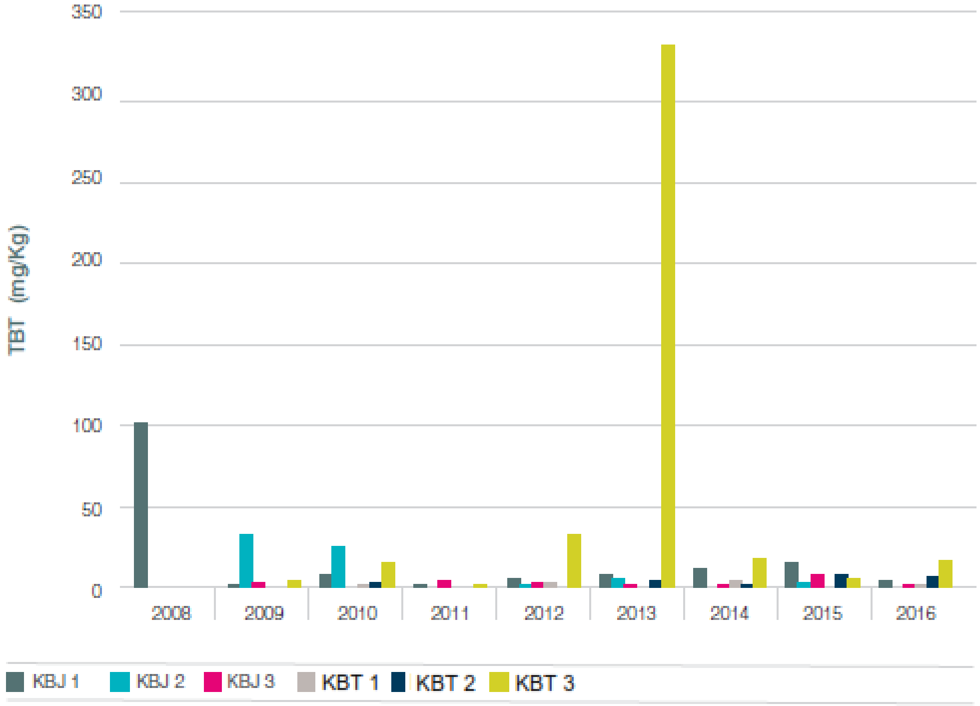
Organic matter content is highest in the fine and silty sediments that accumulate in the deeper, low-energy areas of the Sound. These organically enriched areas accrue particles originating from biota (e.g. dead plankton, faecal material) and typically have a higher nitrogen and phosphorus content—which could contribute to the maintenance of pelagic chlorophyll concentrations in the Sound. Determining whether organically enriched sediments are contributing to phytoplankton dynamics is limited by our present understanding of nutrient release from sediments in Cockburn Sound (also see Section 4.4). However, reductions in nutrient inputs should ultimately reduce the accumulation of organic matter in sediments and, in turn, sediment nutrient fluxes. Such reductions are likely to be slowest in areas such as the Jervoise Bay Northern Harbour where there is limited flushing.

Organotin compounds (TBT and its degradation products, dibutyltin and monobutyltin) are consistently present in Cockburn Sound sediments, particularly in areas around port infrastructure and jetties (Oceanica 2006). Broadscale spatial surveys have consistently found the highest concentrations in the enclosed harbour structures in Jervois Bay and around the naval facility at Careening Bay (DOW 2006, Oceanica 2006). A recent survey of the deep basin of the Sound found TBT concentrations were mostly at or near their limit of reporting (Oceanica 2013). Routine monitoring of sediments from the area surrounding the Kwinana Bulk Terminal and Jetty clearly demonstrates the small-scale heterogeneity in sediment TBT contamination. Temporal trends are small relative to the variability between sites due to sampling TBT hotspots in the sediments (Figure 4.6). TBT hotspots within otherwise low contamination areas are common (Oceanica 2006) and are governed by variations in the release over time from different sized vessels with different coating histories and subsequent dilution and dispersal. Once in sediments, TBT compounds are resilient and hotspots of TBT contamination around relevant infrastructure are expected to persist for some time.

TBT has been replaced by antifouling technologies that mostly use copper as the active ingredient but paints may also contain additional biocides such as zinc pyrithione or organic algaecides (see Section 3.6.3). Within the deep basin of the Sound, sediment copper or zinc concentrations did not exceed the ANZECC and ARMCANZ (2000) Interim Sediment Quality Guideline-Low trigger values at any location (Oceanica 2013). Copper and zinc concentrations, along with most other metals (aluminium, cobalt, lead, mercury, molybdenum, nickel and vanadium) were generally higher in the southern area of the Sound than in northern waters. This is likely due to a higher silt and clay content (smaller sized particles have higher surface area for adsorption) rather than a contamination source in the vicinity. Concentrations of copper around shipping-related infrastructure were occasionally elevated at individual sites, consistent with their use as biocides in antifoulants, but like TBT were highly variable between sites (Figure 4.7). Copper and zinc compounds are the biocides used by the Royal Australian Navy in their TBT-replacement paints. While concentrations of these metals were higher in their harbour precinct than outside, concentrations in mussel flesh do not appear to have increased with the overall use of these copper/zinc-based coatings (Lewis et al. 2010).

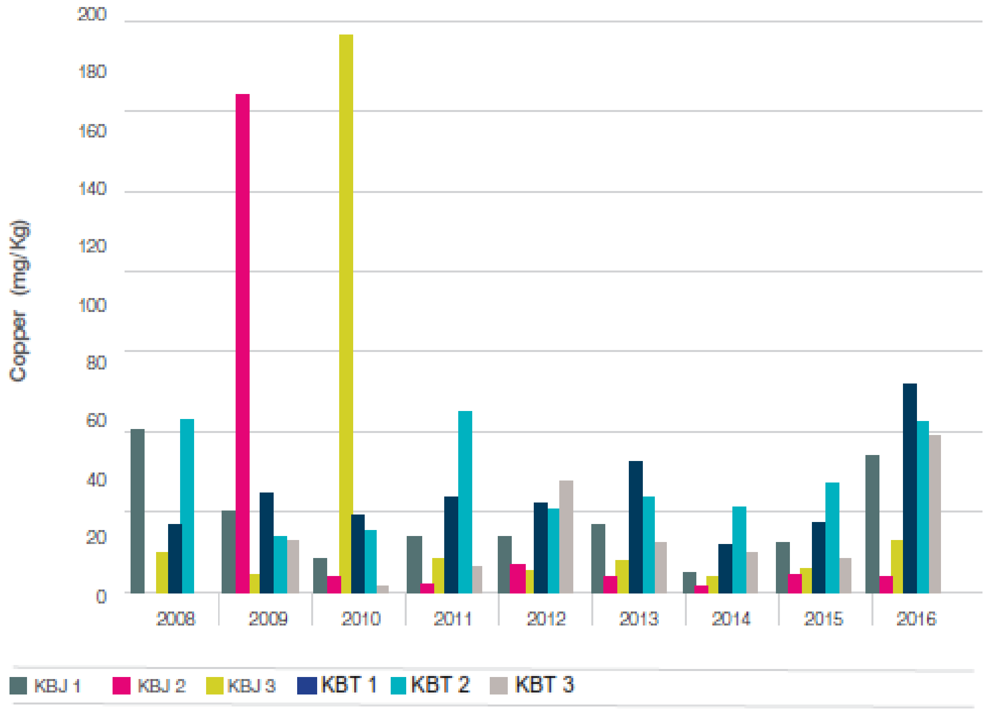
Concentrations of other contaminants in sediments are low. In the deep basin of the Sound, there were no exceedances of the ANZECC and ARMCANZ (2000) Interim Sediment Quality Guideline-Low trigger values for any metal with a guideline available (antimony, arsenic, cadmium, chromium and mercury). Concentrations of most hydrocarbons and organochlorine pesticides were generally below the analytical limits of reporting but some individual sites had detectable concentrations (Oceanica 2013). These contaminants represent a low risk to ecosystem health in Cockburn Sound.

Recent investigations have detected PFAS compounds in localised areas of soil and groundwater on Garden Island (associated with Department of Defence firefighting activities; see Sections 3.3.1 and 3.3.2). To date, PFAS has not been detected in the marine environment of Cockburn Sound but is the subject of ongoing study. Since PFAS are an emerging family of contaminants, research is still being conducted across the world into the potential impacts on people's health and the environment.



Source: Data supplied by Fremantle Ports
Note:
1. KBJ = Kwinana Bulk Jetty; KBT = Kwinana Bulk Terminal

Figure 4.6 Sediment tributyltin concentrations near Kwinana Bulk Jetty and Kwinana Bulk Terminal



Source: Data supplied by Fremantle Ports

Note:

1. KBJ = Kwinana Bulk Jetty; KBT = Kwinana Bulk Terminal

Figure 4.7 Sediment copper concentrations near Kwinana Bulk Jetty and Kwinana Bulk Terminal

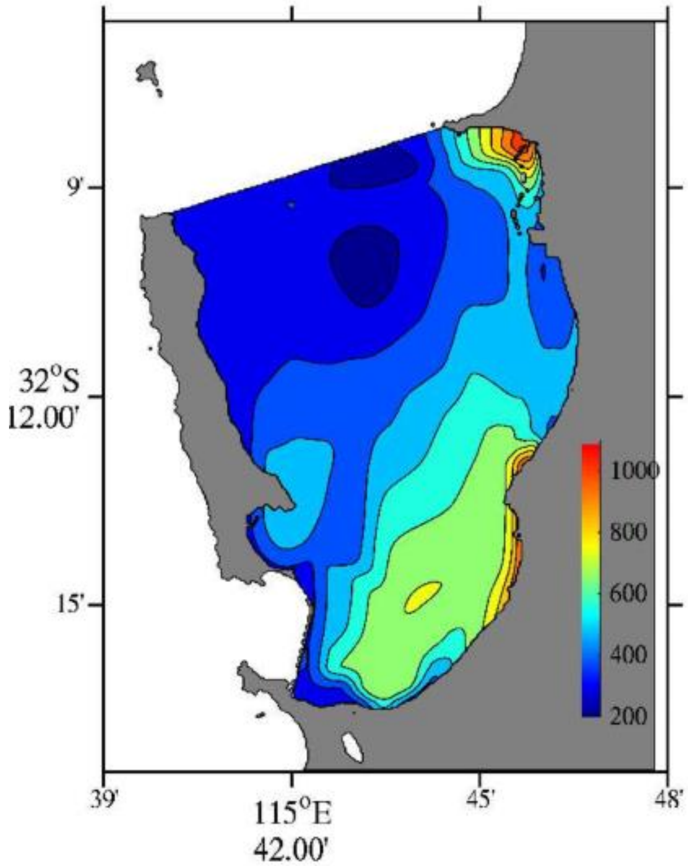
4.6 Phytoplankton primary production, composition and toxicity

Primary productivity

Phytoplankton are microscopic algae that reside in the water column and contribute to biogeochemical cycling of nutrients and overall primary production (the creation of organic matter through photosynthesis) within the Sound. Primary production is distinct from phytoplankton cell density (the number of cells per unit area or volume, also known as standing stock) and biomass (the weight of all cells per unit area or volume). The terms 'biomass' and 'productivity' are therefore not interchangeable (Lalli & Parsons 1997). Measurements of biomass give little information about cell viability or adaptation to their physical environment, whereas measurement of photosynthetic rates indicate whether the phytoplankton are actively growing, are limited by some parameter (e.g. light or nutrients) or are quiescent cells advected from elsewhere. See Section 4.4 for a description of phytoplankton biomass (chlorophyll-a) concentration in Cockburn Sound as it pertains to water quality.

Pelagic primary production has not been directly measured within Cockburn Sound. It has generally been estimated based on biomass (chlorophyll-a) concentrations and an assumed phytoplankton carbon:chlorophyll-a ratio of 50 (Hillman 1986, DEP 1996). Such estimates would underestimate production if, for example, the phytoplankton population was being actively grazed down (Welschmeyer & Lorenzen 1985). Nevertheless, using this approach, primary productivity of the whole of Cockburn Sound was estimated at ~22 000 t C yr^{-1} in 1996 (DEP 1996) and ~14 000 t C yr^{-1} in 2009 (Oceanica 2009a). This suggests that phytoplankton are the dominant contributor (at least 73%) to primary production within the Sound (see Section 4.10; Oceanica 2009a).

A recent parameterised photosynthesis–light relationship mapped to chlorophyll measurements (Greenwood et al. 2016) suggests that production rates are highest in the south-east of Cockburn Sound and in the vicinity of Northern Harbour (Figure 4.8), where chlorophyll biomass is generally highest (Keesing et al. 2016). Based on these production estimates, a nitrogen budget mass balance attributed 90% of the biological nitrogen demand in Cockburn Sound to phytoplankton (Greenwood et al. 2016). Field measurements of phytoplankton productivity, including both spatial and seasonal variability, are needed to better estimate this biological demand (and also to constrain the water-column recycling and seabed deposition flux; Greenwood et al. 2016).



Source: Greenwood et al. (2016)

Note:

1. Contours represent depth-integrated pelagic productivity in milligrams of carbon produced per milligram of chlorophyll-a per square metre per day

Figure 4.8 Estimated distribution of depth-integrated pelagic productivity in Cockburn Sound based on mean chlorophyll-a measurements (2008–2014)

Species composition and toxicity

There are over 300 known phytoplankton species present in Cockburn Sound (DEP 1996). The last comprehensive survey of phytoplankton within the Sound (DEP 1996) identified four main phytoplankton groups: diatoms (Bacillariophyta), dinoflagellates (Dinophyta), silicoflagellates (Dictyochophyceae), and blue-green algae (Cyanophyta).

The only ongoing phytoplankton monitoring within Cockburn Sound is being undertaken by the shellfish aquaculture industry under the auspices of the Western Australian Shellfish Quality Assurance Program (WASQAP; DOH 2016). This program monitors two sites in Cockburn Sound (Southern Flats and the Kwinana Grain Terminal, both mussel aquaculture leases) twice monthly for potentially toxic species. Nuisance species of phytoplankton are a natural part of phytoplankton communities and are usually present in low numbers throughout local coastal waters. Since 2003, there have been no incidences where shellfish have been deemed unsafe to eat due to the accumulation of algal toxins (Dr S Helleren 2017, Dalcon Environmental, pers. comm., 14 August).

In addition to target (nuisance) taxa, the WASQAP samples have also been analysed for total phytoplankton abundance and composition (Helleren 2016)[9]. As the only long-term phytoplankton community monitoring in Cockburn Sound, a full evaluation of this dataset (in conjunction with any shorter-term datasets that exist)[10] is highly recommended. Preliminary analysis shows that prior to 2005, total cell density was fairly uniform and rarely exceeded 500 000 cells per millilitre (mL) but after this date, phytoplankton cell density underwent a stepped change (Figure 4.9). Cell density was increasingly variable and often exceeded 1–2 million cells per mL (Figure 4.9; Helleren 2016).

Phytoplankton community composition (evaluated based on major groups) changed around this same time, with silicoflagellate abundance notably reduced from 2005 onwards (Figure 4.10). In the early 1990s, the silicoflagellate species *Dictyota octonaria* dominated Cockburn Sound waters in autumn/winter (Helleren & John 1995, Helleren 2013), which caused concern because a similar species in northern European waters is associated with broadscale nutrient enrichment (DAL 2001). Using the WASQAP dataset, a potential shift in the seasonality of peak *Chaetoceros* spp. abundance (the diatom species implicated in the November 2015 Cockburn Sound fish kills; see Section 4.9.2) from summer to autumn and winter has also been observed (Helleren 2016).

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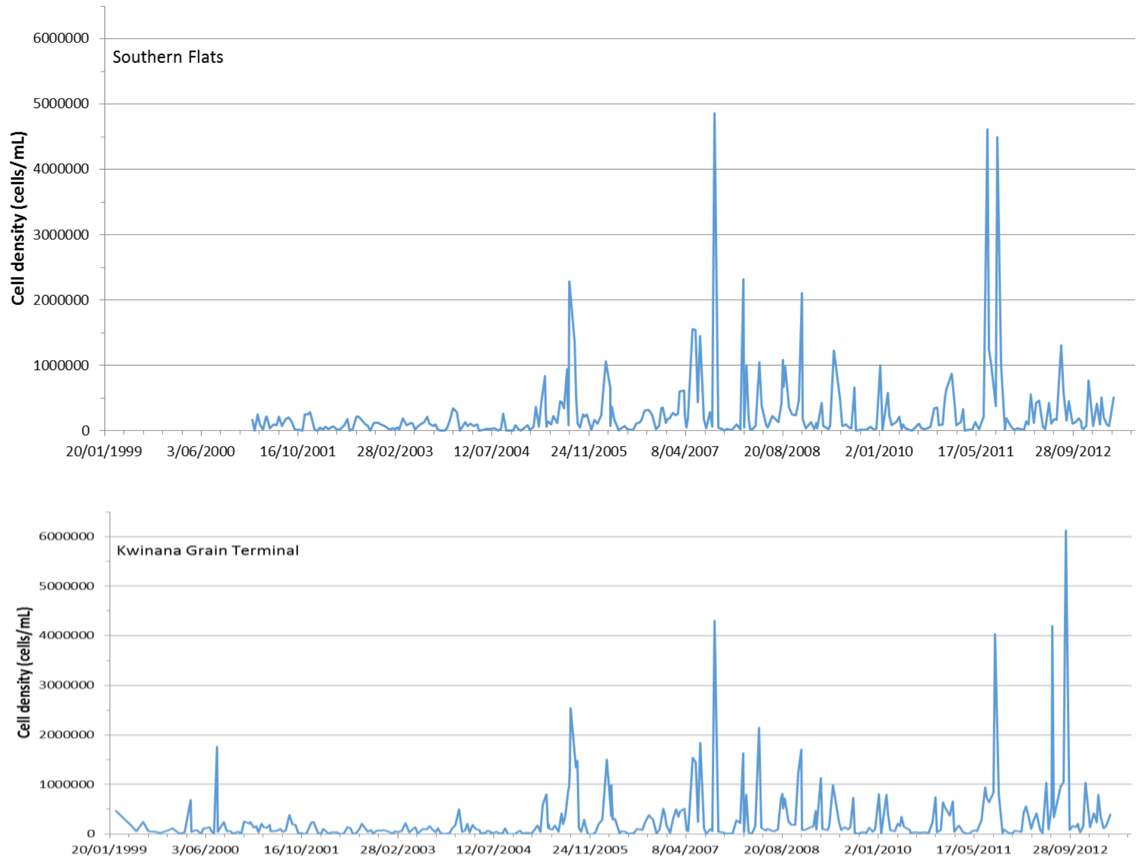
9 *From January 1999 to July 2014, the samples were analysed for the presence and abundance of all phytoplankton taxa. From July 2014 to May 2016, the samples were only analysed for target taxa (as per DOH 2016). From May 2016 onwards, the samples have been analysed for all taxa again (Dr S Helleren 2017, Dalcon Environmental, pers. comm., 23 June).*

10 *Other known phytoplankton datasets include sampling conducted for the Perth Desalination Plant (various studies over 2005–2015) and Jervoise Bay Northern and Southern Harbours (2003–2011; Dr S Helleren 2017, Dalcon Environmental, pers. comm., 23 June).*



Source: Helleren (2016)

Figure 4.9 Phytoplankton cell density at Southern Flats and Kwinana Grain Terminal

Source: Helleren (2016)

Figure 4.10 Mean annual phytoplankton community composition at Southern Flats and Kwinana Grain Terminal

4.7 Zooplankton and pelagic secondary production

Zooplankton are a diverse group of animals that live all or part of their life as plankton within the water column. They play a critical role in the pelagic food web (as grazers of phytoplankton and as a food source for planktivorous fish) and are sensitive to changes in environmental conditions (Richardson 2008, Thompson et al. 2015). Zooplankton biomass has traditionally been estimated using net tows, although optical and acoustical methods are becoming more common (Harris et al. 2000). Estimates of zooplankton grazing rates and secondary production, critical for understanding pelagic food web dynamics, have not yet been measured in Cockburn Sound.

Since the 1991–1994 Perth Coastal Waters Study (reviewed in the 2001 Cockburn Sound Pressure-State-Response Assessment; DAL 2001), the only measurements of zooplankton in Cockburn Sound were completed in 2000–2001 as part of a Fisheries Research and Development Corporation (FRDC) project evaluating the importance of fish species for various nearshore marine habitats (Valesini et al. 2004). The highest zooplankton abundance was measured in summer, and calanoid copepods were the dominant taxa along the eastern Cockburn Sound shoreline (where they comprised ~54% of the overall number of zooplankton caught; Valesini et al. 2004).

4.8 Benthic primary producers

Benthic primary producers are predominantly marine plants, for example seagrasses, but include invertebrates with photosynthetic hosts such as corals. These organisms often grow attached to the seabed, subtidal and intertidal areas, sequester carbon from surrounding seawater or air and convert it to organic compounds through photosynthesis. Seagrasses are the dominant benthic primary producer of Cockburn Sound in terms of production (>3050 t C/yr) and are mainly comprised of species from the genera *Posidonia* and *Amphibolis* (Oceanica 2009a). MPB is also thought to contribute significantly to benthic primary production in Cockburn Sound (~1104 t C/yr), although it remains poorly understood (Oceanica 2009a). Algal epiphytes, which grow on the leaves and stems of seagrasses, contribute ~998 t C/yr, while macroalgae (e.g. *Ecklonia radiata*) and some corals of the Faviidae family, are minor contributors to primary production in Cockburn Sound (~100 t C/yr; Oceanica 2009a).

Because of their central ecological importance, seagrasses have drawn the most attention of the benthic primary producer groups in Cockburn Sound. The three lead indicators used to assess the general vigour of seagrasses in Cockburn Sound are seagrass 'extent', 'lower depth limit' and 'shoot density'.

In terms of seagrass extent, historically (pre-1950s), Cockburn Sound supported large seagrass meadows that occupied ~4000 ha and covered most of the seabed to depths of 10 m (Kendrick et al. 2002). The extent of seagrass meadows in Cockburn Sound declined severely during the late 1960s and early 1970s due to poor water quality. By 1978 it was estimated that only 872 ha (~22%) of seagrass remained (Cambridge & McComb 1984, Kendrick et al. 2002; Figure 4.11). Corresponding with the large loss in seagrass extent, Oceanica (2009a) estimated that there was reduction in primary production of ~92%. However, since the 1980s, water quality conditions have improved considerably and seagrass distribution has stabilised. The most recent estimate of seagrass extent in the assessment area is ~860 ha [11], which is an appreciable improvement from 728 ha in 2008 (Figure 4.11). It appears that much of the recent growth has occurred on the shallow sandbanks south of Woodman Point.

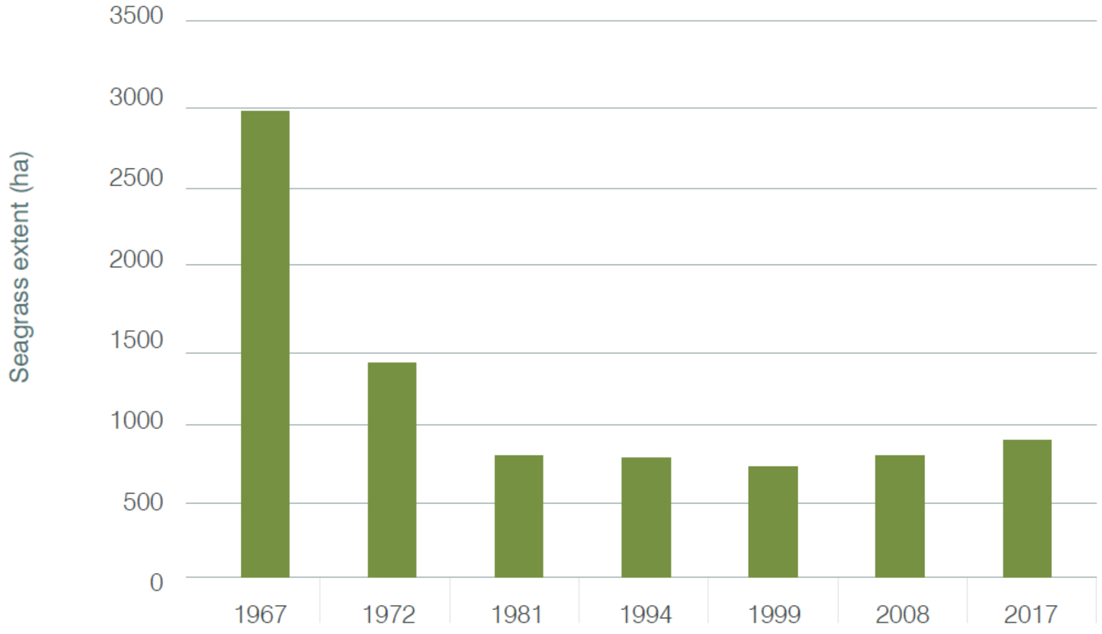
[11] *Estimates of seagrass extent (ha) vary between sources (e.g. Hovey and Fraser 2018 reported seagrass extent in 2018 as 965 ha) depending on the size of the assessment area considered in the investigation. All data presented in Figure 4.11 was standardised to the same area.*

Results from recent monitoring of 'lower depth limit' of seagrass meadows also provide a positive indication that the vigour of seagrass meadows is improving in some locations (Fraser et al. 2017). For example, Garden Island south and Woodman Point monitoring locations have continued to increase in lower depth limit (i.e. deepen; Fraser et al. 2016a, Rule 2015). The increase in stability and distribution of seagrasses in deeper waters suggests that water quality and light availability is generally adequate for seagrass growth given that these seagrasses are growing near their depth limits in Cockburn Sound (Collier et al. 2007).

Despite these positive signs, there remains a long-term decline in seagrass health (shoot density) in some areas within Cockburn Sound (Figure 4.12). Fraser et al. (2017) reported that three potential impact sites (Garden Island Settlement, Kwinana and 'Garden Island 5.5m') have shown significant declines in mean shoot density since 2003, while three additional sites (Southern Flats, Jervoise Bay and 'Garden Island 3.2m') show declining trends (Figure 4.12). The remaining potential impact sites monitored in Cockburn Sound have shown no significant trend in mean or median shoot densities since 2003, and no sites have shown significant increases in shoot density over the monitoring period (Fraser et al. 2017).

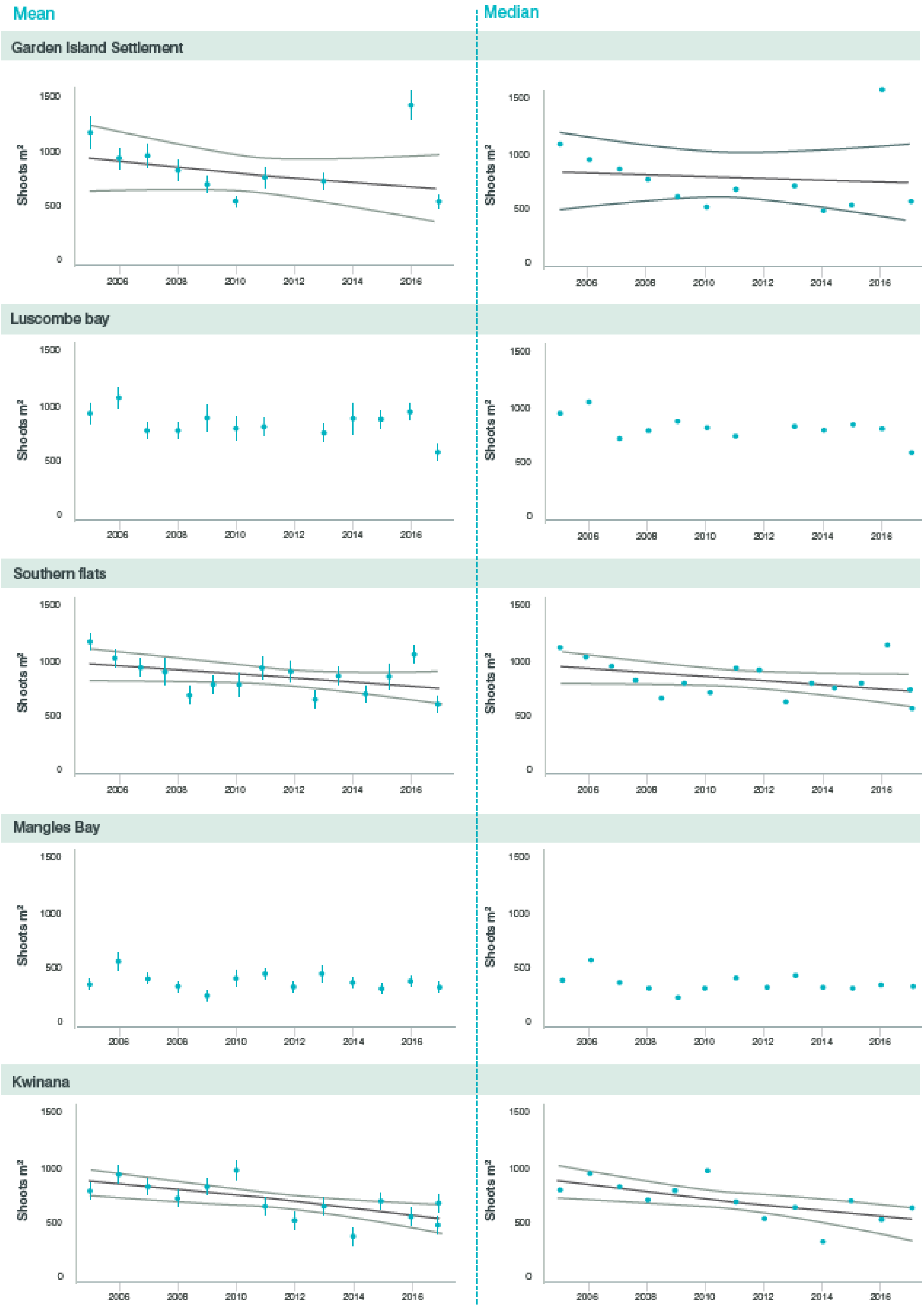
For those areas where seagrass health has continued to decline, explanatory factors driving those changes remain unclear. Mohring and Rule (2013) attempted to link ongoing trends in seagrass density with potential physical and biogeochemical variables in the water column and found the best explanatory factor was temperature. However, this relationship was found to be weak, and it is more likely to involve a combination of stressors acting in concert, including reduced DO. Further investigations by Fraser et al. (2016b) suggest that toxic sulfide intrusion, via the sediments, is also likely to be implicated in changes in seagrass health and is now the centre of investigations into drivers of seagrass declines in Cockburn Sound. It is also probable that long-term monitoring of seagrass health at fixed locations may have introduced a level of sampling disturbance, and resulted in possible declines in seagrass shoot densities.

The lack of conformity among lead indicator trends means it is not possible to provide a confident conclusion on the overarching state of seagrasses in Cockburn Sound. However, it is reasonable to assume that seagrass losses in Cockburn Sound have stabilised and may have reached a new equilibrium which is being expressed as dynamic fluctuations in natural growth patterns. To provide insight to managers and ensure the long-term maintenance of seagrasses in Cockburn Sound, it is important that research continues to investigate not only the reasons for declines in seagrass health, but also the mechanisms driving increases in seagrass extent.



Source: Kendrick et al. (2002), Oceanica (2009a), Seagrass data collected in 2017, supplied by CSMC and Fremantle Ports

Figure 4.11 Change in seagrass extent across Cockburn Sound between 1967 and 2017



Source: Fraser et al. (2017)
Note:

1. Central lines show significant trends (also see Fraser et al. 2017); Bounding lines show 95% confidence bands

Figure 4.12 Trends in mean (+ standard error) and median shoot densities at five potential impact sites in Cockburn Sound

4.9 Marine fauna

4.9.1 Benthic macrofauna

Benthic macrofauna are an important component of marine and coastal ecosystems of Cockburn Sound. In this report, 'benthic macrofauna' refers to infauna and epifauna (described in Table 4.2). They can influence both the physical and chemical properties of the sediment and the overlying water column, and have a number of important functional roles, including the alteration of geochemical conditions at the sediment–water interface and the promotion of decomposition and nutrient cycling (Jernakoff et al. 1996). Benthic macrofauna also occupy an important intermediate trophic position, particularly in their capacity for converting primary production (e.g. phytoplankton) into secondary production (Jernakoff et al. 1996) which is then available to higher trophic levels including fish, crabs and birds (Klumpp et al. 1989, Gartner et al. 2015). Other groups consume detrital or planktonic food sources (e.g. through filtering the water column) and similarly become a food source for higher trophic levels (Jernakoff et al. 1996).

Oceanica (2009a) estimated that the total biomass of benthic macrofauna across the Sound is ~1339 t (ash-free dry weight). Infauna and epifauna in habitat of fine sediment (>10 m water depth) contribute the most (51%) to the overall secondary producer biomass, while infauna and epifauna in habitat of fine sediment (<10 m water depth) and within *Posidonia* spp. seagrass habitat contribute 30% and 13% of benthic secondary producer biomass, respectively (Oceanica 2009a). The total water filtering capacity of benthic invertebrate fauna within Cockburn Sound is estimated at 2.5×10^{10} (or 25 billion) litres/day (L/d) across the entire Sound, or 230 ML/km^2, most of which occurs in unvegetated sediment in >10 m water depth (Oceanica 2009a).

Table 4.2 Key benthic macrofauna within the main habitats of Cockburn Sound

Habitat type	Infauna or epifauna	Parameters
Fine sediment	Infauna	Polychaetes, crustaceans, bivalves
	Epifauna	Echinoderms, anemones, ascidians, gastropods
Seagrass beds	Infauna	Polychaetes, crustaceans, bivalves
	Epifauna	Crustaceans, sponges, echinoderms, gastropods
Reef	Epifauna	Echinoderms (holothurians and ophiuroids), crustaceans (barnacles, crabs), sponges, ascidians

Source: Oceanica (2009a)

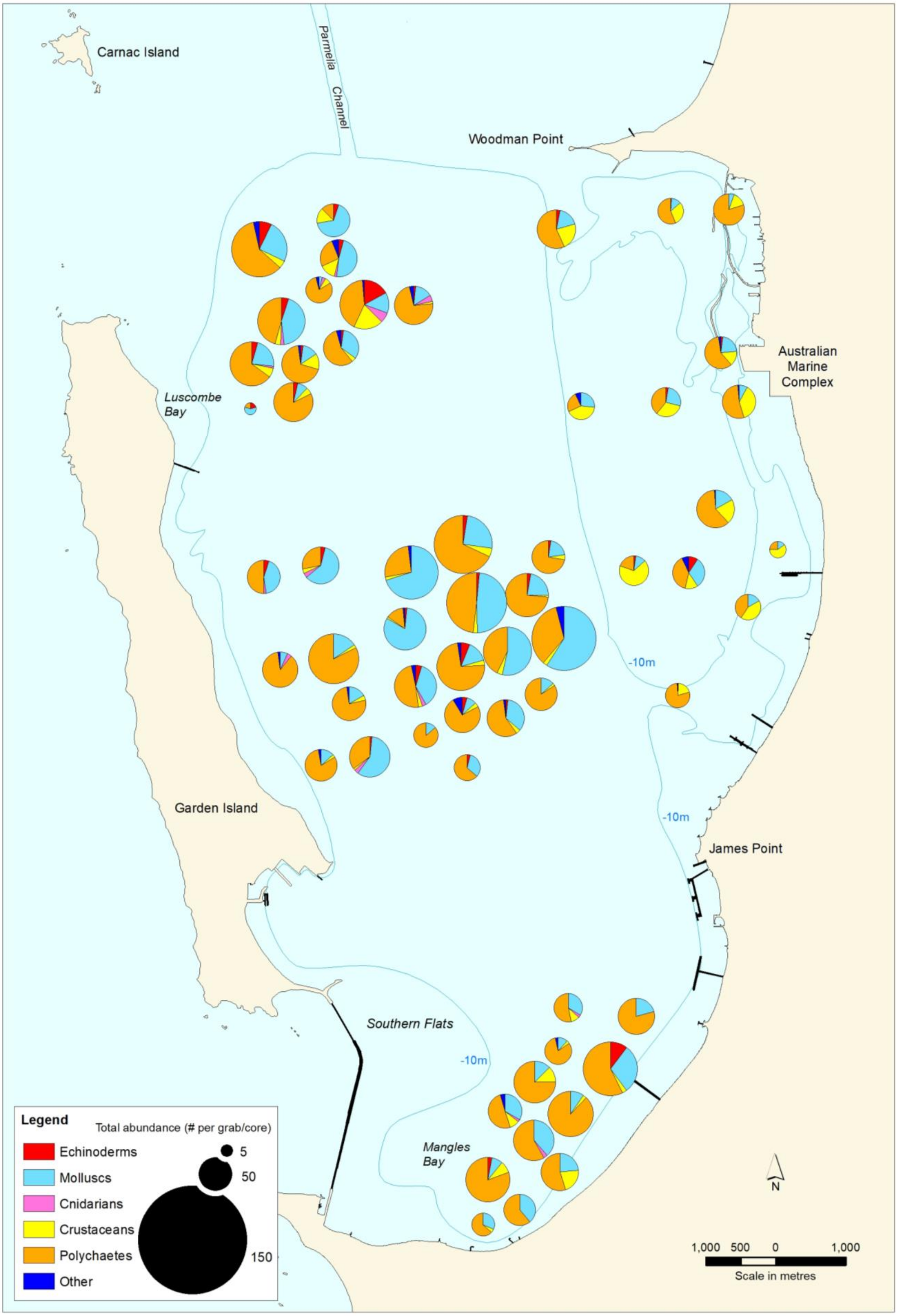
Notes:

1. Infauna are those animals that live within the sediment.
2. Epifauna are animals that live on top of the sediment, seagrass or reef surface.

A large number of environmental factors and ecological interactions influence the abundance and composition of macrofauna. These factors can include changes in seagrass canopy, reduced primary productivity, predation and competition (Jernakoff et al. 1996). In addition, macroinvertebrate assemblages have also been demonstrated to be sensitive to acute changes in a range of physical conditions such as salinity, temperature and DO (Bath et al. 2004). Three comprehensive investigations of benthic macrofauna in the deep basin of Cockburn Sound have been undertaken over the last 40 years. While earlier studies are not directly comparable with later studies (because of differences in the sites sampled, methodologies and taxonomic identifications), it is evident that there have been marked decadal changes in the benthic macrofauna communities between 1978, 1993 and 2006 (Oceanica 2009b). Differences between times include shifts in species abundances and distribution, as well as community indices such as species diversity (Oceanica 2009b). It is probable that modifications to the benthic marine environment, at least in part, explain these shifts. A comparison of the invertebrate communities present within dredged areas on Success Bank of different ages was undertaken during a study to examine the ecological significance of seagrass invertebrates (Brearley & Wells 2000). Sites surveyed included natural (non-dredged) areas, and areas dredged in 1985, 1994, 1996–1997 and 1997–1998. Invertebrate biomass was found to be lower in the most recently dredged areas (<1 year) with the biomass approximately equal to that of naturally deep areas within four years after dredging. Brearley and Wells (2000) compared their results with those in a report summarising the recovery of invertebrate communities after dredging (Newell et al. 1998) and noted their four-year recovery period was slightly longer than the two- to three-year period typically found by Newell et al. (1998).

A survey undertaken in 2008 investigating potential effects associated with construction and operation of the Perth Seawater Desalination Plant also found a marked shift in sediment characteristics and benthic macrofaunal communities throughout the deep basin of Cockburn Sound from 2006 to 2008 (Oceanica 2009b; Figure 4.13). However, it was concluded that the changes in benthic communities were the result of regional effects rather than the result of the operation of the desalination plant (Oceanica 2009b). Examination of the Oceanica (2009b) macrofauna data showed a relatively high abundance and low biomass of several taxa in areas that are not characteristic of disturbed communities.

While there appears to have been long-term shifts in the benthic macroinvertebrate assemblage structure in parts of Cockburn Sound, it is difficult to confirm if the functional and ecological role of the present community has experienced a similar shift. Ecological modelling undertaken by Oceanica (2009a) suggests that benthic secondary production has likely experienced a 30% decline since European habitation, predominantly due to the loss of infauna and epifauna associated with *Posidonia* spp. seagrass habitat. Water filtering capacity has also likely decreased by 68% since European habitation (Oceanica 2009a); again due to the decline in seagrass cover and the abundance of associated filter-feeding epifauna. Further, the current overall rate of sediment turnover across the Sound is estimated to be 8% lower since pre-European habitation, primarily due to the loss of bioturbating fauna in shallow habitats lost to dredged channels and dredge spoil reef (Oceanica 2009a). These declines, however, are estimates only and would require validation through field sampling.



001_01aginfauna10sidA4_20170607

Source: Deep basin data (collected February 2008) supplied by Water Corporation

Figure 4.13 Infauna abundance and contribution made by taxonomic groups

4.9.2 Fish and fish communities

Studies of the fish communities in Cockburn Sound are rare and have principally focused on associations with seagrass (Dybdahl 1979, Vanderklift & Jacoby 2003), although fish communities connected with the extensive soft sediment habitat of the central basin have also recently been reported (Johnston et al. 2008, Wakefield et al. 2009)[12]. Broadly, there are three types of fish communities in Cockburn Sound, including those associated with:

- seagrass: mainly defined by Australian herring (*Arripis georgianus*), weeping toadfish (*Torquigener pleurogramma*), western striped grunter (*Pelates octolineatus*), sixspine leatherjacket (*Meuschenia freycineti*) and snook (*Sphyraena novaehollandiae*)
- extensive areas of soft sediment: mainly defined by rays, for example, southern eagle rays (*Myliobatus australis*)
- areas comprising some form of limestone structure: defined by pink snapper (*Pagrus auratus*), western butterfish (*Pentapodus vitta*) and trevally species (*Pseudocaranx* sp.), among numerous other commercially and recreationally important species.

Beyond isolated investigations, it has been widely acknowledged that there is a scarcity of broadscale ecological investigations examining fish community health within the marine ecosystems of WA, with no long-term collection of data to support understanding of commonly agreed fish community metrics or lead indicators (Johnson et al. 2008). This is in contrast to the generally agreed metrics that are now used for the tracking of individual stocks of exploited fish. As such, it is extremely difficult to piece together the current state of biodiversity of fish communities in Cockburn Sound and to make historical comparisons.

The most comprehensive assessment of fish species in Cockburn Sound is from surveys undertaken in 1977 and 1978, where Dybdahl (1979) found 144 species (130 of which were fish), including 81 species (73 fish and 8 invertebrates) of commercial and recreational interest. Vanderklift and Jacoby (2003) reported 55 fish species and three species of large invertebrates off six beaches around Cockburn Sound (three adjacent to seagrass meadows and three without extensive seagrass beds). While more recently, Johnson et al. (2008) reported a total of 216 taxa from six phyla from the subtidal faunal communities of Cockburn Sound (noting that areas sampled were typically greater than 10 m deep and did not include seagrass meadows). These communities were dominated by small benthic predators and detritivores. The majority of these species were well within their known geographical distributions and have previously been collected in Cockburn Sound. The research of Johnson et al. (2008) suggests that fish diversity decreases moving southwards into the Sound, with the lowest diversity recorded at Mangles Bay (Johnson et al. 2008). Such patterns may be related to an environmental impact gradient, but this was not investigated.

The type of stressors that can potentially impact Cockburn Sound fish communities include commercial and recreational fishing (Section 3.7), climate change (Section 3.8), loss of habitat and decline in water quality (Section 4.4). Historic loss of habitat in Cockburn Sound,particularly seagrasses, has been well documented in this report (Section 4.8 and elsewhere). Seagrasses and associated algal epiphytes provide important feeding, nursery and refuge habitats for fish in Cockburn Sound (Wakefield et al. 2009). Seagrass habitat declines can lead to considerable loss in fish abundance, biomass and changes in community structure (Gartner et al. 2015). Despite this link, there have been very few studies which have been able to quantify the flow-on

[12] *In this context, 'fish communities' refers to a group of organisms or a population of different species occupying a particular area, usually interacting with each other and their environment and not individual fish stocks.*

effect of seagrass loss on fish assemblages (Gillanders 2007) although modelling suggests second and third order consumers are likely to be negatively effected by disturbances of the seagrass canopy (Gartner et al. 2015). On the Eastern Shelf of Cockburn Sound, where considerable loss of seagrass has occurred, Johnson et al. (2008) found the faunal assemblages (including fish) to be markedly different (in abundance and diversity) from other areas of Cockburn Sound. It was suggested by Johnson et al. (2008) that the present seagrass community differed markedly from the seagrass-associated fish community that occurred in the 1950s. However, it was not possible to quantify those changes over time, nor determine what factors may have driven those changes.

While indirect effects and chronic changes to fish communities associated with habitat loss are poorly documented and not well understood, acute fish kills are much more in the public eye and have received considerable attention. In November 2015, a fish kill occurred in Cockburn Sound that resulted in the loss of ~2000 fish and invertebrates, representing over 15 species (DOF 2015). The DPIRD resolved that that the most likely cause of the event was a combination of factors such as low DO levels and the presence of algal diatoms, in particular *Chaetoceros danicus* (DOF 2015). Potential contributing factors to the observed spike in *C. danicus* numbers included nutrient availability and higher than normal water temperatures recorded in the area prior to the event. Subsequent review of available monitoring data revealed that levels of *C. danicus* diatoms in the Sound during the event were significant but not the highest ever recorded, which supports the possible involvement of additional factors, the most likely of which was low DO levels (DOF 2015).

Of recreational and commercial fishing interest, over 250 pink snapper were killed in the event. Pink snapper congregate in Cockburn Sound for spawning during this time of the year and the Sound is considered an important nursery area. Research on pink snapper in WA has shown that recruitment is highly variable and that the fishery can be sustained with periodic spikes or large ‘pulses’ in recruitment which may occur every few years (DOF 2004). This means that there can be lengthy periods of low recruitment, which makes pink snapper populations highly vulnerable to over-exploitation or disturbances. While the fish kill was unlikely to have led to significant declines in local pink snapper stocks, the public profile of the event, coupled with its vulnerability status, was such that it led Recfishwest to coordinate the release of ~100 000 juvenile pink snapper into Cockburn Sound over two successive seasons (summer 2016 and summer 2017). Restocking of Cockburn Sound has been cautiously considered as a possible management strategy to address low stock numbers in Cockburn Sound for several years (e.g. DOF 2004, DOF 2008). However, local mussel aquaculture entities have also recently reported that pink snapper have, in part, been responsible for consuming a large portion of their aquaculture stocks (ABC Rural 2017), thus also highlighting the complexity of managing fish populations in Cockburn Sound in general and the potential for multiple-user conflicts.

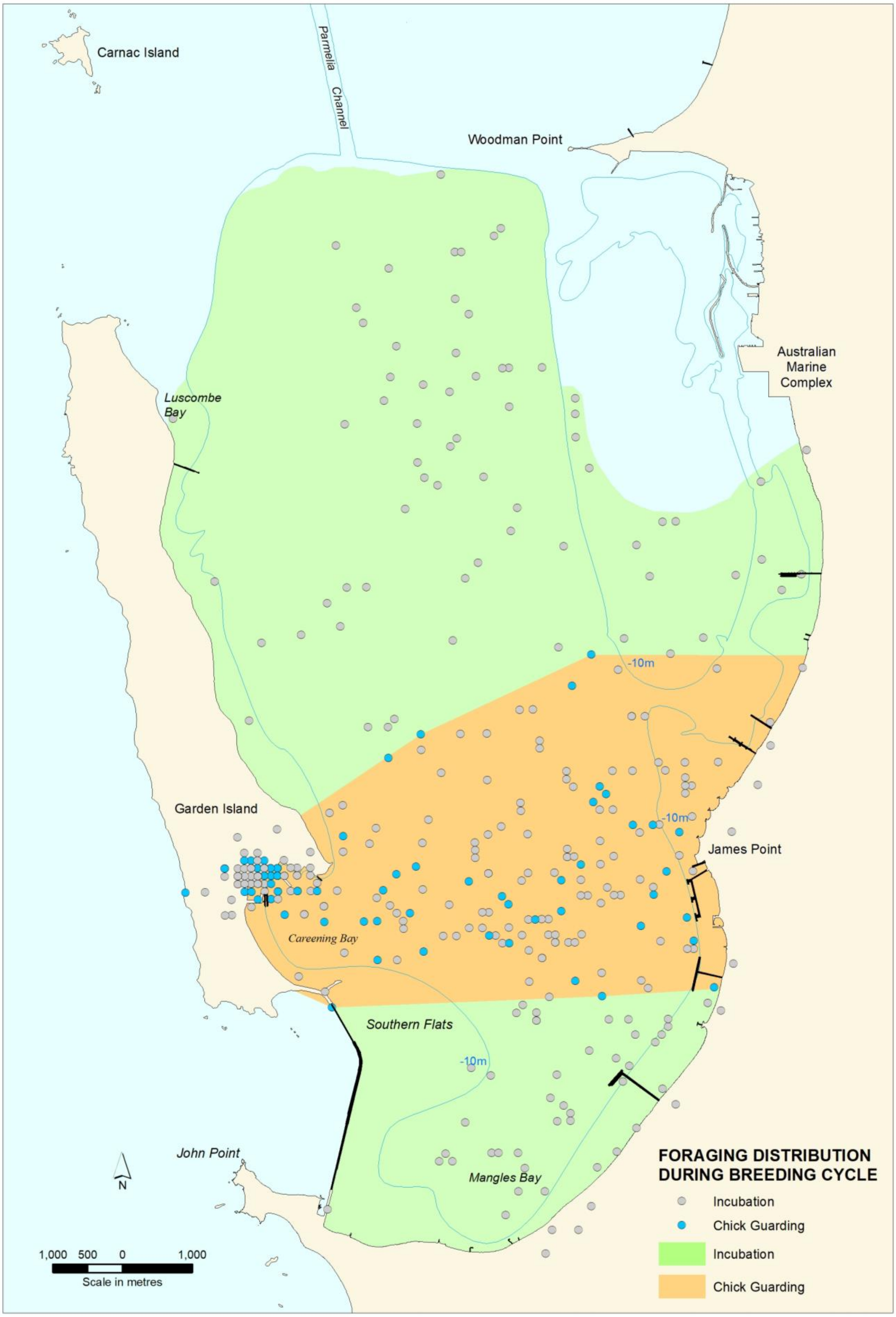
4.9.3 Little penguins

In WA, the distribution of little penguins (*Eudyptula minor*) extends from 10 km south-west of Fremantle at Carnac Island through to the Recherche Archipelago (east of Esperance). Garden Island supports an estimated colony of ~180–200 penguins, which mainly inhabit the rock wall on the western side of Careening Bay (Cannell 2004, Figure 4.14).

While at sea, little penguins from Garden Island remain within Cockburn Sound (Figure 4.14). However, the area of the Sound they use is dependent on the phase of their breeding cycle. When incubating eggs, their foraging area extends from the northern end of the central basin to Mangles Bay in the south and includes the Eastern Shelf (Figure 4.14). When guarding chicks, the penguins are only at sea for a single day and tend only to use the southern half of Cockburn Sound (Figure 4.14). During this time, parents must feed close enough to the colony to be able to return each evening with food for the chicks, and their presence on the Kwinana Shelf and in the northern central basin is much less common. Of the nearby penguin colonies, breeding penguins from Cockburn Sound appear to play the more important role in the long-term maintenance of little penguins in the Perth region, as penguins on Garden Island generally have a higher breeding success than those on Penguin Island (Dr B Cannell 2017, University of Western Australia and Murdoch University, pers comm., 19 March).

The major threats to the little penguins from Garden Island include reduction in food resources, watercraft, entanglements and pollution (Cannell et al. 2016). Of these threats, trauma (45%) and starvation (29%) were determined as the leading causes of mortality following necropsy of 168 carcasses/injured birds collected from 2003 to 2013, between Penguin and Garden Islands (Cannell et al. 2016). Trauma is typically associated with collision with watercraft. Little penguins spend a large portion of their time underwater in the top 1–4 m of the water column (Bethge et al. 1997). Therefore, the probability of a collision between watercraft and penguins is high and increases with increasing watercraft use. It is thought that slow-moving, large ships are less likely to injure penguins than recreational watercraft such as jetskis, windsurfers and motorboats.

Starvation is also considered a significant potential threat to little penguins in Cockburn Sound. Starvation arises due to limited supply of prey, which can be driven by a number of factors including fishing pressures, habitat degradation (which in turn can lead to loss of associated fish assemblages) and changes in oceanic conditions (Cannell et al. 2016). Little information is available on the prey of Garden Island little penguins, but Penguin Island penguins feed on a range of fish including white bait (*Hyperlophus vittatus*), pilchards (*Sardinops neopilchardus*), garfish (*Hyporhamphus melanochir*), anchovy (*Engraulis australis*) and blue sprat (*Spratelloides robustus*). Whitebait comprise a large proportion of the diet of adult penguins and this proportion increases to more than 80% of food during chick-rearing, whereas pilchards predominate the penguins' diet in autumn and early winter. It is probable that the large proportion of mortalities reported by Cannell et al. (2016) associated with reduced availability of white bait may have been linked to oceanic conditions and increased water temperatures (see Section 3.8).



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Source: Cannell (2009)

Note:

1. Data collected in 2008

Figure 4.14 Locations of little penguin activities within Cockburn Sound

4.9.4 Dolphins

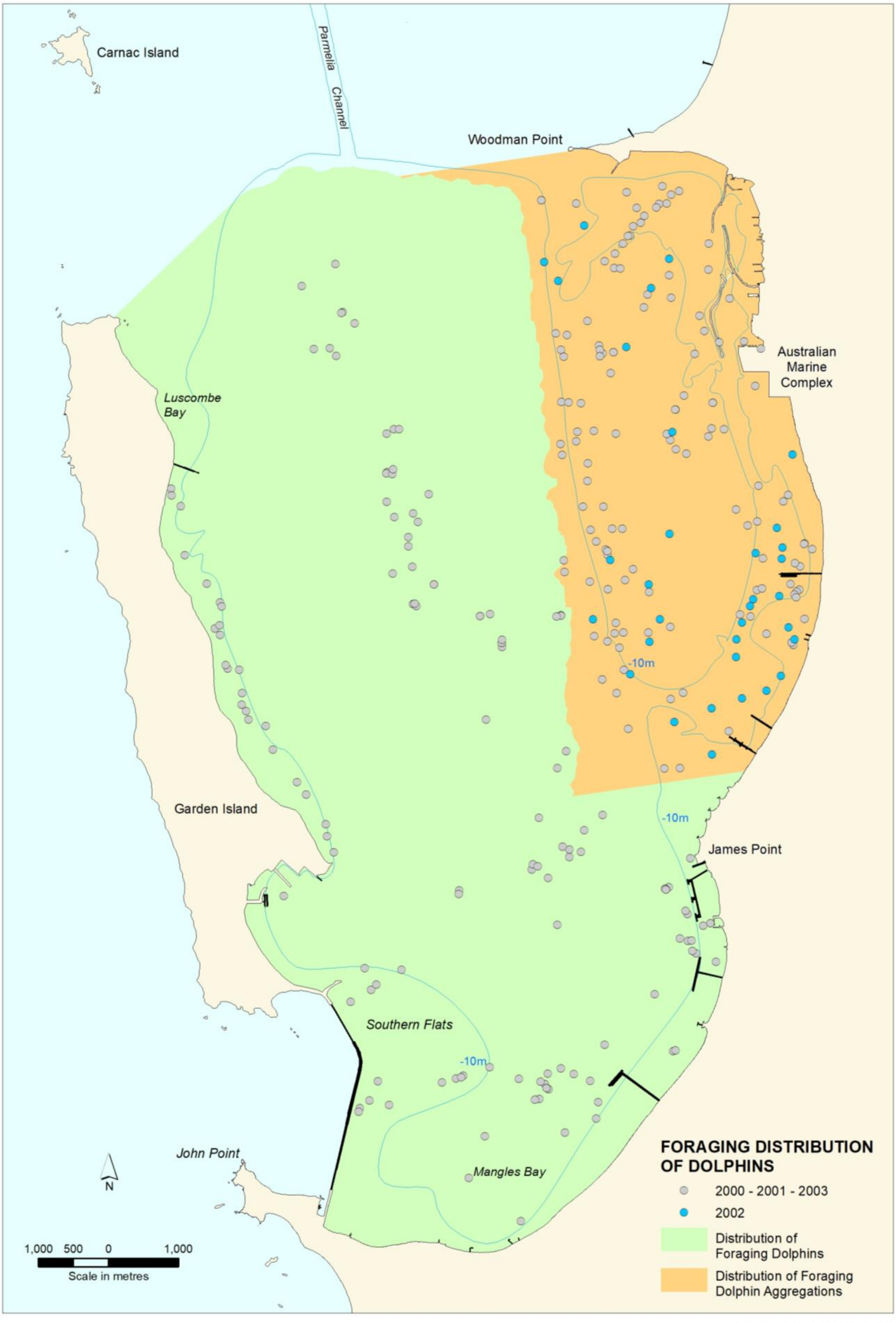
The bottlenose dolphin (*Tursiops* spp.) community in Cockburn Sound are resident year-round and typically forage in a dispersed mode, which means they are distributed around Cockburn Sound individually or in small groups (Finn 2005). During foraging periods when fish are available, they will gather in large feeding aggregations, often on the Eastern Shelf (Finn & Calver 2008). These aggregations may occur on a daily or near-daily basis at certain times of the year. Figure 4.15 shows the observations of foraging dolphins from Finn (2005). Distinctive features of the ecology of bottlenose dolphins in Cockburn Sound include long-term site fidelity and limited home ranges (<100–150 km^2; Chabanne et al. 2017a).

The type of anthropogenic activities that occur in Cockburn Sound with the potential to harm dolphins, either by altering behaviour or causing stress/health-related effects, can include human feeding, indirect effects associated with habitat loss (loss of foraging and feeding grounds and associated prey), recreational fishing (i.e. entrapment in discarded fishing lines) and underwater noise. While dolphins are mobile, one of the consequences of site fidelity is that individuals are unlikely to modify their ranging patterns or migrate elsewhere should impacts occur. It is thought that individuals will remain within their home range and attempt to compensate for the impact by changing aspects of their behavioural ecology (Finn 2011). This is of particular importance if the duration or timing of the disruption is long, or occurs over critical periods (Finn 2011).

Human interactions, especially those that result from feeding, appear to be one of the common stressors acting on dolphins in Cockburn Sound. There have been anecdotal accounts from marine researchers conducting surveys in the area (Mrs R Donaldson 2017, Murdoch University, pers. comm., 14 August) that between the years 2011 and 2013, at least nine adult males approached the research vessels displaying begging behaviour (anticipated to be only a very small subset of times that feeding typically occurs in Cockburn Sound) The short-term negative effects of human feeding can include changes in activity budgets, an increase in field metabolic rates, a reduction in home range sizes and an increase in both intra- and inter-species aggression (Christiansen et al. 2017). In the long-term, animals can become conditioned to human interaction through food provisioning, with animals associating humans with food and therefore seeking close-up interactions (Christiansen et al. 2017). Such close-up interactions can have harmful effects on the conditioned animals, by increasing the risk of injury, disease and possible death (Christiansen et al. 2017).

Loss of benthic primary producer habitat in Cockburn Sound, that potentially supported fish used by dolphins as a prey source, is also considered an important stressor to dolphins in Cockburn Sound. Research by Murdoch University (Mrs R Donaldson 2017, Murdoch University, pers. comm., 14 August) has noted that with lesser food availability, fewer calves may survive until weaning. Moreover, certain dolphin age–sex classes (such as pregnant or lactating females) have high energy requirements and need to spend a considerable proportion of each day feeding in order to maintain themselves and their calves. Nearly all fish species in Cockburn Sound are associated with seagrass and limestone habitats, in at least some stage in the life cycle (see Section 4.9.2). Therefore, any fall in prey quantity, either associated with loss of habitat or via other ecosystem pressures, has the potential to add energetic stress, with associated risks to dolphin mortality such as decline in condition of mother or calf, associated lower immune strength leading to greater vulnerability to disease and lower overall vigilance of mother for predators during feeding (Mrs R Donaldson 2017, Murdoch University, pers. comm., 14 August).

Despite these potential stressors, the size of the dolphin community in Cockburn Sound appears to have remained stable for the past two decades, with differences reported in relative abundance over time more likely an artefact of the survey method, rather than actual changes. Findings from field surveys conducted between 2011 and 2015 suggest that the relative abundance of the resident community in Cockburn Sound was ~64 individuals, and in Owen Anchorage was ~43, with overlap in population ranges (Chabanne et al. 2017b). In earlier investigations undertaken between 1993–1997 and again in 2008, the size of the resident dolphin community in Cockburn Sound was estimated at ~75 individuals, although the composition and age structure of the community differed between times (Finn 2005, Finn & Calver 2008). While over half of the resident adult females from 1993–1997 were re-identified in 2008, only a small number of adult males from 1993–1997 were re-sighted. This finding was not unanticipated, as male bottlenose dolphins have shorter life expectancies than females and many of the 1993–1997 males had already disappeared by 2003. Analysis of the 2008 photo-identification data revealed ~50 new individuals, highlighting the dynamic nature of the population age structure over time.



Source: Finn (2005)

Figure 4.15 Observations of foraging dolphins along belt transects

4.9.5 Protected marine fauna

Marine fauna that are listed as protected species under the Commonwealth EPBC Act (see Section 1.5.3) and/or WA *Wildlife Conservation Act 1950*[13]; and that are considered likely to sometimes occur in Cockburn Sound are denoted in Table 4.3. These few species of protected fauna that occasionally occur in Cockburn Sound are not discussed in detail in this report, since all listed species are infrequent visitors and none are known to have significant habitat affiliations with the Sound.

Table 4.3 Conservation listed fauna that can occur in Cockburn Sound

Common name	Scientific name	Conservation listing
Loggerhead turtle	*Caretta caretta*	Endangered and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Leatherback turtle	*Dermochelys coriacea*	Endangered and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Green turtle	*Chelonia mydas*	Vulnerable and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Southern right whale	*Eubalaena australis*	Endangered and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Humpback whale	*Megaptera novaeangliae*	Vulnerable and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Grey nurse shark	*Carcharias taurus*	Vulnerable and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Great white shark	*Carcharodon carcharias*	Vulnerable and migratory under the EPBC Act, and is a Schedule 1 species under the *Wildlife Conservation Act 1950*
Australian sea lion	*Neophoca cinerea*	Vulnerable under the EPBC Act, and listed as a Schedule 4 species under the *Wildlife Conservation Act 1950*

Note:

1. EPBC Act = Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The three listed species of marine turtles (Table 4.3) are seen only very occasionally in Cockburn Sound, being visitors brought southwards from tropical waters by storms and/or the southward-flowing Leeuwin Current.

Whales with calves were prevalent in Fremantle waters prior to European settlement, including both southern right whales and humpback whales (Botting et al. 2009). However, in recent times, sightings of any whale species within Cockburn Sound are extremely rare and the area is not considered important whale habitat (Cannell 2004). Although southern right whales have been fully protected since 1935 and humpback whales since the late 1960s, population increases have typically been slow, and where significant increases have been reported (Salgado-Kent et al. 2012), these increases have not lead to the re-emergence of whales entering Cockburn Sound or nearby surrounding waters on a regular basis. Further, only a small proportion of southern right whales visiting southern Australia are observed in the Perth metropolitan area (Cannell 2004). The females with calves have a preference for shallow water, with minimum depth requirements of 4–5 m, and can be found within coastal bays in the region, but are unlikely to move into Cockburn Sound (Cannell 2004). Cockburn Sound is not used as part of the southern or northern migration of humpback whales, or as a resting area (DEH 2005).

A male colony of Australian sea lions principally resides on Carnac Island, to the north of Cockburn Sound, using it as a haul-out site during the non-breeding season, and occasionally

[13] *Soon to be repealed and replaced by the Biodiversity Conservation Act 2016 (see Section 1.5.4 and Table 1.4).*

using the waters of the Sound to feed (Campbell 2005). Sea lions are also sometimes seen as single animals hauled out on the beaches of Garden Island (Campbell 2005).

4.10 Ecosystem integrity

The Cockburn Sound SEP defines 'maintenance of ecosystem integrity' as the environmental quality objective for protecting the overall ecosystem health of Cockburn Sound (see Section 1.5.1). Ecosystem integrity is an integrative term that considers both the structure (e.g. the biodiversity, biomass and abundance of biota) and functioning (e.g. food chains and nutrient cycles) of a marine ecosystem. To assist in determining if ecosystem integrity is being maintained, the *EQC Reference Document for Cockburn Sound* (EPA 2017) adopts a multiple lines of evidence approach, with criteria established for phytoplankton biomass, water clarity, seagrass health, DO levels, water temperature, salinity, pH and toxicants in water, sediment and marine biota. Fulfilment of each criteria individually cannot determine whether ecosystem integrity is being maintained, but when considered in concert the criteria afford a good understanding of the state of structural and functional ecological components in Cockburn Sound, (i.e. its status of ecosystem integrity).

Similarly, when considered holistically, the previous subsections of this report—phytoplankton primary production, composition and toxicity (Section 4.6), zooplankton and pelagic secondary production (Section 4.7), benthic primary producers (Section 4.8), water quality (Section 4.4) and sediment quality (Section 4.5)—provide a good indication of the overall ecosystem integrity of Cockburn Sound, which may generally be characterised as a marine system modified by historic nutrient enrichment (eutrophication) and seagrass loss. Indeed, the EPA (2017) considers that while water quality has improved the broadscale seagrass loss in Cockburn Sound, it has significantly altered the diversity and integrity of the marine ecosystem.

Further, to safeguard important habitats such as the seagrass meadows of Cockburn Sound, the EPA's (2017) objective for the environmental factor *benthic communities and habitats* is "to protect benthic communities and habitats so that biological diversity and ecological integrity are maintained" (see Section 1.5.1 and Table 1.3). This objective recognises that marine benthic communities are important components of almost all marine ecosystems and are fundamental to the maintenance of ecological integrity and biological diversity of the marine environment as a whole (EPA 2017). While the EPA (2017) acknowledges that minor loss of benthic habitat can be effectively managed to ensure that ecosystem integrity and biodiversity are maintained in many areas of the state's waters, due to the major loss of seagrass in Cockburn Sound, any proposal that is likely to result in further loss of seagrass will be considered by the EPA in the context of overall impact to ecosystem integrity (and will often require seagrass restoration as a condition of approval).

Ecosystem component characterisation is a modelling approach that can also be used to gauge ecosystem integrity, incorporating an assessment of the attributes of habitat structure (habitat complexity, plus the structure of the communities in each habitat in terms of the biodiversity, biomass and abundance of biota present) and habitat function (biogeochemical cycling and primary and secondary production). Ecosystem component characterisation has been used here to provide a steady-state description of the relative contributions of the various ecosystem components of Cockburn Sound towards overall ecosystem integrity. The relative contribution to the overall ecological integrity made by each habitat unit can be estimated by documenting the relative spatial extent of each habitat type across Cockburn Sound and detailing the characterisation of each habitat type. The detailed habitat maps and method used to calculate the ecological value of each of the habitats present across Cockburn Sound are presented in Appendix C. In summary, 'habitat structure' and 'habitat function' are characterised as follows.

Habitat structure

- *Habitat complexity*: this varies from the two-dimensional habitats of unvegetated areas to the complex three-dimensional habitat available in seagrass meadows and on reefs, with the latter offering more ecological 'niches' for colonisation by macroalgae and animals.
- The *biodiversity*, *biomass* and *abundance* of biota.

Habitat function

- *Primary production*: this is a measure of the growth rates and therefore potential contribution to food webs of the main groups of aquatic plants on the seabed (benthic primary production) and in the water column (water column primary production), as follows:
  - *benthic primary production*: seagrasses, epiphytic algae attached to seagrasses, macroalgae, and microscopic algae on the sediments (MPB)
  - *pelagic primary production*: water column algae (phytoplankton).
- *Secondary production*: this is a measure of the growth rates of the invertebrates and fish present.
- *Water filtering capacity*: this is a measure of the rate at which particulate organic matter (phytoplankton, zooplankton, detritus) in the water column is removed by filter-feeding organisms (e.g. bivalves, sea pens).
- *Biogeochemical cycling*: this is an estimate of the rate at which biologically significant materials (in this case nitrogen) are converted from inorganic forms into organic forms (nitrogen cycling by plants), or cycled within the sediments (e.g. as represented by the degree of sediment bioturbation by invertebrates, as this affects sediment oxygen levels that in turn affect nitrogen cycling within sediments).

Contemporary estimate of ecosystem integrity for Cockburn Sound

For the ecosystem components described above, Figure 4.16 provides an illustration of their current contribution to ecosystem integrity across Cockburn Sound. In summary, the key characteristics of structure include benthic primary producers' habitat and benthic invertebrates (infauna and epifauna). Other marine fauna (e.g. fish, marine mammals) were not included in the model. The model, not surprisingly, identified seagrass as the dominant habitat across Cockburn Sound in terms of contribution to overall habitat complexity (96%), while benthic primary producer biomass across the Sound was estimated at 3264 t dry weight. The biomass of benthic secondary producers (infauna and epifauna) across the Sound was estimated at 1339 t (ash-free dry weight). The greatest portion of secondary production (51%) was estimated to occur in unvegetated habitat in >10 m water depth, while unvegetated habitat in <10 m water depth, and *Posidonia* spp. seagrass habitat contribute 30% and 13%, respectively. The total abundance of benthic invertebrates within the Sound is estimated at 81 billion individuals.

Posidonia spp. was characterised as the dominant habitat in terms of benthic primary production (58%), due to a relatively high production rate and relatively large spatial coverage of seagrass. The overall primary production rate across the Sound, including phytoplankton, was estimated at 18 973 t C/yr. Due to fast growth rates, the primary production of phytoplankton exceeded that of all benthic habitats, contributing 73% (13 718 t C/yr) of the total primary production within Cockburn Sound. The *Southern Metropolitan Coastal Waters Study* (DEP 1996) similarly noted that the primary productivity of the whole of Cockburn Sound was phytoplankton-dominated, though the annual primary productivity of phytoplankton was estimated at 22 009 t C/yr. Given the decreasing chlorophyll-a concentrations since 1996 (Wilson & Paling 2008; Section 4.4), it is likely that the annual primary productivity of phytoplankton has fallen markedly since that time (also see Section 4.6). Unvegetated sediment in >10 m water depth was characterised as the dominant habitat in terms of contribution towards secondary production from infauna and epifauna (33%), followed by water column (zooplankton at 28%) and unvegetated sediment in <10 m water depth (23%).

The total water filtering capacity of benthic invertebrate fauna within Cockburn Sound is estimated at 2.5×10^{10} (or 25 billion) L/d. The estimated water filtering capacity per unit area (230 ML/km^2) is lower than that calculated for Port Philip Bay (790 ML/km^2; Wilson et al. 1993) but within the same order of magnitude. Unvegetated sediment habitat in >10 m water depth dominated the overall filtering capacity (60%) of Cockburn Sound due to the large area it occupies comprising filter feeders.

The overall nitrogen turnover rate of primary producers across Cockburn Sound is estimated as 1560 t N/yr. Phytoplankton dominated the TN turnover (89% or 1384 t N/yr) due to fast growth rates and relatively high nitrogen content of phytoplankton. The overall sediment turnover rate across Cockburn Sound was estimated as 4455 t/d, with the dominant habitats of bioturbating fauna being unvegetated sediment in >10 m water depth, and unvegetated sediment in <10 m water depth.

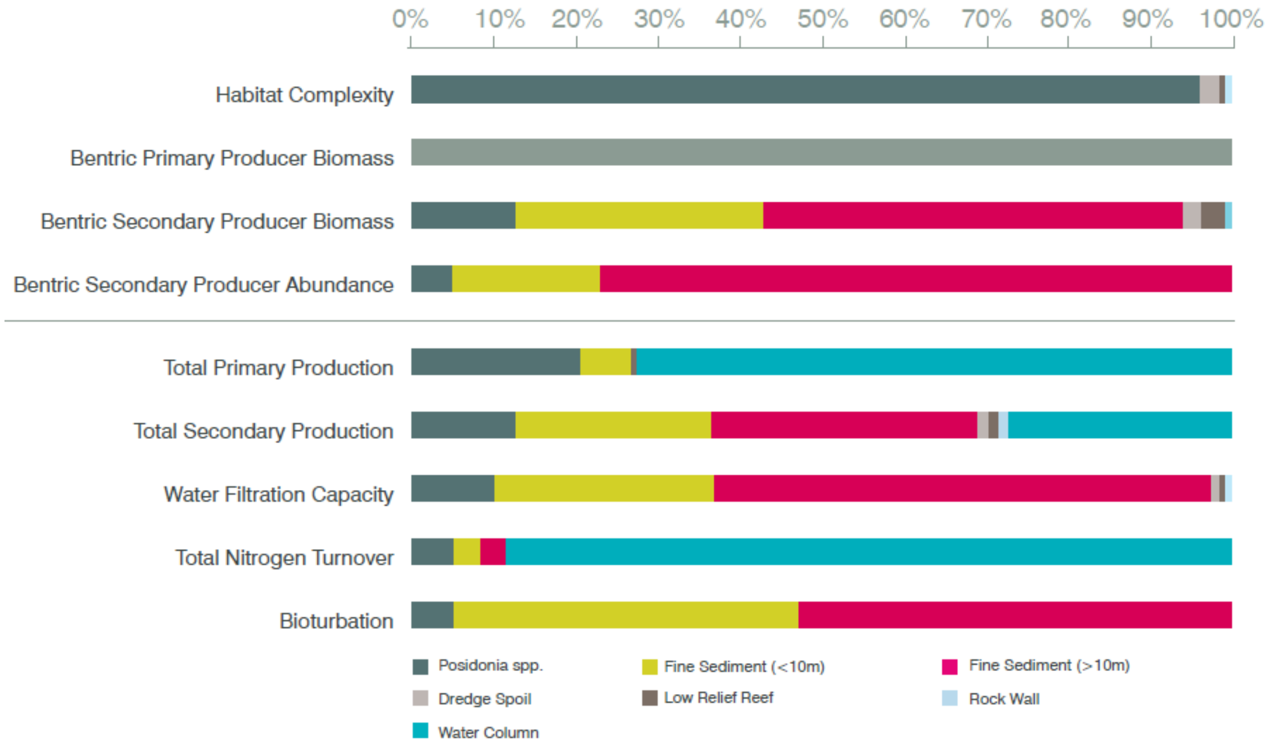


Figure 4.16 Contemporary estimate of the contribution of various components to ecosystem integrity in Cockburn Sound

Changes in ecosystem integrity since European habitation

The change in ecosystem components contributing to ecosystem integrity across Cockburn Sound since European habitation (here defined as pre-1944; see Appendix C), are illustrated in Figure 4.17.

In summary, habitat complexity has decreased by 96% since European habitation, mainly as a result of the widespread loss of seagrass habitat, while biomass of benthic primary producers has experienced a similar decrease (92%), again mainly due to the loss of seagrasses. Biomass of benthic secondary producers has experienced less of a decline (50%), because the new habitats created since European habitation (including unvegetated sediment in <10 m water depth, dredge spoil reef and rock wall) support a relatively high biomass of secondary producers and have helped to offset the loss of fauna associated with the loss of *Posidonia* spp. seagrass habitat.

Total abundance of benthic invertebrates has experienced just a 9% loss since European habitation. This relatively low decline is predominantly due to the maintenance of a high abundance of infauna within unvegetated sediments in <10 m water depth, where seagrass once grew. However, total benthic invertebrate diversity has declined by 29% since European habitation. The majority of this decline is the result of a loss of epifauna species associated with the loss of seagrass cover, and a loss of infauna species within dredged areas. Benthic secondary production has experienced a 30% decline since European habitation, predominantly due to the loss of infauna and epifauna associated with seagrass habitat.

Water filtering capacity has decreased by 68% since European habitation. Again, the decline in seagrass cover and the associated abundance of filter-feeding epifauna have caused much of this decline. Nitrogen turnover rate across the Sound is currently estimated at ~5% higher than the pre-European habitation, due to the higher production rates of phytoplankton in the water column. The current overall rate of sediment turnover across the Sound is estimated to be 8% lower since European habitation, due to the loss of bioturbating fauna in shallow habitats lost to dredged channels and dredge spoil reef.

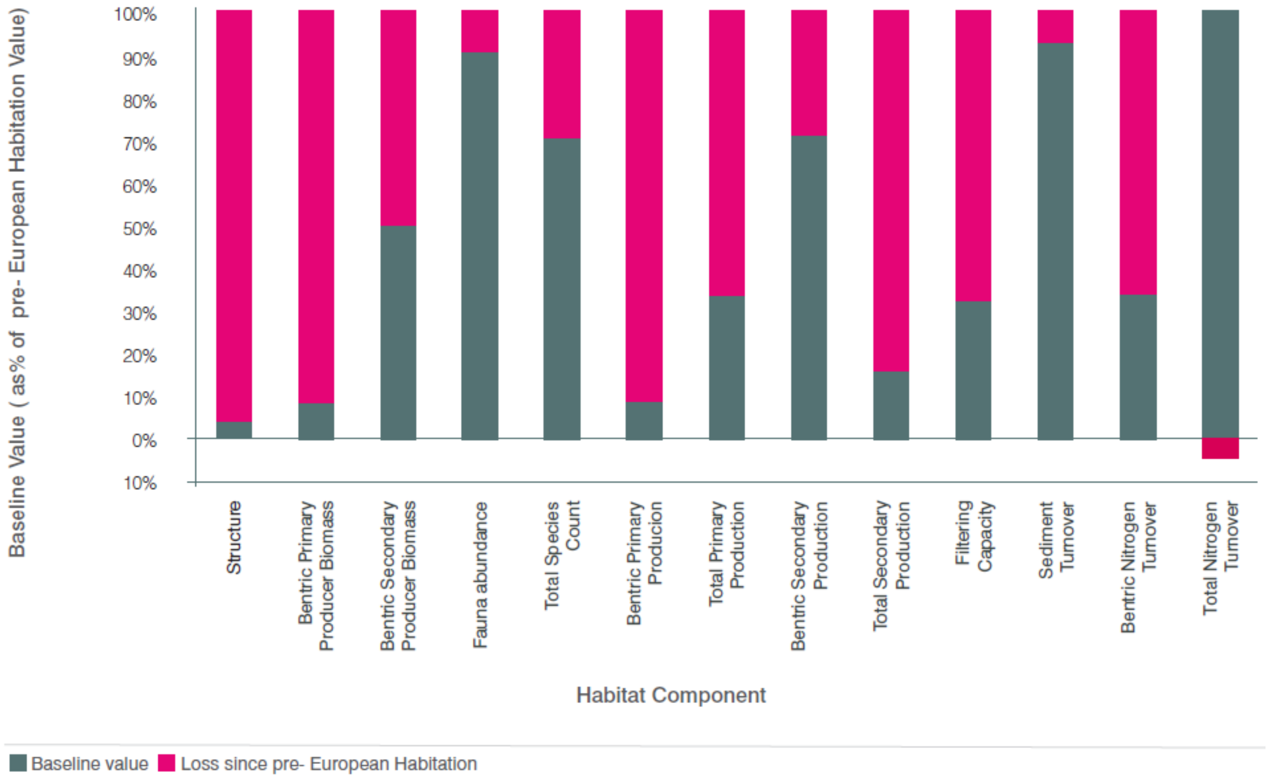


Figure 4.17 Baseline (current) structure and function values across the Eastern Shelf (as a percentage of pre-European habitation values)

4.11 Recreation and aesthetics

4.11.1 Recreational use of the coastal environment

From north to south, the six beaches with public access in Cockburn Sound are (Figure 3.1):

- West Beach
- Challenger Beach
- Barter Road Beach (adjacent to Kwinana Bulk Terminal, to the north)
- Kwinana Beach
- Rockingham Beach

- Palm Beach.

Quantitative data on beach visitation and use is limited. A 2005 survey of beach use in Perth's metropolitan area included Challenger Beach (in the north of Cockburn Sound) and Rockingham Beach (in the south of the Sound) (Eliot et al. 2005). The study found:

- Visitation is mainly from people residing in coastal suburbs south of Swan River.
- Visitation to Rockingham Beach (~200–300 people at any given time on a summer weekend) 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 (~500–700 people on each beach at any given time on a summer weekend).
- Weekday visitation to Rockingham beach (~10–50 people at any given time on a weekday) was much less than weekend visitation.
- The use 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%).
- The main reasons provided for visiting the specific beach were proximity to home (15–25% of respondents), swimming conditions (16–18%) and to meet family and friends (10–11%).

Further study is required to better characterise the contemporary visitation and use of beaches in Cockburn Sound.

4.11.2 Recreational use of the marine environment

Protecting the marine waters of Cockburn Sound for recreational use is a key environmental value recognised by the Government of Western Australia via the Cockburn Sound SEP. The environmental quality objectives for protecting recreational values are:

- maintenance of primary contact recreation, such that primary contact recreation (e.g. swimming) is safe
- maintenance of secondary contact recreation, such that secondary contact recreation (e.g. boating) is safe.

These objectives are framed around safeguarding human health from contaminants that may be ingested or exposed to skin surfaces when undertaking activities in the water (i.e. primary contact) or on the water (i.e. secondary contact, where there is a risk of spray or falling into the water). The DOH administers bacterial water sampling at beaches in Cockburn Sound based on support from the Cities of Cockburn, Kwinana and Rockingham and the Department of Defence (Figure 4.18). Other parameters that indicate whether water is safe for recreational activities include toxicant levels, pH and water clarity. These are measured as part of CSMC's annual summer program.

Since 2009, monitoring has consistently found that Cockburn Sound waters are safe for swimming and other water sports, with no broadscale exceedances of relevant water quality guidelines (e.g. see Table 4.4 and Figure 4.19). The cleanliness of the water has largely been attributed to improvements in stormwater drainage networks by local government and the rerouting of Woodman Point and industrial wastewater outfalls.

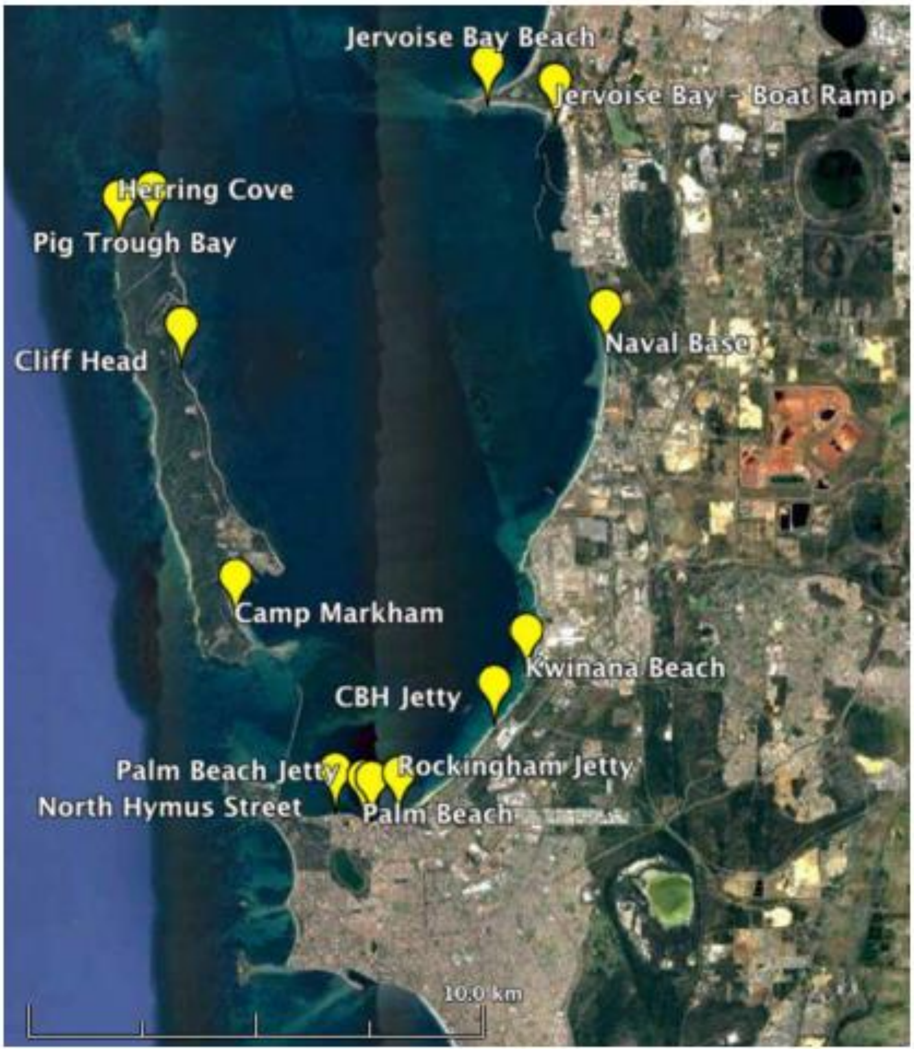


Figure 4.18 Beach public health monitoring locations in Cockburn Sound in 2015–2016

Table 4.4 Assessment of faecal bacteria (*enterococci*) counts at Cockburn Sound beach locations against applicable EQG during the summer of 2015–2016

Location	Type of Site	Number of measurements	EQG Primary contact	EQG Secondary contact	Rolling 5-year 95th percentile of enterococci counts (MPN/100 ml)
North Hymus Street	Program	82	200	2,000	130
Jervoise Bay Beach	Program	74			75
Naval Base	Program	55			10
Rockingham Jetty	Program	54			176
Kwinana Beach	Program	53			20
Palm Beach Jetty	Program	32			52
Cliff Head	Program	17			10
Pig Trough Bay	Program	17			17
Herring Cove	Program	16			10
Camp Markam	Program	15			10
Jervoise Bay Boat Ramp	Reference	54			39
Palm Beach	Reference	34			76
CBH Jetty	Reference	11			61
Assessment		EQG met at all sites			

Source: CSMC (2016a)

Result			
Assessment and Action	Environmental Quality Guidelines met—continue monitoring	Environmental Quality Guidelines not met—investigate against the Environmental Quality Standard	Environmental Quality Standard not met—management response triggered

Source: CSMC (2016b)

Figure 4.19 Assessment of pH and water clarity at Cockburn Sound beach locations against applicable EQGs during the summer of 2015/16

4.11.3 Aesthetic values of Cockburn Sound

In addition to safeguarding public health, protecting the inherent aesthetic values of the marine waters of Cockburn Sound is recognised by the Cockburn Sound SEP. The environmental quality objective is 'maintenance of aesthetic values' and the relevant EQC focus is on maintaining the visual amenity of marine waters. Many of the criteria are subjective and ultimately relate to preventing an overall decrease in water quality that would affect the community's appreciation and enjoyment of Cockburn Sound. As part of CSMC's annual summer program, aesthetic criteria require observations of:

- nuisance organisms
- fauna death
- water clarity
- colour variation
- natural reflectance of the water
- surface films of petrochemicals
- surface or submerged debris
- odour
- fish tainting.

To determine whether aesthetic values are being maintained, consideration is given as to whether observations of the above parameters are of an intensity, recurrence and/or at a location that would trigger community concern. CSMC's annual monitoring reports and report cards sometimes mention localised and occasional algal blooms, surface films and objectionable odours, but rarely to the extent that the overall aesthetic value of Cockburn Sound is compromised. An exception occurred in November 2015, when a large but isolated fish kill triggered public concern (see Section 4.9.2). It is noted that while EQC are specified for fish-tainting substances (EPA 2017), CSMC does not routinely capture information on fish tainting as part of observations collected during annual monitoring.

4.12 Cultural and spiritual values

4.12.1 Indigenous culture and heritage

Indigenous cultural and spiritual values are recognised as a key environmental value of the Cockburn Sound marine area by the Cockburn Sound SEP. The environmental quality objective is "maintenance of indigenous cultural and spiritual values, such that the cultural and spiritual values of the local indigenous community are protected*".* This is an addition to the original Cockburn Sound SEP, which did not recognise indigenous values.

Consideration and protection of indigenous cultural and spiritual values stems from the *National Water Quality Management Strategy* (ANZECC & ARMCANZ 2000). The strategy asserts that cultural and spiritual values of Indigenous Australians connected to marine and coastal environments may relate to a range of uses and issues including animals and plants associated with water, spiritual relationships, customary use, recreational activities and significant sites in the landscape (Collings 2012).

Neither the *National Water Quality Management Strategy* (ANZECC & ARMCANZ 2000) nor the *EQC Reference Document for Cockburn Sound* (EPA 2017) specify EQC or guidance for assessment against the objective of maintenance of indigenous cultural and spiritual values. However, EPA (2017) suggests that:

> Ensuring that the quality of [Cockburn Sound] waters is sufficient to protect ecosystem integrity, protect the quality of seafood, allow people to recreate safely, and maintain aesthetic values, may go some way towards maintaining cultural values, but it is more difficult to define spiritual value in terms of environmental quality requirements.

While there is logic in the EPA (2017) position—and other sections of this report make comment on the state and trends of impact on Cockburn Sound's ecosystem integrity, recreational values and aesthetics—without tangible criteria to assess the maintenance of indigenous cultural and spiritual values it is difficult to assess whether these values are being protected. For example, in the absence of EQC, the most recent *Cockburn Sound Report Card 2015–2016* (CSMC 2016b) does not comment on the status of maintenance of indigenous cultural and spiritual values. It is also noted that the *Terms of Reference* for the CSMC (CSMC 2015) specifies inclusion of a member representing Aboriginal and Torres Strait Islanders within the full council, but this position is presently vacant.

It is suggested that further consultation and engagement with the Noongar people is required to develop mutually agreed criteria that may be used to assess the cultural and spiritual health of Cockburn Sound's marine environment. As described in Section 2.1.2, there is presently a strong driving force for change and recognition of the Noongar people as the traditional owners of the land, with the *South West Native Title Settlement* binding the Government of Western Australia and Noongar people to work together towards a new level of partnership and shared responsibility for the future.

As a starting point, the CSMC's document *Sounding Out – A Way Forward* (Botting et al. 2009) provides a good summary of indigenous history in the Cockburn Sound area. It builds on the CSMC's previously commissioned study of the indigenous heritage of Cockburn Sound (O'Connor 2001; also see Appendix D for a list of known indigenous sites in the Cockburn Sound area). Further, Stocker et al. (2016) have recently published a paper that examines the relationship of the Noongar people with Cockburn Sound, traditionally known as Derbal Nara. The paper describes some of the debilitating impacts of colonisation on the Noongar people, including loss of land, removal of children and massacre, leading to a partial loss of language and culture. It also recounts survival of a culture that is alive and presently being reclaimed, re-energised and rebuilt. Stocker et al. (2016) also contend that the world view and experience of Noongar people complements and enhances sustainable management of marine and coastal environments, for example through traditional knowledge and stories that sustain food sources and make meaning of adaptation to climate change effects (such as the drowning of Cockburn Sound following the last ice age).

Botting et al. (2009) note that some government programs in recent times have aimed at engaging indigenous knowledge in the management of conservation areas in an effort to reverse the degradation of natural and cultural resources. They further comment that these programs have been eagerly taken up by indigenous groups who are keen to actively participate in exercises aimed at reinvigorating traditional knowledge as a means of countering environmental problems; and that in relation to the management of Cockburn Sound, these shifts to include Noongar people in the process are welcome and necessary.

4.12.2 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 (see Section 2.2.2). Cultural values associated with recreational use and aesthetic appreciation of Cockburn Sound have previously been discussed (see Section 4.11). This section considers the presence and protection of maritime heritage values, including shipwrecks and other archaeological or historic sites in Cockburn Sound.

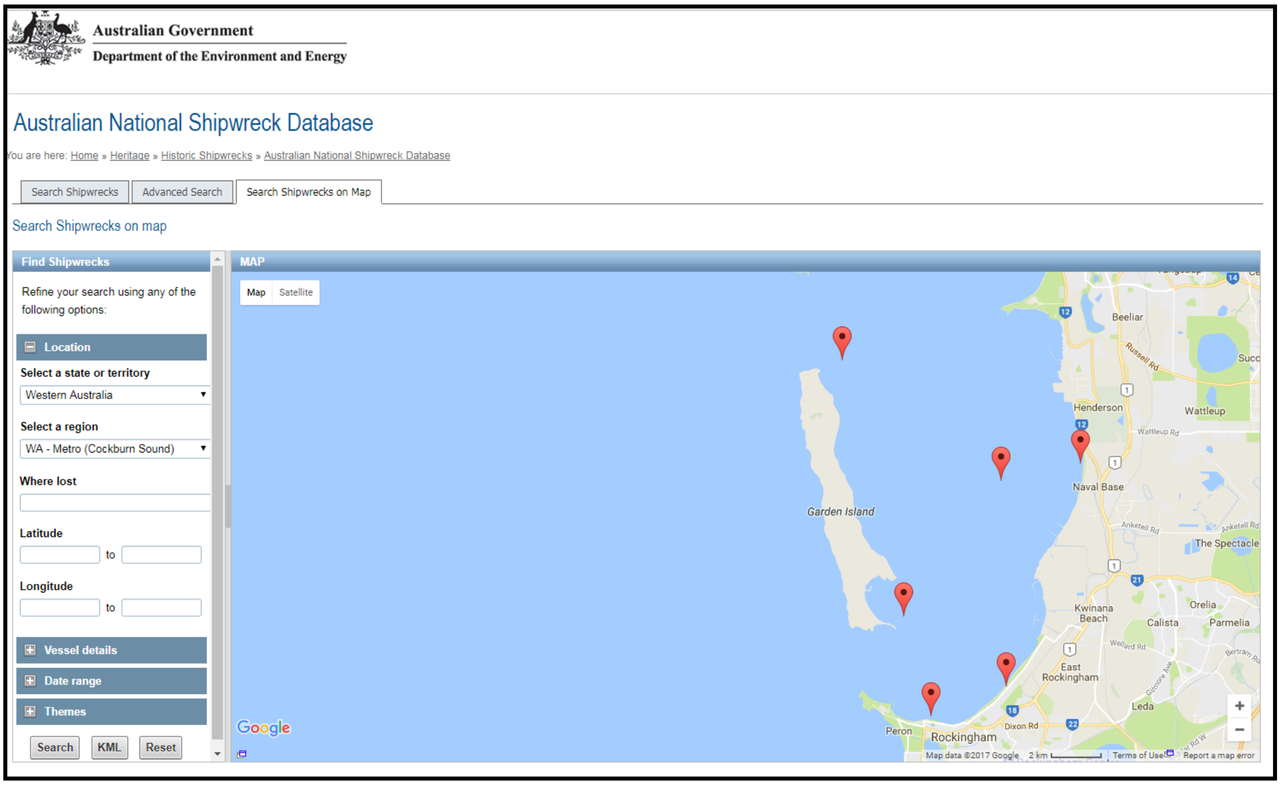
The Western Australian Museum's *Shipwreck Database* (Western Australian Museum 2017) presently lists 31 protected maritime heritage sites within and around Cockburn Sound, as listed in Table 4.5. The *Australian National Shipwreck Database* (DOEE 2017) includes six of these protected shipwrecks (Table 4.5 and shown in Figure 4.20).

Table 4.5 Protected maritime heritage sites in Cockburn Sound as listed on the Western Australian Museum's shipwreck database

Heritage site/shipwreck	When wrecked	Location
*Anti-submarine boom net tower**	World War II	Northern tip of Garden Island to Woodman Point
Lady Stirling	1840	Woodman Point
James Matthews	1841	Woodman Point
Empress	1849	Woodman Point
K8	1942	Jervoise Bay Marina
Ellen	1890	Jervoise Bay Marina
Abemama	1927	Jervoise Bay Marina
Gemma	1893	Jervoise Bay Marina
Alacrity	1931	Jervoise Bay Marina
Redemptora	1898	Jervoise Bay Marina
*Camilla**	1903	Eastern Shelf of Cockburn Sound
*D9 Dredge ex Parmelia**	1962	Centre of Cockburn Sound near the Eastern Shelf
Bombay	1830	Cockburn Sound
Pilot boat	1851	Cockburn Sound
Galah	1961	Cockburn Sound
*Amur**	1887	Near Rockingham Beach
August Tellefsen	1898	Near Rockingham Jetty
*Contest**	1874	Mangles Bay near Palm Beach
Rockingham	1830	Careening Bay
Sleeping Beauty	1943	Careening Bay
*Unidentified**	unknown	Southern Flats near Careening Bay
Unnamed boat	1830	Garden Island
Success's Pinnace	1830	Garden Island
Fanny	1835	Garden Island
Devonshire	1842	Garden Island
Albion	1849	Garden Island
Twinkling Star	1873	Garden Island
Seagull	1895	Garden Island
Guilford	1942	Garden Island
Mary 1	1962	Garden Island
Jessie Lee	1970	Garden Island

Source: Western Australian Museum (2017) shipwreck database
Note:
1. * Also listed on the *Australian National Shipwreck Database* (DoEE 2017), location shown in Figure 4.20

There is a synergistic relationship between safeguarding these maritime cultural heritage sites and protecting the marine environment. For example, maritime heritage sites often act as artificial reefs with the potential to increase marine biological diversity or offset other areas of loss (Mr M McCarthy 2017, Western Australian Museum, pers. comm., 28 June). Further, it is often the combination of maritime and natural heritage that attracts diving and snorkelling visitation, which in itself can increase pressures on the sites, but also raise awareness for conservation (Mr M McCarthy 2017, Western Australian Museum, pers. comm., 28 June).



Source: DOEE (2017)

Figure 4.20 Location of maritime heritage sites listed on the *Australian National Shipwreck Database*

4.13 Industrial water supply

A quality seawater source is fundamental to the operation of the Perth Seawater Desalination Plant and the Water Corporation completes real-time continuous monitoring (of temperature, pH, DO and hydrocarbons) and regular sampling (for *Escherichia coli*, total suspended solids, boron and bromide) of the intake seawater. Thresholds ensure the seawater at the intake remains suitable for desalination and that the quality of the potable water produced is protected (EPA 2017). No other guidelines have been defined for industrial water use but the high standard required for desalination likely demonstrates that it is suitable for all other industrial uses in Cockburn Sound (CSMC 2016b).

5. Management Response

5.1 Current management responses and monitoring efforts

A broad introduction to Cockburn Sound's regulatory management framework is provided in Section 1.5. The implementation of both regulatory and non-regulatory monitoring and management measures in Cockburn Sound are discussed below.

5.1.1 Government of Western Australia measures

The state government's commitment to Cockburn Sound's environmental health was established with a capital infrastructure project to divert the outfall of Woodman Point WWTP out of Cockburn Sound via the SDOOL. The 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 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 government's commitment to protecting the environmental values of Cockburn Sound. Together with the provisions for EIA and regulation of discharges under the EP Act, 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 EQC that are reported by the CSMC to the Minister for Environment
- EIA of new projects, with specific EQC to protect the environmental values of Cockburn Sound—many developments within the Sound are now subject to MISs defining environmental monitoring, management and offset conditions
- ongoing regulation of project-specific emissions, monitoring and management.

Other state 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 DPIRD
- 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.

5.1.2 Industry measures

Since the 1970s, industry within the industrial areas of Cockburn Sound's hinterland has 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 KIA 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 ISO 14 001). 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).

5.1.3 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
- mandating and effecting environmental change at a community level (e.g. in developing dune rehabilitation programs)
- the CSCA, 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.

5.2 Effectiveness of management responses

The effectiveness of management measures can be assessed by examining the recent trends in key pressures upon (Section 3) and current state of (Section 4) ecosystem elements, as follows:

1. Industrial point source discharges are decreasing, which suggests that overall management of these emissions by industry and regulatory agencies has been effective.
2. The trend in pressures arising from contaminated land and groundwater sources are unclear (requiring further catchment-scale studies). The effectiveness of catchment-scale monitoring and management of groundwater intrusion and surface water run-off into Cockburn Sound by regulatory agencies and industry is questionable; and is an area of management response that requires coordination and focus.
3. The hydrodynamics of Cockburn Sound have been graded as fair and stable, indicating that overall management by regulatory agencies has been effective. While the construction of the Garden Island Causeway had a material impact on the hydrodynamics of the southern portion of the Sound, management of further developments has resulted in only localised changes in water movement and not Cockburn Sound scale impacts.
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 moderate (and not significantly affecting ecosystem function). Accepted projections indicate that future impacts on the coastal environment are likely to occur. While coastal management by local governments, industry and regulatory agencies 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, requiring vigilance.

5. While the number of commercial vessels using Cockburn Sound has been stable for several years, 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, while data on recreational fishing catches are limited. In some instances, further studies are essential to understand the causes of decline and effectiveness of management of fish stocks. However, in others it is clear that present catch limits pose a high ecological risk. Scrutiny of regulatory 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. Ecosystem health components (water quality, sediment quality, pelagic and benthic primary production and ecosystem integrity) have been graded as 'fair' to 'good', indicating that overall management by regulatory agencies and industry have been effective in meeting Cockburn Sound's environmental objectives. 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 by relevant agencies).
8. While the status of benthic macrofauna and fish communities have been graded as 'fair', indicating that overall management by regulatory agencies and industry has been somewhat effective, the trend of change in these communities is unclear. Further studies are required on benthic macrofauna and fish communities to determine the ongoing effectiveness of management by relevant agencies.
9. The population status of little penguins, dolphins and protected marine fauna have been graded as 'stable' and 'good', indicating that overall management by regulatory agencies and industry has been effective.
10. While the status of marine recreational use and aesthetic values of Cockburn Sound have been graded as 'stable' and 'good', indicating that overall management by regulatory agencies and industry 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 provide comment on 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 by regulatory agencies and industry.

Cumulatively, the monitoring and management measures described in Section 5.1 are robust, but they are somewhat disparate and not completely coordinated. It is suggested that fostering further interaction between all bodies responsible for mandating and undertaking monitoring and management activities in Cockburn Sound, with consideration for centralisation of environmental and social data attained, would lead to more efficient and effective management outcomes.

Further, 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 focused 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 substantially 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 following question also needs to be asked of stakeholders:

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

Finally, while the EQMF set up by the Cockburn Sound SEP under the EP Act has been effective in addressing water quality issues and protecting the extent of existing seagrass habitat, the flexibility of the policy to consider management effort versus reward requires review. In this respect, the concept of managing impacts to not be significant (as mandated by the EP Act) versus impacts that are 'as low as reasonably practicable' (ALARP; as mandated by environmental legislation elsewhere) is worth consideration. If all the stresses are managed to ALARP, for example, then Cockburn Sound will be as resilient as it can be and the quality of the Sound's ecosystem at any future point in time will be as good as it can be, given the multitude of ecosystem services it is required to provide. Alternative conceptual tools such as ALARP, ecosystem engineering, and/or environmental accounting may be highly useful in helping to devise environmental management (or offset) measures that offer the best value for money in protecting stakeholder values of Cockburn Sound. However, their utility requires review in the context of the regulatory "no significant impact" requirement of the EP Act and Cockburn Sound EQMF.

6. Long-Term Outlook

This DPSIR assessment has highlighted the historical, contemporary and future drivers of pressures on Cockburn Sound's marine environment (Sections 2 and 3), and generally characterised its current state as a marine system modified by historic nutrient enrichment (eutrophication) and seagrass loss. The history of Cockburn Sound's eutrophication and loss of seagrass beds has been well documented and the effective response of government and industry to reduce nutrient loads to the Sound has been acknowledged. The water quality of Cockburn Sound has broadly improved in response to these efforts, but questions remain about the desired end-state of the system (and its capability to adapt to this state), such as:

- Are we trying to rehabilitate marine ecosystem quality and seagrass extent to a pre-disturbed state (and is that possible)? If not, then what state is acceptable?
- Will further nutrient reductions lead to lower phytoplankton productivity (and do we want that)?
- How will climate change compound the pressures on Cockburn Sound's marine environment and its ability to adapt?

Given that the broadscale seagrass loss in Cockburn Sound has significantly—and likely irreversibly—altered the diversity and integrity of the marine ecosystem (EPA 2016b), much 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 (and what state/s can be achieved).

Answers to these questions will be assisted by filling gaps in our 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 growth in Cockburn Sound, against the environment's capacity and resilience to cope with existing and emerging pressures, and in particular, climate change.

6.1 Potential influence of future cumulative development

6.1.1 Approved proposals

Future proposals that have been environmentally approved for development by the EPA and the Minister for Environment include:

- Port Rockingham Marina (MIS No. 826, February 2010 and MIS No. 1041, November 2016)
- Mangles Bay Marina Based Tourist Precinct (MIS No. 974, June 2014)[14].

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 existing EQMF requirements in Cockburn Sound, if implemented and managed in compliance with applicable conditions. That is, with

[14] *In March 2018, the Western Australian Planning Commission, after considering submissions on the precinct, determined that the proposal should not proceed to finalisation (WAPC 2018).*

implementation of these proposals, the EPA and the Minister for Environment have determined that protection of Cockburn Sound's environmental and social values can be achieved.

These determinations do not indicate that environmental impacts will not occur, only that they can be sufficiently managed and/or offset. For example, seagrass clearing is required for the Mangles Bay Marina development, imparting a residual impact that requires replanting (MIS No. 974, June 2014):

> of at least twice the area of seagrass lost by the proposal within 5 years of the commencement of... construction, in the southern end of Cockburn Sound, and ensure that ten years after the commencement of... construction, twice the amount of seagrass lost by the proposal has been re-established to at least 75 per cent cover...

While the intent of regulatory environmental management is clearly adequate, the efficacy of compliance with management measures requires a future assessment of the state-of-environment in Cockburn Sound.

6.1.2 Future proposals

The regulatory environmental management framework for Cockburn Sound (Section 1.5) equally applies to any new future development that may be proposed within or around Cockburn Sound. Particularly, the objectives of the EP Act and Cockburn Sound SEP are to ensure that any new development does not significantly impact on Cockburn Sound's marine environment and that its environmental and social values are protected. Projects that may potentially cause significant environmental impacts are required to undergo rigorous formal, and often public, EIA. The EPA will only recommend approval of project proposals if the environmental mitigation, monitoring, management and/or offset measures proposed and imposed are sufficient to meet the objectives of the EP Act and Cockburn Sound SEP and protect the environmental and social values of Cockburn Sound.

Based on the recommendations of the independent, advisory EPA, the Minister for Environment will reject or allow (and impose environmental conditions upon) a project proposal. The minister typically conforms to the EPA's recommendations, but is also subject to broader whole-of-government advice including from the Premier. On rare occasions, the minister can approve a project proposal that the EPA has not approved, based on overriding social or economic benefits. In such rare circumstances, the overall objectives of the EP Act and Cockburn Sound SEP may not be fully met, and the environmental and social values of Cockburn Sound may be impacted (though it remains a regulatory requirement to minimise such impacts).

Future major developments (that may or may not occur) that have been preliminarily planned, or suggested, but not yet formally proposed and/or assessed under Cockburn Sound's regulatory environmental management framework include:

- Fremantle Ports 'Kwinana Quay' development (FP & DOP 2012)
- the Government of Western Australia proposed ‘Westport’ development
- Indian Ocean Gateway proposal (City of Kwinana 2017)
- Kwinana Managed Aquifer Recharge Concept (GHD 2016)
- potential for future expansion of Perth Seawater Desalination Plant's production capacity and brine discharge.

While these potential projects will be subject to Cockburn Sound's robust environmental management framework described above, there is no doubt that approval and construction of large-scale projects (or multiple smaller projects) will impart some form 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?

6.2 Ecosystem resilience

There are many definitions for the term 'ecosystem resilience' but essentially it is the capacity of an ecosystem to absorb disturbance and still retain its basic function and structure (Walker & Salt 2006). The benefit of understanding ecosystem resilience is that it should afford some capacity to predict the onset of disturbances to key elements of the system, such as eutrophication or the collapse of fisheries (Walker & Salt 2006). Equally, it should also allow the identification of the system's structural features that might impede the risk of systemic collapse or endow a system with the ability to recover from a disturbance (Levin 2015). Understandably, ecological resilience has become a desired concept for environmental managers to understand, particularly where ecosystem services are considered more important to preserve than individual species (Levin 2015).

In compiling this DPSIR assessment of Cockburn Sound, it has become clear that there are many gaps in our understanding of the marine ecosystem (including known thresholds and tipping points), which limits our ability to enable confident predictions of ecosystem resilience. The system is complex, involving many interacting pressures, physical and biogeochemical responses and cascading ecological effects. In the absence of a detailed understanding of this complexity, the below subsections provide discussion around the potential resilience of Cockburn Sound's marine ecosystem to key historic and emerging pressures acting on the system. In this context, it is hoped that considering ecosystem resilience in Cockburn Sound will, to a degree, facilitate a qualitative assessment of ongoing risks to key environmental values (or at least provide commentary on the long-term outlook for these environmental values).

6.2.1 Contaminant and nutrient inputs

In recent years, nitrogen inputs from point source industrial discharges have been steadily reduced by improved management and diversion to the ocean via the SDOOL. Point source nutrient and contaminant loads from this source are now estimated to be immaterial. Total nutrient and other contaminant inputs have stabilised over the long-term, which in turn, appears to have led to general improvements in water quality.

Contemporary biological aspects of Cockburn Sound have therefore withstood an environment of long-term disturbance and modification yet improving water quality. In the absence of any other pressures, it may be argued that species which have been able to maintain viable populations to date should either have the resilience to continue to do so, or have enhanced rates of recovery (as water quality improves). However, there are few, if any, examples of species or population improvements in Cockburn Sound coinciding with reduced nutrient and contaminant loads; seagrass being the key case in point. While it is evident that seagrass health can no longer be regarded solely as a nitrogen-related water quality issue, the reasons for ongoing decline remain speculative. Recent research suggests that physical and biogeochemical variables in the water column and sediment processes may help to explain ongoing stress (see Section 4.4). Such variables may be related to broader climate changes, or alternatively, there may be historical lags in the system associated with earlier nutrient inputs that are preventing recovery. Regardless of the mechanism, it appears from the trend of ongoing decline in seagrass health (Section 4.8) that seagrasses in Cockburn Sound are presently stressed, and unlikely to have any further residual capacity or resilience to tolerate a return to poor water quality for any sustained periods of time.

6.2.2 Coastal modifications

The Cockburn Sound shoreline is the most heavily modified coastal system in WA. The largest changes in shoreline position within Cockburn Sound may generally be attributed to the influence of coastal structures. Much of this infrastructure has been constructed to facilitate industrial development and to improve access to Garden Island, while the rest was specifically intended to modify coastal processes. The presence of these structures at the coastline modifies the longshore sediment transport pathways and consequently shoreline position. Due to the prevailing low-energy conditions (i.e. protection from Garden Island), the coastal response to structural intervention within Cockburn Sound will be slow, with coastal response times in the order of many years to decades (DAL 2001, Stul et al. 2007, BMT Oceanica 2014).

Cockburn Sound's shoreline and coastal processes are still within a cycle of change that is responding to historical modifications to Cockburn Sound. Enhanced patterns of coastal erosion and accretion are ongoing features of this cycle. It is anticipated that climate change may further exacerbate coastal change, with recent predictions forecasting increased rates of coastal erosion associated with sea level rise (Section 3.8). In light of these existing pressures, 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 can cause changes to the biotic environment. However, unlike biotic health which typically has prescribed levels of protection, what is the 'most acceptable' state of the coastline in Cockburn Sound is a social decision that is determined by representative agencies and councils; with the intention to ensure both human uses and environmental values are protected.

6.2.3 Natural resource harvesting and fisheries

The primary objective of fisheries managers is to ensure fisheries and their habitats are sustainable. To understand whether Cockburn Sound's target fish communities are sufficiently resilient to meet this objective, an understanding of present fish stocks, fishing pressures (e.g. harvesting rates) and knowledge of sustainable yields is required. Also required is an understanding of fish biology and ecology and the role of environmental influences on population abundances and reproductive cycles—with climate change now considered a key risk factor (see Section 6.2.4). With such complexity, the resilience of fish communities is difficult to determine.

Further, access to most commercial fishing data is restricted because of commercial confidentially, while data on recreational fishing participation rates is limited (Section 3.7). Therefore, it is not possible to determine the actual status of target fisheries operating wholly within Cockburn Sound, or in turn, understand their level of resilience to current rates of harvest. According to DPIRD, despite recent declines in catches, many fish stocks in the broader West Coast Bioregion, including whiting, octopus, squid and Australian salmon, are being harvested at a rate that is still considered 'sustainable–adequate'. However, for other indicator species, including blue swimmer crabs, Australian herring, pink snapper and southern garfish, DPIRD advise sustainability concerns around commercial and recreational catches (Fletcher et al. 2017), with continued harvest rates in Cockburn Sound considered to pose a high ecological risk in the absence of fisheries closures or restrictions.

In addition to catch rates, management of fisheries must also consider environmental effects that may either inhibit or enhance stock numbers, including emerging pressures associated with climate change (Section 3.8). Unfortunately, for most species, including iconic taxa such as blue swimmer crabs, the relative influence of environmental drivers remains poorly understood. For example, the most recent stock decline of blue swimmer crabs has been related to the combined effects of changes in primary production and dietary limitation, water temperature, increased predation and the negative effects of density-dependent growth, which in turn, appear to have had an effect on the proportion of berried females (Johnston et al. 2017). How these factors are affecting stock numbers in Cockburn Sound remains unclear (Johnston et al. 2017). Without a clear understanding of the role of environmental influences on stock numbers, it remains challenging to determine levels of resilience. Notwithstanding this, if predictions around effects of climate change on WA's fisheries are accurate (Caputi et al. 2015a,b), then it is difficult to argue that the coupling of this environmental pressure with present harvest rates will not further erode the resilience of many target species in Cockburn Sound—especially those that are already considered unsustainable.

6.2.4 Potential flow-on effects of climate change to marine biota

Climate change has profoundly affected many of the physical and chemical properties of the ocean (Section 3.8), with strong evidence of local effects reaching Cockburn Sound, for example the 2011 marine heatwave (Rose et al. 2012, Caputi et al. 2015b). There is now a significant volume of literature which demonstrates that such effects can impact some marine biota (Harley et al. 2006, Poloczanska et al. 2016, Wernberg et al. 2016), although the topic is complex due to the broad range of potentially interacting physical and ecological features that can drive changes (Poloczanska et al. 2016). There also remains a lack of understanding of chronic effects associated with climate change on marine organisms.

Common themes of climate change around the globe include poleward and deeper distributional shifts, advances in spring phenology, changes in calcification and increases in the abundance of warm-water species (Poloczanska et al. 2016). While responses to water temperature are well studied, notable gaps in observations and knowledge include responses to ocean acidification and changing oxygen concentration (Poloczanska et al. 2016). This is also the case for Cockburn Sound, as the impetus for the majority of recent climate change investigations has been the 2011 heat wave. Understanding potential effects associated with non-temperature-related factors in Cockburn Sound can often only be inferred from academic literature.

For phytoplankton, the long-term consequences of climate change in Cockburn Sound remain unclear. Regionally, the Ocean Forecasting Australia Model predicts reduced phytoplankton concentrations off the south-west of WA over 1990–2060 period. This is most likely due to reduced eddy activity associated with decreased Leeuwin Current transport, which in turn is associated with reduced nutrient supply to the upper ocean (Caputi et al. 2015b). However, a large proportion of nutrient inputs into Cockburn Sound are of terrestrial origin (predominantly groundwater) and therefore the relative contribution from oceanic sources may play a lesser role in local phytoplankton dynamics.

Further, the influence of increased atmospheric carbon dioxide on local phytoplankton stocks is unknown. Some literature suggests it may enhance phytoplankton productivity (Schippers et al. 2004) especially when coupled with unseasonal rainfall events and higher water temperatures. For this reason, it is possible that more frequent nuisance phytoplankton blooms may be stimulated, for example potentially facilitating the occurrence of conditions that have been implicated in the 2015 fish kill (DOF 2015). However, if terrestrial/groundwater nutrient sources into Cockburn Sound continue to decline, it is possible that regional drivers associated with climate change may impose a greater relative effect on Cockburn Sound phytoplankton community dynamics.

Seagrass is the other dominant primary producer in Cockburn Sound. Heat waves and spikes in water temperature may possibly result in reduced seagrass growth rates and potential mortality when exposed to extreme conditions (Collier & Waycott 2014). It appears that duration and magnitude of change (in temperature) are both critical factors explaining the probability of impacts to this acute form of stress. However, very little information exists on seagrass tolerances to either factor. The magnitude of the warming of the 2011 heat wave was 2–4°C above ambient temperatures and persisted for ~8 weeks (Rose et al. 2012). While this duration of elevated heat stress far exceeded the six days that Collier and Waycott (2014) observed to have effects on seagrass, it is not clear whether the water temperatures during the 12-week heat wave reached the critical levels required to induce sublethal seagrass stress in Cockburn Sound. Temperature-related effects on seagrasses should be a focus of future studies.

Longer-term increases in average water temperature, a rise in sea level and ocean acidification may also be adding chronic stress to seagrasses in Cockburn Sound. In an assessment of long-term trends in seagrass health in Cockburn Sound, Mohring and Rule (2013) statistically tested for patterns in shoot density with potential physical and biogeochemical variables in the water column such as temperature, salinity, nitrates and DO. While the study found long-term increases in water temperature to be the most consistent predictor, this parameter returned significant correlations in only a limited number of instances (Mohring & Rule 2013), thus making it difficult to conclusively associate climate change with long-term declines in seagrass health. The unknown interactive effect that a rise in sea level has on seagrasses also needs considering as it may contribute to increased light attenuation and changes in hydrodynamics. Similarly, effects on seagrass from local changes in water chemistry associated with absorption of carbon dioxide, and changes in rainfall patterns and salinity, also remain unclear and will need further investigation to fully understand the potential effects that climate change may have on seagrasses in Cockburn Sound.

Perhaps the greatest effort in local climate change research to date has been on fisheries. With the exception of octopus, nearly all commercial fishing catches have declined in recent years, which may be due to a combination of reasons, including environmental factors (Fletcher et al. 2017). Among those, it is suspected that the 2011 marine heat wave may have induced spawning failures in winter 2011 for species such as whitebait, southern garfish and possibly King George whiting, likely resulting in the significantly lower catches of 2012–2013 and 2013–2014 (Fletcher et al. 2017). In 2015, a risk assessment of 35 of WA's key commercial and recreational finfish and invertebrate species was undertaken based on the likely exposure to climate change (Caputi et al. 2015a,b). The assessment identified Australian herring, pink snapper and blue swimmer crabs among those species with a moderate to highest risk ranking (Caputi et al. 2015a,b), while it was speculated that octopus may be a benefactor of climate change due to enhanced growth rates and earlier onset of maturity and reduced fecundity (Caputi et al. 2015a).

The Cockburn Sound blue swimmer crab fishery has also experienced reduced growth followed by poor recruitment in the year following the 2011 marine heat wave (Caputi et al. 2015b). It is now speculated that the recent stock decline may have been related to the combined effects of changes in primary production, water temperature, increased predation and the negative effects of density dependent growth (Johnston et al. 2017). Some of these factors may be related to long-term climate change, but are yet to be fully understood. That being said, Caputi et al. (2015b) did not identify the Cockburn Sound blue swimmer crab fishery as being at risk from climate change. It is also interesting to note that acidification, which is commonly associated as a stressor for marine invertebrates, has not been commonly implicated as a key factor in climate change discussions for large invertebrates in WA. Recent literature suggests that many invertebrate species in their adult life stage have the ability to increase calcification rates to compensate for increased seawater acidity, albeit at the metabolic expense of muscle tissue generation (Wood et al. 2008).

One of the more obvious climate change examples in Cockburn Sound involves the range extension of rabbitfish (*Siganus* sp.). Following the 2011 marine heat wave, this species established a viable breeding population in Cockburn Sound and now regularly contributes to commercial and recreational catches (Caputi et al. 2015a). According to Caputi et al. (2015a), an early (January) onset of the strong Leeuwin Current during 2011 created the opportunity for larvae of this summer-breeding species from the Gascoyne to be transported to the south and settle in nearshore habitats off the lower west coast. The elevated ocean temperature experienced during the two years following the marine heat wave may have subsequently enhanced the survival chances of the newly settled juveniles (Caputi et al. 2015a). Another local example of range extensions into Cockburn Sound include Spanish mackerel (*Scomberomorus commerson*). While historically an irregular visitor to waters off the Perth metropolitan area during the warmer months (late summer/autumn), records available since the marine heat wave reveal increased reports of this species within Cockburn Sound (Caputi et al. 2015a), noting that it is not considered a viable breeding population.

For those species considered to be at risk from the impact of climate change in WA, negative or positive impacts are likely to include changes in timing of spawning, changes in growth and stock productivity, effects on larval dispersal, southern shifts in range extension, and changes in abundance and biomass (Caputi et al. 2015b).

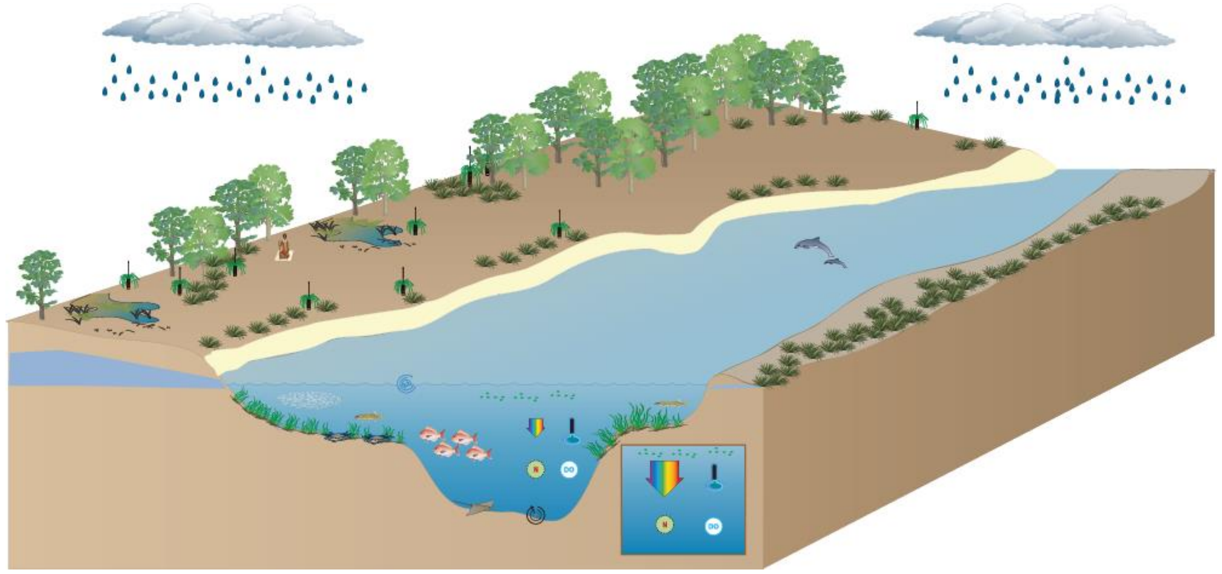
6.3 Characterising the future of Cockburn Sound

This report provides a key platform to assist stakeholders to better plan for future management of Cockburn Sound's marine environment. As illustrated in Figure 6.1 below, 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.

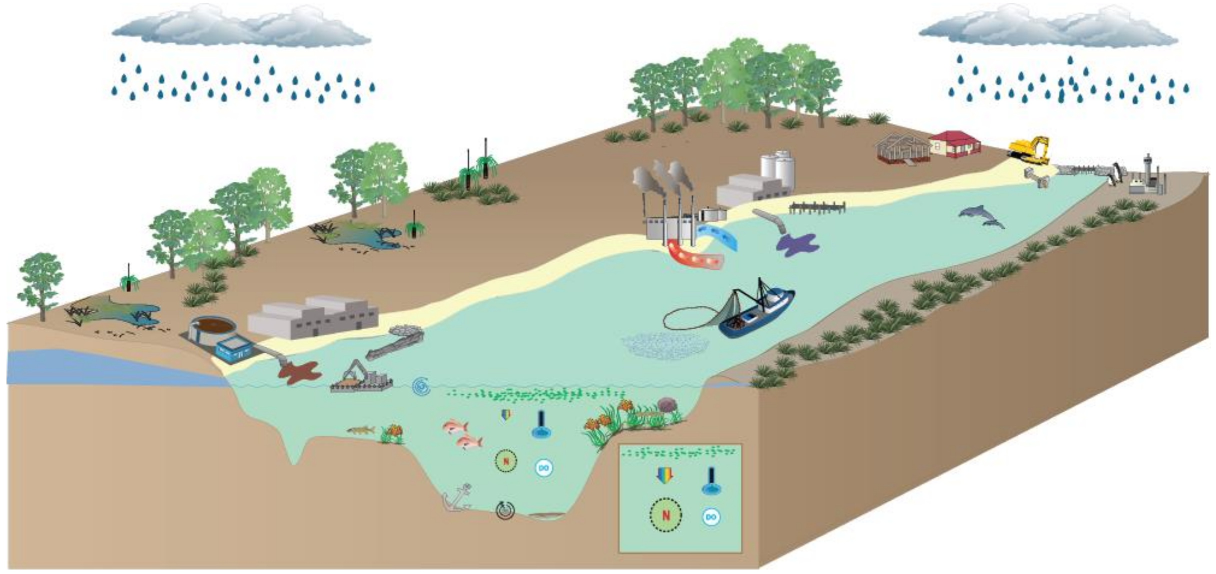
While it is possible to speculate what the future may entail based on the information at hand, the authors acknowledge that the picture presented remains an educated guess at best. Especially when taking into account our limited understanding of cumulative impacts and of ecosystem resilience. Notwithstanding this, and assuming the status quo of ongoing pressures and management measures, it is postulated that the future Cockburn Sound (10–20 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 visitation by commercial and recreational vessels
- increased recreational use of beaches
- unspecified cultural/spiritual values
- greater susceptibility to climate change induced stressors including:
    - reduced groundwater inputs
    - enhanced storm activity and coastal erosion
    - warmer waters and heat waves, which in turn could induce more frequent low-DO events
    - more frequent unseasonal rainfall events, which in turn could stimulate algal blooms
    - emergence of marine species more typically associated with tropical regions
- non-eutrophic water quality, but major primary production from the water column, which in turn could lead to shifts in trophic structure
- stable spatial extent of seagrass habitat
- lack of recovery in historically plentiful fisheries
- water quality that is aesthetically pleasing and suitable for recreational use
- cumulative impacts could reach a tipping point where abundance and diversity of key biota decline, if not appropriately considered or managed.

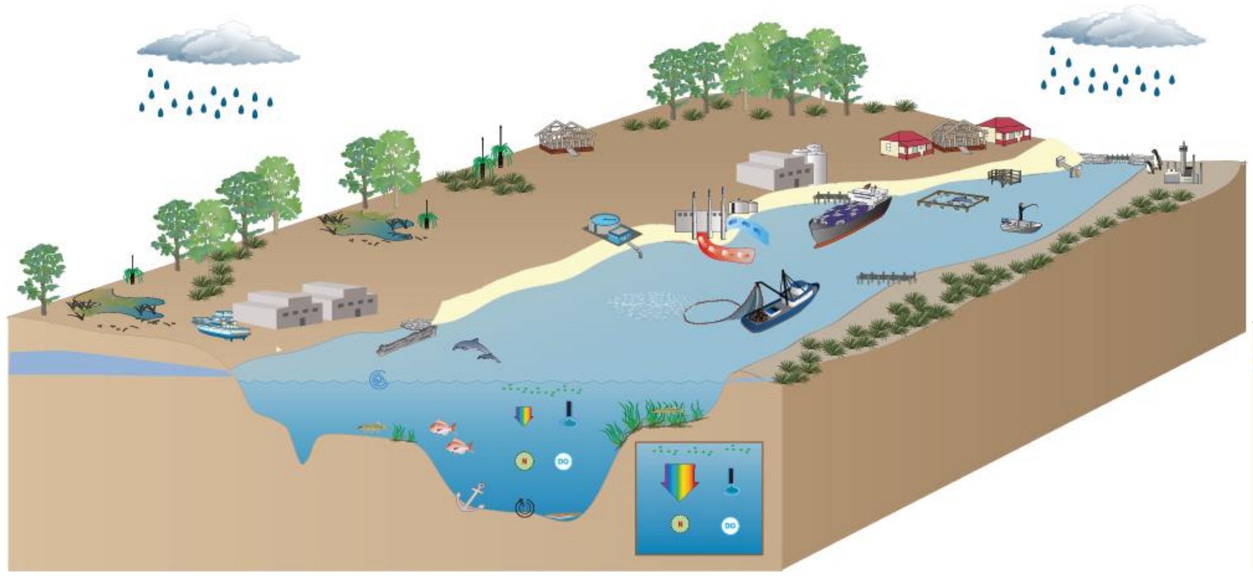
As the foundation for any future whole-of-Sound investigations, Table 6.1 provides a distillation from this report of all the key pressures and environmental cause–effect pathways that should be considered for future management. This table, which is a conceptual 'control model', is relatively simple in that it does not account for synergistic effects, or the severity of disturbances (i.e. the model makes no attempt to account for the interrelationships, magnitude and/or the duration of the cause–effect pathways). However, this DPSIR assessment's grading of risks from key pressures to environmental values (see Table 3.1) has also been flagged in Table 6.1 (colour of warning symbols) to provide an indication of which pressures may require the most focus when attempting to understand cause–effect pathways. This control model is intended as a first step towards conceptualising and better understanding ecosystem dynamics at a whole-of-Cockburn Sound scale, and a precursor to 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.



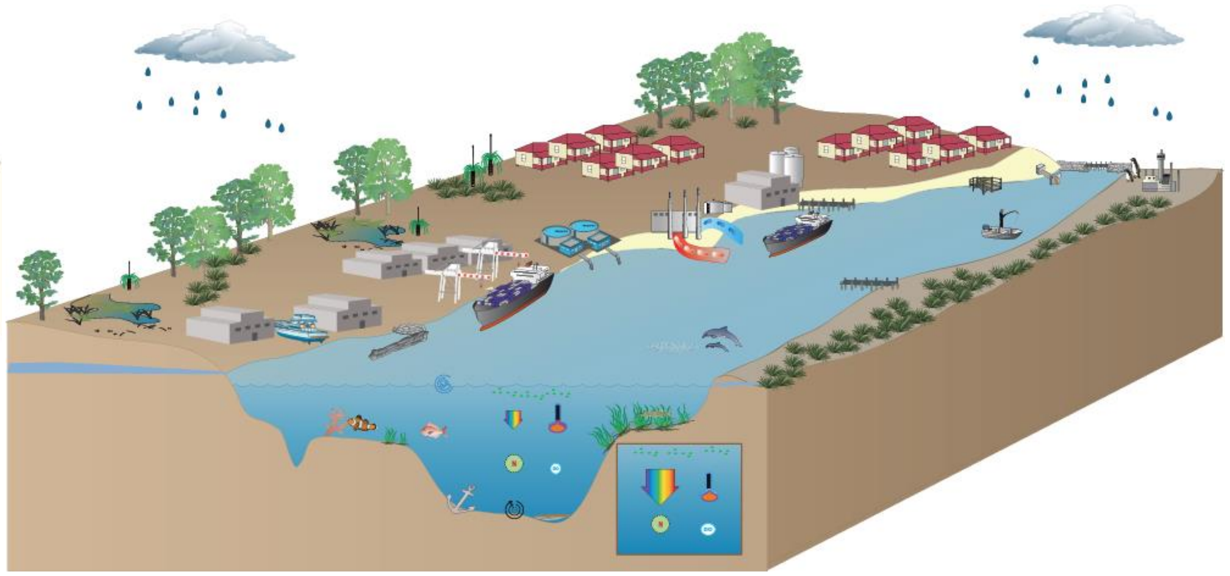
1. Pre-European settlement, earlier than 1950: natural



2. 1950s–1980s: disturbance and severe decline in ecosystem health



3. 1980s–2018: intense management, improved water quality, limited biotic recovery



4. Future state?

Figure 6.1 Identified and predicted key turning points in the state of Cockburn Sound (images are south-facing)

Table 6.1 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:

1. IMS = Invasive marine species; DO = Dissolved oxygen

7. Gaps in Monitoring and Knowledge

This DPSIR assessment has compiled and provided a substantial body of information about:

- the drivers and pressures of impacts on Cockburn Sound's marine environment (Section 2 and 3)
- its current state, in terms of environmental and social values (Section 4)
- the monitoring and management measures emplaced to protect these values (Section 5.1).

The conceptual diagrams of key marine environmental features and human uses of Cockburn Sound (introduced in Figure 1.1 and Figure 1.2) provide a good starting point to better visualise and understand the individual and interlinked components of the system. Many gaps remain in our understanding of these environmental and social components, and their interactions, which represents a challenge to effective management of Cockburn Sound. Gaps in monitoring and knowledge that have been identified through this DPSIR assessment include:

1. While much effort is, and has historically been, placed on monitoring the state of Cockburn Sound's marine environment (the 'receptor'), comparatively little quantitative data is available on catchment inputs to the system, 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—monitored under various programs (including DWER/CSMC's annual monitoring program)—against likely contemporary contaminant sources and pathways should be considered. Particular consideration should be given to emerging potential contaminant risks and derivation of appropriate EQC (such as biocides, organotin replacement substances, microplastics, Methyl tert-butyl ether and PFAS compounds).
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) are yet to be determined.
4. The long-term phytoplankton dataset, provided by WASQAP sampling adjacent to mussel aquaculture locations, provides an excellent opportunity for further evaluation of temporal dynamics and potential shifts in phytoplankton abundance and composition.
5. Contemporary studies of the zooplankton community and pelagic secondary production within Cockburn Sound are required (since very few data exist).
6. The broadscale efficacy of seagrass restoration efforts across Cockburn Sound requires further assessment. 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).
7. Data to determine the level of commercial and recreational fishing pressure is typically not publicly available and therefore difficult to quantify and 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, and not a fisheries, perspective).
8. The impact of seawater intakes and outlets on larval and juvenile fish and other biota needs to be assessed.
9. The inclusion of cultural and spiritual values of Cockburn Sound in the Cockburn Sound SEP is noted. However, dedicated EQC to measure whether values are being protected have not been established, and it is suggested that further consultation between DWER/CSMC and the Noongar people is warranted to develop and agree on appropriate criteria.
10. Further study is required to better characterise the contemporary visitation and use of beaches in Cockburn Sound.

11. Further investigations of the resilience of Cockburn Sound's key ecological components (e.g. plankton communities, fish, seagrass, benthic macroinvertebrates etc.), including in response to climate change pressures.
12. Develop 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 we are now at a point where 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 the key ecosystem levers are and where future management action should be targeted.

8. 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 50 years, 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 this, under the present EQMF 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 next key steps involve:

1. Gain a better understanding of the interrelated physical, biological and human-use cause–effect pathways in Cockburn Sound.
2. Direct management focus on aspects of Cockburn Sound's ecosystem that are highly valued by the community. To date, monitoring and management programs have focused on water quality and seagrass habitat, with less attention given 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. Review 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 ALARP 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 value for money in protecting stakeholder values of Cockburn Sound.

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Appendix A

Stakeholder consultation and responses to request for information

Stakeholder consultation and responses to request for information

Stakeholders with an interest in Cockburn Sound were consulted to request comment and feedback on relevant pressures, issues and data that should be used to inform the DPSIR assessment, as follows:

- A project presentation was provided by BMT Oceanica (Dr Rob De Roach and Dr Adam Gartner) to a full sitting of the CSMC on 28 April 2017 (see Table A.1 for membership) and separately to Marine Branch representatives of the Office of the EPA on 26 May 2017.
- During mid-May 2017, a project briefing note was submitted by BMT Oceanica to CSMC member representatives and many other stakeholder representatives (i.e. that are not members of CSMC, see Table A.1).

The briefing note provided information about the DPSIR assessment including the scope of work, method of assessment, and the key drivers, pressures and issues identified for consideration so far. The briefing note requested a response to the following questions (by mid-June 2017):

1. *What do you/your organisation perceive to be the priority drivers and pressures acting on the Cockburn Sound marine environment?*

2. *What do you/your organisation perceive to be the priority marine environmental issues in Cockburn Sound?*

3. *Do you/your organisation have any general comments about the state of the marine environment in Cockburn Sound?*

4. *Can you provide or cite any significant reports or data that may be used in this assessment of Cockburn Sound's marine environment?*

Of the 30 separate stakeholder requests for information, 29 stakeholders provided responses, which were considered and incorporated into the assessment, as follows:

- Data and reports provided/suggested by stakeholders were disseminated to BMT Oceanica technical authors (also see References).
- Stakeholder comments were captured in a searchable database and categorised into themes of:
  - priority drivers and pressures (e.g. coastal development, recreational boating; see Figure A. 1)
  - priority issues for state of Cockburn Sound (e.g. water quality, seagrass; see Figure A.2).
- Technical authors of each theme (i.e. corresponding to a subsection of the report such as seagrass) were asked to consult the database to access and consider relevant stakeholder comments.

Table A.1: **List of stakeholders consulted to inform the Cockburn Sound DPSIR assessment**

CSMC members	Other stakeholders (not members of CSMC)
• Independent chair • Department of Environment Regulation • Department of Fisheries • Department of Water • Department of Health • Fremantle Ports • Water Corporation • Australian Department of Defence • City of Cockburn • City of Kwinana • City of Rockingham • Kwinana Industries Council • WA Fishing Industry Council • Cockburn Power Boats Association • Recfishwest • Conservation Council WA • Community Representatives (x 3)	• Office of the EPA • Department of Parks and Wildlife • Australian Marine Complex • Department of Mines and Petroleum • Department of Transport • Department of Planning • Western Australian Museum – Maritime Archaeology • State Heritage Office • Department of Aboriginal Affairs • LandCorp

Note:

1. Government department names were correct at the time of consultation, but since 1 July 2017 many departments have changed name and/or been amalgamated.

Appendix B

Potentially contaminated land parcels and contaminants of concern

Potentially contaminated land parcels and contaminants of concern

Based on GHD's (2013) contaminant load review and additional desktop evaluation of DWER's (2017) *Contaminated Sites Database* and the National Pollutant Inventory website, multiple land-use areas on the coast—and associated contaminants—were identified to pose a tangible risk as a potential source of contaminants to Cockburn Sound. A total of 694 land parcels were identified as a known contaminated site within the Cockburn Sound policy boundary area with:

- 35 land parcels identified as 'contaminated–remediation required'
- 19 land parcels identified as 'contaminated–restricted use'
- 640 land parcels identified as 'remediated for restricted use'.

Land parcels classified as 'contaminated–remediation required' and 'contaminated–restricted use' were identified to be potential contemporary sources of contamination into Cockburn Sound (Tables B.1). The following high-risk areas were identified, associated with various land uses along the Cockburn Sound coastline:

- Henderson
- Hope Valley
- Kwinana Beach
- Munster
- Rockingham
- Naval Base
- Garden Island.

Descriptions of risk areas surrounding Cockburn Sound, potentially contaminating land uses and contaminants of concern are provided below and summarised in Tables B.1 and B.2.

Henderson

Henderson is located less than 200 m from the Cockburn Sound coastline with known heavy metal and organotin compounds (such as tributyltin) impacts to groundwater and surface soils. Heavy industry land uses are associated with boat building and maintenance (between 1970–2010), with historical land uses of market garden activities between 1965 and 1974.

Groundwater is ~3 m below ground level near the coastline of Cockburn Sound and therefore there is a potential risk of surface soil contamination (such as heavy metals) leaching into the groundwater and discharging into Cockburn Sound. Contaminants of concern within the Henderson area that may enter Cockburn Sound via groundwater include:

- heavy metals (including copper, zinc and nickel)
- organotin compounds (such as tributyltin)
- organochlorine pesticides (such as dieldrin).

Hope Valley

Hope Valley is ~1.8 km from the Cockburn Sound coastline. There are known areas of heavy metal contamination in groundwater within this zone, sourced from existing heavy industrial land uses such as:

- alumina refining operation
- disposal of mineral processing waste from bauxite/aluminium processing facility
- limestone quarry

- fly-ash disposal facility.

Contaminants of concern in the Hope Valley area that may enter Cockburn Sound via groundwater have been identified as:

- heavy metals including barium, manganese, arsenic, aluminium, molybdenum
- fluoride
- chloride
- elevated alkalinity.

Kwinana Beach

Kwinana Beach is less than 200 m from the Cockburn Sound coastline. Kwinana Beach has areas of known phenol, hydrocarbon and heavy metal contamination in groundwater associated with the following heavy industry land uses:

- fertiliser production and storage
- storage, manufacture and distribution of chemicals
- disposal of mineral processing waste from the adjacent bauxite/aluminium processing facility
- nickel refinery
- railway yard
- bulk fuel terminal.

Known contaminants of concern in the Kwinana Beach area that may enter Cockburn Sound via groundwater have been identified as:

- heavy metals including arsenic, aluminium, molybdenum
- petroleum hydrocarbons
- pesticides
- ammonia
- fluoride
- elevated alkalinity
- nutrients
- ammonium sulfate
- chlorophenols.

Munster

Munster is ~3 km from the Cockburn Sound coastline with areas of known heavy metal and organotin compound contamination in groundwater. Heavy industry land uses in Munster comprise boat building and maintenance activities.

Known contaminants of concern from the area of Munster that may potentially enter Cockburn Sound via groundwater are:

- heavy metals (including copper, zinc, lead, nickel, arsenic)
- organotin compounds (such as tributyltin)
- polycyclic aromatic hydrocarbons
- nutrients.

Rockingham

Rockingham is less than 500 m from the Cockburn Sound coastline with a known area of hydrocarbon contamination in surface soils and groundwater (sourced from a service station), which may potentially enter Cockburn Sound.

Naval Base

Naval Base is less than 200 m from the Cockburn Sound coastline. Naval Base has areas of known hydrocarbon and chromium contamination in surface soils and groundwater, associated with the following land uses:

- coal-fired power station and ancillary uses such as coal storage, bottom ash storage, bulk fuel storage, electrical transformers, workshops and offices
- commercial yard and fuel storage and distribution facility
- bulk storage of petroleum fuels and as a natural gas metering station
- former service station comprising underground storage tanks, fuel bowsers and associated infrastructure
- electricity generation and fuel storage facilities.

Garden Island

HMAS Stirling Naval Base is located on Garden Island and is the Royal Australian Navy's largest base in WA. Garden Island is on Commonwealth land and therefore not included within the jurisdiction of DWER's (2017) *Contaminated Sites Database.* Contaminant source risks to Cockburn Sound from Garden Island were based on knowledge of historical and current Naval Base activities provided by the Department of Defence (unpublished data).

Naval Base activities relevant to potential contaminant sources are comprised of:

- fire training
- ordnance destruction and disposal
- vehicle/vessel/weapons maintenance
- bulk fuel storage
- distribution of above-ground and underground storage tanks.

The Naval Base also contains WWTPs, a liquid trade waste facility, facilities for storage of hazardous materials and several landfills that have been used to dispose waste. Materials placed in the landfill are largely unknown, but records show that wastes included building demolition waste and dredge spoil (DoD 2013).

Information regarding these known potential contamination sources for the Naval Base have been summarised below (DoD 2013).

<u>Above-ground and underground storage tanks</u>
Leakage of fuel is known to have occurred from above-ground and underground storage tanks around the Naval Base. Several isolated zones of fuel-contaminated soil and groundwater have been identified from leakages, including around a former powerhouse, a storage facility, a training facility, the transport yard and a ship sullage storage facility.

<u>Landfills</u>
A wide variety of wastes have been disposed into landfills at the base from the 1970s to 1999. Known contamination found in investigations to date includes some buried asbestos-containing

materials, elevated concentrations of nitrogen compounds, and some slightly elevated levels of heavy metals.

Wastewater treatment

Elevated concentrations of nitrogen compounds, phosphorous and bacteria have been detected in groundwater around the WWTP.

Munitions disposal ground

A munitions demolition and disposal area was established in the 1980s in the northern portion of the island. Munitions disposal operations have resulted in elevated concentrations of heavy metals and firefighting chemicals in soil and groundwater in this area. Elevated levels of phosphorous were also found in groundwater around this area.

Fire training areas

Chemicals used in firefighting (firefighting foam containing PFAS) have been found in soil groundwater around fire training areas at the Naval Base, along with elevated levels of fuel-related compounds and heavy metals. Environmental contamination from PFAS substances is now an emerging issue. PFAS are highly persistent in the environment, moderately soluble, can be transported long distances (in some cases many kilometres) and transfer between soil, sediment, surface water and groundwater. PFAS have been shown to be toxic to some animals, and because they do not break down, they can bioaccumulate and biomagnify in some wildlife, including fish. This means that fish and animals higher in the food chain may accumulate high concentrations of PFAS in their bodies (DoD 2013).

The Naval Base has completed numerous phases of contaminant investigation, including desktop assessments, intrusive investigations, remediation design/feasibility/planning reports and remediation programs (DoD 2013). Ongoing remediation works are currently underway to address some of the fuel-contaminated groundwater around the base. Regular monitoring of groundwater is being conducted at the Naval Base to ensure that remediation works to date have been successful in minimising environmental impact to the surrounding environment, including Cockburn Sound.

Known contaminants of concern from Garden Island potentially capable of entering Cockburn Sound via groundwater are summarised below:

- hydrocarbons from above-ground and underground storage tanks
- PFAS from fire training areas
- heavy metals and nutrients from landfills
- nutrients and bacteria from WWTP.

Table B.1: Potentially contaminated land parcels and contaminants of concern for sites classified as 'contaminated–remediation required' and 'contaminated–restricted use'

Suburb	Medium	Number of land parcels	Land-use category (GHD 2013)	Recorded historical/current land uses	Potential contaminants	Preliminary risk rating	Reason for risk rating
Contaminated–remediation required							
Henderson	Surface soils	1	Heavy industry	• Market garden 1965–1974 • Boat building and maintenance 1970–2010 • Stockpiling of demolition waste	Surface soils: • asbestos	Low risk	• Asbestos in soils is not expected to have a significant impact on the marine environment.
	Groundwater and surface soils	2			Surface soils: • heavy metals (including copper, zinc and nickel) • organotin compounds (such as tributyltin) • organochlorine pesticide dieldrin Groundwater: • heavy metals (including copper and zinc) • organotin compounds (such as tributyltin)	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, are near the receiving marine environment. • Known potential contaminants of concern have been identified in groundwater. • Properties of contaminants can pose a potential impact to the marine environment . • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound.
Hope Valley	Groundwater	3	Heavy industry	• Alumina refining operation • Disposal of mineral processing waste from the adjacent bauxite/aluminium processing facility, and for a pipeline for the transportation of mineral processing waste and operating landfill • Limestone quarry • Fly-ash disposal facility since early 1980s	Groundwater: • heavy metals (including barium, manganese, arsenic, aluminium, molybdenum) • fluoride • chloride • elevated alkalinity	High risk	• Parcels are less than 1.8 km from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern have been identified in groundwater. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with current land use as an alumina refining operation can impact upon groundwater.
Kwinana Beach	Groundwater and surface soils	2	Heavy industry	• Fertiliser production and storage • Storage, manufacture and distribution of chemicals since 1978 • Disposal of mineral processing waste from the adjacent bauxite/aluminium processing facility, and for a pipeline for the transportation of mineral processing waste and operating landfill • Nickel refinery • Railway yard • Industrial purposes–including bulk fuel terminal	Surface soil: • phenols • chlorophenols • arsenic • ammonium sulfate Groundwater: • groundwater plume is migrating in a western direction off-site • ammonium sulfate	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern (including groundwater plume) have been identified in groundwater and surface soils. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with historical and current land uses can impact upon groundwater.
	Groundwater	13			Groundwater: • petroleum hydrocarbons • heavy metals (including arsenic, aluminium, molybdenum) • pesticides • phenol compounds • ammonia • fluoride • chloride • elevated alkalinity • nutrients	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern have been identified in groundwater. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with historical and current land uses can impact upon groundwater.
Munster	Groundwater, surface soils and sediment	3	Heavy industry	• Boat building and maintenance activities–early 1970s to approximately 2010	Groundwater and surface soils: • heavy metals (including copper and zinc) • organotin compounds (such as tributyltin)	Medium risk	• Parcels are ~3 km from the Cockburn Sound coastline and therefore, are not expected to contribute to large contaminant loads into Cockburn Sound. • Groundwater is shallow, ~3 m below ground level and therefore, potential for contaminates in surface soils and

					Sediments: • heavy metals (including lead, arsenic, copper) • organotin compounds (such as tributyltin) • polycyclic aromatic hydrocarbons Surface water: • Heavy metals (including copper, nickel and zinc) • organotin compounds (such as tributyltin) • nutrients		sediment to leach into the groundwater. • Known potential contaminants of concern have been identified in groundwater and surface water. • Properties of contaminants can pose a potential impact on the marine environment.
	Surface soils	1			Surface soils: • pesticides • asbestos (free asbestos fibres, asbestos-containing materials)	Moderate risk	• Parcels are ~3 km from the Cockburn Sound coastline and therefore, are not expected to contribute to large contaminant loads into Cockburn Sound. • Groundwater is shallow, ~3 m below ground level and; therefore, potential for contaminates in surface soils to leach into the groundwater. • Properties of contaminants can pose a potential impact to the marine environment.
Naval Base	Groundwater and surface soils	5	Heavy industry	• Coal-fired power station and latterly as a oil and gas-fired power station and ancillary uses such as coal storage, bottom ash storage, bulk fuel oil storage, electrical transformers, workshops and offices • Commercial yard and fuel storage and distribution facility • Bulk storage of petroleum fuels and as a natural gas metering station • Electricity generation and fuel storage facilities • Former service station comprising underground storage tanks, fuel bowsers, underground piping and associated infrastructure	Surface soils: • petroleum hydrocarbons Groundwater: • chromium • petroleum hydrocarbons	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern have been identified in groundwater and surface soils. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with historical and current land uses can impact upon groundwater.
	Groundwater	1			Groundwater: • petroleum hydrocarbons	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern have been identified in groundwater and surface soils. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with historical and current land uses can impact upon groundwater.
Postans	Groundwater	3	Heavy industry	• Disposal of mineral processing waste from the adjacent bauxite/aluminium processing facility, and for a pipeline for the transportation of mineral processing waste and operating landfill	Groundwater: • arsenic • aluminium • molybdenum • fluoride • chloride • elevated alkalinity	Low risk	• Parcels are ~5 km from the Cockburn Sound coastline and therefore, are not expected to contribute large contaminant loads into Cockburn Sound. • Known potential contaminants of concern have been identified in groundwater. • Properties of contaminants can pose a potential impact to the marine environment. • Low risk of contaminants leaching into the groundwater and discharging into Cockburn Sound as groundwater is deep, ~6.5 m below ground level.
Rockingham	Groundwater and surface soils	1	Heavy industry	• Currently used as a service station, which has been operating since the 1980s	Surface soils: • hydrocarbons groundwater: • free-phase and dissolved-phase hydrocarbons	High risk	• Parcel is less than 500 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants have been identified in groundwater.

							• Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound as groundwater is shallow, ~4 m below ground level. • Contaminants associated with historical and current land uses can impact upon groundwater.
Contaminated–restricted use							
Henderson	Sediment	1	Heavy industry	• Harbour for an adjacent boat building and maintenance facility for ~30 years	Sediment: • tributyltin is present in nearshore marine sediments	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, are near the receiving marine environment. • Known potential contaminants of concern have been identified in sediment. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound.
Kwinana Beach	Groundwater and surface soils	14	Heavy industry	Part of a larger industrial complex area that was subject to a variety of industrial uses since 1954 including: • blast furnace power house • steel merchant • raw material and product storage • production waste deposal, such as the disposal of slag, dusts and demolition waste, mixed and putrescible wastes • waste management facility	Surface soil: • hydrocarbons • industrial slag and cinders that contain heavy metals Groundwater • nitrate	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore, in proximity to the receiving marine environment. • Known potential contaminants of concern (have been identified in groundwater and surface soils). • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound. • Contaminants associated with historical and current land uses can impact upon groundwater.
	Surface soils	1			Surface soil: • organochlorine pesticides (such as aldrin and dieldrin)	High risk	• Parcels are less than 200 m from the Cockburn Sound coastline and therefore near the receiving marine environment. • Properties of contaminants can pose a potential impact to the marine environment. • High risk of contaminants leaching into the groundwater and discharging into Cockburn Sound as groundwater is shallow, ~4 m below ground level. • Contaminants associated with historical and current land uses can impact upon groundwater.
Leda	Groundwater	2	Natural	• Service station • Stockpile phospho-gypsum, limestone and peat since 1976	Groundwater: • sulfate • hydrocarbons	Low risk	• Parcels are over 4 km from the Cockburn Sound coastline and therefore are in proximity to the receiving coastline. • Low risk of contaminants leaching into the groundwater and discharging into Cockburn Sound as groundwater is deep, ~16.5 m below ground level.
Wattleup	Surface and subsurface soil	1	Light industry	• Quarrying occurred between approximately 2003 and 2008 with subsequent infill activity evident following this time	Surface and subsurface soil: • dieldrin and aldrin	Moderate risk	• Parcels are over 4 km from the Cockburn Sound coastline and therefore are in proximity to the receiving coastline. • Moderate risk of contaminants leaching into the groundwater and discharging into Cockburn Sound as groundwater is ~3.5 m below ground level.

Table B.2: Potentially contaminated land parcels and contaminants of concern for sites classified as ''*remediated for restricted use*'

Suburb	Medium	Number of land parcels	Land-use category (GHD 2013)	Recorded historical/current land uses	Potential contaminants
Aubin Grove	Groundwater	29	Urban	• Former piggery	Groundwater: • thermo tolerant coliforms • Enterococci/Faecal Streptococci • *E. coli*
Beeliar	Groundwater	244	Light industry	• Former piggery • Market garden (including bulk storage of pesticides, herbicides, fungicides and waste oil) • Intensive agriculture for 42 years (1970–2012)	Groundwater: • thermo tolerant coliforms • Enterococci/Faecal Streptococci • *E. coli* • fungicide chlorothalonil
Henderson	Groundwater and subsurface soils	60	Heavy industry	• Market garden for ~50 years, from the early 1950s to 1997 • Currently forms part of the AMC Support Industry Precinct, activities within the support industry precinct consist of fabrication, repairs and maintenance of marine vessels • Boat building and maintenance for ~30 years • Uncontrolled landfill prior to 1980	Subsurface soils: • metals Groundwater: • metals and pesticides
	Groundwater and surface soils	4			Surface soils: • metals • hydrocarbons • tributyltin • asbestos-containing materials Groundwater: • metals • tributyltin • pesticides
	Surface soils	1			Surface soils: • asbestos
Kwinana Beach	Groundwater and surface soils	2	Heavy industry	• Service station and has been since 1998 • Storage, treatment and disposal of oil sludge waste, for ~20 years, from 1967 to 1987	Groundwater and surface soils: • hydrocarbons
Leda	Surface soils	1	Natural	• Conservation land	Surface soils: • asbestos
Munster	Groundwater	109	Agricultural	• Intensive agriculture (market gardens) for 45 years (1950–mid-1990s) • Landfill from approximately 1969 to the mid-1970s was then used for horticulture • Historically used as quarry between approximately 1948 and 1969 • Landfill from approximately 1969 to the mid-1970s • Horticulture	Groundwater: • heavy metals • nutrients
	Groundwater and surface soils	170			Surface soils: • heavy metals (including arsenic and zinc) • organochlorine pesticide DDE • asbestos Groundwater: • heavy metals • nutrients • chlorine
	Surface soil	8			Surface soils: • asbestos
Naval Base	Groundwater	1	Heavy industry	• Historically used as part of a coal-fired power station and ancillary uses such as ash storage, workshops and offices	Groundwater: • hydrocarbons
Parmelia	Surface soils	1	Light industry	• Service station for ~35 years	Surface soils: • hydrocarbons
Rockingham	Groundwater	1	Light industry	• Concrete batching plant	Groundwater: • alkaline-impacted groundwater
	Surface soils	1			Surface soils: • asbestos
Success	Surface soils	2	Agricultural	• Unauthorised dumping of waste for an unspecified period of time	Surface soils:

Suburb	Medium	Number of land parcels	Land-use category (GHD 2013)	Recorded historical/current land uses	Potential contaminants
					• asbestos
Wattleup	Groundwater	3	Agricultural	• Fuel storage facility for ~26 years, from 1971 to 1997 • Limestone quarry for ~50 years until 2002 • The site was backfilled with material originating from off-site and has subsequently been used to stockpile material including dredge spoil • The site has also been subject to illegal dumping activities including dumping of asbestos-containing materials	Groundwater: • hydrocarbons
	Surface soils	1			Surface soils: • asbestos

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Appendix C

Assumptions made in assessment of ecosystem integrity

Assumptions in assessment of ecosystem integrity

Detailed benthic habitat maps of Cockburn Sound produced by Fremantle Ports in 2008 (unpublished) were used, as per Figures C.1 and C.2.

To calculate the ecological value of each of the habitats present across Cockburn Sound, data for each attribute was initially expressed in comparable terms (e.g. primary production of all primary producers was expressed in grams of carbon per square metre per year). To model the present distribution and sum of 'ecosystem values' across Cockburn Sound, an area-based approach has been taken. The ecological value (value per unit area) calculated for each habitat type was multiplied by the area of each habitat, to determine a total 'score' for each habitat type. For some attributes (e.g. primary production and secondary production) the contribution of the overlying water column was also considered. The approach used in this report used for estimating the ecosystem structure and function of Cockburn Sound involved a number of assumptions:

To determine existing ecosystem structure and function for Cockburn Sound

1. Values of *Posidonia* spp. beds within the wider Sound were estimated from 2008 shoot density data (Lavery & Gartner 2008) and 2005 seagrass and epiphyte data (Lavery & Westera 2005).
2. MPB biomass within deep basin was estimated using 2008 data (Oceanica 2009). Biomass across other fine sediment areas were estimated as equal to mean of Eastern Shelf values.
3. Infauna and epifauna biomass within deep basin were estimated using 2008 data (Oceanica 2009). Biomass across other fine sediment areas were estimated as equal to mean of Eastern Shelf values.
4. Phytoplankton biomass within deep basin waters was estimated from lowest depth-integrated chloroplyll-a concentration recorded from the offshore margin of the Eastern Shelf, multiplied by the mean depth of the deep basin (19 m). Biomass across other fine sediment areas were estimated as equal to lowest of Eastern Shelf values.

To determine changes in ecosystem integrity since European habitation

1. Low relief reef areas mapped in 2008 were also present before European habitation.
2. Dredge spoil reef areas are artificial and were not included with natural reef features.
3. All sandy areas shallower than -10 m chart datum in 1944 were colonised by *Posidonia* spp. seagrasses (80% cover of these areas assumed).
4. Habitat complexity values of *Posidonia* spp. beds mean of current (February 2008).
5. Functional values of *Posidonia* spp. beds mean of estimates from long-term monitoring sites 'Garden Island 7m' and 'Mersey Point' (to take account of mean depth (~5 m) of historic Eastern Shelf seagrass beds; Lavery & Westera 2003).
6. Biomass of epiphytic algae equal to current plus 15% (assuming higher biomass and production due to lower turbidity). Production re-calculated accordingly.
7. Values of epifauna (all reef habitats and *Posidonia* spp.) are equal to the mean baseline (February 2008)[15].
8. Macroalgal production rates are equal to the current value.
9. Phytoplankton production were estimated as being equal to Warnbro Sound (DEP 1996) (equates to 40% lower phytoplankton primary production than current).
10. Mesozooplankton biomass and production values are equal to current values.

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[15] *Likely to be overestimated as there is currently more food (phytoplankton/zooplankton) for filter feeders than historically.*

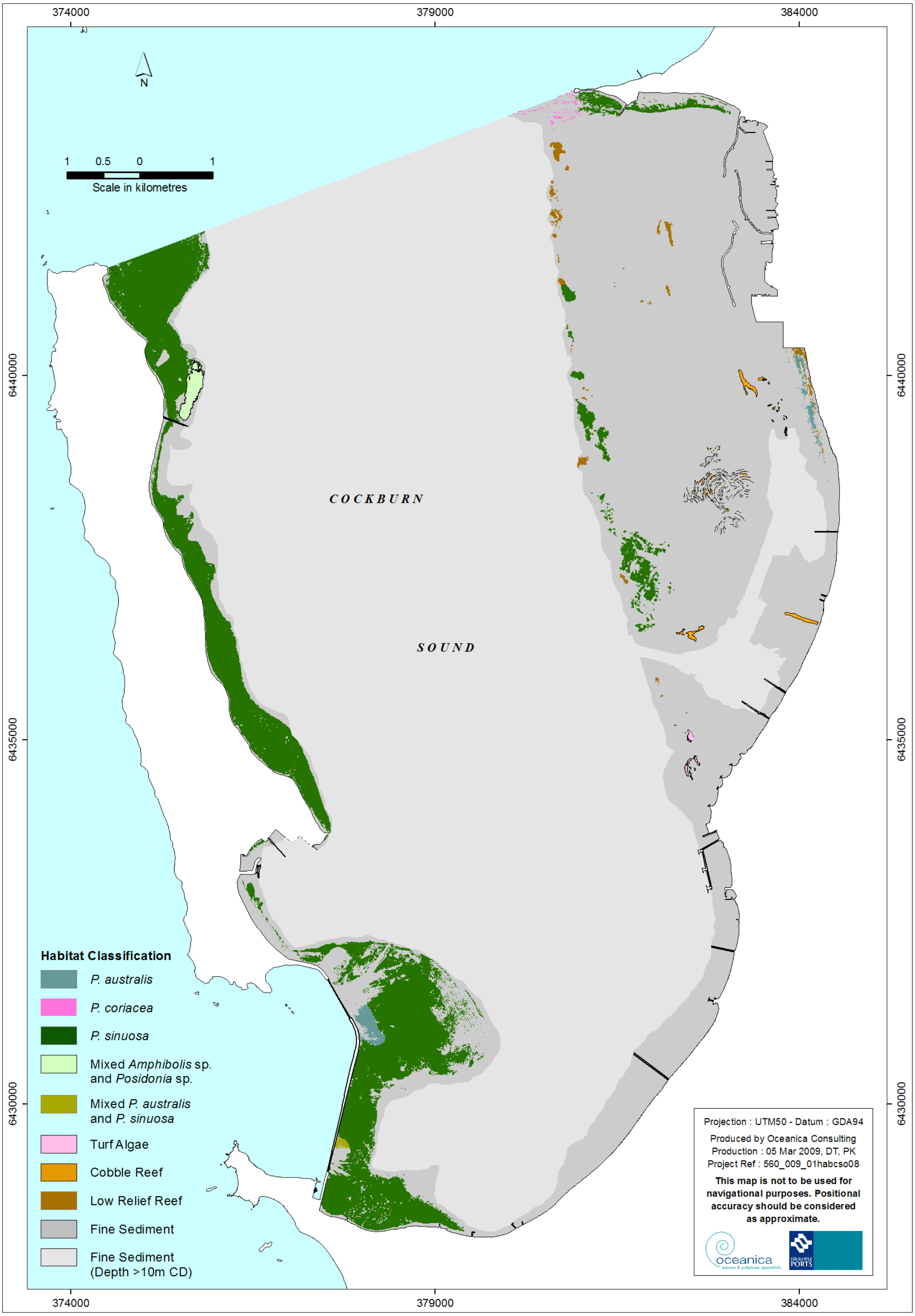

Figure C.1 2008 habitat map of Cockburn Sound

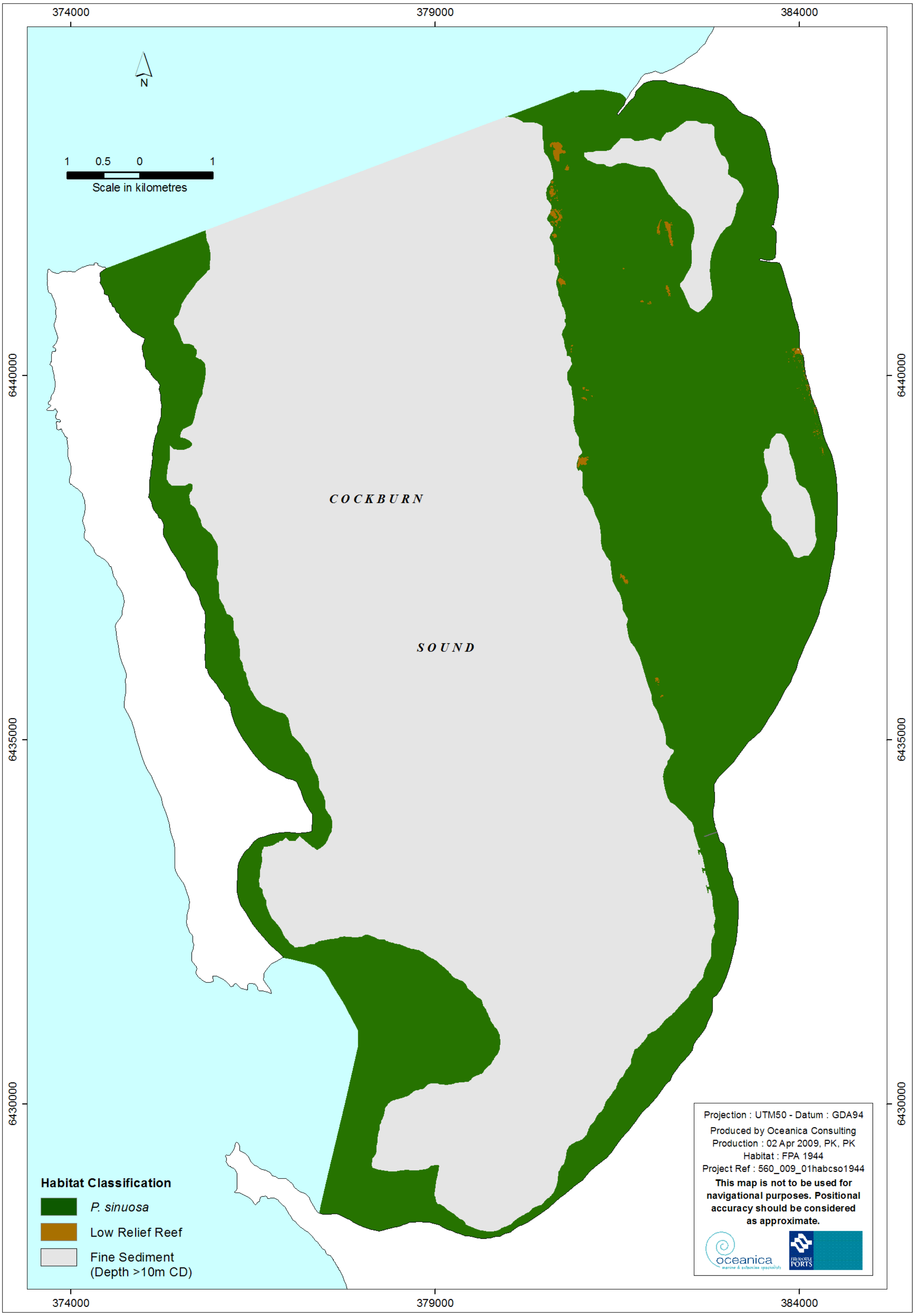

Figure C.2 1944 habitat map of Cockburn Sound

References

DEP (1996) Southern Metropolitan Coastal Waters Study (1991–1994). Department of Environmental Protection, Report No. 17, Perth, Western Australia, November 1996

Lavery P, Gartner A (2008) A Survey of Selected Seagrass Meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound: Health and Status, 2008. Prepared for Cockburn Sound Management Council (Department of Environment and Conservation), Edith Cowan University Centre for Marine Ecosystems Research, Report No 2008-10, Perth, Western Australia, June 2008

Lavery P, Westera M (2003) A Survey of Selected Seagrass Meadows in the Fremantle–Warnbro Sound Region 2003. Lavery P and Westera M, Perth, Western Australia

Lavery P, Westera M (2005) A Survey of Selected Seagrass Meadows in the Fremantle–Warnbro Sound Region. Report No 2005-02, Perth, Western Australia

Oceanica (2009) Fremantle Ports Kwinana Quay Project – Ecosystem Component Characterisation: Habitat Function Assessment. Prepared for Fremantle Ports by Oceanica Pty Ltd, Report No. 560_010/3, Perth, Western Australia, September 2009

Appendix D

Indigenous heritage sites database listings for Cockburn Sound and its hinterland

Aboriginal Heritage Inquiry System

List of Registered Aboriginal Sites

Search Criteria

26 Registered Aboriginal Sites in Custom search area - Polygon - 115.656741590542°E, 32.1545519540021°S (GDA94) : 115.736392469448°E, 32.1336218592502°S (GDA94) : 115.754931898159°E, 32.1286793302828°S (GDA94) : 115.795787305874°E, 32.1266440934666°S (GDA94) : 115.804370374721°E, 32.1295515607348°S (GDA94) : 115.8112368298°E, 32.1289700746933°S (GDA94) : 115.816729993862°E, 32.1269348443627°S (GDA94) : 115.824283094448°E, 32.1278070914921°S (GDA94) : 115.833896131557°E, 32.1248995686335°S (GDA94) : 115.838702650112°E, 32.1251903250885°S (GDA94) : 115.846599073452°E, 32.1289700746933°S (GDA94) : 115.858958692592°E, 32.1280978386822°S (GDA94) : 115.860331983608°E, 32.1493198807369°S (GDA94) : 115.856555433315°E, 32.1583304868074°S (GDA94) : 115.857242078823°E, 32.1914586013611°S (GDA94) : 115.849345655483°E, 32.2135373148888°S (GDA94) : 115.848315687221°E, 32.2187656989966°S (GDA94) : 115.853122205776°E, 32.2504200458248°S (GDA94) : 115.85346552853°E, 32.2605819462963°S (GDA94) : 115.85174891476°E, 32.2649366982938°S (GDA94) : 115.843509168667°E, 32.2727747253385°S (GDA94) : 115.821879835171°E, 32.2809023345318°S (GDA94) : 115.812266798061°E, 32.2875780401515°S (GDA94) : 115.797160596889°E, 32.2878682770744°S (GDA94) : 115.795100660366°E, 32.2832243748313°S (GDA94) : 115.78754755978°E, 32.2765483487387°S (GDA94) : 115.772784681362°E, 32.2855463556796°S (GDA94) : 115.773814649624°E, 32.3090530629369°S (GDA94) : 115.766948194546°E, 32.321239325668°S (GDA94) : 115.744975538296°E, 32.3226899620202°S (GDA94) : 115.732272596401°E, 32.3084727238187°S (GDA94) : 115.7278094006°E, 32.3113743822361°S (GDA94) : 115.695537061733°E, 32.3084727238187°S (GDA94) : 115.6838640881°E, 32.3096333983377°S (GDA94) : 115.680430860561°E, 32.2794510291556°S (GDA94) : 115.678027601284°E, 32.2611625919678°S (GDA94) : 115.682147474331°E, 32.2527428662087°S (GDA94) : 115.668414564175°E, 32.2228320121147°S (GDA94) : 115.658458204311°E, 32.1830324168597°S (GDA94) : 115.652965040249°E, 32.1734430513154°S (GDA94) : 115.657084913296°E, 32.1542612911438°S (GDA94) : 115.656741590542°E, 32.1545519540021°S (GDA94)

Disclaimer

The *Aboriginal Heritage Act 1972* preserves all Aboriginal sites in Western Australia whether or not they are registered. Aboriginal sites exist that are not recorded on the Register of Aboriginal Sites, and some registered sites may no longer exist.

The information provided is made available in good faith and is predominately based on the information provided to the Department of Aboriginal Affairs by third parties. The information is provided solely on the basis that readers will be responsible for making their own assessment as to the accuracy of the information. If you find any errors or omissions in our records, including our maps, it would be appreciated if you email the details to the Department at heritageenquiries@daa.wa.gov.au and we will make every effort to rectify it as soon as possible.

South West Settlement ILUA Disclaimer

Your heritage enquiry is on land **within or adjacent to** the following Indigenous Land Use Agreement(s): Gnaala Karla Booja People ILUA, Whadjuk People ILUA.

On 8 June 2015, six identical Indigenous Land Use Agreements (ILUAs) were executed across the South West by the Western Australian Government and, respectively, the Yued, Whadjuk People, Gnaala Karla Booja, Ballardong People, South West Boojarah #2 and Wagyl Kaip & Southern Noongar groups, and the South West Aboriginal Land and Sea Council (SWALSC).

The ILUAs bind the parties (including 'the State', which encompasses all State Government Departments and certain State Government agencies) to enter into a Noongar Standard Heritage Agreement (NSHA) when conducting Aboriginal Heritage Surveys in the ILUA areas, unless they have an existing heritage agreement. It is also intended that other State agencies and instrumentalities enter into the NSHA when conducting Aboriginal Heritage Surveys in the ILUA areas. It is recommended a NSHA is entered into, and an 'Activity Notice' issued under the NSHA, if there is a risk that an activity will ‘impact’ (i.e. by excavating, damaging, destroying or altering in any way) an Aboriginal heritage site. The Aboriginal Heritage Due Diligence Guidelines, which are referenced by the NSHA, provide guidance on how to assess the potential risk to Aboriginal heritage.

Likewise, from 8 June 2015 the Department of Mines and Petroleum (DMP) in granting Mineral, Petroleum and related Access Authority tenures within the South West Settlement ILUA areas, will place a condition on these tenures requiring a heritage agreement or a NSHA before any rights can be exercised.

If you are a State Government Department, Agency or Instrumentality, or have a heritage condition placed on your mineral or petroleum title by DMP, you should seek advice as to the requirement to use the NSHA for your proposed activity. The full ILUA documents, maps of the ILUA areas and the NSHA template can be found at https://www.dpc.wa.gov.au/lantu/Claims/Pages/SouthWestSettlement.aspx.

Further advice can also be sought from the Department of Aboriginal Affairs (DAA) at heritageenquiries@daa.wa.gov.au.

Coordinate Accuracy
Coordinates (Easting/Northing metres) are based on the GDA 94 Datum. Accuracy is shown as a code in brackets following the coordinates.

Terminology (NB that some terminology has varied over the life of the legislation)

Place ID/Site ID: This a unique ID assigned by the Department of Aboriginal Affairs to the place.

Status:

- **Registered Site**: The place has been assessed as meeting Section 5 of the *Aboriginal Heritage Act 1972.*
- **Other Heritage Place which includes:**
  - **Stored Data / Not a Site:** The place has been assessed as not meeting Section 5 of the *Aboriginal Heritage Act 1972.*
  - **Lodged:** Information has been received in relation to the place, but an assessment has not been completed at this *stage* to determine if it meets Section 5 of the *Aboriginal Heritage Act 1972.*

Access and Restrictions:

- **File Restricted = No:** Availability of information that the Department of Aboriginal Affairs holds in relation to the place is not restricted in any way.
- **File Restricted = Yes:** Some of the information that the Department of Aboriginal Affairs holds in relation to the place is restricted if it is considered culturally sensitive. This information will only be made available if the Department of Aboriginal Affairs receives written approval from the informants who provided the information. To request access please contact heritageenquiries@daa.wa.gov.au.
- **Boundary Restricted = No:** Place location is shown as accurately as the information lodged with the Registrar allows.
- **Boundary Restricted = Yes:** To preserve confidentiality the exact location and extent of the place is not displayed on the map. However, the shaded region (generally with an area of at least $4km^2$) provides a general indication of where the place is located. If you are a landowner and wish to find out more about the exact location of the place, please contact DAA.
- **Restrictions:**
  - **No Restrictions:** *Anyone* can view the information.
  - **Male Access Only:** Only *males* can view restricted information.
  - **Female Access Only:** *Only* females can view restricted information.

Legacy ID: This is the former unique number that the former Department of Aboriginal Sites assigned to the place. This has been replaced by the Place ID / Site ID.

Basemap Copyright

ID	Name	File Restricted	Boundary Restricted	Restrictions	Status	Type	Knowledge Holders	Coordinate	Legacy ID
120	KOGOLUP LAKE 01	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	389819mE 6443595mN Zone 50 [Reliable]	S02967
121	COCKBURN LIGHTHOUSE	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	383907mE 6444038mN Zone 50 [Unreliable]	S02968
3292	THOMSONS LAKE	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	388883mE 6441585mN Zone 50 [Reliable]	S00188
3428	HAMMOND ROAD SWAMP.	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter, Mythological, Hunting Place, Water Source	*Registered Knowledge Holder names available from DAA	391139mE 6444249mN Zone 50 [Reliable]	S02730
3429	BARTRAM ROAD SWAMPS.	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter, Mythological, Hunting Place, Water Source	*Registered Knowledge Holder names available from DAA	391689mE 6443349mN Zone 50 [Reliable]	S02731
3471	ROTARY PARK, ROCKINGHAM	No	No	No Gender Restrictions	Registered Site	Mythological	*Registered Knowledge Holder names available from DAA	378450mE 6428304mN Zone 50 [Reliable]	S02625
3534	SLOANS RESERVE ARTEFACTS.	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter, Arch Deposit, Other: ?	*Registered Knowledge Holder names available from DAA	387164mE 6430249mN Zone 50 [Reliable]	S02546
3568	WALLY'S CAMP.	No	No	No Gender Restrictions	Registered Site	Camp	*Registered Knowledge Holder names available from DAA	391139mE 6428749mN Zone 50 [Reliable]	S02491
3710	THOMAS OVAL.	No	No	No Gender Restrictions	Registered Site	Camp	*Registered Knowledge Holder names available from DAA	386556mE 6433043mN Zone 50 [Reliable]	S02210
3711	SLOANS RESERVE.	No	No	No Gender Restrictions	Registered Site	Camp, Hunting Place	*Registered Knowledge Holder names available from DAA	387181mE 6430628mN Zone 50 [Reliable]	S02211
4357	WATTLEUP ROAD SWAMP	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	389072mE 6439443mN Zone 50 [Reliable]	S00769
15838	LAKE COOGEE 1	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	384700mE 6442659mN Zone 50 [Reliable]	

ID	Name	File Restricted	Boundary Restricted	Restrictions	Status	Type	Knowledge Holders	Coordinate	Legacy ID
15839	LAKE COOGEE 2	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	384116mE 6444399mN Zone 50 [Reliable]	
15840	COCKBURN ROAD	No	No	No Gender Restrictions	Registered Site	Mythological	*Registered Knowledge Holder names available from DAA	383895mE 6444043mN Zone 50 [Reliable]	
15841	WOODMAN POINT	No	No	No Gender Restrictions	Registered Site	Mythological	*Registered Knowledge Holder names available from DAA	382338mE 6444212mN Zone 50 [Reliable]	
15934	THOMPSONS LAKE 01	No	No	No Gender Restrictions	Registered Site	Other: Former camp	*Registered Knowledge Holder names available from DAA	392227mE 6442755mN Zone 50 [Reliable]	
15974	LAKE RICHMOND	No	No	No Gender Restrictions	Registered Site	Ceremonial, Camp, Other: Spiritual significance	*Registered Knowledge Holder names available from DAA	378950mE 6427100mN Zone 50 [Reliable]	
18937	Yangebup Lake	Yes	Yes	No Gender Restrictions	Registered Site	Ceremonial, Historical, Mythological, Plant Resource, Water Source	*Registered Knowledge Holder names available from DAA	Not available when location is restricted	
18938	Thomsons Lake	Yes	Yes	No Gender Restrictions	Registered Site	Ceremonial, Historical, Mythological, Plant Resource, Water Source	*Registered Knowledge Holder names available from DAA	Not available when location is restricted	
20866	Lake Coogee	No	No	No Gender Restrictions	Registered Site	Mythological	*Registered Knowledge Holder names available from DAA	384822mE 6443772mN Zone 50 [Reliable]	
21809	Thomsons Reservoir 1	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	388206mE 6442929mN Zone 50 [Reliable]	
21810	Thomsons Reservoir 2	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	388001mE 6443151mN Zone 50 [Reliable]	
22888	Mooribirdup Ceremonial Grounds	No	No	No Gender Restrictions	Registered Site	Ceremonial, Camp, Named Place, Plant Resource	*Registered Knowledge Holder names available from DAA	378019mE 6427997mN Zone 50 [Reliable]	
25022	Beeliar Regional Park 4	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter, Arch Deposit	*Registered Knowledge Holder names available from DAA	388988mE 6443673mN Zone 50 [Reliable]	

ID	Name	File Restricted	Boundary Restricted	Restrictions	Status	Type	Knowledge Holders	Coordinate	Legacy ID
31265	Sister Kate's Childrens Home (Summer Camp)	No	No	No Gender Restrictions	Registered Site	Historical, Camp, Mission, Water Source	*Registered Knowledge Holder names available from DAA	377546mE 6428189mN Zone 50 [Reliable]	
31742	RIZ 12-01	No	No	No Gender Restrictions	Registered Site	Artefacts / Scatter	*Registered Knowledge Holder names available from DAA	384797mE 6429530mN Zone 50 [Reliable]	

Government of **Western Australia**
Department of **Aboriginal Affairs**

Aboriginal Heritage Inquiry System

Map of Registered Aboriginal Sites

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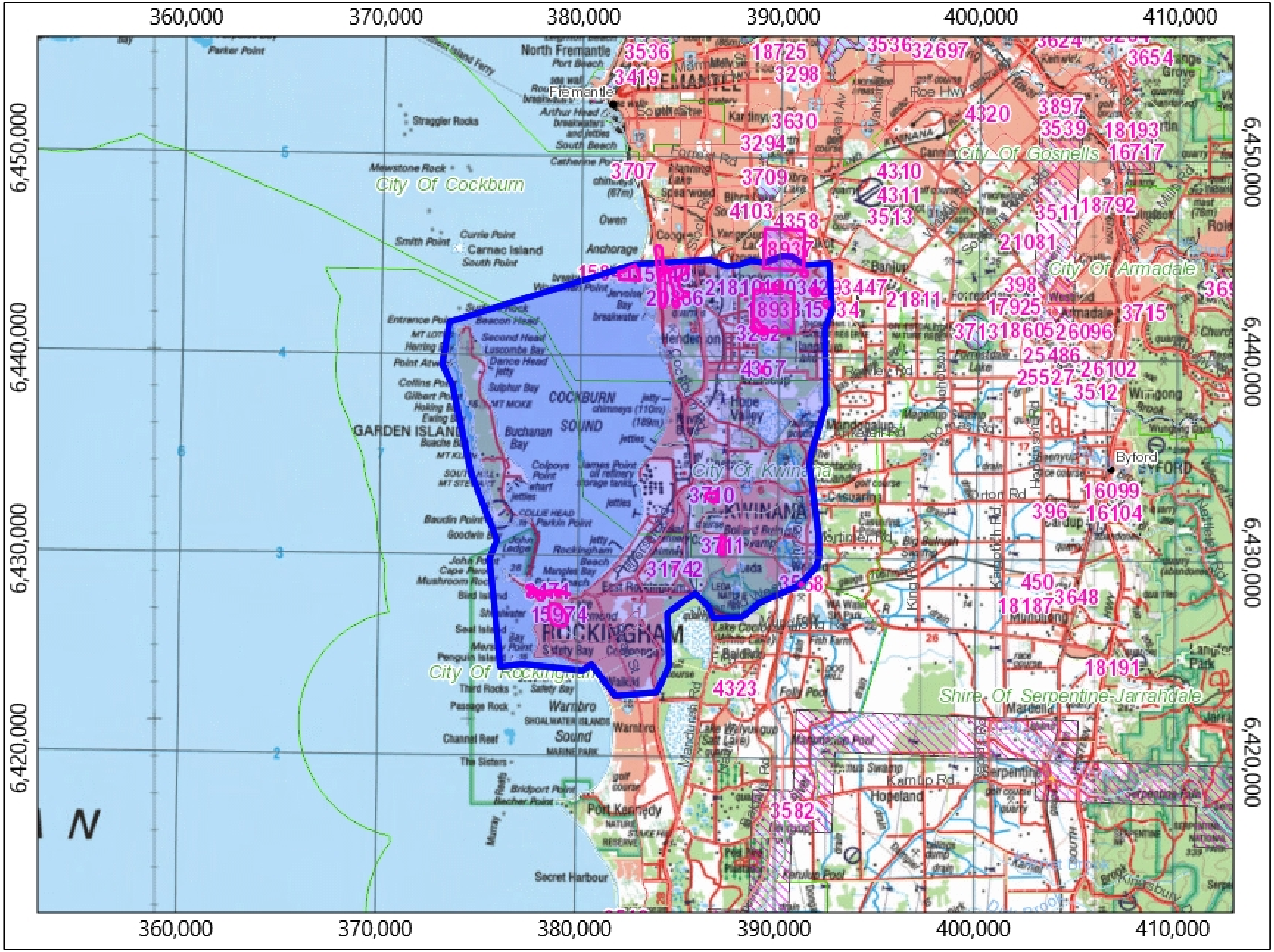


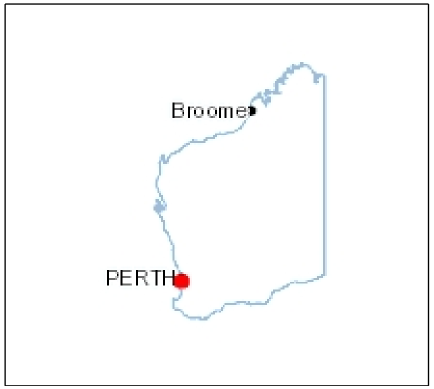
Legend

- Registered Aboriginal Site
- Search Area
- Town
- Road
- River
- Local Government Authority

11.33 kilometres

Map Scale 1 : 343,000

MGA Zone 50 (GDA94)



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