STATE OF THE BAYS 2016

Commissioner *for* Environmental Sustainability Victoria

VICTORIA State Government

Traditional Owners

The Office of the Commissioner for Environmental Sustainability proudly acknowledges Victoria's Aboriginal community and their rich culture and pays respect to their Elders past and present.

We acknowledge Aboriginal people as Australia's first peoples and as the Traditional Owners and custodians of the land and water on which we rely. We recognise and value the ongoing contribution of Aboriginal people and communities to Victorian life and how this enriches us. We embrace the spirit of reconciliation, working towards the equality of outcomes and ensuring an equal voice.

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FOREWORD

Dr Gillian Sparkes
Commissioner for
Environmental Sustainability

Victoria's first *State of the Bays* report is an historic baseline study of the health of Port Phillip Bay and Western Port. Based on existing marine science research, it is a timely stocktake of current knowledge on the two bays, and coincides with a period of sustained high levels of population and economic growth.

Port Phillip Bay and Western Port are at the centre of this growth in Victoria. With Victoria's population now 6 million, and growing at a rate of over 100,000 people per year – the highest increase in Australia – and the population of greater Melbourne over 4 million, our bays will need continued care and attention if they are to stay in good condition and continue to deliver the environmental, economic and social benefits they currently provide.

Recognising these pressures and the need to keep them in check, in 2014 the incoming Victorian Government committed to reporting on the state of the bays every five years. As Commissioner for Environmental Sustainability, I have been asked by the government to issue this, the first *State of the Bays* report. This report brings together what we know about both bays, based on existing research. It is intended as a baseline on which future reports will build and over time, include more of Victoria's marine environment.

The good news is that, despite their proximity to Victoria's largest cities, both Port Phillip Bay and Western Port generally demonstrate healthy systems.

We need to maintain a focus on sustaining the health of the bays and this is best achieved if we work together, and keep the interests of our community and the environment front and centre.

To develop this report, my office worked closely with the Victorian Department of Environment, Land, Water and Planning (DELWP), modelling an approach that can be applied in the future to other crucial environmental studies. I am pleased to have had the opportunity to lead this *State of the Bays* report, a positive and practical example of what can be achieved through collaboration and cooperation.

By bringing together and synthesising this marine science treasure trove, the *State of the Bays 2016* fulfils two critical outputs: 50 assessments of ecosystem health against 36 indicators, and identifying future priorities, to ensure we can maintain the health of the bays.

A third output, establishing a set of indicators for future reporting, will be available soon. The advice from DELWP is that work undertaken by CSIRO has confirmed a provisional set of indicators to take forward for consideration in future *State of the Bays* reporting. It is anticipated that these indicators for future reporting will be made available by DELWP, and published on the Office of the Commissioner for Environmental Sustainability (OCES) website, in mid-2017.

The *State of the Bays 2016* is a significant foundation for future studies and reports on the bays.

Equally as important, it also identifies knowledge gaps and recommends future priorities. To be effective environmental managers, we need an adaptive management framework built on a strong evidence base. This can only be done through increased and targeted research. Similarly, the proposed set of indicators for future reporting (available in 2017) will support a step-change in our approach to monitoring and ultimately managing the bays – a shift from reporting only on what we do know, to reporting on what we need to know.

Plagusia chabrus
Red rock crab

FOREWORD

A clear theme emerged through assessing the science in this report: the need to develop an ecosystem-wide approach to understanding the bays. It became apparent quite quickly that while we may know a lot about how habitats and species within the bays function, there is very little integrated research bringing all of this together. This report proposes a Marine Knowledge Framework be developed to guide an ecosystem-wide understanding of the bays and enable forward-looking and well-considered policy making – policy making that can account for economic and social benefits, as well as environmental; that can inform robust urban planning decisions, and positively and pre-emptively account for climate change impacts.

Digital technology is providing a new path to environmental understanding. Not only can our scientists benefit from using new sensor and monitoring technologies, our citizens will continue to play an important role too, by increasingly monitoring the environment around them, gathering data and participating in reporting. It is incumbent on governments to keep abreast of these technological advances.

The *State of the Bays 2016* has a defined scope. It focuses on bringing together science on the marine and intertidal environments, to assess the overall health of the two bays. It does not include recommendations for management interventions, socioeconomic indicators or comprehensive coastal considerations. However I do note that a large number of the pressures on our bays are derived from our activities on land, and I applaud a continued focus on management and regulatory actions that link activities in our catchments to benefits for Victoria's marine environment.

This report should be seen as the first phase in the move toward a 'state of the coasts' report. Considerable work is needed to develop coastal indicators and to understand and protect Victoria's coast line, which is vulnerable to climate change.

By collaborating with DELWP, other agencies and many of Victoria's marine science experts and academics, we modelled a rigorous, peer-reviewed synthesis reporting approach that can be used for future Victorian environmental reports. This process is set out in the *State and Benefit* framework for the 2018 State of the Environment report (www.ces.vic.gov.au/framework). The framework is the guiding document for my term as Commissioner. It has been endorsed and tabled by the Victorian Government, and roundly supported by key stakeholders including environmental advocacy groups.

I would like to thank the many marine science experts who contributed their time, academic work and generously helped peer review this report.

In addition, I would like to thank my own team and DELWP's dedicated and highly-skilled officers for their commitment to, and enthusiasm for, this project.

The Environmental Reporting Reference Group, the Project Control Board and the Technical Advisory Group also provided invaluable guidance and feedback.

I am pleased to present the inaugural *State of the Bays* report and trust it proves both informative for readers and useful for decision makers.

State of the Bays 2016 is also available in a simplified form and visual web pages with new marine photography from Museums Victoria (www.stateofthebays.vic.gov.au). This site aims to have Victorians care more, and know more, about our precious bays.

Dr Gillian Sparkes
Commissioner for Environmental Sustainability

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Contributors

The Commissioner for Environmental Sustainability, Dr Gillian Sparkes, thanks the following individuals and organisations for their considerable contribution to the development and review of the *State of the Bays 2016*.

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ABBREVIATIONS

ANZECC	Australian and New Zealand Environment and Conservation Council
ARC	Australian Research Council
ARMS	Aquatic Realtime Management System
AUV	Autonomous underwater vehicle
CPUE	Catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DE	Denitrification efficiency
DELWP	Victorian Department of Environment, Land, Water and Planning
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DO	Dissolved oxygen
EMP	Environmental management plan
EPA	Environment Protection Authority Victoria
ERF	Emissions Reduction Fund
EVC	Ecological vegetation class
EWMA	Exponentially weighted moving average
FSANZ	Food Standards Australia and New Zealand
GIS	Geographical information system
IRMP	Intertidal Reef Monitoring Program
LiDAR	Light Detecting and Ranging
MPA	Marine protected area
MPB	Microphytobenthos
NLI	National Litter Index
NTU	Nephelometric turbidity unit
OCES	Office of the Commissioner for Environmental Sustainability
PAR	Photosynthetically available radiation
PPB	Port Phillip Bay
PPBEMP	Port Phillip Bay Environmental Management Plan
PPBES	Port Phillip Bay Environmental Study
RAP	Registered Aboriginal Party
REEF	Reef Ecosystem Evaluation Framework
SEEA	United Nations System of Environmental-Economic Accounting
SEPP WOV	State Environment Protection Policy (Waters of Victoria)
SET	Sediment/erosion table
SRMP	Subtidal Reef Monitoring Program
SST	Sea surface temperature
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
VIC-MOM	Victorian Marine Operational Model
VSOM	Victorian Shellfish Operations Manual
WP	Western Port
WTP	Western Treatment Plant

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Meuschenia hippocrepis
Horseshoe leatherjacket

SCOPE AND METHOD

Victoria's first *State of the Bays* report is an historic baseline study of the health of Port Phillip Bay and Western Port. It fulfils the Victorian Government's election commitment to deliver a five-yearly state of the bays report in the 2014 environmental platform, *Our Environment, Our Future*.[1]

As the first *State of the Bays* report, this document provides a rigorous scientific baseline against which future changes can be measured. As a stocktake report, it considers existing data for Port Phillip Bay and Western Port and makes 50 assessments across 36 indicators of ecosystem health. It focuses on condition and extent indicators of marine environmental assets and, where studies exist, includes the impacts of threats on condition and draws conclusions based on this information.

The Office of the Commissioner for Environmental Sustainability (OCES) process for developing environmental reports is set out in the *State and Benefit* framework for the 2018 *State of the Environment* report (www.ces.vic.gov.au/framework). The framework is the guiding document for environmental reporting by the Commissioner until 2018. It has been endorsed and tabled by the Victorian Government, and roundly supported by key stakeholders and environmental advocacy groups.

The Victorian Department of Environment, Land, Water and Planning (DELWP) developed an estuarine and marine data management system, which was essential for identifying the indicators and data for assessment. It was also important for confirming the scope of the *State of the Bays 2016*:

- **Geographically** – The report, which was initially a commitment to report on Port Phillip Bay only, also includes Western Port because significant data sets were available. The Gippsland Lakes were also considered, but the Lakes will be the subject of a subsequent report issued by East Gippsland Catchment Management Authority and will be considered for future state of the bays reports.
- **Biophysically** – The report generally focuses on marine ecosystems to the high-tide mark, with some exceptions. The report includes some erosion studies and saltmarsh and roosting shorebirds research, for example. The Commission aims to make coastal studies in Victoria a focus in the 2018 *State of the Environment* report. Similarly, estuarine research was excluded because it will be collated for the forthcoming Victorian Index of Estuarine Condition.

Ultimately, the *State of the Bays 2016* report brings together science on the marine and intertidal environments to assess the overall health of the two bays. It does not include recommendations for management interventions; nor does it consider socioeconomic indicators. The Port Phillip Bay Environmental Management Plan (due for release in 2017) will address management priorities for that bay.

Together, OCES and DELWP also developed an exploratory set of environmental–economic accounts for seagrass in Port Phillip Bay. It builds on and aims to shine a light on the work of the Victorian Government in environmental–economic accounting, to demonstrate the relationship between healthy bays and Victoria's economic and social wellbeing. It aligns with the environmental reporting reform articulated in the *State and Benefit* framework.

With an agreed framework and structure in place, OCES collaborated with Victoria's marine science experts and academics, particularly the contributors listed in the **Acknowledgements** (above) and the members of the Victorian Coastal Council's Science Panel. These scientists contributed their published literature and collected data sets, as well as their time to assess the proposed indicators, verify findings and peer review drafts of the report. The *State of the Bays 2016* would not have been possible without the valuable guidance and many contributions of Victoria's exceptional marine science community.

OCES also worked with DELWP and CSIRO on a process to identify indicators for future reporting on the state of the bays. At the time of writing, DELWP advises that work undertaken by CSIRO has confirmed a provisional set of indicators to take forward for consideration in future *State of the Bays* reporting. It is anticipated that these indicators for future reporting will be made available by DELWP, and published on the OCES website, mid-2017.

This proposed set of indicators suggests a step-change in our approach to monitoring and ultimately managing the bays – a shift from reporting only on what we do know, to reporting on what we should and need to know.

The collaboration with CSIRO followed a clear program logic to produce this set of future indicators:

- Develop a conceptual framework for selecting indicators for Port Phillip Bay and Western Port.
- Identify existing data relevant to indicators, and establish causality between pressure, indicator and management action.
- Convene workshops to bring together policy, management and technical specialists.

Effective environmental management needs an adaptive management framework built on a strong evidence base for the bays. This can only be achieved through targeted research directed at management outcomes. The proposed set of indicators for future reporting will reflect an aspirational scope of future scientific enquiry for the bays. The knowledge gaps identified in this report, and the future priorities based on those gaps, represent a pathway to a future scope and alignment with management outcomes.

The report identifies 30 knowledge gaps across the seven themes, which were drawn from multiple sources: the CSIRO-led process to establish future indicators; the indicator assessments from this report; engagement with marine scientists and stakeholders' and a literature review of published gap analyses on the bays.

The report consolidates these knowledge gaps into eight future priorities, based on peer review and further consultation with bay managers and marine experts and scientists. These priorities would form the basis of a Marine Knowledge Framework to provide the evidence base that will support the development of an adaptive management framework; and to assess the proposed future indicators on the state of the bays.

The future priorities fall into two categories:

- enabling better tools, to improve the monitoring and reporting system – two priorities
- improving our understanding of the ecological processes of the bays to build the evidentiary base for decision making – six priorities.

The methodology applied for this reporting process operationalises the environmental reporting vision of the *State and Benefit* framework. An approach to rigorous, peer-reviewed synthesis reporting provides a model for future Victorian environmental reports and improves public value and potential impact from the reporting effort.

Endnote

1 Victorian Labor Publications, ***Our Environment, Our Future*** 2014.

Parma victoriae
Scalyfin

EXECUTIVE SUMMARY

Victoria's first *State of the Bays* report is an historic baseline study of the health of Port Phillip Bay and Western Port. Based on existing marine science research, it is a timely stocktake of current knowledge on the two bays, and coincides with a period of sustained high levels of population and economic growth.

Recognising this pressure and the need to keep the bays healthy, the Victorian Government committed to reporting on the state of the bays every five years. The Commissioner for Environmental Sustainability releases this first *State of the Bays* report under the framework for the 2018 *State of the Environment* (SoE) report, *State and Benefit*.

The *State of the Bays 2016* considers existing data and identifies knowledge gaps. It then prioritises options for addressing these gaps, such as using smarter tools for data collection and coordinating research. It brings together the science on the marine environments of the two bays to assess their overall health. It does not include recommendations for management interventions, socioeconomic indicators or comprehensive coastal considerations.

The report assesses 36 indicators across seven marine-science themes that reflect current knowledge against the following criteria – status, trend direction and quality of the input data. The analysis has many knowledge gaps and a clear theme emerged: the need to develop an ecosystem-wide approach to understanding the bays. There is an imperative to align, target and coordinate research and monitoring effort to create longer-term trends and deeper ecosystem-interdependency knowledge, as well as better understand the nature of threats.

The report identifies the need to develop a Marine Knowledge Framework to ensure a coordinated, prioritised approach to marine science endeavour by the public sector. The Marine Knowledge Framework should, as a priority, focus on these two areas:

- Tools – Two priorities were identified which aim to improve the monitoring and reporting system. These tools include (i) improved monitoring technology, and (ii) expanding habitat mapping.
- Understanding – The report identifies six priority areas to target to improve our understanding of the ecosystems of the bays. They are the impacts of climate change, fisheries and aquaculture, marine pests and pollution, as well as a targeted research program to consider the system-wide dynamics of intertidal and subtidal habitats.

Together, these priorities represent a proposed strategy that will allow for the adaptive management of the bays and provide the evidence base for a suite of future indicators to better track bay health.

In addition to this more detailed report, the Office of the Commissioner for Environmental Sustainability developed a website www.stateofthebays.vic.gov.au. This website provides the community with information that is easy to access and easy to understand, along with striking marine life photography captured by Museums Victoria.

BACKGROUND OF THE BAYS

Victoria's Aboriginal people were the earliest occupants of the bays around south eastern Victoria. Three tribes from the Kulin Nation inhabited the coastlines of what is now Port Phillip Bay and Western Port – the Boonwurrung, the Bunnurong and the Wathaurung. European settlement drastically reduced the Aboriginal population to the extent that, by 1863, only 11 Bunnurong adults survived.

Scientists know the Port Phillip Bay basin dried out for a period between 2,800 and 1,000 years ago. This geomorphological history aligns with the Bunjil dreaming story recalling a time when Port Phillip Bay was a dry basin providing a fertile hunting ground.

Much of the Bunjil dreaming hunting ground now lies below the present water level of Port Phillip Bay's 1,934 km^2. With an average depth of 13 m, the bay and its 333 km of coastline supports over 1,000 species of marine plants and animals. Western Port has an area of 656 km with two large islands, French Island and Phillip Island. The length of coastline including the islands, is approximately 263 km and at 3 m, the average depth is much shallower than Port Phillip Bay.

The bays function differently in several ways determined by the depth, water movement, water clarity, influent water quality and the type and proximity of development. Port Philip Bay is a 'biologically' dominated system – that is, it is dominated by phytoplankton. Further, it has little flush and a lack of tidal range, so nutrients that enter the bay tend to stay in the bay. By contrast, Western Port is a 'biophysically' dominated system – that is, it is governed by shore morphology, wave dynamics, wind and light. It is a shallow, well-flushed, significantly-vegetated bay where large amounts of light reach the sediment.

These differences in the function of the bays create some surprising variations in ecological processes, particularly differences in nutrient cycling, habitat dominance, habitat variety, and species diversity. Given this, the report compares and contrasts the health of each bay in terms of seven key themes: nitrogen cycle, water quality, intertidal habitat, seagrass, reefs, fish and marine-dependent birds.

KEY FINDINGS

Despite their proximity to Victoria's largest cities, both Port Phillip Bay and Western Port generally demonstrate healthy systems. Specific threats linked to population growth include variations in recreational use and variations in litter, nutrients, sediment and pollutant loads to the bays (which may lead to more algal bloom events). Impacts are more significant around the mouths of creeks and drainage systems where human activity is more intense and where nutrients are transported to the bays.

Climate change impacts are likely to include peak rainfall events that transport high loads of nutrients and pollutants to the bays in short time periods, and sea level rise that encroaches on important habitat. Water chemistry, water temperature , wind and storm patterns also contribute to a complex mix of potential impacts.

Marine pests are also a threat. More than 100 introduced marine species (plants and animals) have become established in Port Phillip Bay. Marine pests can compete with native species, alter habitat, reduce important fish stocks and potentially disrupt nitrogen cycling processes. In Port Phillip Bay, an introduced sea star *(Asterias amurensis)* is outcompeting some bottom-dwelling fish for food, causing the populations of those fish to decline.

In future we need to develop a deeper and more timely understanding of the state of, and interactions between, habitats and their associated biotopes. A key finding of the report is to develop a Marine Knowledge Framework to facilitate a more integrated approach to our research effort and to undertake more frequent and extensive monitoring by embracing new technologies.

This study confirmed that our data collection regime is better within the Marine Protected Areas of Port Phillip Bay than in other parts.

Our indicator assessment summary captures the status, trends and existing data quality for 36 indicators.

Indicator	Status and trends: UNKNOWN	POOR	FAIR	GOOD	Data quality
Nitrogen cycle Denitrification efficiency				→ PPB	Good Good data quality but only at two sites
Nitrogen cycle Ratio of nitrogen fixation to denitrification				? WP	Poor
Water quality Nutrients				↗ PPB & WP	Good
Water quality Water clarity		→ WP		↗ PPB	Good
Water quality Salinity				→ PPB & WP	Good
Water quality Dissolved oxygen				→ PPB & WP	Good
Water quality pH				→ PPB & WP	Poor
Water quality Metals				→ PPB & WP	Good (WP – monitoring ceased due to low levels)
Water quality Algae		→ WP		↗ PPB	Good
Water quality Harmful algae blooms			→ PPB		Good
Water quality Sediment contamination			→ PPB & WP		Poor (random surveys)
Water quality Temperature			↗ PPB & WP		Good
Water quality *Enterococci* bacteria				→ PPB	Good
Intertidal vegetation Saltmarsh and mangrove extent			→ PPB		Good

Indicator	Status and trends UNKNOWN	 POOR	 FAIR	 GOOD	Data quality
Intertidal vegetation Saltmarsh condition				→ PPB	Fair
Intertidal vegetation Saltmarsh and mangrove extent			↘ WP Saltmarsh	→ WP Mangrove	Good
Intertidal vegetation Saltmarsh condition			→ WP		Fair
Intertidal vegetation Status of foraging shore birds			↘ PPB		Good
Seagrass Seagrass extent			? → PPB Larger areas stable, other areas variable		Poor
Seagrass Seagrass condition				? PPB	Fair
Seagrass Seagrass dependent fish				→ PPB	Good
Seagrass Seagrass extent			↗ WP		Fair
Subtidal reef Macro algae dominated beds			? NORTH PPB	↘ SOUTH PPB	Poor (north) Good (south)
Subtidal reef Fish	? NORTH PPB			→ SOUTH PPB	Fair (north) Good (south)
Subtidal reef Mobile megafaunal invertebrates			→ PPB		Good
Subtidal reef Sea urchins		↘ NORTH PPB		→ SOUTH PPB	Fair (north) no time series Good (south)

Indicator	Status and trends: UNKNOWN	POOR	FAIR	GOOD	Data quality
Intertidal reef Macroalge				→ PPB	Overall fair (Good in MPAs (Ricketts and Point Lonsdale) but lack of monitoring bay-wide)
Intertidal reef Sessile invertebrates				→ PPB	Fair
Intertidal reef Mobile invertebrates				→ PPB	Overall fair (marine parks) Good (Lack of bay-wide monitoring)
Fish King George whiting				↗ PPB Trend cyclic	Good
Fish Snapper				↘ PPB	Good
Fish Sand flathead		↘ PPB			Good
Birds Status of roosting shorebirds			↘ PPB		Good
Birds Status of waterbirds			↘ WP		Good
Birds Status of piscivorous (fish-eating) birds				↘ WP	Good
Birds Status of little penguins				→ PPB & WP	Good Poor (St Kilda)

The nitrogen cycle

Nutrients entering Port Phillip Bay can have a positive effect when conditions are nutrient-poor. Or, they can have a negative effect when levels are too high leading to algal blooms, particularly after heavy rainfall events. In the marine environment, nitrogen is a more important contributor to algal blooms than phosphorus.

Nitrogen denitrification and fixation are the critical nutrient cycle processes occurring in the bays. Denitrification removes nitrogen from the system while fixation incorporates it into the system. The bays process nitrogen differently because of their different water inflow quality, physical characteristics and ecosystems. Port Phillip Bay is a denitrification dominated system and Western Port a nitrogen fixation dominated system.

The denitrification efficiency process generally maintains the nutrients in Port Phillip Bay at an optimal level for biodiversity. Denitrification efficiency lower than 60% in Port Phillip Bay (40% for Hobsons Bay) indicates the denitrification process is disrupted.

By contrast, there is very little denitrification in Western Port, which is dominated by vegetated, shallow areas. Rather, nitrogen fixation governs its nitrogen cycle. For a healthy Western Port, the ratio of nitrogen fixation to denitrification should be higher.

Two indicators for nitrogen were identified and assessed on available data – one for each bay. The nitrogen cycle indicator for the condition of both bays is considered good.

Water quality

Water quality affects ecological processes and potentially human health.

The Victorian Environment Protection Authority (EPA) and Melbourne Water established monitoring and reporting systems for water quality in Port Phillip Bay and Western Port. Water quality objectives are set by the State Environment Protection Policy (Waters of Victoria) (SEPP WOV) and Australian and New Zealand guidelines for fresh and marine water quality (2000). The Yarra and Bay website (www.yarraandbay.vic.gov.au) publishes information about water quality for Port Phillip Bay during the summer period.

A range of indicators are monitored in Port Phillip Bay (at eight sites) and in Western Port (at three sites). The indicators monitor nutrient levels, water clarity, dissolved oxygen, salinity, algae, metals, water temperature and faecal contamination.

Understanding water quality in Port Phillip Bay and Western Port requires understanding where the water originates. Rural and urban land use activities like housing development and farming have led to broad scale increases in the nutrient loads from the catchments.

Excessive phytoplankton growth can potentially harm aquatic life and even human health. The EPA has been monitoring phytoplankton on a monthly basis at eight sites around Port Phillip Bay since 2008. A sudden increase in rainfall has been linked to rises in phytoplankton. The highest number of phytoplankton (total) was observed at the Hobsons Bay site in December 2009, coinciding with the break of the millennium drought and a 46 mm rainfall event occurring on 22 November 2009. Over the 2008–16 period, fewer than 10% of the samples collected had concerning levels of phytoplankton.

The number of beach advisory (recreational contact) alerts issued during each summer can vary greatly, depending on how much rain and stormwater enters Port Phillip Bay. Over the past three summers, most (94–97%) of the 36 beaches monitored in the bay met EPA's SEPP objectives for swimming.

Eleven water quality indicators were identified and assessed on available data. Water clarity and algae are considered poor in Western Port but good in Port Phillip Bay. Sediment contamination is fair in both bays. The remaining indicators are all considered good.

Intertidal habitat

Intertidal vegetation comprises three broad community types: seagrass, mangroves and saltmarsh. The non-vegetated intertidal zone is predominantly comprised of rocky reefs and soft sediments.

Compared with its state before European settlement, Port Phillip Bay has retained about 50% of its saltmarsh area. During the same period, Western Port retained 90–95% of its mangrove habitat, and 90–95% of its saltmarsh.

Research into the condition of saltmarsh revealed these ecosystems face some critical challenges. Time series data (2000–16) demonstrated sea level rise is affecting mangrove encroachment and expanding saltmarsh pools in the north of Western Port, fragmenting the saltmarsh. The invasive pest *Spartina* (cordgrass) is another threat.

The soft sediments are a poorly understood component of intertidal habitats – particularly given their predominance in Western Port. The status of foraging shorebirds is linked to intertidal habitat health.

Five intertidal habitat indicators were identified and assessed on available data – three for Port Phillip Bay and two for Western Port. Saltmarsh and mangrove extent are considered fair in Western Port. In Port Phillip Bay, saltmarsh extent is fair and mangrove extent is good. Saltmarsh condition is good in Port Phillip Bay and fair in Western Port. The status of foraging shore birds in Port Phillip Bay is fair.

Seagrass

Unlike seaweeds, seagrasses obtain most of their nutrients from the sediments in which they grow. They have extensive root systems that help stabilise coastal sediments and reduce erosion. Seagrasses act as ecosystem engineers, dramatically influencing biodiversity and ecosystem function. Seagrass meadows provide the majority of important habitat within the bays. Their three-dimensional structure protects juvenile fish from predators and seagrass plants support algae and invertebrates that are an important food source.

The seagrass meadows in Port Phillip Bay can be divided into three broad categories: persistent (relatively stable over time), ephemeral (nutrient-limited) and ephemeral (light-limited). Ephemeral beds are much more variable and have shown major increases and declines over the past half century.

During the last major drought (1997–2009), Port Phillip Bay lost large areas of seagrass. There is insufficient information to measure the extent of recovery since the drought ended in 2010.

In Western Port, seagrass declined in the mid-1970s to 1984, then increased in the mid-1990s to 1999. The causes of the decline are unclear, but recovery of seagrass is inhibited in Western Port by water quality, particularly dynamic factors such as suspended sediments that reduce light. Nutrient levels and nutrient availability are also important.

Fisheries Victoria monitored fish species, biomass and diversity within seagrass beds from 2008–12. The research concluded a loss of seagrass or reduction in seagrass condition at different depth ranges may affect different fish species to varying degrees. Shallow seagrass is particularly important for King George whiting.

The most predominant seagrass habitat in the bays, *Zostera*, has been found to be the most critical for fish biodiversity in Western Port because of its extensive spatial cover and unique role for fish larval settlement and development. It also supports unique species, particularly pipefish and seahorse.

Four seagrass indicators were identified and assessed on available data. Seagrass extent in both bays is fair and condition in Port Phillip Bay is good. The biomass of seagrass dependent fish species is good. Data quality for these indicators was variable, ranging from poor to good.

Reef habitats and dependent species

The intertidal, subtidal and deep reefs (including the deep canyon reef at Port Phillip Heads) are important ecological assets of Port Phillip Bay, providing valuable ecosystem services for Victorians.

Reefs act as a wave break protecting beaches from erosion, reef-associated algae act as a nutrient sink, and reefs are sites of detritus production that underpins the detrital food chain in soft bottom habitats.

Rocky reefs occupy only a very small part of Western Port, but three areas are notable — Crawfish Rock, an unusual habitat with very high biodiversity; a small reef near San Remo that is significant for its opisthobranchs; and intertidal reefs along the south western coast, particularly Honeysuckle Reef, that have a high biodiversity. Intertidal reefs in Western Port are likely to be highly vulnerable to sea level rise.

Intertidal reefs are the most accessible component of marine environments, so these habitats have important social and cultural values. Due to their accessibility, intertidal reefs are subject to human pressures, including collecting animals for food and fishing bait, trampling, and pollution from catchment discharges.

Research on reefs outside the marine protected areas has been fragmentary, and we have little information about the drivers influencing these reef communities and how they differ from the open coast.

PORT PHILLIP BAY NORTH

Most reefs in the north are low wave energy and have been permanently changed by native urchins and the highly-invasive Japanese kelp *(Undaria pinnatifida)*, which exploits the disturbance caused by the urchins. The ecological status of this habitat is highly variable, trends are currently unknown and longer term monitoring is necessary to identify patterns.

The numbers of reef fish in the north are low but variable. The exception to this is snapper, which is declining. Limited fish monitoring occurs in the north of the bay.

Megafaunal invertebrates are very diverse in the north, in part due to the additional nutrients from the Western Treatment Plant, Yarra River and Kororoit Creek inflows. Urchin barrens and sessile sponge and coral communities benefit from the carpets of sediment-covering brown algae, and the diversity of red algae.

PORT PHILLIP BAY SOUTH

Monitoring in the south is better than in the north of Port Phillip Bay. The past decade demonstrates the southern reefs of Port Phillip Bay are healthy – with the exception of decreasing numbers of seastars.

Pope's Eye, the most popular dive site in Victoria, has been protected from all forms of fishing since 1978. Pope's Eye demonstrates great fish density and diversity.

Greenlip abalones are recovering in terms of abundance and size – both in the marine protected areas and at the reference sites outside these areas.

Seven indicators were identified and assessed on available data.

Subtidal reef communities have remained in good condition in the south and fair condition in the north of Port Phillip Bay (based on data for macroalgae, fish and mobile megafaunal invertebrate indicators from Parks Victoria's Subtidal Reef Monitoring Program). Urchins are abundant in the bay's south. However, they are overabundant in the north and numbers are increasing.

Intertidal reef communities in Port Phillip Bay (and Mushroom Reef Marine Sanctuary) have remained in good condition since 2003 (based on data for macroalgae, sessile and mobile invertebrate indicators from Parks Victoria's Intertidal Reef Monitoring Program).

Fish

A high proportion of Victoria's recreational fisheries catch is sourced from Port Phillip Bay and Western Port. This report focuses on King George whiting, snapper and sand flathead as key species that indicate the health of fish in the bays and other ecological processes:

- King George whiting show a long term increasing trend since 1978–79. Catch rates increased in 2015–16, after a recent low period from 2013–15.
- For snapper, the juvenile trawl surveys in Port Phillip Bay indicate good juvenile recruitment rates over the past 12 years, which are expected to maintain the stock in a healthy state over the coming years. Declines in adult catch rates over the past three years are evident for both the commercial and recreational fisheries in Port Phillip Bay. The decline should stabilise as the fishery transitions with the new wave of healthy recruitment over the past 12 years. None of the catch rate data show long term sustained declines.
- Trawl surveys of juvenile sand flathead show recruitment in Port Phillip Bay remains poor when compared with levels recorded in the late-1980s and 1990s. Recruitment over the past five years remains well below the long term average and the most recent year is one of the lowest recorded. Research indicates sand flathead recruitment in Port Phillip Bay is heavily influenced by climatic variability.

The abundance of a range of other benthic fish species (including rays, stingarees and gurnards) also declined substantially during the drought period, with the greatest declines occurring in the deeper, central parts of the bay. Step-change reductions in the abundance of three species that exhibited high dietary overlap with the introduced seastar *(Asterias amurensis)* was attributed to competition with this species in the deeper regions of the bay.

Port Phillip Bay and Western Port are important spawning areas for anchovy. In contrast to anchovy, pilchards spawn primarily in offshore coastal shelf waters and rarely in Port Phillip Bay. Both species are an important food source to predators such as squid, fish and seabirds (including little penguins). Anchovy populations in Port Phillip Bay exhibited consistent recruitment from 2008 to 2011. Port Phillip Bay supported the largest commercial anchovy fishery in Victoria, before phasing out of commercial fishing started in 2016.

The Western Port Science Review analysed recreational fishing research data obtained from boat ramp interviews, fish identification and fish measurements over a 15-year period. The result is some baseline information for assessing stocks of important recreational species, including new information on the spatial distribution and habitat use of important fish populations in Western Port. The results suggested variation in catches by recreational fishers was primarily influenced by the environmental drivers of recruitment of young fish to the Western Port ecosystem.

Three indicators were identified and assessed on available data. Based on good data quality, the status of King George whiting and snapper is assessed as good and sand flathead status is poor.

Marine-dependent birds

Information is available on the health of a range of waterbirds in Western Port, including fish-eating birds, while the Port Phillip Bay analysis is restricted to roosting and foraging shorebirds.

Shorebirds are declining around the world, including populations that spend the non-breeding period in Australia. Migratory shorebird conservation involves identifying important shorebird habitat, and monitoring changes in shorebird populations.

Red-necked stint, curlew sandpiper and sharp-tailed sandpiper are the three key species of roosting shorebirds for Port Phillip Bay. Shorebirds in Port Phillip Bay are declining in line with populations throughout the world in the past 20 years.

Annual summer count data of shorebirds was collected at key sites in the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site from 1981–2010. For 16 migratory shorebird species examined, 10 species (62%) had significantly declined since 1981, with curlew sandpipers and lesser sand plovers experiencing particularly strong declines.

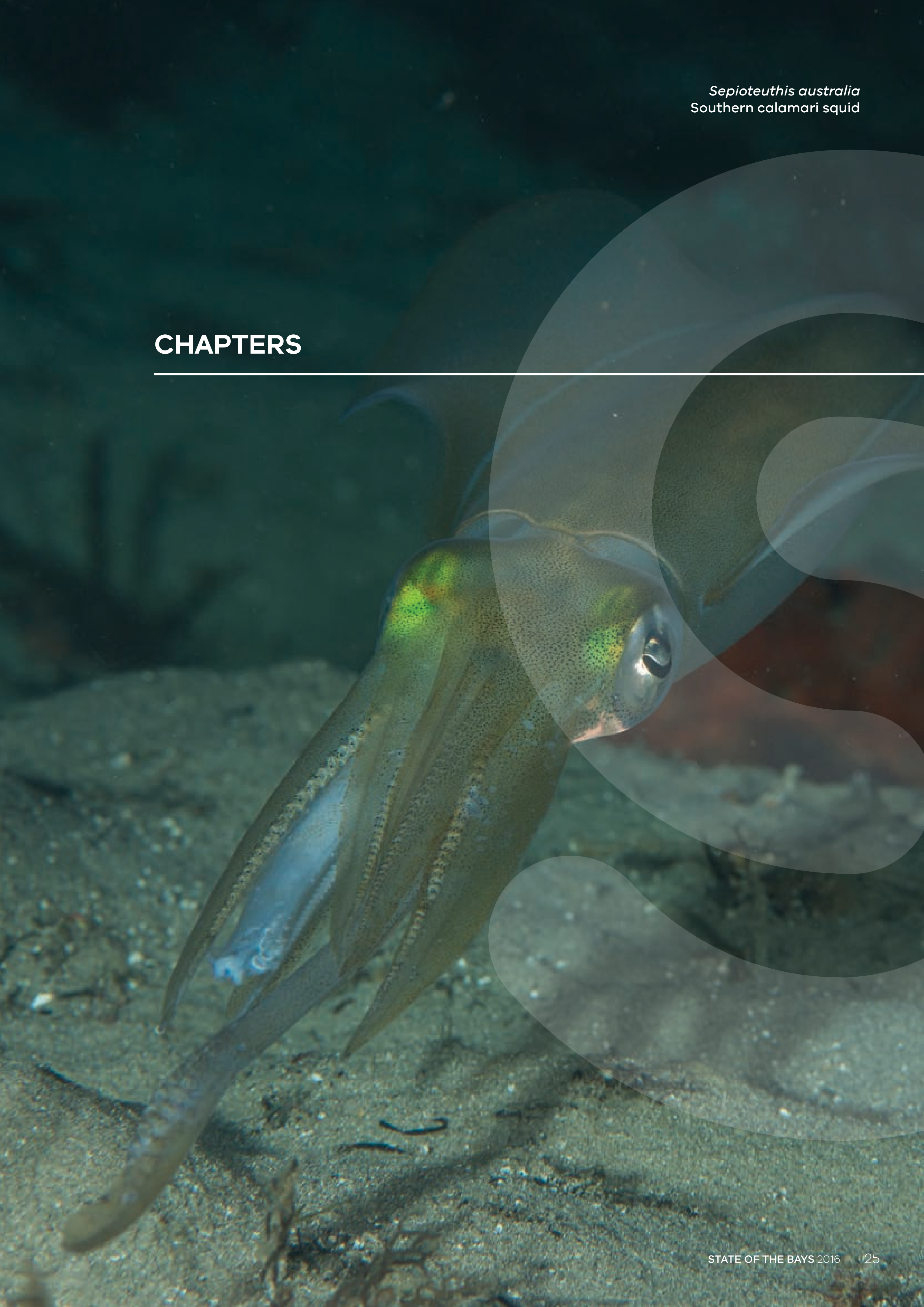
Similarly, several species of water birds in Western Port experienced serious declines, and very few are increasing. Terns, cormorants and the Australian pelican are decreasing at Western Port, but increasing at West Corner Inlet. Falling tern numbers account for most of the decline in piscivorous (fish-eating) birds in Western Port. This result suggests feeding conditions for terns (and to a lesser extent for cormorants and pelicans) in Western Port have deteriorated compared with feeding conditions in the comparable site, West Corner Inlet.

The Phillip Island little penguin breeding population has experienced periods of decline and increase generally associated with their major food source, pilchards. However, climate change will be a critical and complex pressure on penguin communities. Warmer sea surface temperatures are likely to increase breeding productivity and first-year survival, but increased frequencies of fire, higher temperatures and drought will threaten adult penguin survival.

Gannets are an important, iconic species in the bays and a top predator. The gannets in Port Phillip Bay represent a large biomass and are an important indicator of the health of the bay. The total number of gannets breeding within the bay has not been surveyed for several decades and information on this species remains an important knowledge gap.

Four indicators were identified and assessed on available data. The status of roosting shorebirds in Port Phillip Bay and water birds in Western Port is fair, while piscivorous (fish-eating) birds in Western Port is good and little penguins in both bays is also good. Data quality for little penguins at St Kilda is poor, otherwise the available bird data was good.

Reef at Flinders Pier,
Western Port


Sepioteuthis australia
Southern calamari squid

CHAPTERS

Elysia coodgeensis
Sea slug

BACKGROUND OF THE BAYS

Introduction

Scientists estimate humans have occupied Victoria's south east for at least the past 30,000 years[1] and the archaeology of sites in Victoria illustrate Traditional Owners' cultural association with the land.

In recent decades, governments and communities have acted to protect and preserve sites of significant cultural value. State and federal government legislation[2] helps to protect and preserve significant Aboriginal places, areas and objects (on land and in the water).

Victoria's Traditional Owners consider working on country as a cultural responsibility. Currently, they are working with scientists, archaeologists, developers and the broader community, to identify key culturally significant areas around the bay. Together, these groups are managing the effects of human development and climate change.

Traditional Owners

Victoria's Aboriginal people were the earliest occupants of the bays around south eastern Victoria, and are identified as the Kulin Nation. The Kulin Nation comprised five tribes, three of which inhabited the coastlines of what are now Port Phillip Bay and Western Port:

- The Boonwurrung and Bunnurong country traversed between the Mornington Peninsula and Western Port.
- The Wathaurung country ran the length of the Bellarine Peninsula, the Otway Ranges and west of the Werribee river to Streatham.[3]

Each tribe comprised clans that adhered to kinship structures, which determined the values and behaviours about relationships and interactions.

European explorers and sailors had random encounters with Victoria's Aboriginal people, but the land's Traditional Owners experienced widespread dispossession from 1835 onwards, when Europeans settled in large numbers in Melbourne. European settlement had a devastating and long-lasting impact on Victoria's Aboriginal people, such as the loss of association to country, the loss of traditional and cultural values and ill health from introduced diseases (such as small pox).

Settlement drastically reduced Aboriginal populations; indeed, only 11 Bunnurong adults survived by 1893.[4] European influence also displaced Aboriginal cultural traditions, many of which are now lost. Academic scrutiny undermined many Aboriginal oral narratives, for example.

However, scientists examining climate change have found connections between key geological events and traditional recollections, which gives us a rich foundation for Australian geomythology. One of the most cited geomythological stories is the flooding of Port Phillip Bay. The clans who inhabited the area surrounding the bay recall a time when the land was a wide, dry basin where people gathered, lived and hunted. Then, there was a dramatic change in the environment: a 'hurricane – trees bending to and fro – then the earth sank, and the sea rushed in through the heads'.[5]

In Australian Aboriginal mythology, Bunjil the eagle (or eaglehawk) is a creator deity, culture hero and ancestral being.[6] Aboriginal oral narratives describe changing sea levels and Bunjil's intervention:

Port Phillip was once dry land where kangaroos and emus were hunted. One day some small boys were throwing toy spears near some wooden troughs full of water when one spear upset a trough. This was a magic trough and held a lot of water, which came rolling down engulfing all of the land and threatening to drown all the people. Bunjil felt sorry for them and placed a rock where Mornington now is, and told the water not to go any further. Then with the two other rocks he made heads, and told the water to run out between them and meet the ocean. (Presland 1998)

Murray, an Aborigine, assured me that the passage up the bay, through which the ships came, is the Yarra River, and that the river once went out at the heads, but that the sea broke in, and that Hobsons Bay which was once a hunting ground, became what it is. (William Hull's testimony to the Parliamentary Committee, 9 November 1858)[7]

Scientific developments and ongoing archaeological digs continue to qualify Aboriginal oral narratives. Holdgate et al. (2011) traced seismic mapping of the basin's floor which confirms that Port Phillip Bay dried up 2,800–1,000 years ago.

SEA LEVEL RISE

Scientists and Aboriginal leaders are working together to identify areas that hold significant cultural value, and then implement measures to protect and salvage traditional Aboriginal territory around Port Phillip Bay and Western Port.

The Victorian *Aboriginal Heritage Amendment Act 2016* makes it an offence '… to damage, interfere with or endanger an Aboriginal place, object or human remains except in accordance with a Cultural Heritage Management Plan'.[8] Given this, the Victorian Government commissioned a report[9] into Aboriginal heritage around Port Phillip Bay, in 2011. The project had several objectives:

- assess how climate change (particularly sea level rise and extreme weather events) may affect Aboriginal sites on the Port Phillip Bay coast
- train Traditional Owners on methods used to officially record and register Aboriginal places
- seek funding to stabilise coastal sites identified by Traditional Owners.[10]

The steering committee comprised Registered Aboriginal Parties (RAPs), RAP applicants and key Traditional Owner representative groups, Parks Victoria, Aboriginal Affairs Victoria, Heritage Victoria and Port Phillip and Western Port Catchment Management Authority.[11]

Environmental scientists used impact modelling to identify 'areas of archaeological sensitivity and areas of cultural value that are likely to be affected by sea level rise over the next century'.[12] The project identified 60 Aboriginal sites, containing articles such as human remains, stone features and artefact scatters.[13] The modelling also suggested sea levels will rise by 0.15 m by 2030, 0.47 m by 2070 and 0.82 m by 2100. To date, 20 of the 60 sites are already submerged or close to inundation.

The steering committee found that the lack of resources meant not every site could be protected and that private land regulations could prohibit any safety measures.

The climate and topography of Port Phillip Bay and Western Port have evolved over time, influenced by a range of natural and man-made factors. This chapter describes the current biophysical composition of both bays, as well as the bays' early history.

Today, Port Phillip Bay has over 1,000 species of marine plants and animals.[14] Western Port is no less vital, with two large islands – French Island and Phillip Island. Both bays host an internationally-recognised biological treasure trove.[15]

CLIMATE AND TOPOGRAPHY

Era[16]	Period	Epoch	Age commenced (millions of years)
Cenozoic	Quarter-nary	Holocene	0.01
		Pleistocene	2.6
	Tertiary	Pliocene	5.3
		Miocene	23.0
		Oligocene	33.9
		Eocene	55.8
		Paleocene	65.5

Pre-Pleistocene

Geological formations and samples of sediment and organisms taken from lakes and sand dunes provide insights into how Port Phillip Bay and Western Port were formed.[17] Around 450 million years ago, south eastern Victoria was a part of a giant marine basin that formed Gondwana. Over millions of years, molten (igneous) rock formed mountains around the Mornington Peninsula. Gradually, a mountain range began to erode on a fringe of Gondwana, an area that would eventually become Port Phillip Bay.

The lakes and swamps around the area were formed during the Triassic epoch, when earth movements disrupted the surface. Then, approximately 180 million years ago, the sea formed a marine embayment and rivers began to feed the bays.

Pleistocene epoch

Earth has followed a cycle of global temperature increase and decrease for billions of years. The transition from a warm and verdant Pliocene era to a cooler, icy Pleistocene started around 2.6 million years ago. The Pleistocene epoch transformed the global climate and landscape, with the chilling temperatures and expansive glaciers that now define the Ice Age. According to Kershaw (1995), 30% of the earth's surface was covered in ice and sea levels were approximately 120 m lower than today. The mean annual temperature in south eastern Victoria at this time was 3–10°C below our recorded contemporary temperature ranges[18] and the sea surface temperature around the Victorian coastline would have been 2–4°C lower than today.[19]

Though Australia is now defined by its isolated geographical location,[20] land topography and coastal borders changed dramatically in the last Ice Age. The continent's land mass reached north to Papua New Guinea and south to Tasmania. The Bass Strait was dry, and the Bassian Plain was a long and expansive sand bank that connected Tasmania to mainland Australia, and engulfed Melbourne's bays.

At the point when the glaciers were at their greatest extension in the Last Glacial Maximum, Australia was covered in arid desert and sand dunes, providing a wealth of preserved geological formations that indicate the climate at the time. What are now the bay floors of Victoria were constituted mostly of shrubs and grasslands.[21] Over time, the gradual temperature increase caused the ice sheets to retract, and forests and woodlands overtook the shrubs in Australia.[22] The result was a rise in precipitation,[23] particularly around Western Port and Port Phillip Bay.

Holocene epoch

The Holocene epoch followed the Pleistocene and started approximately 11,500 years ago, and continues to the present day. It is marked by the retreat of the glaciers in an ongoing thawing of the previous Ice Age.

Around south-eastern mainland Australia, scientists believe a high level of vegetation replaced the Pleistocene grasslands and herb-fields (based on significant amounts of pollen detected).[24] Woody plants such as southern beeches began to spread, encouraged by rising precipitation, temperature and rainfall levels, which peaked between 7,000 and 4,000 years ago.[25]

Scientists believe water filled Port Phillip Bay about 10,000 years ago, when the ice sheets melted. However, some scientists challenge that Port Phillip Bay was a constant marine ecology. Holdgate et al. (2011) examined the rise and fall of sea levels in the bay, by using seismic dating and core dating of the basin's surface. The results suggested the basin dried out some time between 2,800 and 1,000 years ago, presumably caused by a sand blockage at the heads, coupled with high evaporation rates.

FLORA IN THE PLEISTOCENE

Indigenous Australians occupied the land surrounding the bays from about 30,000–40,000 years ago[26] and survived on local food sources, 'adapting to conditions unrecognisable today'.[27] With little precipitation, strong winds and such low temperatures, Victoria's flora was sparse,[28] low-lying and particular to the Pleistocene. Through the ebb and flow of climate, there were periods of lush forests and woodlands, but during the Pleistocene, the vast majority of Australia was treeless. According to Kershaw (1995), even the iconic Casuarina and Eucalyptus plants were rare, sheltered in wetter 'micro-habitats' or 'eco-niches'.

PREHISTORIC ANIMALS IN THE BAYS

Some of the best preserved and most abundant fossils can be found at Beaumaris Bay. In fact, Port Phillip Bay is world-famous among palaeontologists because of its diversity of marine and terrestrial fossils and is home to Australia's richest marine fossil site.[29]

Fossils that can be found around the bays include extinct marine mammals, molluscs, brachiopods, echinoderms, corals, crustaceans. Beaumaris Bay was home to the only Australian fossil found belonging to the shark genus, Megascyliorhinus.[30] Recent discoveries also include the incomplete leg bone of an indeterminate species of 'thunder bird' Dromornithidae[31] dating as far back as the late Miocene and which was also found in the black rock sandstone at Beaumaris. Before the Pleistocene epoch, when the bays were dry, the aquatic basins hosted marine mammal (cetacean) fossils dating back to the early Oligocene, which ended with the start of the Miocene around 23.8 million years ago.[32]

NEW AND OLD SPECIES – THE LAST 100 YEARS[33]

A hundred and fifty years ago, Port Phillip Bay and Western Port were home to marine animals that have since become locally extinct. Grey nurse sharks were plentiful in the bay in the 19th Century, before being exploited by trophy hunters. Specimens exist of harlequin fish, which has not been found in the bays since.

In recent years, exotic species, such as the northern Pacific seastar *(Asterias amurensis)* and Japanese kelp *(Undaria pinnatifida)*, have altered the composition of the seafloor fauna and flora (see **Nutrient cycle**).

Port Phillip Bay

Between 1992 and 1996, the CSIRO conducted the comprehensive Port Phillip Bay Environmental Study.[34] The aims of the study were to assess the health of the bay, identify the factors having an environmental impact and determine how best to manage the bay in the long term. The study examined the physics, chemistry and biology of the bay, and found nutrient cycling plays a key role in maintaining water quality.

Developed in 2001, the first Port Phillip Bay Environmental Management Plan (EMP) has been an important guiding document for management of the bay. The 2001 EMP specified a set of environmental objectives to manage two priority risks to the bay: nutrients (specifically nitrogen) and marine pests. One of the major objectives of the 2001 EMP was to reduce the annual nitrogen load to the bay by 1,000 tonnes through upgrades to the Western Treatment Plant (WTP) and improved stormwater management in the catchments.

With significant progress made towards existing targets and the scientific understanding of Port Phillip Bay much greater than in 2001, a new EMP is due to be finalised in 2017 and will provide an overarching framework for government, community and business to work together to address key issues that impact the health of the bay.

Understanding Port Phillip Bay

Recent studies on the state of Port Phillip Bay show that despite over 4 million people living within Port Phillip Bay's catchment, including two major cities: Melbourne and Geelong, the bay is generally in good health. However, human impacts are still locally significant around the mouths of creeks and drains, and in the northern part of the bay adjacent to the Yarra River and the WTP at Werribee.

Between 1990 and 2011, Port Phillip Bay experienced two major ecological disturbances. The first was a prolonged drought from 1997–2009. The second was the introduction of the invasive northern Pacific seastar – a native of the northwest Pacific and a voracious predator, which peaked in population at 56% of benthic fish biomass in 2000 (Parry and Hirst 2016).

SIZE AND VOLUME

Length	58 km (Altona to Rye)
Width	41 km (Portarlington to Seaford)
Depth	The average depth is 13 m. The greatest depth is 24 m; nearly half the bay is less than 8 m deep.
Volume	25 km^3
Coastline	333 km (Point Lonsdale to Point Nepean)
Total area	1,930 km^2
Catchment area	9,790 km^2
Population	Over 4.5 million people live around the bay.

Waters of Port Phillip Bay

Salt content – despite input of freshwater from the Yarra River and other streams, about 660 km^3 of ocean water from Bass Strait enters the bay every year through tidal action, making the bay a marine system. Variation in freshwater input contributes to variations in salinity, such as the rise in salinity recorded during the millennium drought (1997–2009).

Catchment inputs – eight major creeks and rivers flow into the bay. The Yarra River is the largest single source of freshwater. Treated effluent from the WTP is the largest source of nutrients. On average, freshwater inputs to Port Phillip Bay are equivalent in volume to evaporation from the bay, which is conducive to a healthy marine environment.

Water movement – several natural forces drive circulation in the bay: tidal movement, wind generated waves and surface currents, and salinity and temperature gradients.

Mixing – the bay is well-mixed, reflecting its shallow nature and large surface area, which allow winds and currents to mix the water column. Waters in the bay have a long residence time – greater than 400 days.[35] This is a significant difference between Port Phillip Bay and Western Port.

Sedimentation – silt, mud and organic debris enter the bay from the rivers, creeks and drains. The total input of sediment has been estimated to be 15,000–80,000 tonnes a year (t/y), with an average of 30,000 t/y. Wave action drags finer, lighter material and transports it further offshore to the deep central basin. Chemical analysis of the bottom sediments shows the central basin contains mostly mud and silt (silica particles) with about 5% organic matter. Bacteria compose a negligible fraction of the sediment.

For more information see **Water quality** chapter.

Nutrients

Nutrients, particularly nitrogen, are important for marine ecosystems to function, but they have a negative effect when levels are too high (eutrophication), which can lead to algal blooms and drift algae.

Despite its proximity to Victoria's largest cities, the nutrient levels of Port Phillip Bay are low and the nutrient cycle demonstrates a generally healthy system. However, the bay experiences seasonal variations in the nitrogen and chlorophyll concentrations because the freshwater input volume varies with rainfall. The **Nitrogen cycle** chapter has more information and explains denitrification efficiency – an important process in Port Phillip Bay's nitrogen cycle.

The WTP and catchment inflows (from both rural and urban land) are the major sources of nutrients for the bay.

Life in Port Phillip Bay

Port Phillip Bay hosts a diversity of ecosystems and habitats, including sandy beaches, rocky shores, saltmarsh, mangroves, seagrass, sand beds, rocky reefs and open water.

The Convention on Wetlands of International Importance, also called the Ramsar Convention, is an intergovernmental treaty for the conservation of wetlands. Australia is host to many Ramsar listed sites, including two Ramsar sites in Port Phillip Bay that were listed in 1982: Port Phillip Bay (Western Shoreline) and Bellarine Peninsula.

Within Port Phillip Bay are four of Victoria's marine protected areas (a marine national park and three marine sanctuaries) that were established in 2002 and are managed by Parks Victoria. The marine national parks and sanctuaries are highly protected no-take areas which cover approximately 63,000 hectares or 5.3% of Victorian state marine waters. The areas in Port Phillip Bay are:

- Port Phillip Heads Marine National Park
- Jawbone Marine Sanctuary
- Point Cook Marine Sanctuary
- Ricketts Point Marine Sanctuary.

The bay is home to thousands of species of marine flora and fauna:

Plant life – four main kinds of aquatic plants live in the bay, all of which use light energy from the sun to transform carbon dioxide and elements such as nitrogen and phosphorous into organic matter and oxygen (the process called photosynthesis). These include:

- **phytoplankton** – single-celled algae, which include diatoms and dinoflagellates
- **microphytobenthos** – microscopic algae living on the seafloor, they grow over the surface of the sediment, and play a critical role in processing nitrogen inputs for the bay
- **macroalgae** – large, multi-celled algae generally known as 'seaweeds'. Scientists have recorded 60 species of green algae, nearly 100 species of brown algae and about 260 species of red algae.
- **seagrasses** - seagrass beds provide food and shelter for many marine animals. About 95% of the bay's seagrasses occur in waters shallower than 5 m (typically on the low-energy western and southern coastal fringes), reflecting their reliance on access to sunlight and low-energy conditions.

Animal life – animal life in the bay ranges from microscopic single-celled organisms through to sharks, as well as marine mammals such as seals and dolphins:

- **zooplankton** – small invertebrate animals living in the waters of the bay, including small microscopic single-celled protozoa, invertebrate larvae and copepods. Scientists estimate the free-swimming zooplankton alone probably filter the volume of the bay about twice a month, and the benthic (seafloor) filter feeders are similarly active.
- **zoobenthos** – invertebrate animals that live in (infauna) or on (epifauna) the sediments. They vary in size from protozoa to quite large epifauna such as sponges. Infauna is dominated by crustaceans, worms (polychaetes) and molluscs, whereas epifauna includes starfish, sea squirts, sponges, sea spiders, bryozoans, sea anemones and corals. Zoobenthos also contribute important roles in bioturbation and benthic-pelagic coupling, and are food for many fish species.
- **fish** – the **Fish** chapter discusses fish species in Port Phillip Bay. The major species are King George whiting, snapper and flathead. The government introduced legislation *(Fisheries Amendment Bill 2015)* to end commercial netting in Port Phillip Bay in October 2015. Corio Bay will be closed to netting by April 2018, with netting to be phased out in the rest of the bay by 2022.
- **bird and marine mammals** – St Kilda has a small colony of iconic little penguins. The WTP and nearby Ramsar sites have an abundance and diversity of shorebirds, while Pope's Eye has an Australasian gannet colony. The bay has a healthy population of dolphins and is visited by large whales, including humpbacks, southern rights and killer whales (but they don't stay permanently). A number of seals have also taken up residence, using shipping buoys and beacons.

Monitoring lesions and the health of resident dolphins

Dolphin Research Institute researchers use photographs to monitor the population size, movements, relationships, births and skin health of dolphins in Port Phillip Bay. They can identify individuals from unique markings on dolphin dorsal fins that act like 'fin prints'.

Over time, researchers have identified five distinct types of skin lesions on 73 resident Port Phillip Bay dolphins. Scientific evidence links the skin health of dolphins to environmental water quality. Researchers believe the lesions may suggest animals are under stress and with weakened immune systems.

In early 2011, Institute researchers photographed a resident dolphin covered with skin lesions that were more severe than anything previously recorded in the bay. The sighting coincided with the breaking of the long drought, with massive inflows from the catchment. Photo surveys since 2011 showed the lesions on some individual dolphins healed rapidly. However, the Institute hopes to identify the cause of the lesions from a three-year dolphin health study funded under the National Whale and Dolphin Protection Plan. Outcomes will include a systematic tool to measure the nature and extent of dolphin skin lesions, new survey methods and a citizen science program.

This work will become part of the Institute's long term core research program and will help bay managers understand the status of the resident dolphins.

For more information, please visit: www.dolphinresearch.org.au

Pests – over 160 introduced marine species have been recorded in Port Phillip Bay, many introduced by international shipping traffic in ballast or fouling on ship hulls. Marine pests are species (often non-native) that significantly harm endemic biodiversity and habitats, shipping, coastal infrastructure, seafood industries and coastal communities, and can have immense economic impacts. Notable pest species include the northern Pacific seastar, the European fan worm *(Sabella spallanzanii)* and the Japanese kelp. The northern Pacific seastar and the Japanese kelp only occur in Port Phillip Bay, but the European fan worm is also found in Western Port.

Western Port

Western Port is a large shallow embayment that is divided into five basins or segments by large islands and mudflats and several narrow constrictions. The bay's waters provide a range of ecosystem services, including nutrient cycling and support of fishing and other recreational activities. Western Port has also hosted an important commercial shipping port (Hastings) for many years. The shipping port was developed in the 1960s and takes advantage of the natural deep water channel of Western Port.

Western Port and its islands are criss-crossed by seven seismically-active fault lines and the Western Port area experiences numerous minor earthquakes every year. Western Port and its surrounds have also been recognised internationally, with **UNESCO's Man and the Biosphere program** designating it as one of just over 500 Biosphere Reserves around the world.

Previous studies of Western Port have included *Understanding the Western Port Environment: A summary of current knowledge and priorities for future research* (2011), which was undertaken by Melbourne Water and built on the Western Port Bay Environmental Study (the Shapiro report) in the 1970s. *Understanding the Western Port Environment* was an expert review of the scientific knowledge of Western Port and its aim was to better inform decision making on natural resource management, environment protection, planning, on-ground works and future research.

SIZE AND VOLUME

Depth	The greatest depth is 6 m. The average depth is 3 m
Coastline	295 km (including the northern boundary of Phillip island)
Total area	680 km^2

Understanding Western Port

Cardinia and Casey shires are experiencing remarkably fast population growth. The proportion of growth occurring in Casey and Cardinia from 2005 to 2015 was 14%.[36] The Victorian Planning Authority reported in the *State of the State* report, September 2016 that Wyndham was the fastest growing municipality in Melbourne, followed by Casey and Whittlesea.[37] In addition, land use has changed in the mixed urban-agricultural land around Western Port. Management agencies have also been active and commercial fishing is being phased out.

The water flows in Western Port include catchment inflows and resuspended bay sediments, resulting in poorer water quality (and higher residence times) in the east. There is also short term variation in water quality over tidal cycles – outgoing tides transport muds and sediments from mudflats, while incoming tides flush the bay with cleaner oceanic water.

Over a third of Western Port is intertidal seagrass and bare mudflat yet little is known about nutrient transformation in these environments. The decline and limited recovery of seagrass in the eastern section of the bay is symptomatic of sediment loads exceeding the system's capacity to process and assimilate them.

Habitats of Western Port

Water column – the water column in Western Port is inhabited by microscopic single-celled organisms (phytoplankton), small animals that drift passively with the currents (zooplankton), and larger, passively drifting animals such as jellyfish. The phytoplankton are important indicators of environmental impacts such as elevated nutrients.

Mudflats – mud covers about two-thirds of Western Port. The area of unvegetated sediments has increased following the loss of seagrass beds. The extensive intertidal flats are important foraging grounds for shorebirds. The mud contains a high diversity of ghost shrimps, brachiopods (that are considered living fossils), rare rhodoliths and various endangered species.

Seagrasses – Western Port experienced extensive loss of seagrasses in the 1970s, followed by some recovery. However, large areas that lost seagrass have not recovered, and recovery has been poor in areas where water quality is a concern.

Mangroves – Western Port harbours some of the southernmost mangroves in the world, and they line much of the shore. Historical comparison shows some loss, especially near Hastings. Localised destruction, disturbances and changes in the sediment budget of the bay have contributed to changes in mangrove distribution.

Saltmarshes – Western Port has about 1,000 ha of saltmarsh, much of which is likely to be very vulnerable to sea level rise and other consequences of climate change, especially rising air and water temperatures. Saltmarshes have been progressively lost already, mostly as agriculture and industry developed around the western and northern shores.

Life in Western Port

Although similar to Port Phillip Bay, there are more complex intertidal habitats in Western Port, which include:

- extensive mudflats
- two large islands (Phillip Island and French Island)
- tidal flats that are cut by deep channels
- several catchments
- mangroves and saltmarshes that fringe much of the coastline
- extensive seagrass meadows on mudflats and below the low-tide level
- scattered rocky reefs that add to the diverse mix of habitats
- extensive habitat for shorebirds, with much of its shoreline being important for international migratory birds.

Western Port was listed as a Ramsar site in 1982. One of the largest breeding populations of pied oystercatchers *(Haematopus longirostris)* is found on French Island. The site is also listed as part of the Western Port Biosphere Reserve.

Within Western Port are three of Victoria's marine national parks that were established in 2002 and are managed by Parks Victoria:

- Churchill Island Marine National Park
- French Island Marine National Park
- Yaringa Marine National Park.

Mushroom Reef Marine Sanctuary is located just outside Western Port's western entrance.

Fish – Western Port has high diversity and productivity of fish, including:

- small fish that live in the extensive seagrass beds
- pelagic (open sea) species such as Australian anchovy.

Western Port is a breeding habitat for species such as elephant fish and school shark. The greatest threat to fish in Western Port is the loss of their habitat, in particular the potential loss of seagrass habitat.

Birds – Western Port is home to the iconic little penguins of Phillip Island. But there are an abundance and diversity of bird populations, and it is an important refuge against drought. It is also a non-breeding area for migrant shorebirds from the northern hemisphere and New Zealand. As such, Australia has obligations under a suite of international treaties and agreements. Western Port is also designated as part of the global network of Birdlife International's Important Bird Areas. The greatest threats to birds in Western Port are loss of habitat, reductions in food supply through extraction (particularly fish-eating birds), seagrass loss (most species) and high levels of disturbance from human recreational activity (shorebirds).

Pressures affecting Western Port

Over the past 200 years, humans have altered the Western Port environment by clearing vegetation, draining the expansive Koo Wee Rup swamp and expanding agriculture, industry and residential areas. Given the close connection between the health of the catchment and the health of the bay, dramatic changes such as these are expected to put considerable pressure on the marine and coastal environment.

Sea levels are expected to rise, which will affect Western Port's gently sloping shoreline. Climate change could also impact catchment discharges, alter bay water chemistry, and change wind and storm patterns. Increased temperature and evaporation can cause desiccation on exposed mudflats.

Drifting sediments are the most important aspect of water quality, and have been a target of management action for some time. Nutrients are an issue in some parts of Western Port (around Watsons Creek and in the Corinella segment) and toxicants, particularly those associated with the eastern catchments. Recreational fishing is an important pressure requiring attention.

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Heliocidaris erythrogramma
Sea urchin

THREATS TO THE BAYS

Threats

While much is being done to conserve the health of the bays, population growth and climate change will put increasing pressure on their environmental assets. Given this, it is vital that the bays and their catchments are managed to keep them healthy and resilient in the face of these challenges, and that a strong research program is funded to provide the evidence base. Collaborative, informed, adaptive and ongoing management of the bays and catchments is necessary to ensure they can continue to support the values important to all Victorians.

POPULATION GROWTH

Over the past 200 years, humans have altered the environment by clearing vegetation, draining the expansive Koo Wee Rup swamp and using the land for agriculture, industry and residential areas. Given the close connection between the health of the catchments and the health of the bays, dramatic changes such as these are expected to put considerable pressure on the marine and coastal environment.

Around 4 million people live within Port Phillip Bay's catchment,[1] including two major cities: Melbourne and Geelong. *Victoria in Future 2016*[2] population projections suggest Melbourne's population will double over the next 35 years, from around 4 million to over 8 million people. Significant growth is also predicted in other settlements around the bay.

The Victorian Planning Authority reported in the *State of the State* report, September 2016 that, 'Wyndham was the fastest growing municipality in Melbourne, followed by Casey and Whittlesea, with Greater Geelong being the fastest growing regional area. Victoria's population is now 6 million, and is growing at a rate of over 100,000 people per year – the highest increase in Australia.'[3] The proportion of growth occurring in Casey and Cardinia from 2005 to 2015 was 14%[4].

This growth presents challenges for maintaining bay health. More people will use and enjoy the bays in the future. Intensive development within the bays' catchment will increase runoff and require expanded drainage and sewerage systems. These factors, in turn, will increase drainage of nutrients and other pollutants into the bays.

Plan Melbourne

Plan Melbourne is the Victorian Government's metropolitan planning strategy. It is a strategy to tackle the challenge of protecting and enhancing Melbourne's sustainability while the city grows.

Plan Melbourne is undergoing a review to better reflect a long-term vision to address issues including liveability and climate change.[5] Plan Melbourne Refresh is due for release in 2016. Submissions to Plan Melbourne, and submissions to its refresh, are available online.[6]

Drifting sediments and sediments resuspension are the most important aspect of water quality in Western Port, and have been a target of management action for some time. Nutrients are an issue in some parts of Western Port (around Watsons Creek and in the Corinella segment) and toxicants, particularly those associated with the eastern catchments, are a potential concern. How stormwater pollutants affect both bays is poorly understood and may also emerge as significant.

Commercial net fishing is being phased out of Port Phillip Bay (as is already the case in Western Port), making the impacts of recreational fishing more important. This report identified this as a key priority for future research (see **Future priorities** chapter).

Litter also remains a significant challenge. It is estimated that 95% of litter found on Port Phillip Bay's beaches has been transported from suburban streets through the stormwater system. Litter reduces visual amenity, reduces water quality and can harm marine animals. Microplastics – small (< 5 mm diameter) pieces of plastic that flow into the marine environment, and are then ingested by marine animals – are an emerging concern.

LITTER IN PORT PHILLIP BAY

In 2012, the Victorian Government[7] announced partnerships with water corporations, investing more than $1 billion in programs and initiatives to improve the health of the Yarra River and Port Phillip Bay. More recent initiatives include:

- The Victorian Litter Innovation Fund, which will target marine and coastal litter, and illegal dumping issues that affect the Yarra River and Port Phillip Bay catchment area.
- Sustainability Victoria[8] has a targeted plan – the Victorian Waste Education Strategy – to tackle litter state-wide, starting with enhancing Victoria's waste and resource recovery infrastructure system.

Of the litter found on our beaches, 95% comes from suburban streets through the stormwater system. Cigarette butts are the number one item picked up during litter clean-ups and can take up to 12 months to break down in freshwater and up to five years to break down in seawater. Drink containers and paper are the other major pollutants.

The Victorian Government spends approximately $80 million each year cleaning up litter, with 7,850 tonnes of litter and debris removed just from waterways around Melbourne in 2012–13.[9]

Victoria is measured against a National Litter Index (NLI), which is Australia's only independent and quantitative measure of litter. The 2016 figures provided by the NLI show that Victoria is 47% lower than the national average, which is a 27% decrease on 2015.[10]

Despite this, we are still witnessing thousands of marine birds, mammals, reptiles and fish that are killed or injured every year due to litter.[11]

THREATS TO AUSTRALIAN FUR SEALS[12]

From 1997–2013, researchers found 359 entangled Australian fur seals at Seal Rocks, Phillip Island. Seals are particularly at risk of entanglement in lost or abandoned fishing nets (which account for 45–93% of entangling material). In most cases, seals cannot remove the tangled material without human intervention, which means that most cases are likely to be fatal.

The incidence of entanglement involving fur seal pups increases over winter and spring and is most likely attributable to the age of the pups. Seal pups spend more time in the water as they grow and are weaned during spring. As the juvenile grows, the entangled object continues to constrict the seal's neck. Rescued seals may take months to heal from this kind of damage and can often be permanently scarred.

Plastic twine or rope objects from fishing activities account for around 50%[13] of entanglement incidents, while plastic waste (such as balloons and plastic bags) account for another 20%. The rest is a combination of anthropogenic litter and commercial fishing waste.

CLIMATE CHANGE

"Over recent decades Victoria's climate has become drier and warmer. The recent Millennium Drought was the worst drought Australia has experienced on record.

Stream flows could reduce by around 50 per cent in some catchments by 2065 (figure T.1). This has serious consequences for everyone – households, industry, agriculture, recreation, cultural values, and liveability and for waterway health, our environment and native plants and animals.

Climate change will also bring more extreme events including drought, floods and heatwaves, which can increase human and environmental demand for water, impact on productivity, and also threaten water infrastructure."

'Water for Victoria', Victorian Government, October 2016[14]

FUTURE IMPACT ON CATCHMENT RUNOFF

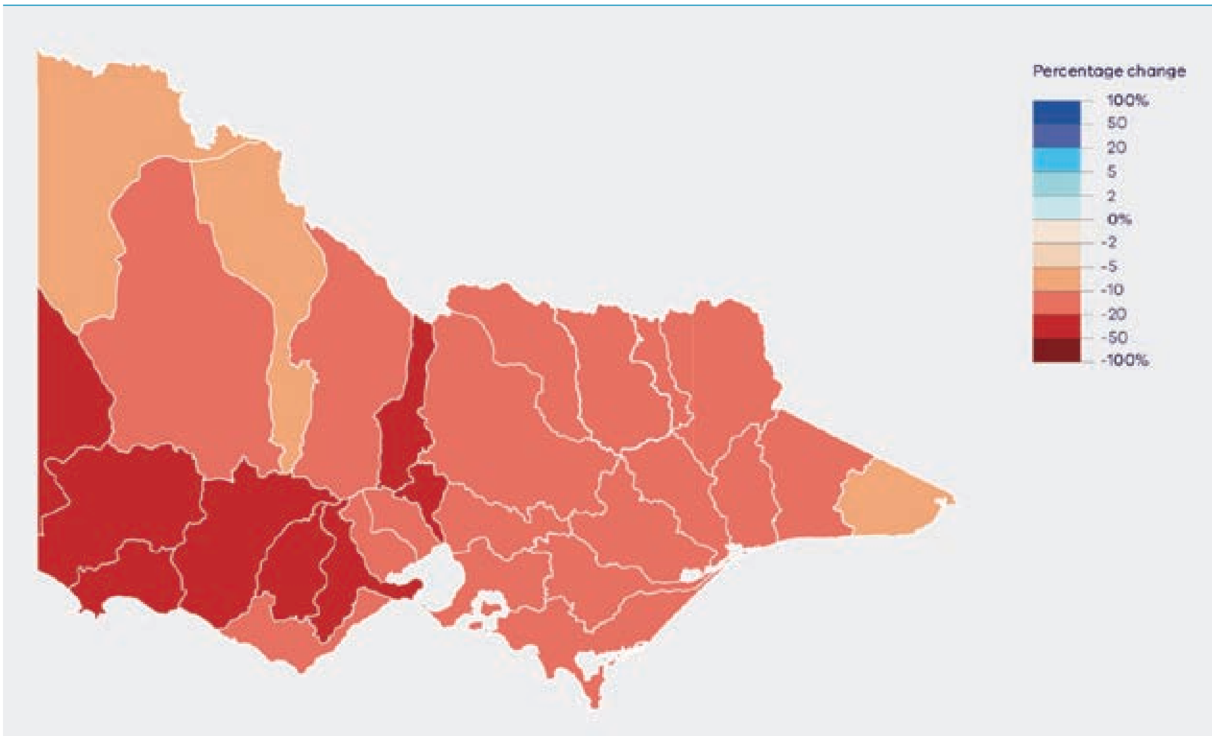

Figure T.1: Projected changes in runoff for 2065 under medium climate change[15]

The impact of climate change on the bays requires further study (refer **Future priorities**). Climate change will reduce overall rainfall, but increase the number of intense rainfall events, which will result in higher event-related flows, increasing nutrients, sediments and other pollutants draining into the bays. Increasing nutrients and pollutants will, in turn, cause more algal blooms and reduce water quality during wet periods, potentially closing popular beaches.

Climate change could impact catchment discharges in other ways, alter bay water chemistry, and influence changes to wind and storm patterns.[16] Increased temperature and evaporation can cause desiccation on exposed mudflats.

Climate change is also expected to contribute to rising sea levels. EPA modelling in Western Port suggests rising sea levels combined with expected lower inflows may reduce pressures from the catchments.[17] Specifically, catchment flows will enter a larger volume of embayment water and be diluted/mixed more than is currently the case. Under this scenario, it will be the enhanced coastal processes and increased tidal exchange – likely to increase wave energy, coastal erosion, current velocities and sediment resuspension, which will be the significant future pressure on the bays' water quality and habitats.

Some evidence suggests global sea level rise, estimated at 14 cm[18] may already be affecting estuarine vegetation in Western Port, including:

- mangrove encroachment of saltmarsh
- expansion of saltmarsh pools due to poor drainage in the north of the bay
- dieback of Melaleuca forest in some locations, including the Rhyll saltmarsh.

Sea level rise is particularly significant for intertidal vegetation in Western Port because of impediments to landward encroachment such as roads and levee banks.

MARINE PESTS

Marine pests also present a significant risk to the bays' ecology. More than 100 introduced marine species (plants and animals) have become established in Port Phillip Bay, for example. Marine pests can compete with native species, alter habitats, reduce important fish stocks, and potentially disrupt nitrogen cycling processes. Further studies to understand the impact of marine pests on the bays is recommended in the **Future priorities** chapter.

SHIPPING

Given that both bays have active ports, the impact of shipping is considered as a threat for the purposes of this report and, in particular, in relation to determining future priorities.

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Macrocystic angustifolia
String kelp

CHEMISTRY OF THE BAYS

THE NITROGEN CYCLE

Port Phillip Bay and Western Port have clean and healthy nitrogen cycles compared with similar embayments close to population centres across the world.

The denitrification efficiency process maintains the nutrients in Port Phillip Bay at an optimal level for biodiversity.

By contrast, there is very little denitrification in Western Port, which is dominated by intertidal, shallow areas. Rather, nitrogen fixation governs its nitrogen cycle.

A denitrification efficiency lower than 60% in Port Phillip Bay (40% for Hobsons Bay) indicates the denitrification process is disrupted. No event since 1994 has been large enough to reduce DE for more than a month, and even then only in Hobsons Bay.

Not since 1994 has Victoria experienced a storm event large enough to reduce Port Phillip Bay's denitrification efficiency for more than a month. And even then, only Hobsons Bay was affected.

For Western Port to remain healthy, the ratio of nitrogen fixation to denitrification should be higher.

On average, Western Port receives ~1,080 tonnes of nitrogen/year (~650 tonnes from the catchments and ~430 tonnes from nitrogen fixation) and loses ~230 tonnes/year though denitrification. Scaled-up rates indicate that over a year, approximately 40% of Western Port's total nitrogen input resulted from nitrogen fixation.

Approximately 40% of the total nitrogen input to Western Port was as a result of nitrogen fixation. Further, sensitivity analysis confirmed that while the loss of seagrass would affect the magnitude of the bay-wide flux of nitrogen on these tidal flats, nitrogen fixation remains the dominant process.

Introduction

This chapter examines the role of nitrogen in maintaining the health of marine environments in Port Phillip Bay and Western Port. Nitrogen is critical for maintaining the health and viability of marine ecosystems. Specifically, nitrogen provides the fuel for phytoplankton growth (figure N.1). This contrasts with terrestrial (or freshwater) systems, where phosphorous and light determine productivity.

The nitrogen cycle, and the associated productivity, in both Port Phillip Bay and Western Port demonstrate clean and healthy systems.

Port Phillip Bay is a 'biologically' dominated system – that is, it is dominated by phytoplankton. Further, it has little flush and a lack of tidal range, so nutrients that enter the bay stay in the bay. The denitrification process maintains nitrogen at an optimal level for biodiversity. Denitrification efficiency (DE) measures the effectiveness of this process.

By contrast, Western Port is a 'biophysically' dominated system – that is, it is governed by shore morphology, wave dynamics, wind and light. It is a shallow, well-flushed, significantly-vegetated bay where large amounts of light reach the sediment. As a result, it contains both benthic vegetation (seagrass) and microphytobenthos (MPB), which have a high demand for nitrogen.

Further, nutrients do not pose the same level of risk in Western Port as they do in Port Phillip Bay because Western Port is a highly-flushed system with a shorter residence time of the water. That is, the nutrients that enter the bay as runoff from the catchments are spread across the large surface area of Western Port.

There is little denitrification in this environment, so nitrogen fixation governs the nitrogen cycle. We measure the health of the nitrogen cycle by monitoring the ratio of nitrogen fixation to denitrification.

The chapter includes a summary of key knowledge gaps for further research. Potential initiatives include exploring alternative indicators to understand the influences on the nitrogen cycle in different marine habitats (and to assess the impact on broader ecosystem health); and improving the understanding of the impact of marine pests on the nitrogen cycle.

MEASURING THE NITROGEN CYCLE

Nitrogen fixation and denitrification are the critical nutrient cycle processes occurring in Port Phillip Bay and Western Port. Denitrification removes the food (nitrogen) from the system while fixation brings it in.

Nitrogen fixation

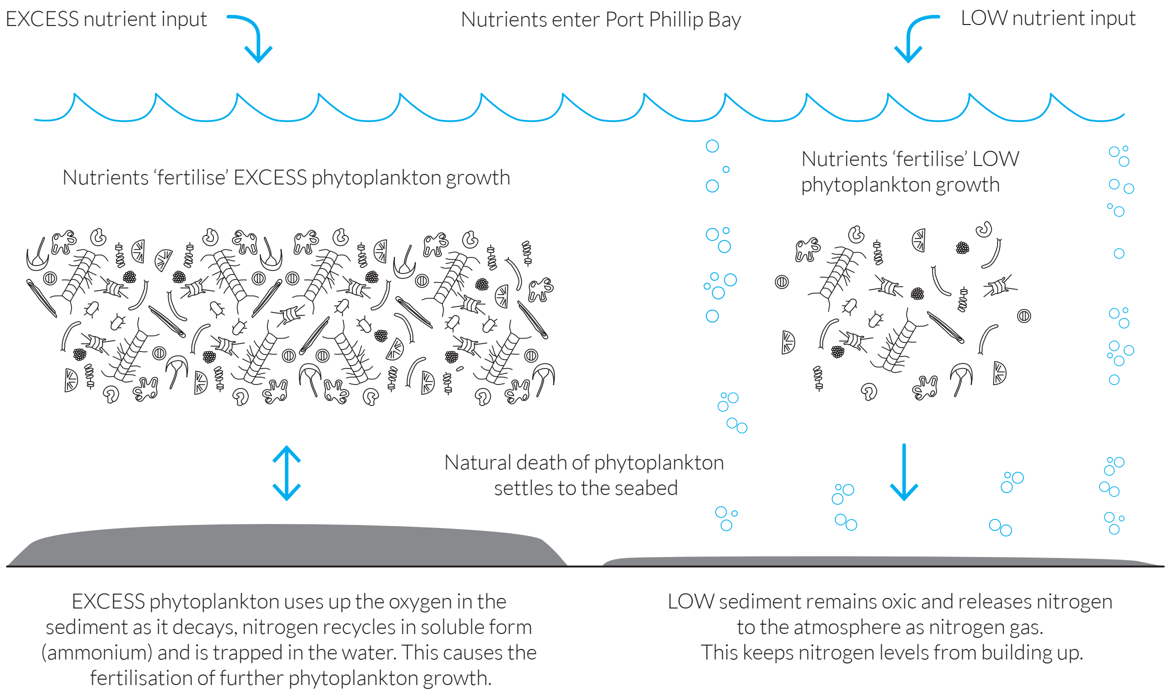
Nitrogen enters the water through precipitation, runoff, or as N_2 from the atmosphere. However, phytoplankton needs nitrogen in biologically available forms to synthesise organic matter. Therefore N_2 must undergo nitrogen fixation, a process performed predominately by cyanobacteria.

Denitrification efficiency

Denitrification efficiency (DE) is the proportion of recycled (metabolised) nitrogen lost to the atmosphere as nitrogen gas, compared with the total of inorganic nitrogen forms released by the microbial breakdown of organic matter. DE is estimated by measuring the movement between the sediment and the water column of the inorganic nitrogen forms – ammonium (NH_4+) and oxidised nitrogen (NO_2- and NO_3-) – and comparing that with N_2, which is created when organic matter decomposes in the sediment (figure N.1).

High DE represents a system that effectively removes nitrogen that could potentially cause algal blooms, which can affect the health and recreational amenity of marine and estuarine waters.

NUTRIENT CYCLING IN PORT PHILLIP BAY



NITROGEN CYCLE WESTERN PORT

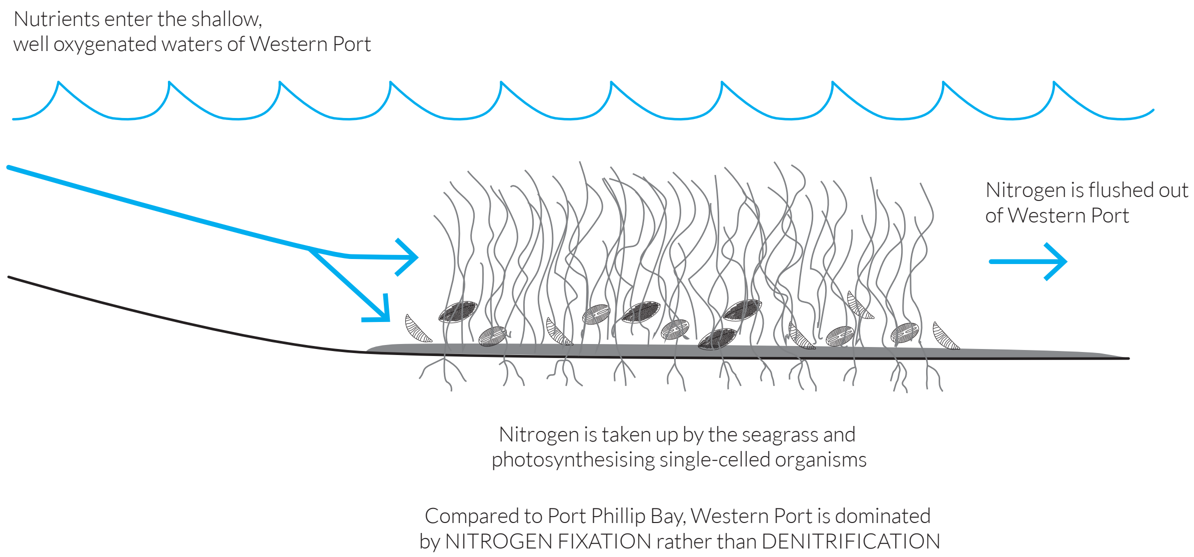


Figure N.1: Conceptual models of nutrient cycling in Port Phillip Bay[1] and Western Port

INDICATOR ASSESSMENT: THE NITROGEN CYCLE

Legend

Status

Status	
Unknown	Data is insufficient to make an assessment of status and trends.
Poor	Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.
Fair	Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.
Good	Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear

↘ Deteriorating

→ Stable

↗ Improving

Data quality

Data quality	
Poor	Evidence and consensus too low to make an assessment
Fair	Limited evidence or limited consensus
Good	Adequate high-quality evidence and high level of consensus

	Summary	Status and trends
Indicator Denitrification efficiency (DE) **Region** Port Phillip Bay **Measures** DE – flux between sediment and water column **Metric** Denitrification efficiency **Thresholds** High > or = to 80% Low < 60% Low < 40% (Hobsons Bay) **Data custodian** DELWP	DE was high throughout 2014-15, and spatial differences were as predicted by the conceptual model.[2] No event since 1994 has been large enough to reduce DE for more than a month, and even then it affected only a restricted area (Hobsons Bay). An annual target (based on the CSIRO's Port Phillip Bay Environmental Study 1996) aims to keep gross nitrogen loads to the bay below 6,000 tonnes N each year, split between the Western Treatment Plant (WTP) (3,100 t) and catchments (2,900 t). There is high confidence that targets from the WTP have been met.	UNKNOWN POOR FAIR GOOD Status: Good; Trend: Stable → DATA QUALITY: Good Good data quality but only at two sites

	Summary	Status and trends
Indicator Ratio of nitrogen fixation to denitrification **Region** Western Port **Measures** Denitrification-isotope pairing technique; nitrogen fixation – acetylene reduction **Thresholds** SEPP (Waters of Victoria) **Data custodian** EPA	In most parts of Western Port, the ratio of nitrogen fixation to denitrification is high (that is, nitrogen fixation is more common than denitrification). Low denitrification indicates the water column is starved of nutrients because the vegetation is processing it. This ratio is inverted in less vegetated areas of Western Port (that is, denitrification is higher than nitrogen fixation). On average Western Port receives ~650 tonnes of nitrogen a year from the catchments, ~430 tonnes a year from nitrogen fixation and loses ~230 tonnes a year though denitrification. Approximately 40% of the total nitrogen input to Western Port resulted from nitrogen fixation.[3]	UNKNOWN POOR FAIR GOOD ? DATA QUALITY Poor

The nitrogen cycle: knowledge gaps

The following knowledge gaps focus on improving our understanding of the nitrogen cycling processes to ensure the ongoing health and sustainability of the bays.

The studies proposed below should be considered and/or conducted within the scope of a Marine Knowledge Framework for the marine and coastal systems of Port Phillip Bay and Western Port.

UNDERSTAND PORT PHILLIP BAY'S NUTRIENT CYCLE[4]

Denitrification in Port Phillip Bay is a key measure of ecosystem function and a high value ecosystem service within the bay. It is the key nutrient cycling process in the muddy sediments that cover approximately 70% of the bay. However, it may not be the most appropriate indicator of nutrient cycling in all parts of the bay.

Given that, researchers need to identify alternative indicators for these areas. Specifically, modelling and research to identify the causes of stress observed in some northern and western nearshore habitats (for example, seagrasses and reefs) is recommended.

Conclusions on DE in Port Phillip Bay are drawn from monitoring at only two sites. More extensive monitoring to draw bay-wide conclusions is required. For example, the model output[5] has not yet revealed DE in different areas of the bay (other than the two monitoring sites); nor has it identified clearly the near-shore areas potentially at risk. Nitrogen cycling in Port Phillip Bay may be vulnerable to high nutrient loads from storms, yet catchment loads, particularly those following large storm events, have not been quantified as accurately as loads from other sources.[6]

Further, current understanding of nitrogen cycling in Port Phillip Bay is in relation to mud sediments and does not apply to the sands that cover 30% of the bay. A robust sediment map is needed because DE varies depending on the nature of the sediment.

Importantly, the science behind the Port Phillip Bay Environmental Study (PPBES) is now almost 20 years old. Over that period, substantial changes have occurred to inputs from both the WTP and riverine catchments. Since the PPBES, little progress has been made in clarifying the roles of MPB and bioirrigation by infauna in denitrification – including at the sediment surface, and at regional and local scales. Recent research indicated current inputs could have important localised, small-scale effects in near-shore areas in the north and west of Port Phillip Bay but these events have not been investigated.

Further modelling and field work should be undertaken to identify the scale at which Port Phillip Bay values are threatened and what role nutrient inputs play in threatening those values. However, nitrogen cycle processes must be conceptualised correctly – especially in sand sediments – before any more modelling is conducted.

UNDERSTAND WESTERN PORT'S NUTRIENT CYCLE

Similarly, a research program to address the gaps in our knowledge of the nitrogen cycle in Western Port is recommended. The influence of vegetation and MPB on the net flux of nitrogen through the processes of denitrification and nitrogen fixation is not fully understood.

Microphytobenthos present on non-vegetated tidal flats can help stimulate bioavailable nitrogen production, with extremely high rates of nitrogen fixation observed in the presence of blue-green algae. However, researchers have not compared the relative importance of these two drivers of nitrogen fixation.

An Australian Research Council (ARC) Linkage Project (Monash University and University of Melbourne) currently underway aims to understand the factors controlling seagrass distribution, options for recovery and the links between seagrass and nutrient cycling on tidal flats. This project is not modelling nutrient cycling explicitly; rather the focus is seagrass distribution, plume dynamics and turbidity. But it starts a more detailed analysis of the issues raised in this chapter.

UNDERSTAND HOW MARINE PESTS AFFECT THE NITROGEN CYCLE[7]

Denitrification also remains potentially vulnerable to introduced marine pests (and some native species), so assessing that vulnerability further is recommended. The highest risk posed by nutrients is to subtidal reefs, where increased nutrients can affect species composition and macroalgal cover. On reefs where grazing by over-abundant native sea urchin species reduces the cover of macroalgae, nutrients indirectly contribute to further macroalgal loss by favouring turfing algae. The increased production of drifting kelp due to nutrient inputs also helps maintain urchin barrens on these reefs.[8]

Nutrient supply was not a significant factor in promoting urchin invasion of reefs, but it is possible that once barrens are established, urchin populations are able to persist due to the supply of drift algae in the west and north of Port Phillip Bay. One hypothesis is that declines in drift algae (the preferred food for urchins) – due to reduced catchment inputs – led to urchins switching to feeding on attached macroalgae.[9]

Marine pests may affect nitrogen cycling by:

- displacing or consuming the infauna living in the sediment that are thought to be important for enhancing denitrification by pumping water through the sediment (bioirrigation), or by mixing freshly fallen organic matter deeper into the sediment (bioturbation)

- intercepting organic matter before it reaches the sediment (short-circuiting denitrification), and/or
- increasing nutrients in the water column by injecting wastes directly into the water column rather than into the sediment.

Impacts of exotic species on nutrient cycling have been demonstrated in small scales in Port Phillip Bay,[10] though marine scientists are not aware of any documented cases elsewhere in the world where introduced marine pests have led to a system-wide collapse of nutrient cycling. More research is required to understand the impact of specific pest species. No recent surveys have been taken of the distribution and abundance of any exotic species in Port Phillip Bay. Current research has measured the impact on DE of only two[11] of the approximately 150 existing exotic species (see below). The effect of future exotic species is also unknown.

KEY PESTS THAT MAY AFFECT NUTRIENT CYCLING[12]

Raeta pulchella: an invasive, threatening species

Raeta pulchella was first detected at Sandringham in 1991, but by 1999 had spread throughout Hobsons Bay and at the Port of Melbourne Dredge Material Ground.[13] By 2004, *Raeta* was the most abundant bivalve at a site near Williamstown.[14]

As a filter feeder, *Raeta* eats by filtering organic matter from water. It is likely to affect nitrogen cycling by intercepting such matter before it can reach the sediment, and excreting waste directly into the water column (bypassing sedimentary denitrification).

Macreadie (2004) found that over the range of *Raeta* densities at Williamstown, DE declined from about 70% with no bivalves to near zero – this corresponding figure suggests that the species negatively affects nutrient cycling. Such an impact has not been demonstrated elsewhere.[15]

Sabella spallanzanii and *Asterias amurensis:* non-invasive species

Other more widespread exotic fauna, such as the European fanworm, *Sabella spallanzanii* and northern Pacific seastar, *Asterias amurensis*, do not significantly affect DE at existing population densities.[16] In *Sabella* populations, researchers attributed a decrease in DE to *Sabella* trapping organic matter in the water column, before it reaches the sediment.[17]

In Hobsons Bay and central Port Phillip Bay, DE was similar before and after the peak of the *Asterias* invasion in 2000, suggesting *Asterias* has had little impact on this key process at these sites.

The nitrogen cycle: science stocktake

THE NITROGEN CYCLE IN PORT PHILLIP BAY[18]

Port Phillip Bay hosts many species of birds, fish, large (macroscopic) and small (microscopic) plants, and animals and microbes living in the water column or on and in the sediment. Nutrient inputs affect all of these organisms either directly (plants) or indirectly (animals).[19]

Denitrification is the key nitrogen cycling process in the muddy sediments that dominate the large central basin in Port Phillip Bay, and where phytoplankton is the key primary producer. However, denitrification may be less important in near-shore sandy sediments, where MPB, macroalgae or seagrass dominate. Habitats in these areas more closely resemble Western Port.

Some signs of stress in reefs and seagrass beds in the north and west of Port Phillip Bay could be associated with nutrient inputs (most likely from the WTP, the Werribee River and the Yarra/Maribyrnong rivers) and poor light conditions.[20]

Between 1992 and 1996, the CSIRO conducted the comprehensive PPBES,[21] following community concerns the bay could not assimilate external inputs of nutrients and toxicants. The study examined the physics, chemistry and biology of the bay, and found nutrient cycling plays a key role in maintaining water quality. Nutrients supporting plant growth are supplied from the catchment, recycled in the water column, and recycled at the seabed.

The Port Phillip Bay Environmental Management Plan (PPBEMP) established arrangements to manage risks to the nitrogen cycle in Port Phillip Bay, including a nutrient cycling monitoring program. This program commenced in 2002 to detect changes in critical elements of nitrogen cycling in the bay.

The measurements are intended 'to detect, as early as possible, changes beyond expected variability to critical elements of nitrogen cycling processes in Port Phillip Bay that indicate an increased risk of eutrophication at bay-wide or regional scales'.[22] Eutrophication refers to the nutrient enrichment of an ecosystem to the extent that it leads to undesirable outcomes such as algal blooms, anoxia, fish kills etc. The flux of nutrients between sediment and water column is measured at two sites (Hobsons Bay and central Port Phillip Bay) twice each year, while the water column salinity, temperature, dissolved oxygen and plankton biomass (chlorophyll) are measured continuously at three sites (Hobsons Bay, central Port Phillip Bay and Long Reef – see **Water quality** chapter). Figure N.2 illustrates these sites.

Spring and summer were selected for benthic flux measurements as the periods when denitrification was likely to be most stressed (high river flows in spring, and high plankton growth and high temperature in summer). A series of reports summarises this monitoring.[23]

BAYSIDE MONITORING LOCATIONS

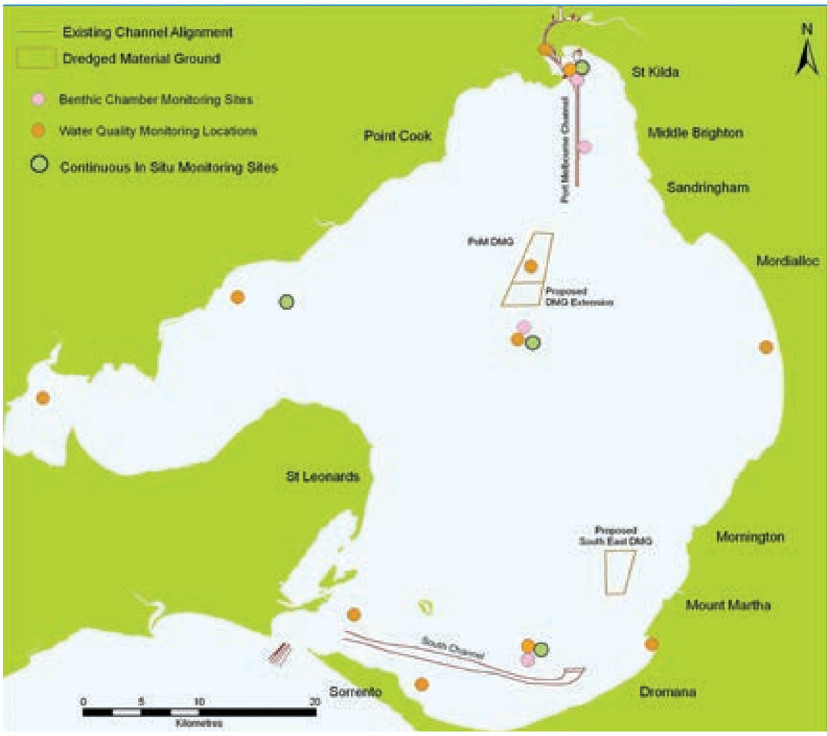
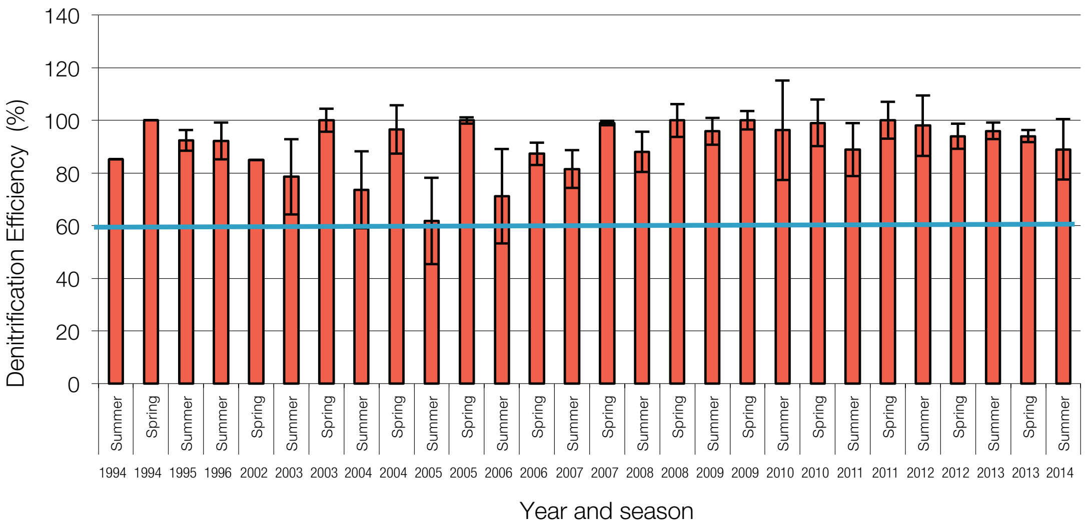


Figure N.2: Water quality sampling sites in Port Phillip Bay[24]

The CSIRO recommended an annual target for nitrogen in the bay, to keep the load well below levels that could risk eutrophication, but still support productivity for fisheries. Specifically, the CSIRO recommended keeping annual gross nitrogen loads to the bay below 6,000 t of nitrogen each year, split between the WTP (3,100 t) and catchments (2,900 t).[25]

There is high confidence that targets from the WTP have been met, based on weekly measurements of nitrogen in the discharges. Similarly, recent catchment modelling (based on monitoring data) indicated the annual nitrogen reduction target of 1,000 t each year has also been met (figure N.3). The notional DE trigger lines – 60% in Port Phillip Bay and 40% in Hobsons Bay – illustrates the resilience of DE in Port Phillip Bay to disruptive events such as storms and drought.

(a) CENTRAL PORT PHILLIP BAY



(b) HOBSONS BAY

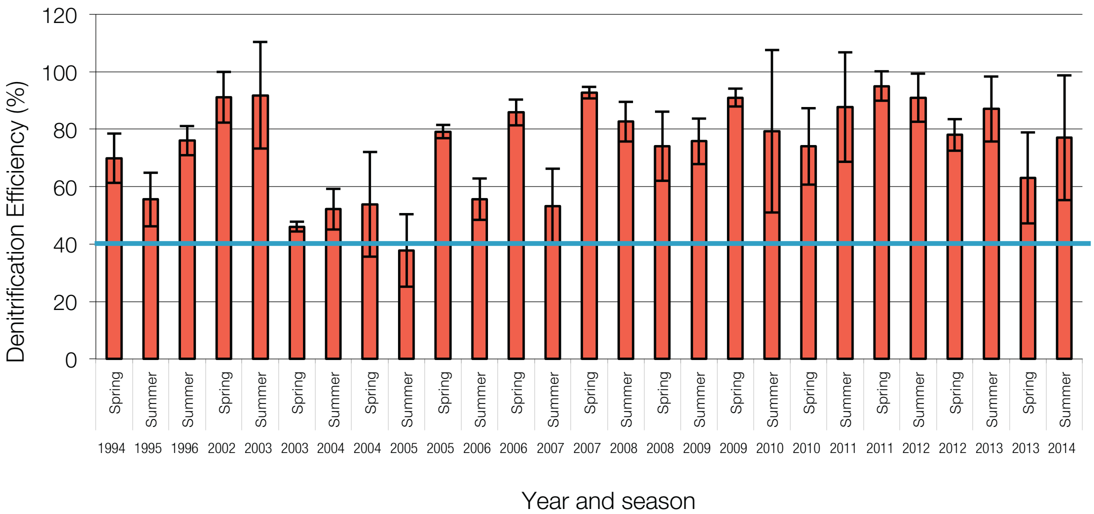


Figure N.3: Denitrification efficiency (DE) in spring and summer in (a) central Port Phillip Bay and (b) Hobsons Bay, 2002–15
Note: Error bars indicate standard error of the mean. Blue lines indicate notional trigger values.

Denitrification remains an ecosystem service critical to maintaining high water quality in Port Phillip Bay. No event since 1994 has been large enough to reduce DE for more than a month, and even then only in a restricted area (Hobsons Bay). Observations since 1994 and modelling of storm flood impacts suggests denitrification is resilient to loads from the WTP and the catchments expected over the next 20 years.

However, localised reductions in DE are likely following storm events (for example, in Hobsons Bay). These events are likely to create acute short-term impacts (for example, algal blooms, beach closures), particularly if the projected nitrogen load increase is not mitigated. The new PPBEMP will need to consider new approaches to managing these impacts.

ALGAL BLOOM EVENTS IN PORT PHILLIP BAY

Noctiluca scintillans blooms can appear as red, orange or brown/rust discoloured water along the beach or at piers or jetties. They may also have a phosphorescent blue glow at night, when water is disturbed by waves or boats. They are a low risk to health, although the EPA advises avoiding contact in case they irritate the skin.

These short-lived blooms occur regularly at many different locations around Port Phillip Bay. They often follow heavy rainfall and warmer weather, and are likely caused by freshwater and nutrients flowing into the bay, increasing organic matter or food sources for this species.[26] Reports of blooms increase when there are calm sea conditions, which allow algae to accumulate at the food sources. They get broken down with increased wind and rougher sea conditions, as well as being dispersed by bay currents.

Noctiluca is present in Port Phillip Bay at low background levels year round, but increase in numbers to form blooms when conditions are favourable. The most recent blooms in Port Phillip Bay have been caused by high nutrients and calm bay conditions.[27]

The nitrogen cycle in Western Port

Western Port is generally considered to have low nutrient inputs relative to other bays such as Port Phillip Bay. It does not receive a direct sewage discharge, and the catchment inputs are comparatively small. The most significant catchment inputs are in the Upper North Arm (for example, Watsons Creek) and Corinella segments – and these are relatively small.[28] The Bass River is also an important source but it discharges into well-flushed parts of Western Port.[29]

Recent research by Monash University[30] studied rates of denitrification and nitrogen fixation in three intertidal seagrass *(Zostera muelleri)* meadows and adjacent non-vegetated tidal flats within Western Port. Russell et al (2016) found nitrogen fixation typically dominated over denitrification, in both vegetated and non-vegetated sediments. Specifically, on average, Western Port receives ~650 t of nitrogen a year from the catchments, ~430 t a year from nitrogen fixation and loses ~230 t a year though denitrification. Therefore, approximately 40% of the total nitrogen input to Western Port was as a result of nitrogen fixation. Further, sensitivity analysis confirmed that while the loss of seagrass would affect the magnitude of the bay-wide flux of nitrogen on these tidal flats, nitrogen fixation remains the dominant process.

Russell et al (2016) concluded that in a healthy Western Port bay, the ratio of nitrogen fixation to denitrification should be higher. Indeed, in most parts of Western Port, the ratio of nitrogen fixation to denitrification is high (that is, nitrogen fixation is higher than denitrification). Low denitrification indicates the water column is being starved of nutrients because the vegetation is processing it. This ratio is inverted in less vegetated areas of Western Port with lower turbidity where denitrification is higher than nitrogen fixation.

Unlike Port Phillip Bay, Western Port is dominated by tidal flats that are highly productive environments due to their large surface area, exposure to high light intensities and the presence of benthic vegetation (seagrass) and/or MPB.[31] However, the influence of vegetation and MPB on the net flux of nitrogen through the processes of denitrification and nitrogen fixation is not well understood.

Seagrass represents one of the common types of vegetation found on tidal flats. Although often overlooked, seagrass meadows also can alter how nutrients such as nitrogen are cycled[32] compared with non-vegetated sediments that contain MPB. In seagrass meadows, nitrogen fixation is the dominant nitrogen transformation process, increasing the pool of bioavailable nitrogen.

Seagrass meadows encourage nitrogen fixation via the mutualistic relationships between the seagrass roots/rhizomes and nitrogen-fixing microbes in the sediment, such as sulphate-reducing bacteria. The root systems of seagrass exude carbon into the sediment, which increases the activity of nitrogen fixing microbes, resulting in higher rates of nitrogen fixation.[33] In addition, seagrass outcompetes nitrifying/denitrifying microbes for available NH_4+ and NO_3- (via vegetative assimilation), which limits the loss of nitrogen through denitrification.[34]

Non-vegetated tidal flats with an abundance of MPB can also alter the cycling of nitrogen. Microphytobenthos present in non-vegetated tidal flats can help generate bioavailable nitrogen,[35] with extremely high rates of nitrogen fixation observed in the presence of cyanobacteria (photosynthetic bacteria also known as blue-green algae). However, the relative importance of these two nitrogen fixation drivers is unknown.

Understanding their relative contribution to nitrogen fixation is important because this may indicate how the composition of microbial communities may change if seagrass is lost.

As well as vegetation, other site-specific differences such as turbidity and nitrogen concentrations may also affect the cycling of nitrogen in marine environments. Increased nitrogen concentrations decrease rates of nitrogen fixation[36] and increase denitrification rates,[37] while increased turbidity can limit light and cause seagrass loss.[38] And because seagrass can stimulate nitrogen fixation activity, seagrass death will likely lower nitrogen fixation rates. Therefore, it is important to understand how the balance of denitrification and nitrogen fixation in coastal ecosystems will respond to further reductions in seagrass coverage, and to investigate how site-specific controls affect the relative importance of the major nitrogen transformations.

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Aplysilla rosea
Rose sponge

CHEMISTRY OF THE BAYS

WATER QUALITY

Nitrogen and phosphorous are essential nutrients for plant and animal growth. These nutrients reach coastal waterways via rivers and streams, and through exchange with the atmosphere and ocean.

Rural and urban land use activities like housing development and farming have led to broad scale and significant increases in the nutrient loads from the catchments. Excessive levels of nutrients can greatly modify aquatic plants, and subsequently general water quality, by promoting the growth of organisms like blue-green algae at the expense of other species. This in turn can affect the entire food chain.

Changes to the Western Treatment Plant or new coastal infrastructure should consider how it affects light and in turn, the health of seagrass beds in this area.

In 2013–14, the EPA and CSIRO Coastal and Environmental Modelling Team developed and implemented the Victorian Marine Operational Model (VIC-MOM). VIC-MOM predicts the dispersal of marine pollution and ship ballast discharges across Victorian marine waters.

Understanding water quality in Port Phillip Bay and Western Port involves understanding the linkages to inputs originating from their surrounding catchments.

Introduction

The Victorian Environment Protection Authority (EPA) and Melbourne Water established monitoring and reporting systems for water quality in Port Phillip Bay and Western Port, to protect healthy bay environments from pollution and waste. Water quality objectives are set by the State Environment Protection Policy (Waters of Victoria) (SEPP WOV) and Australian and New Zealand guidelines for fresh and marine water quality (2000).[1]

The Yarra and Bay website (www.yarraandbay.vic.gov.au) publishes information about water quality for Port Phillip Bay on daily, monthly and annual reporting timeframes. Users can access daily alerts for pollution, fish death and algal blooms, or read annual trends and scores about water quality of individual waterways, and the bay as a whole. The EPA is working to expand the report card to include Western Port (and other areas of Victoria) in the near future.

Three main programs inform the Yarra and Bay website:

- bay-wide and catchment water quality monitoring (pollution alerts and report card)
- Beach Report
- Yarra Watch.

Water quality data, indicators and threshold levels are organised in an Aquatic Realtime Management System (ARMS), which generates reports through the website using summary tables, charts and graphics.

This chapter summarises the water quality of the bays, both recently and historically, and describes the EPA's monitoring regime. The chapter also includes additional information from the EPA's broader work program, including:

- phytoplankton behaviour and assemblages in Port Phillip Bay
- the links between water quality and seagrass health in Port Phillip Bay
- the Victorian Marine Operational Model (VIC-MOM).

The chapter includes a summary of key knowledge gaps for further research. Potential initiatives include:

- building on the current systems – developing a broader scale monitoring network and better integration of monitoring data
- developing the applications and understanding of the data that these systems produce – improving modelling to understand ecosystem sensitivities and the impacts of pollution.

Legend

Status

Unknown – Data is insufficient to make an assessment of status and trends.

Poor – Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.

Fair – Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.

Good – Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear

↘ Deteriorating

→ Stable

↗ Improving

Data quality

Poor – Evidence and consensus too low to make an assessment

Fair – Limited evidence or limited consensus

Good – Adequate high-quality evidence and high level of consensus

Indicator

Nutrients

Region

Port Phillip Bay (PPB) and Western Port (WP)

Measures

Total nitrogen (TN), total phosphorus (TP) Schedule F8 also measures and lists dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), because they represent the readily bio-available species of nutrients

Metric

Concentration (mg/L)

Thresholds

SEPP WOV)

Data custodian

EPA

Summary

Nitrogen and phosphorus are essential nutrients for plant and animal growth. These nutrients reach coastal waterways via rivers and streams, and through exchange with the atmosphere and ocean. Rural and urban land use activities like housing development and farming have led to broad-scale and significant increases in the nutrient loads from the catchments. Excessive levels of nutrients can greatly modify aquatic plants, and subsequently general water quality, by promoting the growth of organisms like blue-green algae at the expense of other species. This in turn can affect the entire food chain.

Status and trends

UNKNOWN	POOR	FAIR	GOOD
			↗ PPB WP

DATA QUALITY

Good

	Summary	Status and trends (UNKNOWN / POOR / FAIR / GOOD)
Indicator Water clarity **Region** Port Phillip Bay and Western Port **Measures** Turbidity (NTU) Suspended solids (mg/L) **Thresholds** SEPP WOV **Data custodian** EPA	Turbidity is a measure of water clarity. High turbidity (low clarity) is caused mainly by large concentrations of sediments[2] that are washed off catchments into streams and rivers and ultimately into the marine and estuarine environments. Coastal erosion is a significant contributor to poor water clarity in some locations (e.g. Western Port). In Western Port, high concentrations of sediments are detrimental to the aquatic ecosystem because it reduces the light available for photosynthesis. Sediment also carries other materials (toxicants, pathogens and organic matter) that consume oxygen in the water column. Sediments from catchments and resuspension in Western Port settle out and smother seagrass and block light for seagrass growth.	POOR: WP GOOD: PPB DATA QUALITY Good
Indicator Salinity **Region** Port Phillip Bay and Western Port **Measures** Electrical conductivity (µS/cm) and TDS (mg/L) **Thresholds** SEPP WOV **Data custodian** EPA	Salinity refers to how much salt is in water. The water in rivers and streams is usually fresh, oceans are salty and estuaries are highly variable depending on tides and freshwater flows. Salinity levels may fluctuate quickly (periods of hours and days) with the tidal cycles, and when currents and wind mix fresh and marine waters. Salinity can also vary over seasonal cycles with large freshwater flows from the catchments during wetter months. Most aquatic organisms have evolved to function within an optimal salinity range and tolerate natural cycles within this range. Long-term changes to salinity distributions and their natural cycles can severely affect the health of aquatic organisms.	GOOD: PPB WP DATA QUALITY Good
Indicator Dissolved oxygen **Region** Port Phillip Bay and Western Port **Measures** % saturation **Thresholds** SEPP WOV **Data custodian** EPA	Dissolved oxygen (DO) refers to the amount of oxygen contained in water, and is a critical measure of the living conditions for oxygen-requiring (aerobic) aquatic organisms. Most aquatic organisms need oxygen to be above a certain concentration for respiration and efficient metabolism – DO concentration changes above or below this value can negatively affect their physical wellbeing. Discharges of wastes rich in organic matter (e.g. from sewage treatment plants, paper manufacturing, food processing and other industries) are produced in large quantities in urban population centres, and can substantially reduce dissolved oxygen concentrations. Even short-lived conditions of low DO (anoxic or hypoxic events) can cause major deaths of aquatic organisms, such as fish, and are observed from time to time.	GOOD: PPB & WP DATA QUALITY Good

	Summary	Status and trends (UNKNOWN / POOR / FAIR / GOOD)
Indicator pH **Region** Port Phillip Bay and Western Port **Measures** pH units 0–14 scale **Thresholds** SEPP WOV **Data custodian** EPA	pH is a measure of acidity or alkalinity of water from acidic (pH less than 7) through to neutral (pH 7) and alkaline (pH greater than 7). Most aquatic organisms require pH to be within a particular range. If water is too alkaline or too acidic, an organism's physiological processes may be disrupted. Local geology creates natural sources of alkaline and acid flows, but changes are often due to mine waste disposal and chemical spills. Acidic waters also help dissolve metal toxicants, which can have severe ecosystem impacts. pH is generally very stable in marine systems due to strong buffering. Changes in ocean acidification associated with climate change are a major future pressure on marine systems.	GOOD: PPB, WP DATA QUALITY Unknown – not measured routinely in the bays (only in catchments)
Indicator Metals **Region** Port Phillip Bay and Western Port **Measures** Arsenic, cadmium, chromium, copper, lead, nickel and zinc (µg/L) **Thresholds** SEPP WOV **Data custodian** EPA	Metals occur naturally in the Earth's crust, and are released into the environment via physical and chemical weathering of rocks. The background concentration of metals is mostly controlled by the geological characteristics of the catchment. However, anthropogenic (human) sources of metals include industrial and municipal waste products, urban and agricultural runoff, atmospheric deposition and antifouling paints applied to marine vessels. Most metals are toxic to organisms above a certain concentration and some accumulate in animals and plants (including fish, mangrove vegetation and seagrasses). They enter the food chain through body and respiratory surfaces and by ingestion.	GOOD: PPB, WP DATA QUALITY Good PPB & WP (WP – monitoring ceased due to low levels)
Indicator Algae **Region** Port Phillip Bay and Western Port **Measures** Chlorophyll-a (µg/L) **Thresholds** SEPP WOV **Data custodian** EPA	Chlorophyll-a is a green pigment found in plants. It absorbs sunlight and converts it to sugar during photosynthesis. Chlorophyll-a is a commonly used measure of water quality and concentrations indicate phytoplankton abundance and productivity in aquatic environments. Higher concentrations typically indicate poor water quality, usually when high nutrient concentrations maintain high algal production. It is natural for chlorophyll-a concentrations to fluctuate over time; they are often highest after rain, particularly if the rain flushes nutrients into the water, during the warmer, sunnier months of the year.	POOR: WP GOOD: PPB DATA QUALITY Good

	Summary	Status and trends (UNKNOWN / POOR / FAIR / GOOD)
Indicator Harmful algae blooms **Region** Port Phillip Bay **Measures** Identification, abundance and diversity **Thresholds** SEPP WOV **Data custodian** EPA	Marine algae occur naturally and are present year-round in all marine waters, including Port Phillip Bay. Under the right conditions, marine algae can rapidly increase to create an algal bloom. Algal blooms can develop in the days or weeks after heavy rain, particularly during periods of warm, sunny and calm weather. They generally dissipate within a few days to one to two weeks.	FAIR (→) DATA QUALITY Good
Indicator Sediment contamination **Region** Port Phillip Bay and Western Port **Measures** Degree of contamination **Thresholds** SEPP WOV ANZECC **Data custodian** EPA	In the immediate areas of high concentration, toxic contaminants in sediment can kill marine life (e.g. fish and invertebrates). Other acute effects may include changes in the abundance, composition and diversity of biological communities and habitats. Some toxicants persist in the environment and may progressively accumulate in sediments or in biological tissues to levels that are much higher than water column concentrations (e.g. bioaccumulation). Chronic effects of bioaccumulated toxicants in organisms include changes to growth, reproductive success, competitive abilities and deformities such as imposex. For this reason the ANZECC guidelines provide safe toxicant concentrations in sediments to protect aquatic ecosystems. Elevated toxicant concentrations in organisms (e.g. fish and shellfish) may also pose health risks to consumers of those organisms (including humans). For this reason, toxicant concentrations in food are regulated by Food Standards Australia and New Zealand (http://www.ozcoasts.gov.au/indicators/toxicants.jsp).	FAIR (→) PPB WP DATA QUALITY Poor (random surveys)

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Temperature **Region** Port Phillip Bay and Western Port **Measures** °C **Thresholds** SEPP WOV **Data custodian** EPA	Water temperature regulates ecosystem functioning both directly through physiological effects on organisms (such as photosynthesis and aerobic respiration) and the growth, reproduction, metabolism and the mobility of organisms. Unnatural changes in water temperature impact indirectly upon biota through loss of supporting habitat such as coral reefs, by changing the solubility of oxygen and calcium carbonate, or by influencing the extent to which physiological processes assimilate metal contaminants and other toxicants (http://www.ozcoasts.gov.au/indicators/toxicants.jsp).	PPB WP DATA QUALITY Good
Indicator Enterococci bacteria **Region** Port Phillip Bay **Measures** Number of bacteria cells per 100 ml of water sample **Thresholds** (>400 org/100 mL) **Data custodian** EPA	*Enterococci* are a group of bacteria found in the intestinal tracts of warm blooded animals. Elevated levels of *Enterococci* are a sign of possible faecal pollution. The World Health Organisation and the National Health and Medical Research Council recognise these bacteria as the best indicator for primary contact (swimming, diving or surfing) recreational water quality in marine environments. Most beaches around Port Phillip Bay have met SEPP WOV objectives for swimming in recent years. Over the past three summers, for example, most of the 36 beaches monitored in the bay (94–97%) met objectives for swimming.	DATA QUALITY Good

Water quality: knowledge gaps

The following is recommended further research to fill the knowledge gaps identified in this chapter.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

DEVELOP A BROADER SCALE MONITORING NETWORK

A robust water quality monitoring discipline is in place for Port Phillip Bay and Western Port. However, the current network could be improved, considering the importance of this monitoring and the pressures an increasing population will create for the bays. Most importantly, broadening the current monitoring network is recommended, to improve observation of periodic and short-term pulse pollution events that can significantly affect marine environmental values.

IMPROVE INTEGRATION OF MONITORING DATA

Coordinated research requires comparable methods of analysis among agencies and researchers, and studies that complement each other. Otherwise excellent research is sometimes undermined by a lack of integration with pre-existing sites and data. Coordination is particularly important when developing water quality models. Better integration of water quality monitoring data with modelling tools allows researchers to build and improve on the existing models.

VIC-MOM and the Integrated Marine Observing System are good examples of partnerships where this integration is already occurring for marine research.

IMPROVE MODELLING TO UNDERSTAND SENSITIVITIES

Victoria requires state-of-the-art monitoring technology. Reporting regimes must adopt higher resolution data and more complex hydrodynamic modelling, to better resolve coastal processes and understand the sensitivities of different marine systems.

UNDERSTAND THE IMPACTS OF POLLUTION

A key discipline to improve the management of the bays involves better understanding how pollution affects aquatic ecosystems and other marine values and how they recover over time (for example, developing a stronger set of marine biological indicators of water quality and understanding legacy toxicants in embayment sediments). In particular, better understanding of the impacts of emerging chemicals entering embayment waters is critical (for example, pharmaceuticals from stormwaters, microplastics, litter and toxicants).

This work could build on the VIC-MOM partnership.

Water quality: the science stocktake

BAY-WIDE AND CATCHMENT WATER QUALITY

The EPA currently samples water quality monthly at eight sites in Port Phillip Bay and three sites in Western Port. The Port Phillip Bay sites measure anthropogenic inputs at major bay inflows (Hobsons Bay, Patterson River, Long Reef and Corio Bay) and at remote locations (Dromana Bay and Central Bay). The EPA also started sampling at Popes Eye (an open ocean entrance) and Newport (a Yarra River entrance) in 2008 (figure WQ.1).

PORT PHILLIP BAY MONITORING LOCATIONS

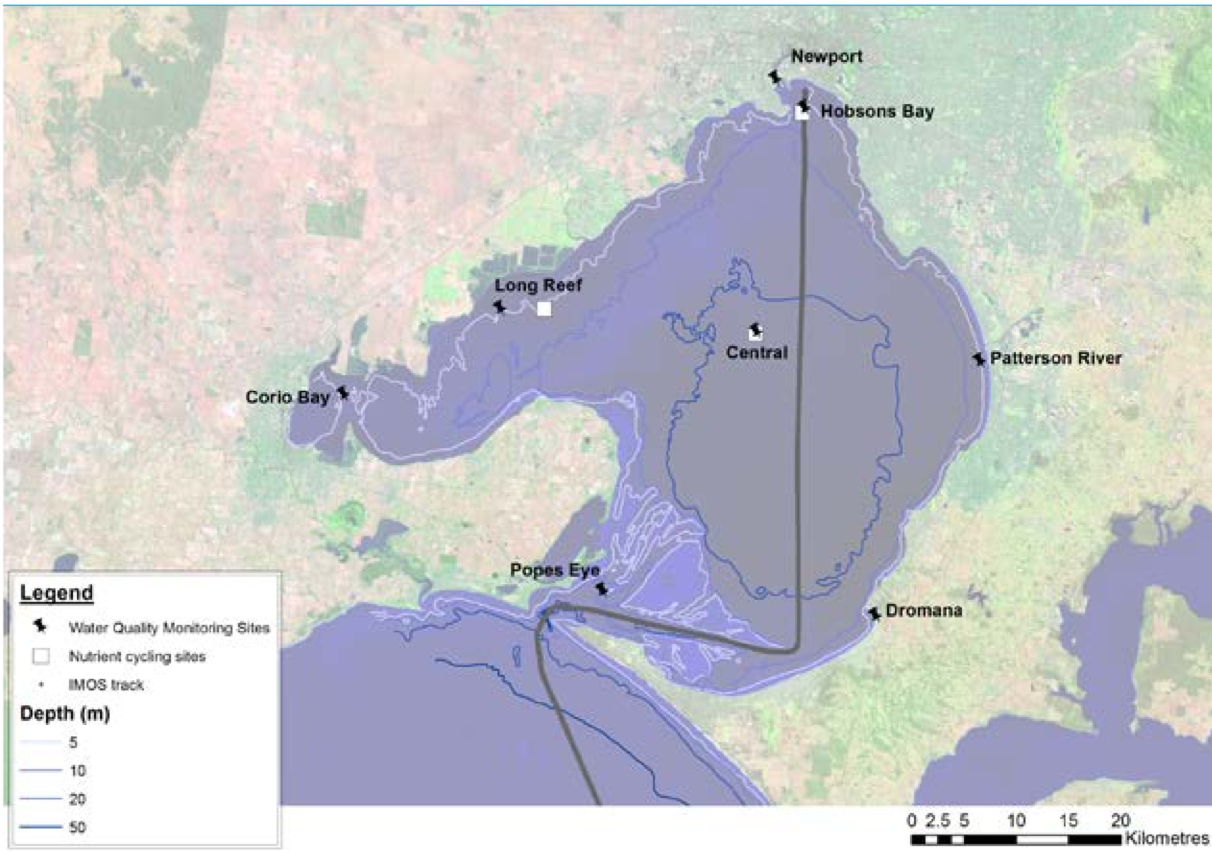

Figure WQ.1: Location of long-term water quality monitoring sites in Port Phillip Bay

WESTERN PORT MONITORING LOCATIONS

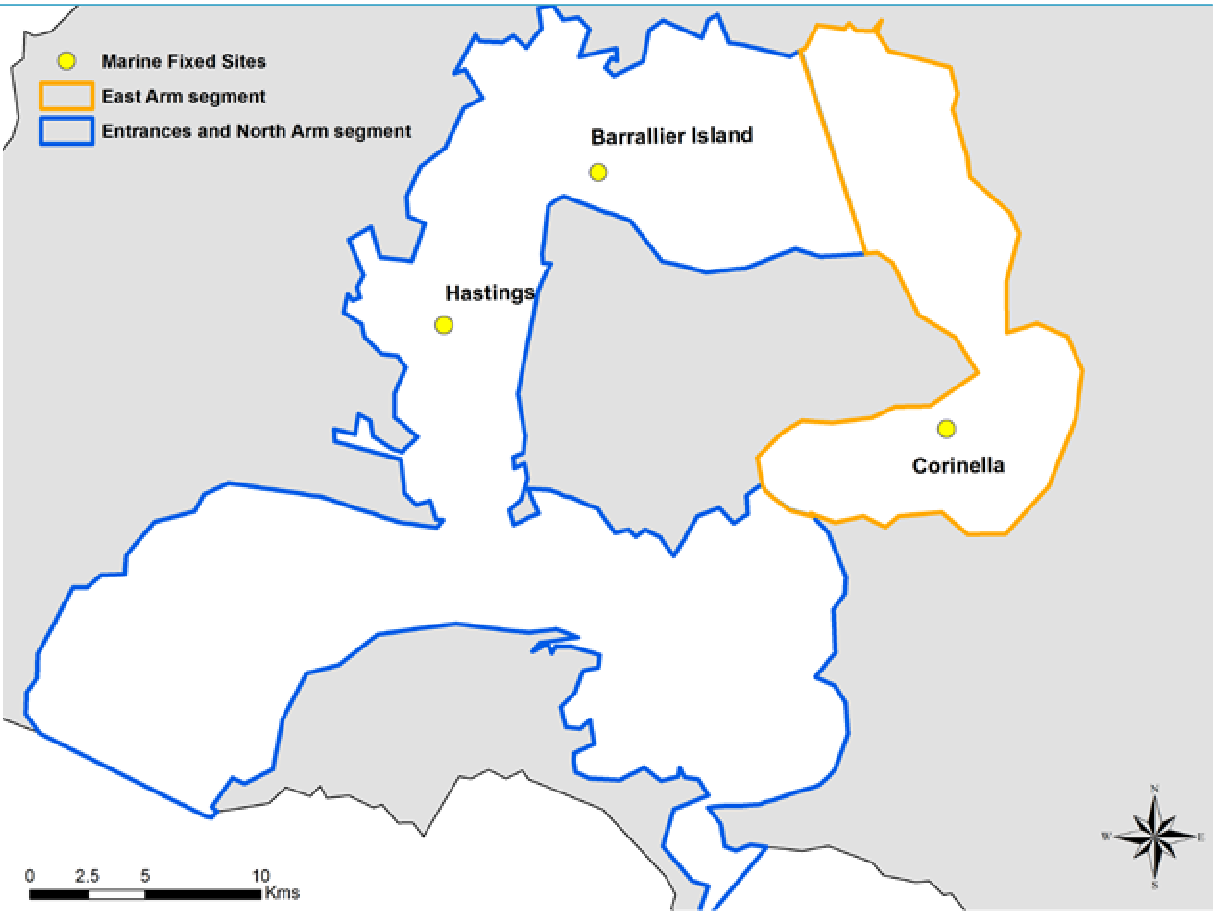

Figure WQ.2: Location of long-term water quality monitoring sites in Western Port

The three sites in Western Port are located near Hastings, Barrallier Island and Corinella (figure WQ.2).

The indicators sampled in the bays include:

- nutrients (nitrogen, phosphorus and silicate)
- water clarity, measured by total suspended solids, light beam attenuation (or PAR – photosynthetically available radiation), and turbidity
- dissolved oxygen
- salinity
- algae as chlorophyll-b and c and chlorophyll-a fluorescence, and plankton identification counts (abundance and diversity)
- metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc)
- water temperature.

The State Environment Protection Policy (Waters of Victoria) (SEPP WOV) sets the upper and lower threshold levels for environmental quality and indicator objectives for recognised segments of Port Phillip Bay and Western Port.

Understanding water quality in Port Phillip Bay and Western Port involves understanding the linkages to inputs originating from their surrounding catchments (figure WQ.3).[3] The biophysical landscape ecology and human land uses of these catchments vary. The Port Phillip Bay catchments cover over 9,790 km^2. The rivers that run into the Port Phillip Bay include the Yarra, Maribyrnong, Werribee, Patterson, Little River and smaller creeks like Kananook, Mordialloc and Kororoit. The Western Port catchment covers 3,721 km^2 and contains 2,232 km of rivers and creeks.

PORT PHILLIP BAY AND WESTERN PORT CATCHMENT DISTRIBUTION

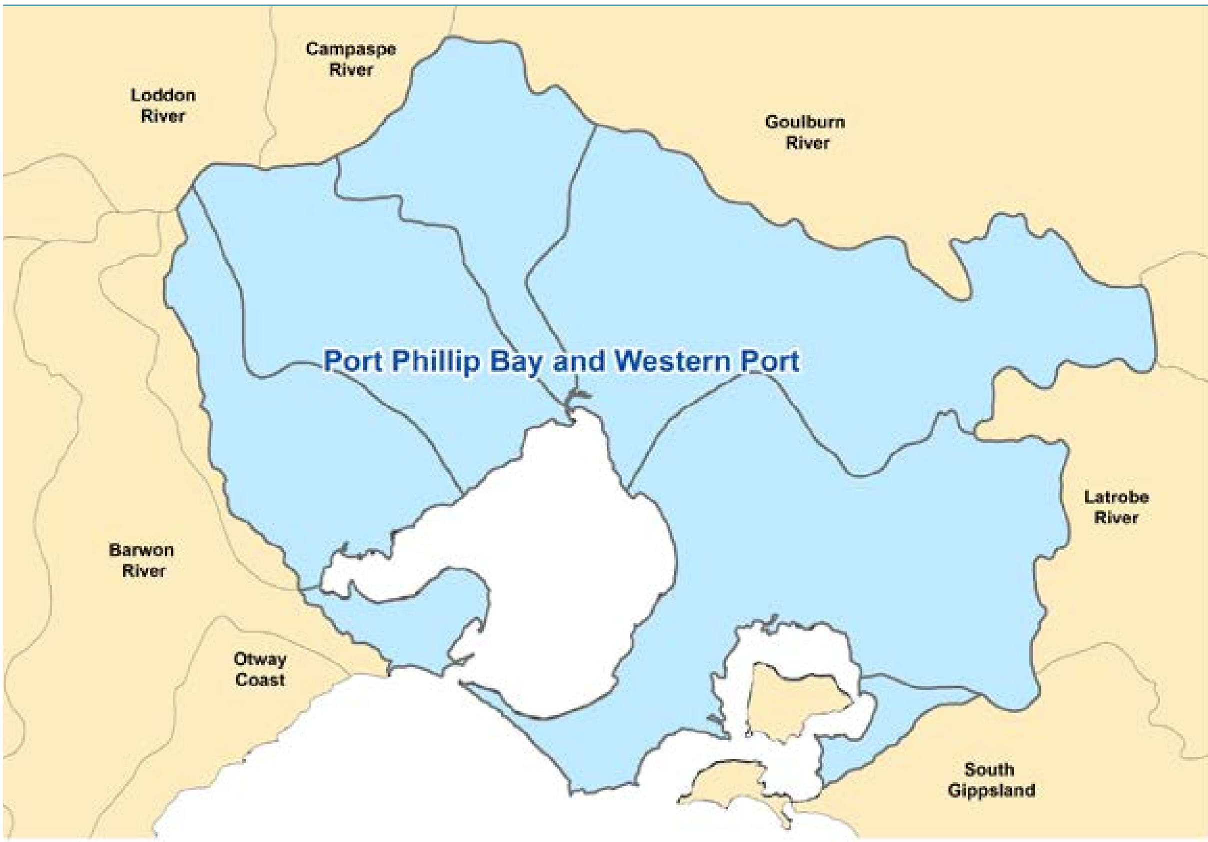

Figure WQ.3: Distribution of catchments surrounding Port Phillip Bay and Western Port

For the adjoining catchments, Melbourne Water samples 134 sites monthly in the Werribee, Maribyrnong, Yarra, Dandenong, Mornington and Western Port catchments as part of its waterways water quality monitoring program. Many sites are located in or around the main urban waterways, including the lower Yarra River and lower Maribyrnong River, where urban development typically affects water quality. Relatively few sites in the upper Yarra catchment are forested and in near natural condition.

The range of indicators sampled include:

- nutrients (nitrogen and phosphorus)
- water clarity (turbidity)
- dissolved oxygen
- salinity (conductivity)
- pH (acidity or alkalinity)
- metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc)
- water temperature
- faecal contamination *(E. coli)*

Recreational water quality in Port Phillip Bay

The report card on the SEPP environmental quality and indicator objectives provides an overall score for each indicator at each site (figure WQ.4). Each water quality indicator is calculated from annual monitoring data, using the relevant statistic that applies to each indicator defined in the SEPP.

The index comprises different parameters for catchment and marine environments, generally because the relative importance of parameters changes between the two. Including suspended solids as a marine parameter is a legacy of different monitoring approaches for marine and fresh water environments.

Indicator	Catchment parameter	Marine parameter
Nutrients	Total nitrogen Total phosphorus	Total nitrogen Total phosphorus
Water clarity	Turbidity	Suspended solids
Salinity	Electrical conductivity	Salinity
Dissolved oxygen	Dissolved oxygen % saturation	Dissolved oxygen % saturation
pH	pH	✖
Metals	Arsenic, cadmium, chromium, copper, lead, nickel and zinc	
Algae	✖	Chlorophyll-a

Figure WQ.4: Indicators used in the report card

Recreational water quality in Port Phillip Bay and the Yarra River

Beach Report monitors water quality at 36 Port Phillip Bay beaches, while Yarra Watch monitors water quality at four sites along the Yarra.

These programs have three broad objectives:

- Provide information about beach water quality so the community can make informed decisions about swimming.
- Identify trends in recreational water quality.
- Strategically improve water quality.

Water quality is sampled each week between December and Labour Day weekend in March. Beach Report samples measure *Enterococci* bacteria levels. It is the most suitable indicator of faecal contamination of marine recreational waters and is used to determine whether beaches and water are safe for primary recreational use. Similarly, Yarra Watch samples measure *E. coli* bacteria levels, which indicate faecal contamination of recreational freshwater.

Water quality forecasts (based on the weekly samples) are posted each day during the December to March period on the Yarra and Bay website and the EPA Twitter account. EPA conducts follow-up investigations when triggers are exceeded, to identify faecal origin and determine location of contamination sources. Both Beach Report and Yarra Watch have quality assurance requirements to ensure data is reliable and represents environmental conditions.

FINDINGS

Most beaches around Port Phillip Bay have met SEPP WOV objectives for swimming in recent years. Over the past three summers, for example, most of the 36 beaches monitored in the bay (94–97%) met objectives for swimming (figure WQ.5).

BEACHES MEETING SWIMMING OBJECTIVES IN THE BAY

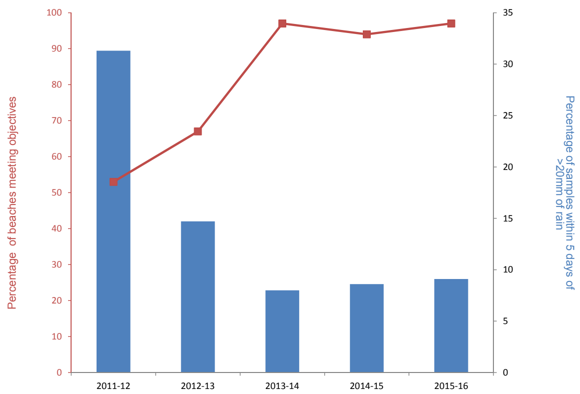

Figure WQ.5: Percentage of beaches meeting SEPP WOV objectives for swimming and the influence of stormwater pollution after heavy rain

Stormwater pollution following heavy rain was the principal cause for Port Phillip Bay beaches not meeting objectives in 2011–12 and 2012–13. Microbial water quality can increase risk of illness to swimmers (for example, via gastroenteritis). The EPA generally advises to avoid swimming near stormwater or river outlets 24–48 hours after heavy rain. If the Beach Report detects poor microbial water quality during dry weather, a beach advisory appears on the Yarra and Bay website and EPA Twitter, and the EPA works with councils to put signs up at beaches.

The number of advisories issued each summer varies, depending on rainfall, and the intermittent and unpredictable nature of dry weather sources impacting microbial water quality. Figure WQ.6 shows beach advisories issued in the past five years.

	No. of beach advisories	Cause of advisory
2011–12	0	
2012–13	0	
2013–14	1	Rye Beach – dry weather discharge from an open drain
2014–15	0	
2015–16	3	Dromana Beach – dry weather discharges from a stormwater drain

Figure WQ.6: Beach Report beach advisories issued over the past five summers

Generally, dry weather discharges caused high microbial levels in the water. Discharges were intermittent, short-lived and unpredictable, and therefore difficult to track. The EPA encourages the public to report pollution.

Phytoplankton behaviour and assemblages in Port Phillip Bay

With significant catchment discharges to the bay (predominantly in the north), and relatively slow flushing rates, Port Phillip Bay can experience periods of enhanced plankton activity. Some of the plankton types observed in the bay can harm aquatic life and even human health.

PORT PHILLIP BAY NETWORK

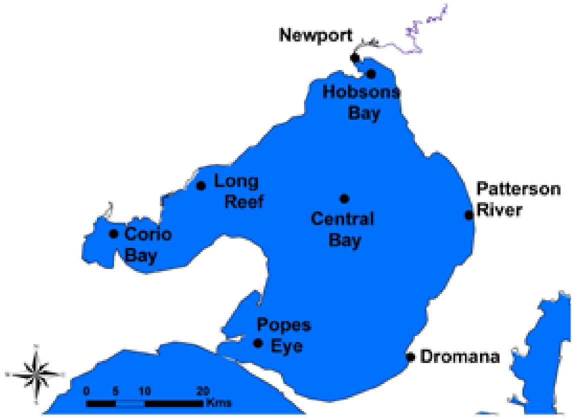

Figure WQ.7: EPA's marine fixed sites network in Port Phillip Bay

To monitor long-term trends on phytoplankton species and abundance, the EPA has collected monthly samples at eight sites since 2008 (figure WQ.7), as part of its marine fixed-sites sampling. The phytoplankton dataset encompasses changes in climate; capturing the last years of the millennium drought (2008–09), a wetter period (2010–11) and a return to dry conditions (figure WQ.8).

ANNUAL RAINFALL ANOMALY – VICTORIA (1900-2015)

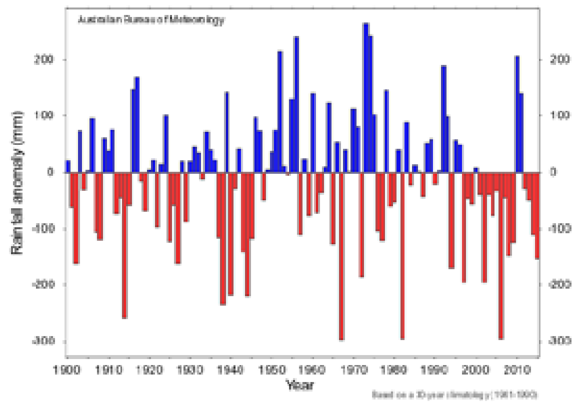

Figure WQ.8: Annual rainfall anomaly in Victoria

Source: Bureau of Meteorology.

The results in the section below investigate how this climatic variation has been expressed by the phytoplankton communities across the bay.

SPATIAL AND TEMPORAL PATTERNS

The highest number of total phytoplankton (9.9 million cells/L) was observed at the Hobsons Bay site in December 2009, and coincided with the break of the millennium drought and a 46 mm rainfall event on 22 November 2009. However, fewer than 10% of the samples collected over the 2008–16 period have total phytoplankton numbers exceeding 2 million cells/L – 1–2 million cells/L is considered a 'bloom'. A third of those samples were collected during the wetter years (figure WQ.9a) at sites close to freshwater inputs associated with nutrients, typically in the north of the bay. They were most frequent during the spring and summer months (figure WQ.9b) when temperature and light availability are optimal. The exception was the increased phytoplankton activity at the Corio Bay site observed in March and April.

NO. OF SAMPLES WITH TOTAL PHYTOPLANKTON > 2 MILLION CELLS/L (2008–2016)

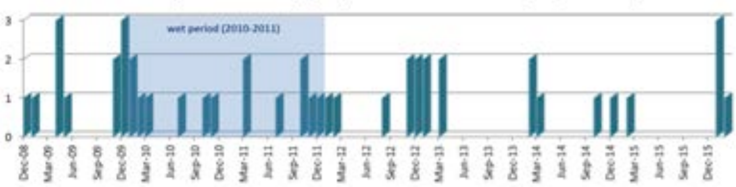

Figure WQ.9a: Number of samples with total phytoplankton exceeding 2 million cells/L

NO. OF SAMPLES WITH TOTAL PHYTOPLANKTON EXCEEDING 2M CELLS/L (2008–2016)

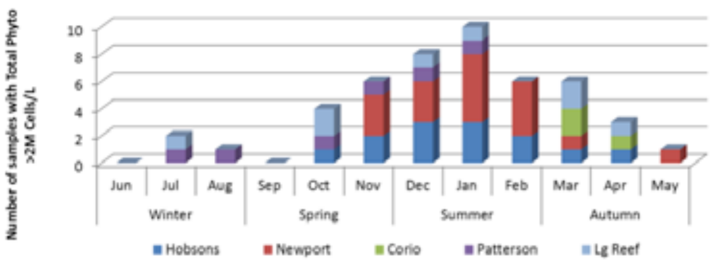

Figure WQ.9b: Number of samples with phytoplankton exceeding 2 million cells/L, by site

Almost all (96%) of those peaks in phytoplankton activity are attributable to increased levels of diatoms (figure WQ.10), which account for an average 85% of the phytoplankton community and most often corresponding to the diatoms *Skeletonema japonicum/pseudocostatum* (70% of the time).

RELATIVE ABUNDANCE OF DIATOMS & DINOFLAGELLATES AT HOBSONS BAY (2008–2016)

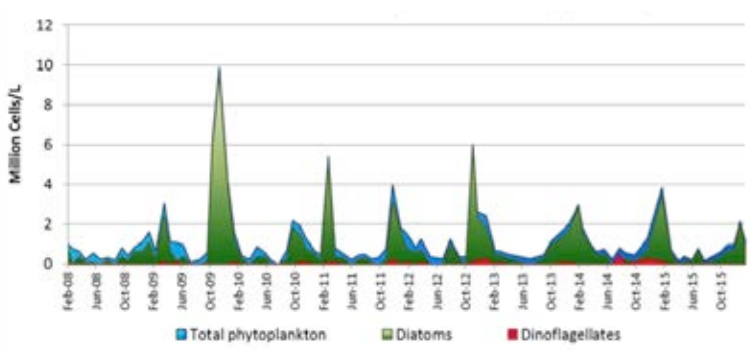

Figure WQ.10: Relative abundance of diatoms and dinoflagellates at Hobsons Bay

NUMBER OF EXCEEDENCES OF TOXIC PHYTOPLANKTON SPECIES (VSOM ACTION LEVELS)

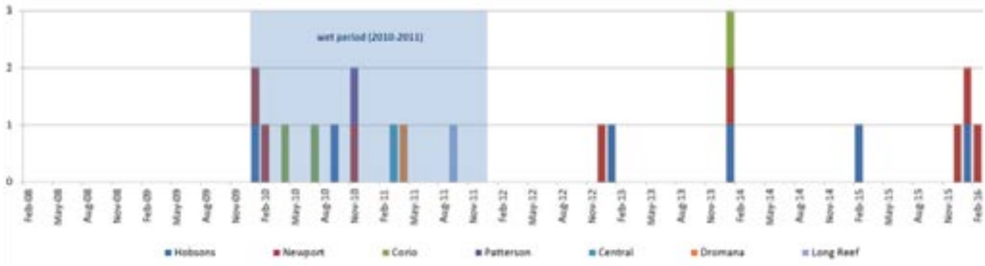

Figure WQ.11a: Exceedances of the VSOM action level (2008–2016)

An exception was observed at the Newport site in January 2009, where cryptophytes accounted for 45% of the phytoplankton community, with *Plagioselmis sp.* and *Hemiselmis sp.* respectively contributing to 21% and 19% of the total phytoplankton numbers.

By contrast, assemblages in the south of the bay (for example, Pope's Eye) are generally more diverse. 'Other' flagellates (all species other than diatoms and dinoflagellates) regularly exceed the number of diatoms and on average account for 45% of the phytoplankton community.

Some phytoplankton species produce toxins that can harm marine biota and human health, by consuming tainted shellfish. The Victorian Shellfish Operations Manual (VSOM) defines action levels for potentially toxic species. Between 2008 and 2016, action levels were exceeded on 21 occasions, 11 of which occurred during the wet period (figure WQ.11a). Similar to the pattern for total phytoplankton numbers, most episodes occurred in the north of the bay (66% between the Newport and Hobsons Bay sites, figure WQ.11b), and during spring (62%). Most episodes corresponded with elevated levels of the diatom *Pseudo-nitzschia spp.* (figure WQ.11c).

EXCEEDENCES OF THE VSOM ACTION LEVELS PER SITE (2008–16)

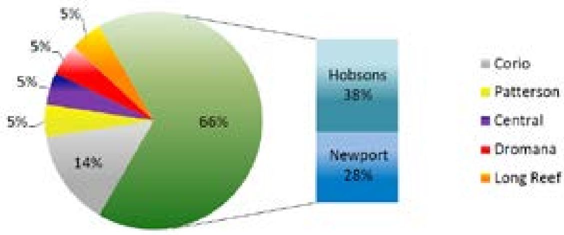

Figure WQ.11b: Exceedances of the VSOM action level per site

Species listed on the VSOM	Number of exceedences (2008–2016)
Pseudo-nitzschia spp	13
Gymnodinium catenatum	5
Dinophysis acuminata	3
Alexandrium catenella	1
Rhizosolenia amaralis (=cf. chunii)	0
Alexandrium tamarense	0
Alexandrium minutum	0
Dinophysis caudata	0
Dinophysis fortii	0
Prorocentrum lima	0
Karenia mikimotoi	0

Figure WQ.11c: Number of exceedances of the VSOM action levels per species (2008–16)

An alert about each exceedance since December 2013 has appeared on the Yarra and Bay website.

Understanding links between water quality and seagrass health in Port Phillip Bay

A recently completed three-year research program on seagrass resilience has improved our understanding of the relationship between water quality and important ecosystems in Port Phillip Bay.[4] The seagrass resilience program focused on the relationship between the dominant seagrass in Port Phillip Bay, *Zostera nigricaulis*, and its physical environment, particularly sediments and nutrients, to better understand how seagrasses recover following loss.

*Zostera nigricauli*s occurs around the margin of the bay, from the shallow subtidal zone to depths of up to 8 m. It provides crucial ecosystem services such as stabilising sediments, improving water quality, reducing coastal erosion, increasing biological productivity for the marine food chain and providing nursery habitats for key recreational and commercial fish species. Like all plants, *Zostera* requires sufficient available light, nutrients and substrate to grow, persist and recover from losses caused by disturbances to its environment.

Port Phillip Bay is generally a nutrient-poor environment and seagrasses obtain nutrients in various forms of nitrogen and from a range of sources. Dissolved nitrogen enters the bay from the catchment and the Western Treatment Plant (WTP), and can be recycled through plankton growth and decay processes. It also occurs in groundwater beneath the sediments of the bay, and can even be fixed from nitrogen in the atmosphere.

At bay-wide scales, seagrass distribution is determined by exposure to waves and depth/light availability. Wave exposure excludes seagrasses from colonising wave-exposed coastlines, while the depth that seagrasses can live at in Port Phillip Bay is determined by the availability of light for photosynthesis.

MODELLED WAVE CONDITIONS

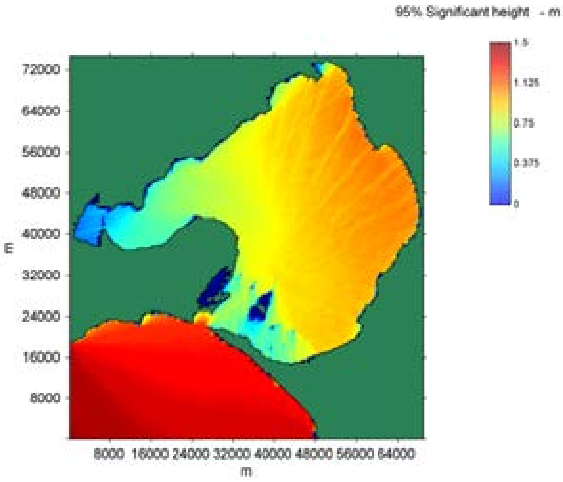

Figure WQ.12: Modelled wave conditions, July 2009 to July 2011

Note: The black outline indicates seagrass distribution.

In Port Phillip Bay, the largest expanses of seagrass meadows are located in regions protected from the prevailing westerly winds and subsequent waves, such as Swan Bay, Corio Bay and the western section of the Geelong Arm. By contrast, eastern Port Phillip Bay, which experiences the highest wave heights and longest fetch, has little seagrass (figure WQ.12).

Within Port Phillip Bay, regional areas experience varying patterns of presence and absence of seagrass and patterns of loss and recovery over time. These patterns are influenced by nutrients, turbidity (affecting light clarity) and sediment movement. The seagrass resilience program identified three broad regions of *Zostera* habitat in Port Phillip Bay, and the differences between these areas had important links to water quality:

- Areas of *Zostera* with relatively stable cover over time ('persistent' seagrass beds) such as Swan Bay and Corio Bay (SB and CB in figure WQ.13a). These areas are relatively isolated from the catchment, and are protected from current and wave exposure (figure WQ.12). These seagrasses live in fine, muddy sediments, and most of their nutrients come from internal breakdown and recycling of detritus and fixation of atmospheric nitrogen.

SEAGRASS REGIONS AND SITES

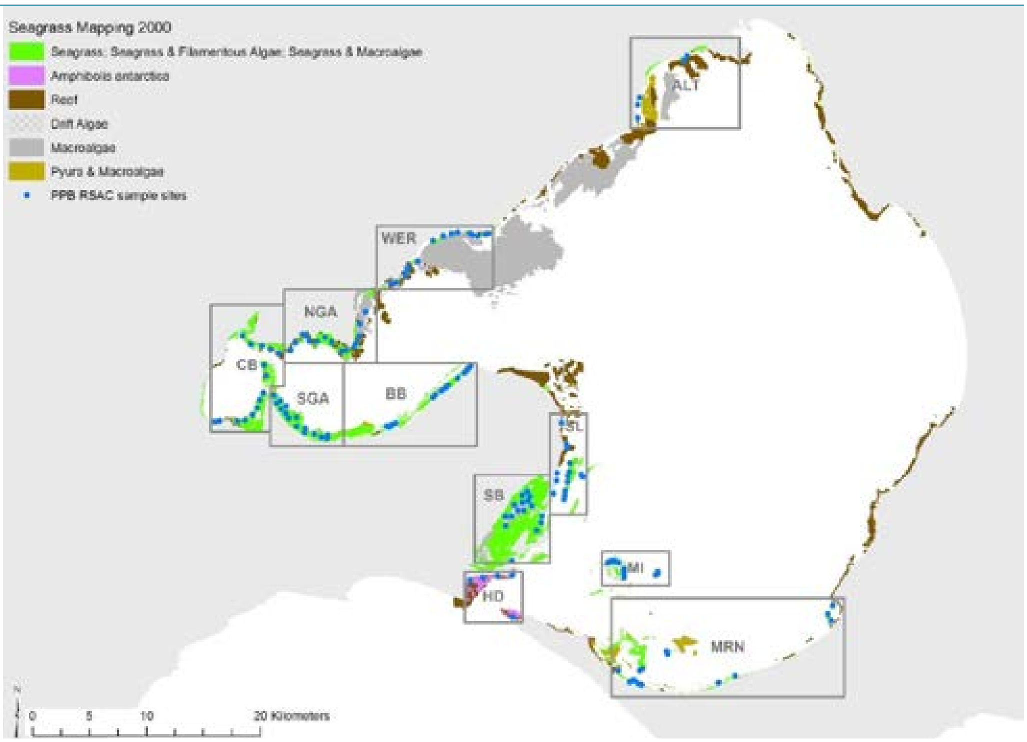

Figure WQ.13a: Seagrass regions and sites sampled in seagrass resilience program

Note: ALT: Altona, WER: Werribee, NGA: North Geelong Arm, CB: Corio Bay, SGA: South Geelong Arm, BB: Bellarine Bank SL: St Leonards, SB: Swan Bay, HD: PPB Heads, MI: Mud Islands, and MRN: Mornington Peninsula.

- Seagrasses experiencing major increases and declines since the middle of last century ('ephemeral' seagrass beds), particularly the Bellarine Bank and the southern areas of the bay (BB and MRN in figure WQ.13a). These seagrass beds occur in more exposed parts of the bay (figure WQ.12), are nutrient limited, and experience sediments moved by currents and waves. Major losses of *Zostera* occurred in these areas during the Millennium drought when catchment inputs of nutrients were low. These areas may have also changed in response to climatic shifts during the drought, affecting seagrass distribution.
- Another distinct category of ephemeral seagrass habitat occurs along the north west coast of the bay (WER figure WQ.13a) where nutrients are derived from the WTP and are unlikely to be limiting. However, the combination of fine sediments and wave exposure means turbidity is often relatively high, reducing light availability and limiting seagrass growth.

The distinct areas of *Zostera* habitat respond differently to changes in water quality parameters such as nutrients and sediments. 'Persistent' beds are largely unaffected by changes to catchment and other inputs, and sediment transport processes, and so are relatively stable. By contrast, 'ephemeral' beds are quite sensitive to changes in catchment nutrient inputs and sediment transport processes and are relatively unstable. They are expected to show significant cycles of loss and recovery over time. Researchers combined results from several projects to develop a broad conceptual model for seagrass regrowth in Port Phillip Bay (figure WQ.14).

CLIFTON SPRINGS SEAGRASS MODEL

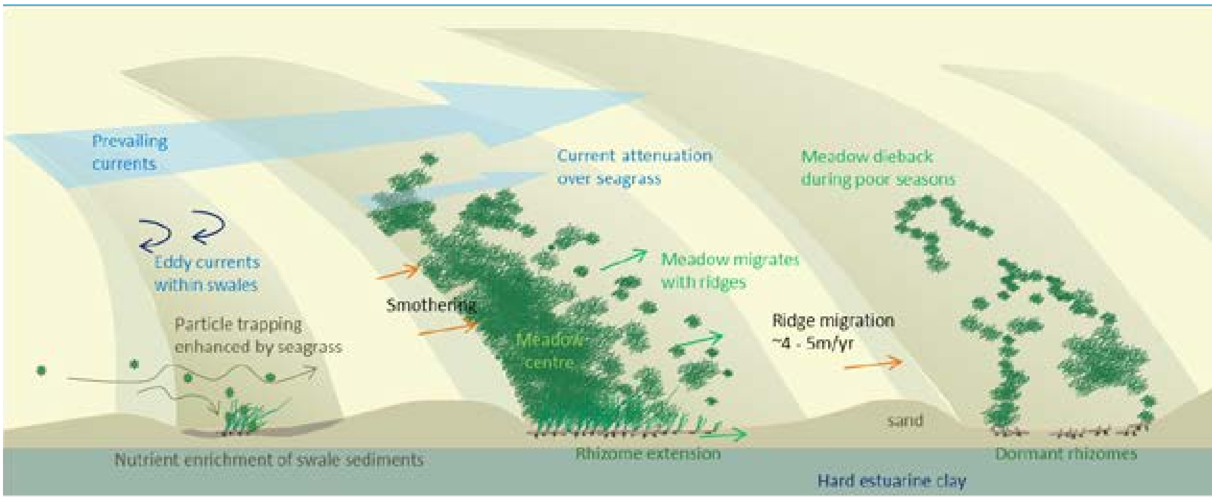

Figure WQ.14: Conceptual model of seagrass growth relative to sand bar movement on the Bellarine Bank

Identifying seagrass regions helps bay managers develop future management actions. Regions with 'ephemeral' seagrasses provide a useful ecosystem metric because they show the greatest sensitivity to shifts in sediment dynamics and fluctuations in remote nutrient sources. In the bay's north west, changes in seagrass abundance will reflect changes in nutrient sources and resuspended silts that reduce light clarity and compromise seagrass health. Therefore, changes to the WTP or new coastal infrastructure should consider how this may affect light and in turn, the health of seagrass beds in this area.

Large patches of seagrass in the Geelong Arm mitigate wave energy that erodes the coast of the Bellarine Bank. Shifts in wave climate or new coastal structures (such as breakwaters and marinas) that alter wave behaviour risk seagrass health by altering sediment patterns in these areas. Genetically isolated seagrass beds are vulnerable to disturbances in their environment. They are not well-connected to other habitats and they lack seed banks, which lead to poor recovery rates. Genotypes may need to be artificially introduced to improve their future resilience.

The Victorian Marine Operational Model – VIC-MOM

In 2013–14, the EPA and CSIRO Coastal and Environmental Modelling Team developed and implemented an operational modelling system – the Victorian Marine Operational Model (VIC-MOM). VIC-MOM predicts the dispersal of marine pollution and ship ballast discharges across Victorian marine waters. Bay managers use this modelling to control contamination and biosecurity threats to and from marine conservation assets, aquaculture and fisheries, shipping and ports, oil and gas facilities, and coastal discharges such as sewage treatment plants.

Designed to provide a timely response to reports of unapproved spills and discharges, the model was recently tested and produced results within 20 minutes for a simulated exercise. The system was designed to improve the EPA's response capability, but free online access and ease of operation means other government and industry participants, as well as coastal and marine environment researchers can use the system. The online user interface (Connie2) is available at: http://www.csiro.au/connie2/?loc=VIC

A broad range of applications include:

- rapidly assessing pollution reports from the community
- assessing risk for new coastal activities or developments
- tracing sources of contaminant such as unauthorised discharges (figure WQ.15a)
- investigating and responding to pollutant spills and unauthorised de-ballasting of ships
- assessing the risk of pest expansion via viable larvae dispersion from infested locations (figure WQ.15b).

BACKTRACKING BEACHED MATERIAL

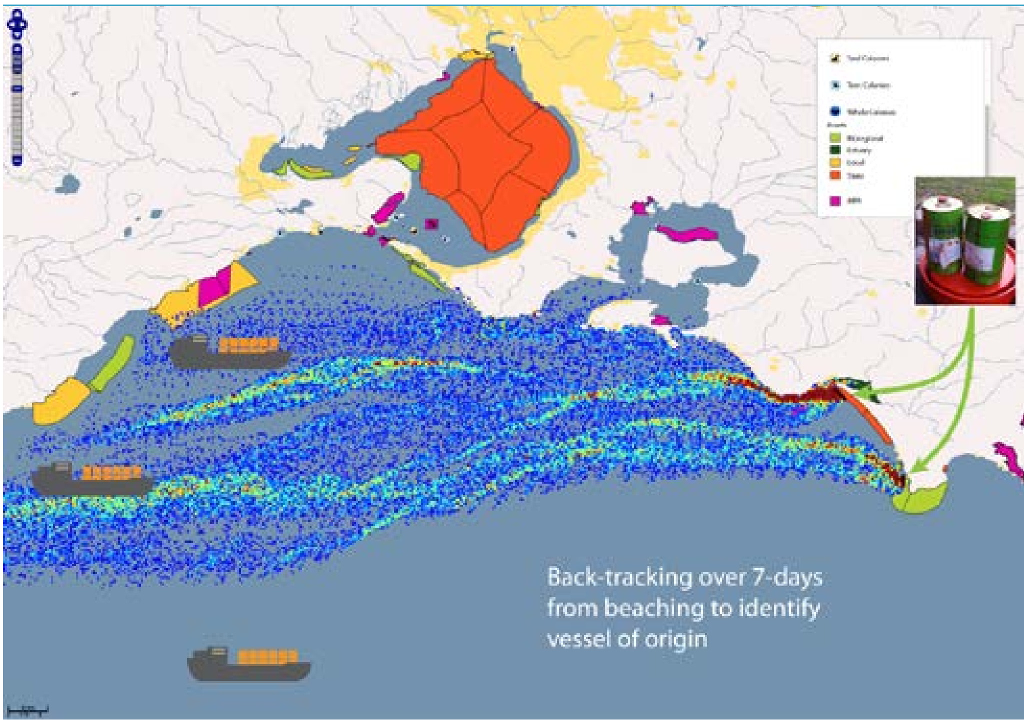

Figure WQ.15a: Example of backtracking beached material to a source

PORT PHILLIP BAY – ASTERIA LARVAE

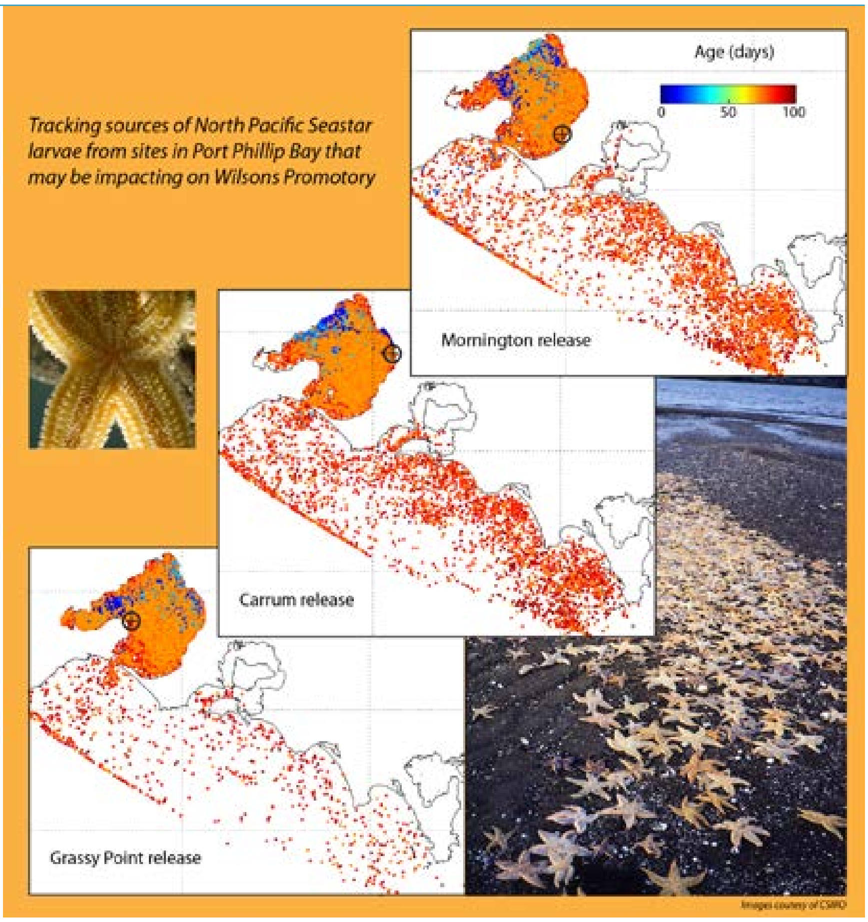

Figure WQ.15b: Example of Asteria larvae from Port Phillip Bay

Water quality: references

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Environment Protection Authority Victoria 2003, ***State Environment Protection Policy (Waters of Victoria)***, publication no. 905, EPA Victoria, Carlton.

Environment Protection Authority Victoria 2011, ***Port Phillip And Western Port receiving water quality modelling: Lagrangian dispersal***, A water quality improvement plan for Port Phillip Bay and Western Port and their catchments, A report developed for the Better Bays and Waterways Program, publication no. 1378, EPA Victoria, Carlton.

Jenkins GP, Keough MJ, Ball D, Cook PLM, Ferguson A, Gay J, Hirst A, Lee R, Longmore AR, Macreadie P, Nayar S, Sherman ,C, Smith T, Ross DJ and York P 2015, ***Seagrass resilience in Port Phillip Bay***, Final report to the Seagrass and Reefs Program for Port Phillip Bay, University of Melbourne, Melbourne.

Spooner D, Walker T, Acevedo S and Morris E 2011, ***Port Phillip Bay environmental data review: Marine biophysical assessment of climate change***, Fisheries Victoria internal report no. 27, Department of Primary Industries, Queenscliff, Victoria.

Water quality: endnotes

1 The 2001 F8 schedule of the State Environment Protection Policy (Waters of Victoria) (SEPP WOV) outlines specific water quality objectives for Western Port, while the 1997 schedule F6 of the SEPP WOV outlines the specific objectives for Port Phillip Bay.

2 Turbidity measures suspended particulate matter, which can also include algae and zooplankton. Indeed, excessive phytoplankton growth due to excess nutrients is a major cause of increased turbidity. Low turbidity due to excessive phytoplankton may explain changes in seagrass extent in the west of Port Phillip Bay.

3 Environment Protection Authority Victoria 2011, ***Port Phillip And Western Port receiving water quality modelling: Lagrangian dispersal***, A water quality improvement plan for Port Phillip Bay and Western Port and their catchments, A report developed for the Better Bays and Waterways Program, publication no. 1378, EPA Victoria, Carlton; Spooner D, Walker T, Acevedo S and Morris E 2011, ***Port Phillip Bay environmental data review: Marine biophysical assessment of climate change***, Fisheries Victoria internal report no. 27, Department of Primary Industries, Queenscliff, Victoria.

4 Jenkins GP, Keough MJ, Ball D, Cook PLM, Ferguson A, Gay J, Hirst A, Lee R, Longmore AR, Macreadie P, Nayar S, Sherman ,C, Smith T, Ross DJ and York P 2015, ***Seagrass resilience in Port Phillip Bay***, Final report to the Seagrass and Reefs Program for Port Phillip Bay, University of Melbourne, Melbourne.

Avicennia marina
Mangroves

HABITATS AND THEIR DEPENDENT SPECIES

INTERTIDAL HABITATS AND DEPENDENT SPECIES

Seagrass, mangroves and saltmarsh bury carbon at a rate 35–57 times faster than tropical rainforests and can store carbon for thousands of years. Recent global data estimate vegetated coastal habitats contribute 50% of carbon burial in the oceans – a function called 'blue carbon'.

About 40% of the Western Port area is intertidal mudflats. Extensive intertidal flats are important foraging grounds for shorebirds. Several hundred species of infaunal and epifaunal organisms have been recorded, including a high diversity of ghost shrimps, brachiopods that are 'living fossils', rare rhodoliths, and other species listed as endangered.

Mangroves are not a major component of intertidal vegetation in Port Phillip Bay compared with Western Port. It is not known how much mangrove was present when Europeans settled, but researchers estimated it would have been comparable with the 6 ha present in 2011.

Saltmarsh restoration has occurred in some areas of Western Port – particularly around the northern and western shores of the bay. However, concerns over declining saltmarsh extent remain. Erosion is a problem on the eastern shoreline. Although loss of saltmarsh to mangrove habitat in Western Port is low (5–10% of saltmarsh area) compared with the mean figure of 30% across south east Australia – it remains a challenge for bay managers.

Planning for sea level rise should include designating land for wetland migration to offset the mangrove encroachment.

Compared with its state before European settlement, Port Phillip Bay retained about 50% of its saltmarsh extent. During the same period, Western Port retained 90–95% of its mangrove habitat, and 90–95% of its saltmarsh extent.

The largest potential for soil carbon loss is through a decline in seagrass habitat.

Introduction

This chapter explores the critical intertidal habitats of Port Phillip Bay and Western Port.

Intertidal vegetation comprises three broad community types: seagrass, which occupies the lower intertidal zone and tolerates long periods of immersion between tidal cycles; mangroves, which occupy the mid-intertidal zone and are subject to daily inundation and drainage; and saltmarsh, which tends to occupy the area between the mangrove zone and the upper tidal limit, and is inundated during the spring tidal cycles. The non-vegetated intertidal zone is predominantly comprised of rocky reefs and soft sediments.

The intertidal zone provides important ecosystem services including filtration, roosting habitats, fish nurseries and erosion protection. Intertidal habitats are often found adjacent to human settlement, so not only are they our marine environment's most visible assets – but also our most vulnerable, exposed to development pressures.

Recent studies reveal considerable information about the extent of mangrove, and the extent and condition of saltmarsh, in both bays (figure I.1).

Compared with its state before European settlement, Port Phillip Bay retained about 50% of its saltmarsh extent. During the same period, Western Port retained 90–95% of its mangrove habitat, and 90–95% of its saltmarsh extent.[1]

Research into the condition of saltmarsh revealed that, although the saltmarshes are floristically diverse and healthy, these ecosystems face some critical challenges. Time series data (2000–16) demonstrated sea level rise is affecting mangrove encroachment (shading out saltmarsh) and expanding saltmarsh pools in the north of Western Port (which fragment saltmarsh). The invasive pest *Spartina* (cordgrass) is another threat.[2]

The soft sediments are a key knowledge gap in our understanding of intertidal habitats – particularly given their predominance in Western Port. This report includes a Port Phillip Bay study on foraging shorebirds as a substitute indicator for the health of invertebrate species in exposed sediments. It serves as a preliminary study, and emphasises the need for a more comprehensive research program for soft sediments.

PORT PHILLIP BAY SALTMARSH, MANGROVE & MUDFLAT LOCATION

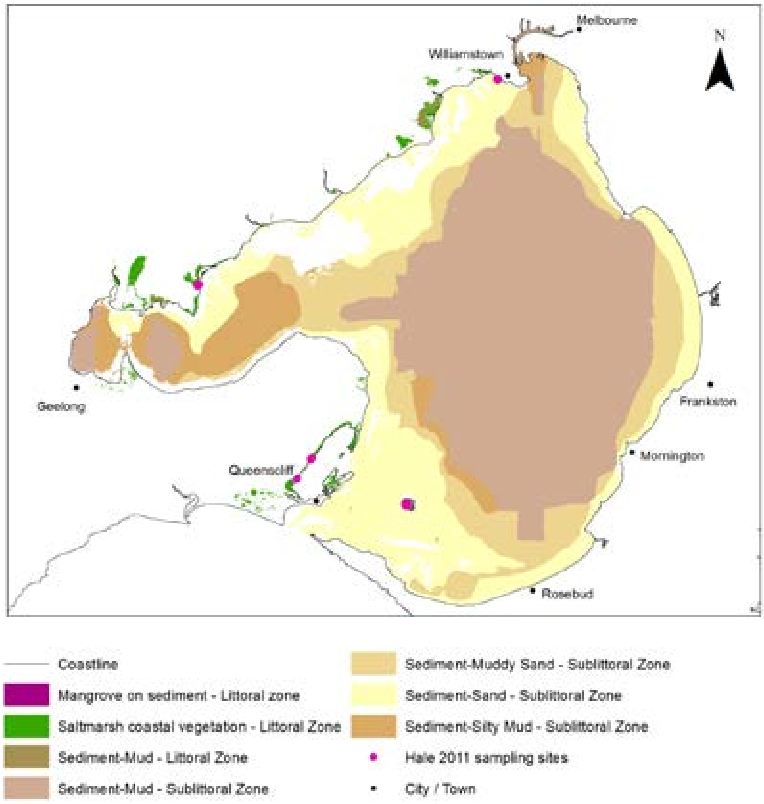

Figure I.1: Location of saltmarsh, mangrove, mudflat in Port Phillip Bay by CBICS and Hale (2011)

This chapter also includes a vignette on the critical role that seagrass, mangroves and saltmarsh perform as carbon sinks. This vegetation buries carbon at a rate 35–57[3] times faster than tropical rainforests and can store carbon for thousands of years. Recent global data estimated vegetated coastal habitats contribute 50% of carbon burial in the oceans – a function called 'blue carbon'.[4]

The chapter includes consideration of knowledge gaps for intertidal research for Port Phillip Bay and Western Port. Importantly, maintaining and building on the 2011 baseline map for intertidal habitats is recommended to help bay managers understand trends and manage the intertidal zone. A better understanding of the impacts of climate change and sea level rise (particularly erosion) is critical, as well as the link between sediment delivery, surface elevation and the consequences for intertidal habitats.

Seagrass and rocky reefs are also important intertidal habitats in the bays, and are considered in the **Seagrass and dependent species** and **Reef habitats and dependent species** chapters respectively. Similarly, the **Marine-dependent birds** chapter includes a more extensive review of bird data, beyond foraging shorebirds in Port Phillip Bay.

INDICATORS ASSESSMENT: INTERTIDAL HABITATS AND DEPENDENT SPECIES

Legend

Status

Unknown
Data is insufficient to make an assessment of status and trends.

Poor
Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/human health, OR inadequate protection of natural ecosystems and biodiversity.

Fair
Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/human health, OR moderate protection of natural ecosystems and biodiversity.

Good
Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear | ↘ Deteriorating | → Stable | ↗ Improving

Data quality

Poor
Evidence and consensus too low to make an assessment

Fair
Limited evidence or limited consensus

Good
Adequate high-quality evidence and high level of consensus

	Summary	Status and trends
Indicator Saltmarsh and mangrove extent **Region** Port Phillip Bay **Measures** (i) Extent of saltmarsh-mangrove communities (embayment scale) (ii) Extent of saltmarsh communities (Port Phillip Bay selected sites) **Metric** (i) Change in extent (ha) of saltmarsh and mangrove using aerial remote sensing (ii) Change in extent (ha) of saltmarsh and mudflats **Thresholds** (i) Departure or retention in relation to modelled extent at 1750 (ii) Departure or retention in relation to recent historic data **Data custodian** DELWP	Before European settlement, Port Phillip Bay had an estimated 3,710 ha of saltmarsh; by 2011 about 50% (1,767 ha) of its saltmarsh extent remained. Mangroves are not a major component of intertidal vegetation in Port Phillip Bay compared with Western Port. It is not known how much mangrove was present when Europeans settled, but researchers estimated it would have been comparable with the 6 ha present in 2011.[5]	UNKNOWN / POOR / FAIR / GOOD Status: Fair; Trend: Stable (→) DATA QUALITY Good

	Summary	Status and trends
Indicator Saltmarsh condition **Region** Port Phillip Bay **Measures** (i) Species richness, projected foliage cover of saltmarsh species and canopy condition (ii) Proportion of benchmark species, weeds and disturbance categories within each ecological vegetation class (EVC) (habitat hectares) **Metric** (i) Number and relative abundance of species (% cover) and cover estimates in relation to bare ground (ii) Habitat hectare condition scores **Thresholds** (i) Departure or retention in relation to recent historic data (ii) Departure or retention of benchmark species and relative disturbance **Data custodian** DELWP	Saltmarsh health was monitored annually at four sites in Port Phillip Bay between 2008 and 2011. Measures included surveys of saltmarsh community boundaries, species composition, and cover and condition of saltmarsh. Monitoring found no detectable change outside expected variability in saltmarsh health. Increased exotic species, changes in community composition, a reduction in canopy cover and a corresponding increase in bare sediment can indicate a decline in saltmarsh condition. Increased rainfall in late 2010 and early 2011 led to localised ponding of water, with lower areas of the saltmarsh covered in pools of water and extensive algal growth, particularly at the Jawbone site. The increased rainfall also affected salinity with the freshwater inflows to the bay from the catchment reducing salinity bay-wide. The health of shrubby glasswort at Mud Islands declined in 2010, when a newly established ibis rookery killed over 80% of the plants. The site experienced a partial recovery in 2011.[6]	UNKNOWN POOR FAIR GOOD DATA QUALITY Fair Historically good but currently no ongoing monitoring.

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Saltmarsh and mangrove extent **Region** Western Port **Measures** (i) Extent of saltmarsh-mangrove communities (embayment scale) (ii) Extent of saltmarsh-mangrove communities (Western Port selected sites) **Metric** (i) Change in extent (ha) of saltmarsh and mangrove using aerial remote sensing (ii) Change in extent (ha) of saltmarsh and mangrove **Thresholds** (i) Departure or retention in relation to modelled extent at 1750 (ii) Departure or retention in relation to recent historical data (1939–99) **Data custodian** DELWP / Macquarie University, NSW and University of Wollongong, NSW	Compared with its state before European settlement in the mid-nineteenth century, Western Port retained 90–95% of its mangrove habitat (1,230 ha remains from approximately 1,320 ha), and 90–95% of its saltmarsh extent (1,287 ha remains from approximately 1,460 ha).[7] Vegetation mapping demonstrated saltmarsh extent declined by approximately 20% and mangrove increased by 56% at Rhyll over a 60-year period. In addition to the impact of mangrove encroachment and subsequent saltmarsh displacement along tidal creeks, significant portions of saltmarsh were removed for agriculture. Saltmarsh has been restored in some areas, particularly around the northern and western shores of the bay (e.g. near Tooradin airport). However, concerns over declining saltmarsh extent remain. Erosion is a problem on the eastern shoreline where recent change is evident. Although loss of saltmarsh to mangrove habitat in Western Port is low (5–10% of saltmarsh area) compared with the mean figure of 30% across south east Australia, it remains a challenge for bay managers.[8]	Saltmarsh: Fair (declining) Mangrove: Good (stable) DATA QUALITY (BOTH SALTMARSH AND MANGROVE) Good
Indicator Saltmarsh condition **Region** Western Port **Measures** Surface elevation and sediment accretion **Metric** Sediment height at SETs compared with feldspar marker horizons; and tidal elevation recording **Thresholds** Departure in rate from historical Pb-dating baseline set by Rogers et al. 2005 **Data custodian** Macquarie University, NSW and University of Wollongong, NSW	Saltmarsh in Western Port is generally in good condition. The saltmarshes are floristically diverse and healthy, but there are threats to their resilience. Current rates of sedimentation in saltmarsh are consistent with long-term trends over the past century. However, sedimentation in saltmarsh in Western Port is not translating into surface elevation gain. Given sea level rise, this increases the time that water covers saltmarsh, which facilitates mangrove encroachment. A considerable time series (1950–2016) demonstrated the effect of sea level rise on mangrove encroachment (shading out saltmarsh) at several sites within Western Port including Rhyll, Koo Wee Rup, French Island and Quail Island. Rising sea levels threaten the sediment equilibrium in saltmarsh.[9]	Fair (stable) DATA QUALITY Fair

Indicator

Status of foraging shore birds

Region

Port Phillip Bay

Measures

(i) Number of individuals (counts) of migratory and resident species at intertidal habitat where they forage

(ii) Biomass of edible invertebrates at shorebird foraging sites

(iii) Extent and topography of intertidal habitat at selected shorebird foraging sites

Metric

(i) No of individuals at low tide

(ii) Dry mass per m^2

(iii) Extent in m^2 of habitat and relative elevation height and emersion time of this habitat in relation to the low tidal range

Thresholds

Internationally agreed thresholds on numbers apply to the shorebird significant site network.

Data custodian

Arthur Rylah Institute/Birdlife Australia

Summary

Foraging shorebirds (red-necked stint, curlew sandpiper and sharp-tailed sandpiper) are in decline but this trend is consistent with larger scales. The reduction in sharp-tailed sandpiper numbers reflects the species relocating inland after the drought.

A resident shorebird – the pied oyster catcher – is increasing in numbers.

Key threats to foraging shorebirds include changes to tidal flats (e.g. reduced exposure due to sea level rise) and seagrass – both less seagrass extent and increased density of seagrass (which hinders foraging) can affect shorebirds. Land use change in flyways also significantly affects migratory birds.[10]

Status and trends

UNKNOWN POOR FAIR GOOD

DATA QUALITY

Good

Intertidal habitats and dependent species: knowledge gaps

To protect the critical intertidal habitats of Port Phillip Bay and Western Port, further studies are recommended to understand the habitats and the ecosystem services they provide.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

MAINTAIN REGULAR MAPPING DISCIPLINE OF SALTMARSH AND MANGROVE

Ongoing monitoring requires periodic mapping of saltmarsh and mangrove communities, to update the benchmark mapping of EVCs conducted by Boon (2011).[11] This mapping represents a finer scale of floristic community classification than that used by Hale (2011),[12] and links to a broad range of policy and legislative drivers.

The mapping could be supplemented by continuing two components of the existing on-ground monitoring:

1. fixed vegetation plots in mangrove and saltmarsh, potentially extended to the saltmarsh-*Melaleuca* boundary, and
2. ongoing sedimentation/erosion tables (SETs) monitoring of sedimentation and surface elevation gain, coupled with water level recorders in the mangrove and saltmarsh.

Mapping and remote sensing will help bay managers to understand the extent of pest invasion, and other threats to intertidal habitats, and identify the early indications of those threats.[13]

IMPROVE OUR KNOWLEDGE OF THE IMPACT OF SEA LEVEL RISE (AND OTHER CONSEQUENCES OF CLIMATE CHANGE) ON SALTMARSH AND MANGROVES

It is important to understand the ways tidal inundation affects waterlogging and salinity regimes in saltmarshes – including invasion by mangrove, and the expansion of saltmarsh pools (the best early indicator of saltmarsh fragmentation). In particular, it is critical to understand how these regimes affect the saltmarsh plant communities that provide food and habitat for terrestrial and aquatic animals.[14]

Also recommended is a continued analysis of the link between rising sea levels and mangrove encroachment on, and shading of, saltmarsh. Improved modelling of the impact of climate change on mangroves is also important. Mangroves are resilient to gradual sea level rise – benefitting from the increased nutrients and sediments; but rapid sea level rise would have a detrimental impact on mangroves, killing communities and probably causing seagrass beds to expand into what were previously mangrove habitats.

The susceptibility or resilience of saltmarshes to other threats such as nutrient enrichment, oil pollution, weed invasion (such as *Spartina*), and altered salinity and hydrological regimes are also an important research gap.

UNDERSTAND EROSION PATTERNS IN THE BAYS

Erosion is an immediate problem for saltmarsh on the eastern shoreline of Western Port, where recent change is evident. Continuing the erosion studies on the eastern shore would allow assessment of the contribution of eroded shoreline to sedimentation in intertidal environments elsewhere in the bay. Measuring the feldspar marker horizons (vertical sediment accretion) in the wetlands will test the hypothesis that inter-annual variability in erosion and sedimentation within the bay are linked.

Potential research might include:

1. comparing the timing of erosion and sedimentation events at appropriate timescales
2. geochemical typing of the sediment source, if possible.

Often, more erosion occurs in saltmarsh communities when mangroves are not present. Mangroves can help saltmarsh, by preventing erosion; but mangroves also compete with saltmarsh for sunlight and can shade saltmarsh.

Erosion is complex and different erosion types have different effects. More understanding is required of the role of elevation, erosion, sediment provenance (the original source of sediments being deposited), sedimentation rates, and the impacts of storm surges in intertidal habitats in the bays, as sea level rise impacts these ecosystems.

ASSESS SOFT SEDIMENTS AND SEDIMENT DELIVERY

The bays are home to rare biotopes that have not been found outside of Port Phillip Bay and Western Port. Monitoring these biotopes is critical.

Most of the research on soft sediments in Western Port is 35–45 years old, so a survey to compare the current biodiversity with past records and adjacent bays is recommended. Researchers could also use this information to assess various disturbances and invasive species.

Other research priorities include:

- understanding the functional roles of benthic organisms and how they contribute to the productivity, sediment dynamics and nutrient fluxes in Western Port[15]
- exploring the sediment delivery to mangrove and saltmarsh that supports these habitats. Sourcing the sediment contributing to surface elevation will help prevent perverse management outcomes associated with sediment trapping in the catchment, and shoreline stabilisation where sediment transport is a natural process required by intertidal wetlands. Geochemical tracing techniques may be useful for this task.
- examining the impact of elevated nutrients on vegetation structure and consequent ecosystem services, including root structure, elevation gain, shoreline protection and ecosystem structure. Manipulative experiments introducing higher levels of nutrient within a monitoring program would provide important insights.[16]

UNDERSTAND WATERBIRDS USE OF INTERTIDAL HABITATS

Further studies to understand how birds (and bats) use the intertidal habitats are recommended. An estimated 30–40 species of birds inhabit the intertidal habitats of Port Phillip Bay and Western Port. These species are distributed across the habitats – some are attracted to the exposed soft sediments, others to the fresh water inputs or the open saltmarsh (like the endangered orange-bellied parrot), and others to the ponding water, both fresh and salt.

Mapping the extent of soft sediments is important for foraging shorebirds in particular. This task could be done periodically using LiDAR (light imaging, detection and ranging). This exercise is critical in Port Phillip Bay (where the tidal range is less than a metre) and in the narrow tidal flats (which are particularly susceptible to sea level rise).

Examining how upgrades at the Western Treatment Plant (WTP) have affected several species of threatened shorebirds is also recommended. In particular, numbers of eastern curlew, ruddy turnstone and several other species have fallen at the WTP.

ASSESS FORAGING SHOREBIRD TRENDS

Using shorebirds as an indicator of local intertidal health is problematic when global populations are falling. Researchers must track shorebird trends in a broad region (for example, multiple sites in Victoria or in south east Australia), and then compare specifically managed local sites with the broader trends to understand if shorebirds at the WTP (for example) are doing better, worse, or about the same as shorebirds in other sites in the same region.

The Arthur Rylah Institute (DELWP) and Birdlife Australia are comparing the sites of foraging shorebirds across the state.[17] This is important work but citizen science initiatives of this size require coordinating very large numbers of volunteers to be successful.

Intertidal habitats: the science stocktake

INTERTIDAL HABITATS ABOVE THE MEAN SEA LEVEL: MANGROVES AND SALTMARSH

Mangrove and saltmarsh are foundational habitats in Western Port and Port Phillip Bay, providing important ecological values and services associated with fisheries, migratory bird habitat and shoreline protection. Intertidal vegetation provides important ecological functions at the interface of coastal lands and marine waters. The vegetation filters ground and stormwater before it reaches the estuarine waterways and reduces bank erosion, for example. It also provides roosting habitat for migratory wading birds (and for rare species such as the orange-bellied parrot), and serves as nursery grounds for juvenile fish.[18]

The key long-term threat to mangrove and saltmarsh is the effect of sea level rise on plant tolerance and distribution; and other consequences of climate change, especially rising air and water temperatures. Linked to this threat is the influence of changes to sediment and nutrient delivery. Other threats include the introduced saltmarsh *Spartina* and converting saltmarsh to other land uses, mostly agriculture and industry, around the western and northern shores of Western Port.

Melbourne Water and Parks Victoria actively manage *Spartina* in the Bass estuary and the inlets, implementing a 10-year management plan to eradicate the species from Western Port. The management plan includes monitoring distribution change as well as the health of saltmarshes.

The **How the bays work** and **Threats** sections discusses the pressures affecting intertidal habitats in more detail.

MANGROVES

Mangroves are salt-tolerant trees that grow in the intertidal region of sheltered embayments and estuaries. Only one species, *Avicennia marina*, occurs in Victoria; nearby Corner Inlet supports the southernmost extent of this species in the world. Mangroves are a sink for terrigenous sediment inputs, which helps them act as an erosion buffer, water quality filter and carbon sequester. Further, mangroves dampen waves and currents, which can reduce coastal erosion. Mangroves also function as a microhabitat for benthos, and shelter juvenile fish.[19]

Mangroves are not a major component of intertidal vegetation in Port Phillip Bay compared with Western Port. Mangroves line most of the shore of Western Port and are represented in the three marine national parks. The bay has experienced some loss of mangroves since European settlement, especially near Hastings. Localised destruction, and disturbances and changes in the bay's sediment budget have reduced mangrove distribution, for example. Habitat loss and fragmentation are serious threats to mangroves, and landward retreats are needed to prevent the loss of mangroves as the sea level rises.

SALTMARSH

Port Phillip Bay and Western Port support a diverse saltmarsh flora, particularly herbs and low shrubs such as *Halosarcia, Juncus, Sporobolus* and *Sarcocornia*. The relative abundance and area occupied is determined by the nature of the coastal land and shoreline topography, geology, tidal cycles, and dynamic processes such as sedimentation and water runoff.

Saltmarshes occur around much of the coast of Western Port, generally between the mangrove fringe on the seaward side, with more terrestrial vegetation (such as swamp paperbarks and manna gum woodlands) on the landward side. A number of the larger saltmarshes in Western Port occur in protected areas, such as the Yaringa (980 ha), French Island (2,800 ha) and Churchill Island (670 ha) marine national parks.[20]

MANGROVES AND SALTMARSH IN PORT PHILLIP BAY

The Victorian Saltmarsh Study (2011)[21] conducted a comprehensive mapping and classification study, using a suite of historical information to document the change in the extent of intertidal vegetation since European settlement in Victoria. The study produced spatial information products depicting change in extent from 1750 compared with 2008 and new EVCs.

The study estimated Port Phillip Bay now retains only approximately 50% of its historical saltmarsh area (3,710 ha reduced to 1,767 ha by 2011). It is not known how much mangrove was present at the time of European settlement, but the study estimated it would have been comparable to the 6 ha present in 2011.[22] It also recommends an assessment method and species-specific indicators to assess condition of each intertidal EVC.

Similarly, Hale[23] conducted a time series monitoring program of saltmarsh habitats in Ramsar-designated areas, as part of the bay-wide monitoring program related to the Channel Deepening Project (2008–11). This program assessed saltmarsh extent, saltmarsh health and intertidal mudflat extent at the following sites in Port Phillip Bay (figure I.1):

- Jawbone Marine Reserve
- The Spit Conservation and Nature Reserve
- Swan Bay
- Mud Islands.

Monitoring found no detectable change outside expected variability in saltmarsh extent or health and mudflat extent from 2008 to 2010.

The key changes in saltmarsh condition for Port Phillip Bay between 2008 and 2011 can be summarised as follows:

- No increase in exotic species or significant change in species composition
- A decline in the health of shrubby glasswort at Jawbone Marine Reserve and The Spit in 2011, that may be linked to the ponding of freshwater at these sites following heavy rains in late 2010 and early 2011
- A notable decline in the health of shrubby glasswort at Mud Islands in 2010, due to the establishment of an ibis rookery, which killed over 80% of the plants. This was followed by a partial recovery in 2011 at this site.[24]

In addition, increased rainfall in late 2010 and early 2011 led to localised ponding of water, with lower areas of the saltmarsh covered in pools of water and extensive algal growth, particularly at the Jawbone site. The increased rainfall also reduced salinity throughout the bay; indeed salinity in the bay was less than that in Bass Strait in December 2010 for the first time since 2006. This increased inundation and lower salinity may have affected the health of saltmarsh plants, but this remains a knowledge gap.

MANGROVES AND SALTMARSH IN WESTERN PORT

The geomorphology of Western Port provides a large number of different habitat types within a relatively confined area. These habitats range from reefs typical of the open coasts in the south west of the bay to sheltered mangroves and mudflats in the north. The large tidal range, particularly in the north, produces extensive intertidal habitats.

Western Port has more extensive mangrove habitats than Port Phillip Bay. Ross and more recently Dittman and Boon reviewed mangroves and saltmarshes for Western Port.[25]

The Victorian Saltmarsh Study (2011)[26] estimated Western Port retained approximately 90–95% of its original mangrove extent (1,230ha remains from approximately 1,320ha) since European settlement.[27] Similarly, it has retained 90–95% of its original saltmarsh extent (1,287 ha remains from approximately 1,460 ha) over the same period.[28]

Saltmarsh reclamation has occurred in some areas – particularly around the northern and western shores of the bay (such as near Tooradin airport). However, concerns over declining saltmarsh extent remain. Loss of saltmarsh to mangrove habitat in Western Port is low (5–10% of saltmarsh area) compared with the mean figure of 30% across south east Australia, but it remains a challenge for bay managers.[29]

To understand the effect of human development on saltmarsh, the Department of Environment, Land, Water and Planning (DELWP) has been collecting data on extent, mangrove-saltmarsh vegetation structure, and changes in rates of sedimentation and surface elevation since 2000.[30] By comparing 'impact' sites (sites in Rhyll and Koo Wee Rup where human development was expected to affect wetlands) and 'control' sites (remote sites on French Island, Quail Island), the department found land use activities caused increased sedimentation, compaction and freshwater run-off. These effects in turn facilitated mangrove encroachment into saltmarsh communities.

WESTERN PORT MANGROVE & SALTMARSH VEGETATION

Site	Vegetation Type	Vegetation Express 1959	1967	1973	1999	Precinct Change
Koo Wee Rup	Mangrove	11.32		14.40	18.13	60.09
	Salt marsh	41.57		31.96	23.02	-44.61
Rhyll	Mangrove	40.04		57.86	62.28	55.54
	Salt marsh	174.27		153.72	139.83	-19.76
Quail Island	Mangrove			73.84	97.47	32.00
	Salt marsh			157.52	138.71	-11.94
French Island	Mangrove		185.16	17.32	189.23	2.20
	Salt marsh		518.65	510.92	490.63	-5.40

Figure I.2: Change in area (ha) of mangrove and saltmarsh vegetation at four study sites in Western Port between 1939 and 1999[31]

Vegetation mapping found evidence of mangrove encroachment at Rhyll over a 60-year period – saltmarsh extent fell by approximately 20% and mangrove increased by 56% (figure I.2). In addition, significant portions of saltmarsh were reclaimed for agricultural land.[32]

The department also analysed rates of sedimentation accretion, erosion and subsidence calculated from SETs (figure I.3). This information monitors how mangrove and saltmarsh respond to changes in sea level: new sediment accretion and root system development offsets the compaction of soft sediment, potentially allowing the wetland to maintain or increase elevation as the water level changes.

WESTERN PORT MANGROVE & SALTMARSH ELEVATION

			Period 1		Period 2 *		Period 3 *	
Site	Zone	Measurement	October 2000 to November 2001		November 2001 to November 2002		November 2002 to November 2003	
French Island	Mangrove	Elevation	6.69	(1.80)	-13.98	(2.06)	1.15	(1.92)
		Accretion	16.75	(2.65)	12.08	(0.99)	9.49	(2.69)
	Salt marsh	Elevation	8.79	(1.04)	5.10	(1.19)	1.73	(1.14)
		Accretion	4.39	(0.37)	4.01	(0.43)	4.37	(0.51)
Koo Wee Rup	Mangrove	Elevation	15.65	(2.30)	-9.62	(3.21)	-6.76	(2.19)
		Accretion	11.62	(0.92)	10.41	(0.48)	7.20	(0.85)
	Salt marsh	Elevation	-0.28	(1.12)	-2.80	(1.03)	2.24	(1.42)
		Accretion	1.87	(0.36)	1.51	(0.26)	2.03	(0.32)
Quail Island	Mangrove	Elevation	-5.70	(3.38)	-4.92	(1.59)	4.77	(2.23)
		Accretion	9.48	(2.14)	6.92	(1.93)	6.77	(0.79)
	Salt marsh	Elevation	4.43	(4.68)	-1.93	(1.06)	-0.64	(1.07)
		Accretion	3.52	(0.23)	2.18	(0.50)	2.35	(0.96)
Rhyll	Mangrove	Elevation	2.78	(1.61)	-6.69	(1.98)	8.44	(3.15)
		Accretion	8.79	(1.63)	7.58	(2.65)	5.10	(0.72)
	Salt marsh	Elevation	1.02	(1.14)	-0.25	(0.95)	1.08	(0.57)
		Accretion	1.94	(0.27)	1.41	(0.41)	1.59	(0.19)

Figure I.3: Mean (±SE) rates of surface elevation change (mm) and sediment accretion (mm) in the mangrove and saltmarsh zones in Western Port

* At Quail Island only Period 2 extends from November 2001 to January 2003 and Period 3 from January 2003 to November 2003.[33]

Trajectories of sediment accretion and surface elevation change in the mangrove and saltmarsh of Rhyll, Koo Wee Rup, Quaill Island and French Island are high, compared with similar sites elsewhere in the research network. This higher rate of sedimentation is attributed to the greater tidal range, reactivating sediments deposited as subtidal mudbanks. However, the relatively high sedimentation rate does not translate directly into surface elevation gain, with one exception. Aside from the saltmarsh at French Island, elevation gain is low in mangrove and negligible in saltmarsh, and lagging well behind the regional sea level trend.[34]

Those saltmarsh sites not gaining elevation as sea levels rise are more likely to be colonised by mangrove. This result is the prevailing situation across south east Australia, including Western Port. It is facilitated by local factors, including drought-related subsidence, and local alterations to drainage.[35]

Current rates of sedimentation in saltmarsh are consistent with long-term trends over the past century estimated from radiometric dating of sediment cores from the same locations. However, sedimentation in saltmarsh in Western Port is not translating into surface elevation gain (sedimentation is simply offsetting upper level subsidence/auto-compaction). Given eustatic (global) sea level rise, this increases time saltmarsh is covered in water, which in turn facilitates mangrove encroachment.

Based on this evidence, Saintilan et. al predicted continued sea level rise will lead to the:
(a) further invasion of saltmarsh by mangrove;
(b) dieback of fringing *Melaleuca* at the seaward edge of the terrestrial zone; and (c) dieback of saltmarsh leading to the expansion of saltmarsh pools (fragmentation).[36]

More recent research on the impact of projected sea level rise incorporated sedimentation and other surface elevation drivers.[37] This research suggests the survival of saltmarsh in developed estuaries will depend on managing hard structures (such as roads and levees) and other impediments to wetland retreat. Based on this assessment, planning for sea level rise should include designating land for wetland migration to offset the mangrove encroachment.[38]

Mapping ocean wealth: valuing the economic, social and environmental benefits of Victoria's most important marine habitats[39]

NATURE'S WEALTH

The economic language of 'dollars and jobs' provides a common language and currency that all can comprehend which has been a gap in communicating economic, social and environmental benefits. In the past, the benefit of protecting or restoring nature has been communicated in terms of 'biodiversity' and 'species', which many find difficult to understand or value. As a result, nature often comes off second best, despite the wealth of economic, social and cultural benefits it provides.

Translating nature's benefits into a common language that engineers, policy makers and managers understand can transform how all Victorians think about and value nature.

VALUING THE MARINE HABITATS OF PORT PHILLIP BAY AND WESTERN PORT

Mapping Ocean Wealth combines some of Victoria's best marine researchers and practitioners from Deakin University, the Victorian Government, recreational fishers and conservation groups to quantify and communicate the benefits provided by important marine habitats such as saltmarshes, mangroves and seagrasses.

The ecosystem services provided by these habitats include:

Coastal protection

Saltmarshes and mangroves can reduce the impact of ocean swell, wind, and storm surge by up to 66% across 100 m and their structure can stabilise shorelines, to prevent erosion.[40]

Carbon storage

To examine the carbon storage potential of Port Phillip Bay and Western Port, researchers from Deakin University took sediment cores in saltmarshes, mangroves and seagrasses and then calculated a dollar value per hectare across blue carbon habitats. These results were then applied to blue carbon habitats across Port Phillip Bay and Western Port. Cool and warm colours denote low and high carbon values respectively, spanning a range from $1,000 to > $8,001 per ha.

Fish production

Researchers compared published fish biomass values of commercially important fish species in seagrass areas with similar unvegetated habitats to calculate annual production value.[41] These values were then mapped across known seagrass extent in Port Phillip Bay and Western Port.

Intertidal habitats below the mean sea level: sediments and foraging birds

Soft sediments comprise the most extensive environment in Western Port. The most recent survey found 525.5 km^2 (77%) of Western Port marine environment is unvegetated soft sediments.[42] Since the 1970s, the extent of bare sediments has been increasing at the expense of seagrass beds, which declined by 70% between 1973 and 1984, although some seagrass recovered up to 2009.[43]

The tidal divide north-east of French Island – which has extensive intertidal mudflats – is internationally significant.[44] About 40% of the Western Port area is intertidal mudflats.[45] Extensive intertidal flats are important foraging grounds for shorebirds. Several hundred species of infaunal and epifaunal organisms have been recorded, including a high diversity of ghost shrimps *(Thalassinidea)*, brachiopods (similar to shellfish, they are considered 'living fossils'), rare rhodoliths (red algae), and other species listed as endangered.[46]

Despite the significance of the intertidal mudflats, most of the research on soft sediments in Western Port is 35–45 years old, and requires updating. In many instances, soft (mobile) sediment habitats are newly created (in the past 50–100 years) so their faunal assemblages and relative importance to the system must be assessed in context.

In the absence of more recent comprehensive data, we use two recent studies to inform our knowledge of soft sediments in the bays. The first considers sediment inputs into Western Port and the role of bank erosion, as part of a series of studies to clarify the distribution and dynamics of sediments once they are in the bay. The second explores the role of foraging shorebirds in Port Phillip Bay to understand some of the dynamics of the soft sediments of that bay.

QUANTIFYING SEDIMENT INPUTS INTO WESTERN PORT[47]

The CSIRO, in collaboration with Melbourne Water, has been quantifying the sediment inputs into Western Port since the early 2000s. The work has become even more important following the outcomes from a project led by Monash University[48] on the effects of water quality variables on seagrass abundance and distribution in the bay. The Monash project showed suspended sediments (not nutrients) were the key factor leading to seagrass stress and decline. The sediments inhibit photosynthesis by reducing light penetration in the water column and smothering the plant leaf area.

Early results from CSIRO (from 2001–03) provided useful, albeit indirect, measures of erosion and pointed to significant sediment inputs from two sources: the tributary streams, and erosion of an 8 km stretch of alluvial banks that form the coastline near Lang Lang. The CSIRO is conducting further work to quantify the sediment supply and transport rates from the tributary streams.

Between the 1860s and the 1930s, human disturbance in many of the tributaries is well documented, including channelling, dredging, draining the Koo Wee Rup swamp, and straightening and constructing levees. Significant flood events and subsequent erosion during this time exacerbated the problem, releasing vast quantities of sediments into Western Port. This could be seen as prominent deltas formed on the tidal flats where the tributaries debouched into the bay.[49]

Undoubtedly, the historical channel erosion was a major source of sediment into the bay and may also have caused rapid sedimentation that occurred post-1950 in the area east of Corinella. It may have also been a key driver of the observed decline in seagrass distribution in the bay in the 1970s and 1980s.[50] However, it is also likely that more recent rates of sediment delivery are much less than the historical rates because of sediment exhaustion in the tributary catchments.

Hopefully, the CSIRO tributary study will shed more light on these assertions.

THE BANK EROSION STUDY

The bank erosion study aimed to determine the present rates, processes and spatial distribution of coastal bank erosion in Western Port, set in context with historical records and observations. The study targeted the erosion hot spot at Lang Lang (Jam Jerrup). The monitoring site consisted of a small bay and headlands, reflecting the typical morphology of the Lang Lang coastline.

The study found the average (or gross) bank erosion rates measured over 12 months were 2.6 cm each month or 0.31 m each year, which was consistent with the long-term average derived from the aerial photographs of 0.42 m each year over 65 years. This equated to a sediment input into the bay of 233,000 m^2 over 65 years or an average sediment yield of 4.2 kilotonnes (kt) each year, and an estimated overall sediment input of 270 kt since 1947. There was significant spatial and temporal variability in erosion, with maximum bank erosion rates potentially equalling or exceeding 1 m in some years, and sediment yields potentially being more than double.[51]

The main controls on erosion rates were:

1. sediment characteristics
2. orientation of the coastline relative to the dominant wind-wave directions and the direction of longest fetch (the length of water over which a given wind has blown)
3. high frequency inundation through the tidal cycle, and
4. seasonal wind patterns with winds predominantly from a westwards direction.

Sediment characteristics determine the resistance of the banks to erosion, while the other three controls determine wave energy and the magnitude of wave power on the bank surface.

The Lang Lang site showed strong cohesion and a strong resistance to erosion. Interestingly, erosion of the banks was by parallel retreat through the physical processes of abrasion and quarrying (plucking) of sediment from the bank surface by wave action. Bioturbation (holes and tunnels) also appeared to enhance sediment detachment.

The data also suggested wetting and drying of the bank surface over the tidal cycle could be important. Indeed, seasonal variability in erosion rates were strongly correlated with the seasonal variation in evaporation recorded at a nearby Bureau of Meteorology weather station, even more so than the modelled wave power. Greater evaporation in the summer months must be leading to greater desiccation (cracking) of the bank surface, which enhances the abrasion and quarrying processes.

The CSIRO's current work uses remote sensing to reconstruct an historical record of turbidity in the bay since at least 1987. Another project is modelling seagrass to examine sediment transport and resuspension in seagrass beds. Both projects will help to clarify the distribution and dynamics of sediments once they are in the bay and will complement the work on sediment sources.

FORAGING SHOREBIRDS IN PORT PHILLIP BAY

The relationships between numbers of shorebirds and benthic invertebrates are complex. Indeed, shorebird numbers at particular tidal foraging sites depend on the total number of shorebirds in the whole WTP (partly a product of events elsewhere in the flyway), the exposure of those flats at any one time (or the mean exposure over a longer period) and the abundance of benthic invertebrates on those flats.

The health of benthos is difficult, expensive and time-intensive to monitor, but significant positive relationships have been found between local foraging abundance of shorebirds and the density of benthic invertebrates. So the abundance of foraging shorebirds is used as a reasonable substitute for the health of invertebrates in the soft sediments.

The WTP is a very large sewage treatment works on the north western shoreline of Port Phillip Bay between Werribee and Point Wilson, which treats some 55% of Melbourne's sewage. The nutrient rich water discharged to the bay supports the high level of infauna productivity, which in turn supports the high populations of intertidal shorebirds.[52] These shorebirds include migratory species that breed in northern Asia and are subject to international agreements to protect migratory birds and their habitats. They are among the principal biological assets that contributed to the site being listed as a wetland of international significance under the Ramsar Convention. Melbourne Water manages the WTP and has obligations to protect shorebird habitat under legislation including the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Shorebirds use a range of habitats at and near the WTP, especially the tidal flats along 11 km of coast from the Werribee River to The Spit Nature Reserve (managed by Parks Victoria). Shorebirds also forage and roost on shallow non-tidal wetlands in and near the WTP. However, the tidal flats appear to be the main foraging habitat for the most numerous shorebird species, all of which are migrants that nest in Arctic Siberia or Alaska. The shorebirds feed on benthic invertebrates in the tidal flats, and high densities of benthic invertebrates have been attributed to nutrient enrichment from the WTP.

Several studies monitor the response of shorebird species and attempt to understand their ecology, to manage and mitigate any changes to the environment.[53] This research focused on the tidal flats and the three most numerous migratory shorebird species that forage on them: red-necked stint, curlew sandpiper and sharp-tailed sandpiper.

Shorebirds at the WTP exhibit strong seasonal patterns in occupancy (winter to summer), while overall numbers are influenced by annual rainfall patterns and/or factors elsewhere in the East Asian-Australasian Flyway. Individual species also vary due to a combination of climatic trends and factors within the flyway. For example, occupancy of some species declines in Port Phillip Bay when water is plentiful in inland Australia.[54] At a local scale, the biomass of invertebrates (food) and tidal properties (availability) determine foraging habitat selectivity by shorebirds.

None of these species showed a stronger decline at the WTP during the 2000s than at other Victorian sites:

- Red-necked stint numbers declined at the WTP during the 2000s, but no more so than at other Victorian sites.
- Curlew sandpiper numbers also fell during the decade as part of a global decline in this species. Numbers of both species at the WTP were positively correlated with numbers at other Victorian sites.
- Sharp-tailed sandpipers were influenced by availability of water inland, and hardly any visited the WTP in the summer of 2011 after the 12-year drought broke. In other years, they showed a weak tendency to be more numerous at the WTP in years when they were scarce at other Victorian sites.

Several species of threatened shorebirds also use the WTP site (in low numbers because they are threatened) and it is unclear how the upgrades at the WTP have affected these species. Species such as eastern curlew *(Numenius madagascariensis)* are very vulnerable and numbers have declined at the WTP, for example. While the decline there is similar to other sites, a site-specific cause is possible. The decline in nutrients (or some geomorphological process changing average particle size of sediments in the WTP intertidal area, especially at The Spit) may have triggered a change from large polychaete worms to other taxa, which could affect this large species of migratory shorebird. Ruddy turnstone *(Arenaria interpres)* and several other species have also declined at the WTP. The reasons have not been investigated.

Studies of benthic invertebrates revealed some striking changes over this short period of time, with a large decline in worms and a corresponding increase in crustaceans (mainly amphipods) in the middle of the decade. This is likely to affect some shorebird species.

The WTP also conducted several infauna studies, as well as carbon and nitrogen isotope studies, which link the productivity of the intertidal zone to the carbon and nitrogen from the WTP discharge. Within periods of low tidal range, tide height strongly influenced the numbers of birds foraging on tidal flats. The proportion was highest on the lowest spring tides (<0.20 m), and lower on tides of 0.35–0.5m, even though some tidal flats were still exposed. The studies identified key areas, where shorebirds could forage at high tidal levels. These areas could be crucial for conserving shorebirds during neap tides[55] when many areas of tidal flat can remain inundated and inaccessible to shorebirds for days at a time. Nontidal wetlands on the WTP may perform a similar function.

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54 This is important when interpreting any data. If the particular indicator changes (in either direction), how can we be confident that the change is related to events occurring within the bay (or area) being studied? This concern is particularly important for bird species affected by land-use changes along flyways, which are likely to impose a long-term declining trend, and it may be very difficult to separate these effects from any locally driven ones. See Knowledge gaps in this chapter for further discussion.

55 A tide immediately following the first or third quarters of the moon when there is least difference between high and low water.

Phlyctenactis tuberculosa
Swimming anemone

HABITATS AND THEIR DEPENDENT SPECIES

SEAGRASS AND DEPENDENT SPECIES

During the last major drought (1997–2009), Port Phillip Bay lost considerable areas of seagrass, including over 90% of seagrass extent along the Bellarine Bank.

Unlike seaweeds, seagrasses obtain most of their nutrients from the sediments they grow in and have extensive root systems that help stabilise coastal sediments and reduce erosion, trap sediments (hence improving water quality) and sequester nutrients and carbon in the sediments.

A loss of seagrass or reduction in seagrass condition at different depth ranges may affect different fish species differently. Shallow seagrass is particularly important for King George whiting.

Zostera seagrass habitat was the most critical for fish biodiversity in Western Port, maintaining fish biodiversity in Western Port relies on significant areas of *Zostera*, particularly in the intertidal, shallow subtidal zones.

The seagrass meadows in Port Phillip Bay can be divided into three broad categories: persistent, ephemeral (nutrient-limited) and ephemeral (light-limited). Persistent seagrass beds are relatively stable over time; ephemeral beds are much more variable and have shown major increases and declines over the last half century.

In Western Port, seagrass declined in the mid-1970s to 1984, then increased in the mid-1990s to 1999. The main driving factor affecting seagrass in Western Port is water quality, particularly dynamic factors such as suspended sediments that reduce light. Nutrient levels and availability are also important.

Seagrasses act as ecosystem engineers, dramatically influencing biodiversity and ecosystem function. Seagrass meadows provide the majority of important habitat within the bays because their three-dimensional structure protects juvenile fish from predators and seagrass plants support algae and invertebrates that are an important food source.

Introduction

Seagrasses are an important part of many coastal systems. But human activities threaten seagrass meadows in many areas, via habitat loss and reductions to water quality.[1]

Seagrasses are closely related to land plants and share many of their attributes. As a consequence, seagrasses are typically restricted to shallow coastal waters where there is ample light to support growth, and sandy/muddy bottoms where seagrass roots can acquire sufficient nutrients without being up-rooted and washed away by waves and currents.

Unlike seaweeds, seagrasses obtain most of their nutrients from the sediments they grow in and have extensive root systems that help stabilise coastal sediments and reduce erosion. In Port Phillip Bay, the largest expanses of seagrass are located in shallow (<4 m depth) waters protected from prevailing westerly winds.

PORT PHILLIP BAY SEAGRASS HABITATS

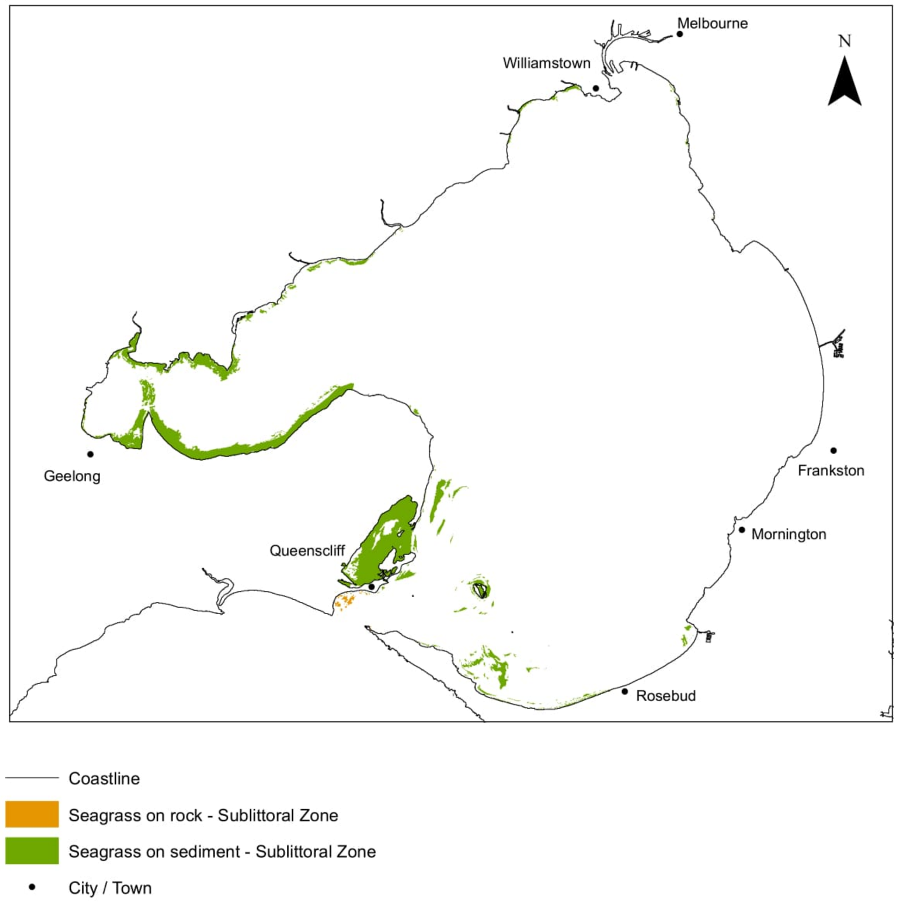

Figure S.1: Seagrass habitats in Port Phillip Bay

WESTERN PORT SEAGRASS HABITATS

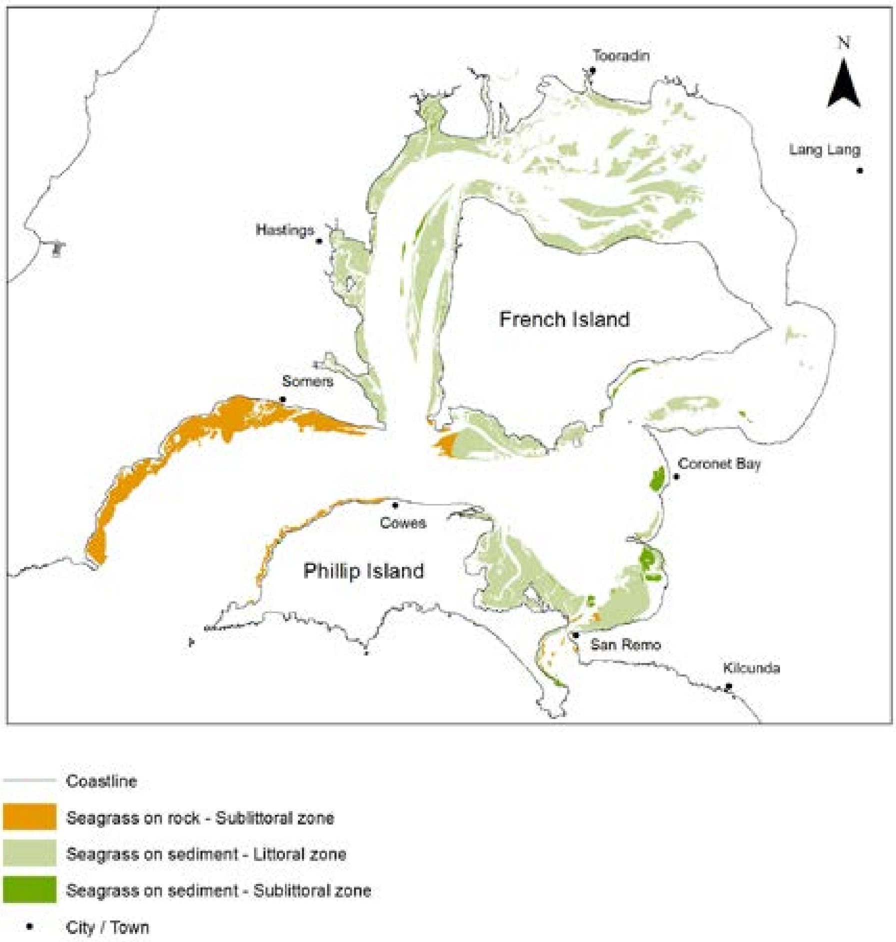

Figure S.2: Seagrass habitats in Western Port

Meadow forming seagrasses in Port Phillip Bay (figure S.1) and Western Port (figure S.2) are dominated by two species, long eelgrass *(Zostera nigricaulis)* and short eelgrass *(Zostera muelleri)*. A third species, wire weed or sea nymph *(Amphibolis antartica)*, is restricted to the more exposed regions of these bays.

Short eelgrass tends to occur in intertidal and very shallow subtidal habitats, whereas long eelgrass is almost exclusively subtidal (that is, always submerged regardless of the tides) growing to a maximum depth of 8 m within Port Phillip Bay. The small, ephemeral seagrass *Halophila* grows in deeper areas of the bay. It does not form dense beds and its importance is largely unknown, although it may be important in recolonising denuded seagrass habitats in other parts of the world.

Zostera seagrasses also act as ecosystem engineers, dramatically influencing biodiversity and ecosystem function. *Zostera nigricaulis* meadows provide the majority of important habitat within these bays. Their three-dimensional structure protects juvenile fish from predators and seagrass plants support algae (epiphytes) and invertebrates that in turn, provide food for higher trophic groups.

Seagrasses also stabilise coastal sediments, reduce erosion, trap sediments (hence improve water quality) and sequester nutrients and carbon in the sediments. Seagrass meadows (seagrass and algal epiphytes) also support many coastal food webs through high rates of primary productivity. Seagrasses take up nutrients above ground (through leaves) and below ground (through roots and rhizomes) and nutrients can move between these compartments. Seagrasses can also take up nutrients from the sediments indirectly through the bacterial breakdown of detritus that releases nutrients.[2]

This chapter considers recent critical analysis on seagrass habitats in Port Phillip Bay[3] and Western Port[4], including:

- recent and historical changes to seagrass extent
- the role of physical processes (nutrients, sediments, wave exposure and light) in explaining current, and historical changes to, seagrass distribution in each bay, and
- the ecological processes that contribute to recovering and maintaining connectivity.

The **Water quality** chapter also discusses water quality studies undertaken in the seagrass habitat at the Bellarine Bank.

The chapter includes a summary of key knowledge gaps for further research. Potential initiatives include:

- updating and maintaining mapping of seagrass meadows in the bays
- understanding the role of nutrients in seagrass habitats, and
- improving our knowledge of seagrass habitats along the Werribee coastline.

INDICATOR ASSESSMENT: SEAGRASS HABITATS AND DEPENDENT SPECIES

Legend

Status

Unknown Data is insufficient to make an assessment of status and trends.	**Poor** Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.	**Fair** Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.	**Good** Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear	↘ Deteriorating	→ Stable	↗ Improving

Data quality

Poor Evidence and consensus too low to make an assessment	**Fair** Limited evidence or limited consensus	**Good** Adequate high-quality evidence and high level of consensus

	Summary	Status and trends
Indicator Seagrass extent **Region** Port Phillip Bay **Measures** Area of seagrass that is identifiable using remotely sensed data **Metric** Change in extent and/or cover of seagrass (m^2) **Thresholds** Parks Victoria is developing control charts[5] **Data custodian** DELWP/Fisheries Victoria	During the last major drought (1997–2009), Port Phillip Bay lost considerable areas of seagrass, including over 90% of seagrass extent along the Bellarine Bank (figure S.3). There is insufficient information to measure the extent of recovery, if any, since the drought ended in 2010. The last data point is 2011.[6]	UNKNOWN / POOR / FAIR / GOOD: Fair (?) – Larger areas are stable. DATA QUALITY: Poor

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Seagrass condition **Region** Port Phillip Bay **Measures** Cover, stem/shoot density and length and epiphyte cover **Metric** Change in cover, density and epiphyte cover **Thresholds** Parks Victoria is developing control charts[7] **Data custodian** DELWP/ Fisheries Victoria	The condition of seagrass in Port Phillip Bay is good but based on only four years of data (2008–11). Condition health is spatially variable, and the data establish no overall trend. The study was too small to draw bay-wide conclusions.[8]	? DATA QUALITY Fair – good time series but short in duration
Indicator Seagrass dependent species (fish) **Region** Port Phillip Bay **Measures** Census of fish species and their biomass from seagrass beds at different depth ranges **Metric** Change and relative abundance, diversity and biomass of fish **Thresholds** Parks Victoria is developing control charts[9] **Data custodian** DELWP/Fisheries Victoria	Fisheries Victoria monitored fish species, biomass and diversity within seagrass beds from 2008–12. Biomass and species dominance varies with seagrass beds at different depth ranges,[10] and geographic location.[11] For example, large numbers of small schooling fish, such as atherinids, dominate in shallow seagrass but are not found in deep seagrass. The research concluded a loss of seagrass or reduction in seagrass condition at different depth ranges may affect different fish species differently. Shallow seagrass is particularly important for King George whiting. The data range is limited to only three sites in the southern area of Port Phillip Bay and has similar limitations to seagrass condition data (above). Most previous seagrass studies were limited to a depth of 3 m but the range of this data is as deep as 5–6 m.	DATA QUALITY Good – data is from 2011 and has limited geography and time series

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Seagrass extent **Region** Western Port **Measures** Area of seagrass that is identifiable using remotely sensed data **Metric** Change in extent and/or cover of seagrass (m^2) **Thresholds** Parks Victoria is developing control charts[12] **Data custodian** DELWP/Fisheries Victoria	Walker (2011) undertook a literature review on the status of seagrass in Western Port based on historic research projects. Seagrass declined in the mid-1970s to 1984, then increased in the mid-1990s to 1999. Most variability was observed in the *Zostera* dominated beds, while *Amphibolis antartica* beds remained relatively stable. The main driving factor affecting seagrass in Western Port is water quality; particularly dynamic factors leading to light reduction such as suspended sediments. Nutrient levels and availability are also important and interplay.	DATA QUALITY Fair – data is good but from 2011

Seagrass habitats and dependent species: knowledge gaps

To protect the critical seagrass habitats of Port Phillip Bay and Western Port, more research is required to understand the habitats and the ecosystem services they provide.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

UPDATE AND MAINTAIN SEAGRASS MAPS

The seagrass maps that support the evidence in this report were compiled over a four-year period (2008–11) and are now over five years old. There is no ongoing mapping of seagrass extent, or monitoring of seagrass condition, which is a critical knowledge gap in our understanding of the drivers of seagrass health in Port Phillip Bay and Western Port.

Updating and maintaining mapping of seagrass meadows in the bays (via ongoing monitoring) will help bay managers to understand changes to seagrass cover and implement an adaptive management cycle.

Jenkins et al. (2015) identified the following critical areas for managing seagrass in the bays, which could be prioritised for strategic, frequent mapping:

- Bellarine Bank (where 90% of seagrass was lost between 2000 and 2011)
- Werribee coastline
- Corio Bay and Point Henry
- Blairgowrie
- Mud Islands.

Mapping of other regions could occur less frequently.

Targeting mapping to address key management questions is recommended, such as what processes inhibit seagrass recovery and what actions can be taken to address these pressures. A robust mapping regime would increase the spatial cover and support ongoing small-scale sampling, which is necessary to understand epiphyte cover, density and grass lengths, etc. (see below).

The frequency of monitoring and mapping activity should allow researchers to identify natural cycles of seagrass loss and recovery, and unnatural changes due to human impact.

Technologies like NearMap (already being employed in Western Port seagrass research) could supplement mapping, by repurposing existing aerial photography for different objectives; and/or extending existing research partnerships such as the CSIRO landsat mapping of Western Port vegetation.

ADOPT TECHNOLOGICAL ADVANCES IN MONITORING SEAGRASS

Also recommended, is the continued small-scale sampling and monitoring to provide data that aerial photography cannot – epiphyte cover, density, grass lengths – and to confirm what is observed from the air. Further, aerial photography is less effective with monitoring change in subtidal seagrass, particularly in depth of more than 4 m and/or turbid conditions (for example, Yaringa). Aerial photography cannot always establish the correct ratios of macroalgae to seagrass.

New technology can improve seagrass monitoring (autonomous underwater vehicles, drones, 3D mosaic mapping), revolutionise how seagrass (and other habitats) are mapped, understood and managed, and be used to reclassify old data to provide better trend and historical data.

IMPROVE INTEGRATION OF RESEARCH

Critically, more coordinated field research to understand seagrass dynamics and their impacts on the ecosystem services of seagrass is required. Coordinated research requires comparable methods of analysis and undertaking studies that complement each other. Otherwise excellent research is sometimes undermined by a lack of integration with pre-existing sites and data. As a first step, academic institutions could collaborate more closely to overcome these inefficiencies.

Ecological projects investigating seagrass-dependent fish are not part of a regular time series, and are generally ad hoc. Jenkins et al. (2011) reviewed historic fish-related projects associated with seagrass. More examples of meta-analyses will foster a more integrated approach to seagrass research.[13]

UNDERSTAND THE ROLE OF NUTRIENTS IN SEAGRASS HABITATS (WESTERN PORT)

The role of nutrients as a driver of seagrass growth in Western Port is a knowledge gap. As discussed in this chapter, uncertainties surround the cause of the loss of seagrass in Western Port in the 1970s. It is unknown what role, if any, nutrients performed in the loss of seagrass or in its recovery.

An ARC Linkage Project (Monash University and University of Melbourne) is currently underway to understand the factors controlling seagrass distribution, options for recovery and the links between seagrass and nutrient cycling on tidal flats. This project is focusing on seagrass distribution, plume dynamics and turbidity, not nutrient cycling. But, it is the start of a more detailed understanding of seagrass meadows in Western Port.

IMPROVE OUR KNOWLEDGE OF SEAGRASS HABITATS ALONG THE WERRIBEE COASTLINE (PORT PHILLIP BAY)

The Werribee coastline, adjacent to inflows and the nutrients emitted by the Western Treatment Plant (WTP), requires further study to help us understand the causes of seagrass fluctuations on the Werribee coast and the pressures imposed on seagrass meadows by human development.

Research would examine the role of water quality and light in limiting seagrass growth along the Werribee coastline. The seagrass habitat in the Altona area (from the treatment plant to Avalon) is not as healthy as you would expect of a community with that much light, and at that depth. Possible causes include suspended sediment, fresh water, drift algae or epiphytes.[14] The area is very variable and it is critical we understand the link between the health of these seagrass beds and their immediate environment.

Seagrass habitats and dependent species: the science stocktake

SEAGRASS HABITATS AND DEPENDENT SPECIES IN PORT PHILLIP BAY[15]

Port Phillip Bay is not a uniform water body, but a large embayment with wide variation in physical processes – for example, ranging from strong tidal currents and coarse sands in southern parts, to complex, wind-driven circulation and fine sediments in the northern parts and up the Geelong Arm. Human activities also vary, with higher population density around the northern half, catchment inputs at a few places, and the major influence of the WTP on the western shore.

Seagrass in Port Phillip Bay is dominated by the eelgrass, *Zostera nigricaulis*, which occurs around the margin of the bay from the shallow subtidal zone to depths of up to 8 m (figure S.1). *Zostera* provides crucial ecosystem services such as stabilising sediments and improving water quality, reducing coastal erosion, increasing biological productivity via marine food webs, and providing nursery habitats for key recreational and commercial fish species. *Zostera muelleri* tends to be restricted to the intertidal zone or very shallow subtidal habitats.

The distribution of seagrass in Port Phillip Bay is principally constrained by the influence of two physical processes: wave exposure and light/depth.[16] The former excludes seagrasses from colonising wave-exposed coastlines, while the latter directly determines the depth profile of seagrasses via its influence on the availability of light at depth. The maximum *Zostera nigricaulis* depth in Port Phillip Bay, at about 8 m, broadly corresponds with the minimum light requirements for this species[17] at 10–20% of surface irradiance.[18]

In Port Phillip Bay, the largest expanses of seagrass are located in shallow (<4 m) waters protected from prevailing westerly winds (and hence waves) such as Swan Bay, Corio Bay and parts of the southern shore of the Geelong Arm and western shore of the Bellarine Peninsula (figure S.1).[19] By contrast, there is little seagrass on the eastern shore of Port Phillip Bay – the coastline most exposed to prevailing winds and waves.

Seagrass area is not constant in Port Phillip Bay and changes considerably in some regions. Mapping from aerial photography over at least 50 years shows the most extensive areas of seagrass are in the south western quadrant of Port Phillip Bay. Reconstructed historical trends using aerial photography[20] found reductions in seagrass area over the past 70 years matched dryer periods in Victoria's climate.[21] Seagrass area was lowest following the World War II drought in the 1940s and during the recent Millennium drought (1997–2009).

Given this result, Jenkins et al. (2015) suggested climatic variability may be important in controlling total seagrass area in Port Phillip Bay via its influence on the availability of nutrients to seagrasses. During the recent drought (1997–2009), the greatest seagrass losses occurred on the Bellarine Bank on the southern coast of the Geelong Arm and in the southern part of Port Phillip Bay (figure S.3). Findings[22] showed seagrass area was lost in regions of the bay most dependant on nitrogen from the catchment; this contribution declined significantly during the Millennium drought.[23]

PORT PHILLIP BAY SEAGRASS AREA

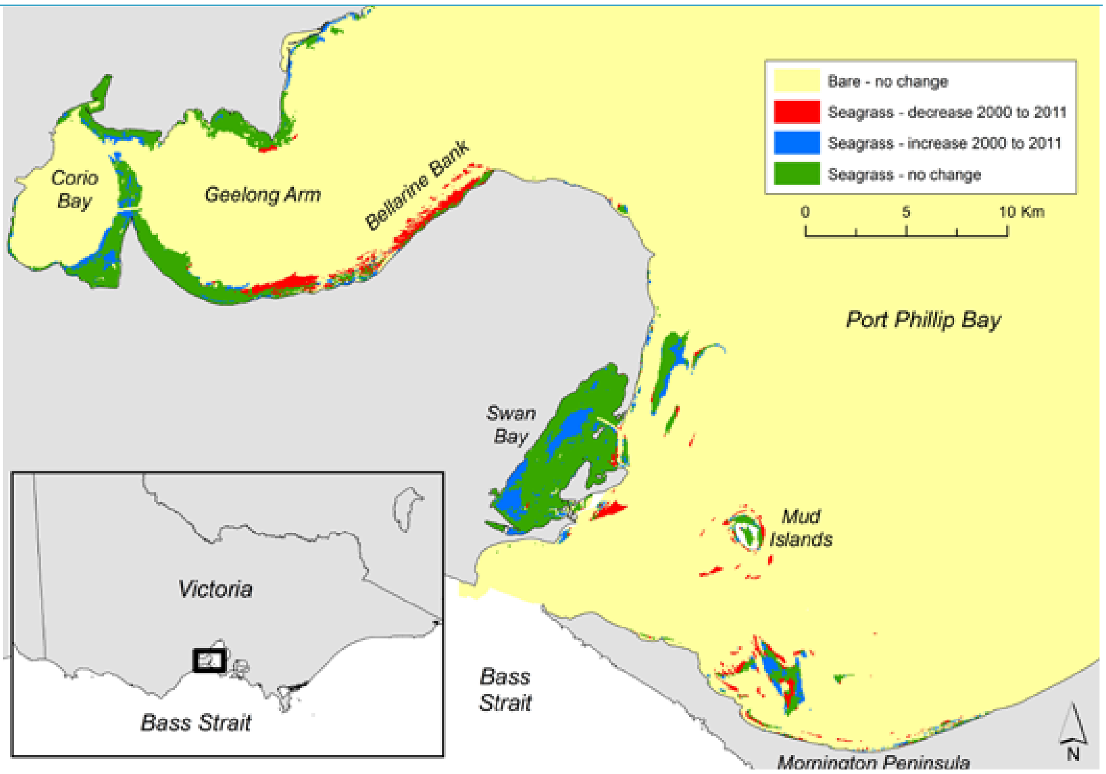

Figure S.3: Change in seagrass area between 2000 and 2011 in southern and western Port Phillip Bay[24]

Zostera meadows in Port Phillip Bay obtain nutrients from a number of sources. These nutrients principally come from the catchments (riverine inputs), treated sewage (WTP), seasonal influxes from Bass Strait and the atmospheric inputs (primarily nitrogen fixation).[25] Nitrogen fixation provides varying amounts of the nitrogen used by seagrasses,[26] but it appears to be the dominant source only in Swan Bay.[27]

A significant proportion of nutrients entering seagrass ecosystems are subsequently recycled via decomposition of leaf (seagrass and epiphytes) material which regenerates nutrients, returning them to a soluble form. Nutrients released in dissolved forms can be reused by seagrasses or other primary producers. Much of this primary productivity is exported to other locations as leaf detritus, transported by waves and currents, to support coastal foods adjacent to seagrass beds.

CATEGORIES OF SEAGRASS MEADOWS

The studies summarised in Jenkins et al. (2015) indicated seagrass meadows in Port Phillip Bay can be divided into three broad categories: persistent, ephemeral (nutrient-limited) and ephemeral adjacent to the Werribee coastline (and possibly light-limited due to proximity to the WTP).[28]

Persistent seagrass beds are relatively stable and resilient over time, whereas ephemeral beds are much more variable and have shown major increases and declines over the past half century. Persistent beds tend to be found in locations protected from high wave exposure (for example, Corio Bay and Swan Bay). These seagrasses live in fine, muddy sediments, and most of their nutrients come from fixed-nitrogen and the internal recycling of detritus.[29]

By contrast, seagrasses living in more exposed parts of the bay, particularly the Bellarine Bank and the southern areas of the bay, have shown major increases and declines since the middle of last century ('ephemeral' seagrass beds). Field and experimental studies indicated these seagrass beds are nutrient-limited, and major losses of *Zostera* occurred in these areas during the Millennium drought when catchment inputs of nutrients were low.[30] These areas were also subject to major changes in wind and wave regimes during the Millennium drought, which may have increased burial and erosion of seagrass beds in these regions.

The third category of seagrass habitat occurs along the north west coast of the bay, where nutrients are derived from the WTP. Nutrients are unlikely to be limiting, but the combination of fine sediments and wave exposure means turbidity is often relatively high and limiting for seagrass growth.

Benefits of seagrass habitats in Port Phillip Bay: an environmental-economic accounts case study

Environmental assets are fundamental to our economy and societal wellbeing. A healthy environment has unique intrinsic values and benefits people via activities such as fresh food and fibre production, nature-based recreation and tourism, air and water filtration, and resilience to natural events.

Marine and coastal environmental-economic accounting Port Phillip Bay: Report to the Commissioner for Environmental Sustainability is an important exploratory study undertaken by DELWP. It builds on past work of the Victorian Government in environmental-economic accounting, to demonstrate the relationship between healthy bays and Victoria's economic and social wellbeing. It aligns with the environmental reporting reform articulated in the Commissioner for Environmental Sustainability's *State and Benefit* Framework. The study and the Framework are both available on the Commissioner's website.

The study used available data to produce a draft set of environmental-economic accounts for seagrass in Port Phillip Bay. It demonstrates it is possible to provide information on ecosystems and their changing condition through time in an environmental-economic accounting format that is consistent with the United Nations System of Environmental-Economic Accounting.

The accounts provide a snapshot of seagrass ecosystems in Port Phillip Bay in 2000, because time series data is not available. Nonetheless, accounts for a single point in time can provide useful information on the location of seagrass beds and the benefits those assets generate.

Importantly, past studies on the extent of seagrass indicate a pattern of frequent, localised and small-scale fluctuations across Port Phillip Bay.[31] It is not clear what causes the fluctuations and how it may affect ecosystem services. This is an important area for future work.

ECOSYSTEM SERVICES AND BENEFITS

Seagrass beds make up only 3.7% of Port Phillip Bay's total environmental assets, but they deliver a number of ecosystem services that benefit people significantly.

Ecosystem service	Description
Provisioning	
Uncultivated marine plants, algae and animals for food	Seagrass ecosystems provide fish and shellfish which can be taken up for food (commercially or recreationally), providing a benefit to people.
Nutrients and natural feed for cultivated biological resources	Nutrient resources for aquaculture products.
Regulating	
Climate regulation	Seagrass ecosystems sequester and store carbon dioxide. This reduces greenhouse gases in the atmosphere, mitigating the impact of climate change.
Water cycle regulation	Seagrass ecosystems contribute to the oxygenation of oceans by generating oxygen through photosynthesis. Seagrass ecosystems also absorb nutrients, slow the flow of water and stabilise sediments with their roots. Combined, this provides a benefit to people and the environment by improving water quality.
Water flow regulation, mass flow regulation	Seagrass ecosystems trap sediments with their roots which helps stabilise the sediment, prevent coastal erosion and buffer coastlines against storm events. This provides coastal protection benefits to communities and infrastructure.
Maintenance of habitat and nursery populations	Seagrass ecosystems provide habitat and nutrients to support spawning and recruitment of species. Some organisms are permanent residents of seagrass ecosystems, while others are temporary visitors.
Cultural	
Recreation	Seagrass ecosystems contribute to seascape character and biodiversity of species for recreation (e.g. snorkelling, diving, fishing).
Information and knowledge	Seagrass ecosystems contribute to seascape character and biodiversity of species for scientific research and education.
Spiritual and symbolic	Seagrass ecosystems contribute to seascape character and biodiversity of species that have cultural heritage values, provide a sense of personal and group identity (sense of place), or have spiritual and religious function.
Non-use (existence and for future generations)	Seagrass ecosystems provide ecosystem capital for future generation of ecosystem services.

Table – Qualitative list of ecosystem services from seagrass

The study quantified the flow of two ecosystem services provided by seagrass ecosystems – maintaining nursery population and regulating climate.

MAINTAINING NURSERY POPULATIONS

Seagrass establishes habitat to support spawning and recruitment processes for fish species. A study on fish enhancement by seagrass habitat in southern Australia estimated total annual enhancement across a number of species that are commercially fished in Port Phillip Bay.[32] Estimated total enhancement (across all age classes) provided by a hectare of seagrass each year for particular species was:

- King George whiting – 46.4 kg
- Australian anchovy – 0.2 kg
- southern sea garfish – 2 gr.

Based on these estimates, the 7,350 ha of seagrass in Port Phillip Bay enhance fish stocks by around 343 tonnes.

Maintaining nursery populations benefits the economy and society through commercial and recreational fishing, as well as passive recreational activities such as snorkelling and diving. The value of this benefit can be estimated using market prices for seafood. Again using estimates for King George whiting (a market value of fish stock enhancement of $824.07 / ha), Australian anchovy ($1.91 / ha) and southern sea garfish ($0.06 / ha), the study estimated the total minimum market value of fish stock enhancement per ha – $826.04. Based on this estimate, the minimum value of fish stock enhancement across 7,350 ha of seagrass in Port Phillip Bay is $6.1 million per year.

The study has several caveats. First, it does not include all species. Second, the estimated value represents the total quantity of fish stock provided by seagrass, not realised catch by commercial fisheries.

CLIMATE REGULATION – CARBON SEQUESTRATION AND STORAGE

Seagrass removes carbon dioxide from the atmosphere and stores it in organic-rich sediments. The sequestration rates in Port Phillip Bay are unknown. Estimates from some parts of the world indicate a rate of up to 0.83 tonnes per hectare per year.

Based on a lower bound of the cost of abatement in Australia through the Emissions Reduction Fund (average price of $10.23 per tonne of CO_2-e) and an upper bound of the social cost of carbon ($57 per tonne of CO_2-e), carbon sequestration benefits are valued at up to $0.06–0.35 million per year.

In terms of carbon storage, a study has found that 38.2 tonnes of carbon is stored per hectare of seagrass. Carbon is stored in living plant biomass for relatively short timescales (years to decades), while carbon stored in sediment can remain for long time periods (centuries). This suggests that around 280,700 tonnes of CO_2-e is stored in seagrass in Port Phillip Bay. Using the same carbon prices outlined above, the value of this stock would be $2.9–16.0 million. It should be noted that this is not an annual benefit received but rather the value of the total stock held in Port Phillip Bay seagrass.

Blue carbon sequestration in vegetated coastal habitats[39,40]

Vegetated coastal habitats – seagrasses, saltmarshes and mangroves – bury carbon at a rate 35–57 times faster than tropical rainforests and can store carbon for thousands of years. Recent global data estimated vegetated coastal habitats account for 50% of carbon burial in the oceans – a function that has become known as 'blue carbon'.

In 2014, researchers from Deakin University conducted Port Phillip Bay and Western Port's first blue carbon stock assessment, focussing on sedimentary organic carbon.

FINDINGS

- Seagrass beds comprise 54% of the carbon stocks.
- Saltmarsh comprises 31% of the carbon stocks.
- Mangroves represent the smallest proportion of the carbon stock (15%), but had the second highest average carbon values (carbon stock per unit area).
- Areas in the upper reaches of the estuaries – areas further inland, which seemed to receive greater fluvial deposition, were associated with higher carbon stocks.

The relatively anaerobic soils of vegetated coastal habitats prevent organic carbon remineralisation and tend to promote long-term sequestration.[41] As such, carbon may be stored for centuries to millennia, as opposed to the decadal scales typical for terrestrial systems. Further, the vertical accretion of sediment in these habitats suggests carbon can be accumulated continually.

Saltmarshes have the highest carbon stock per unit area of all the blue carbon habitats, followed closely by mangroves. However, seagrasses in Port Phillip Bay and Western Port store 54% of the catchment's sedimentary carbon, reflecting their large distribution.

The largest potential for soil carbon loss is through a decline in seagrass habitat.

A number of 'at risk' locations or large areas of habitat could be restored, including sections of north western Port Phillip Bay and much of the northern coastline of Western Port.[42] A large portion of the bank at Lang Lang in north eastern Western Port is eroding and appears to be the most vulnerable to losses of sediment carbon stock.

The future research priorities for blue carbon in the bays would be:

1. maintaining and updating seagrass, mangrove and saltmarsh distribution maps, and
2. researching the distribution and carbon storage potential of freshwater wetland ecosystems.

Seagrass habitats and dependent species in Western Port

Compared with Port Phillip Bay, Western Port seagrass is a far more dominant habitat (figure S.2) and there are more extensive intertidal areas. Four species of seagrass are present in the bay:

- *Amphibolis antarctica* occurs in the oceanic Western Entrance segment
- *Zostera muelleri* occurs on the intertidal mudflats
- *Zostera nigricaulis* occurs mainly in the shallow subtidal areas and on the lower intertidal mudflats
- the small seagrass *Halophila australis* also occurs, but its distribution is patchy and, compared with *Zostera*, is usually in deeper, darker water.[43]

In the early 1970s, Western Port had approximately 250 km^2 of seagrass meadows, covering 37% of the bay dominated by *Zostera nigricaulis* (135 km^2), *Zostera muelleri* (40 km^2) and *Amphibolis antarctica* (20 km^2). *Z. nigricaulis* dominated the muddy intertidal banks and dendritic channels in the north and eastern regions of the bay, whereas *Z. muelleri* grew higher in the intertidal zone and *A. antarctica* dominated the well-flushed, sandy and exposed southern sections of Western Port.[44]

Between the mid-1970s and 1984, seagrass area in Western Port fell from 250 km^2 to 72 km^2. The greatest losses were in the intertidal banks of the northern and eastern sections of Western Port, and *Zostera nigricaulis* was the main species lost. The subtidal seagrass meadows in the dendritic channels and in the south western section of the bay survived much better.[45]

Seagrass total area increased from approximately 59 km^2 in 1983–84 to 93 km^2 in 1994;[46] increasing to 154.5 km^2 by 1999.[47] Of this area, 129.7 km^2 (84%) was either seagrass or a mixture of seagrass and algae. The dominant vegetation (in terms of area) was 'Dense *Zostera/Heterozostera* with Algae', comprising 43.2 km^2 (28% of the total vegetation mapped). The two seagrass species could not be distinguished on aerial imagery.

Comparisons of seagrass areas between different years must be made with caution, because mapping techniques and field verification methods varied between times and teams.

The large-scale loss of seagrass area in Western Port during the 1970s and 1980s has been attributed to a range of hypotheses[48] including physical smothering of leaves by sediment in shallow water and a consequent reduction in light reaching the seagrass leaves.[49] *Zostera tasmanica* has higher light requirements at higher water temperatures, and is more likely to be negatively affected by reductions in light during the warmer months.[50]

While the initial causes of the seagrass loss in Western Port are not well understood, the causes of the slow and limited recovery are. As described earlier, the loss of seagrass in some enclosed water bodies may lead to greater losses via a positive feedback-loop. That is, seagrass loss increases turbidity, further reducing water clarity. This occurs because seagrass rhizomes stabilise sediments. When seagrass plants die, the rhizomes stabilising the sediment are lost, increasing sediment resuspension. Increased turbidity then kills more seagrass, which in turn releases more sediment, further extending the area of seagrass loss. Such conditions may hinder seagrass recolonisation, growth and survival.

Mudbanks where the major seagrass losses occurred were still unsuitable for *Zostera nigricaulis* in the late 1990s, when transplants died within weeks from desiccation and smothering.[51] A survey in 1994 found 5,000 ha of seagrass had regrown, mostly in the south eastern section of the inlet, but little recovery occurred in the north eastern region.[52]

The role of excess epiphyte, macroalgal or phytoplankton growth in shading seagrass leaves and negatively affecting seagrass health is generally agreed to be a prevalent mechanism in seagrass decline worldwide.[53] Morris et al. (2007) concluded Western Port seagrass habitat was sensitive to increased loads of nutrients within the water column with the Blind Bight region most at risk.[54]

CURRENT SEAGRASS STUDIES IN WESTERN PORT

Longer-term project monitoring of seagrass data for Western Port, other than seagrass habitat mapping, is a knowledge gap. Researchers have conducted such mapping and classification at various time intervals (described above) and at various scales for a range of purposes.[55]

Cook et al. (in progress) and Wilkinson et al. (in progress) are further investigating new ways to monitor seagrass extent and condition by identifying the relationships between catchment inputs, marine sediment and water quality, and ecological responses.[56] The outcomes expected from this work in 2017 include:

- determining a preliminary nitrogen and phosphorous budget
- measuring nutrient cycling in major habitats (unvegetated soft sediments and seagrass habitat)
- assessing the degree of nutrient and light limitation of the major primary producers – seagrass (and possibly microphytobenthos), and
- determining water quality targets for sediments and nutrients that support seagrasses (and possibly microphytobenthos).

To improve knowledge about fish–habitat associations more broadly, Jenkins et al. (2013) compared fish assemblages in *Zostera* seagrass beds with other habitat assemblages (*Amphibolis*-dominated, *Caulerpa*-dominated, reef-macroalgae, rhodolith beds and sedentary invertebrate isolates). *Zostera* seagrass habitat was the most critical for fish biodiversity in Western Port because of its extensive spatial cover and unique role for larval settlement and development in shallow areas. It also supported some unique species, particularly pipefish and seahorse species. Although alternative habitats provide potential refuge for older juveniles and adults of some fish species in the event of *Zostera* loss, maintaining fish biodiversity in Western Port relies on significant areas of *Zostera*, particularly in the intertidal, shallow subtidal zone.[57]

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Cheilodactylus nigripes
Magpie perch

HABITATS AND THEIR DEPENDENT SPECIES

REEF HABITATS AND DEPENDENT SPECIES

Hormosira banksii (Neptune's necklace) is an intertidal algal that forms large beds. It provides habitats for other flora and fauna including macroinvertebrate grazers, predators, scavengers and microfauna that live on the algae.

There is great diversity of megafaunal invertebrates in the north of Port Phillip Bay, in part due to the additional nutrients from the Western Treatment Plant, Yarra River and Kororoit Creek inflows. Urchin barrens and sessile sponge and coral communities benefit from the carpets of *Caulerpa* and sediment-covering brown algae, and the diversity of red algae.

Western Port's evidence base on shallow reefs is not as robust as that available for Port Phillip Bay.

Rocky reefs occupy only a very small part of Western Port, but three areas are notable – Crawfish Rock, an unusual habitat with very high biodiversity; a small reef near San Remo that is significant for its opisthobranchs; and intertidal reefs along the south-western coast, particularly Honeysuckle Reef, that have a high biodiversity.

Intertidal reefs are the most accessible component of marine environments, so these habitats have important social and cultural values. Due to their accessibility, intertidal reefs are subject to human pressures, including collecting animals for food and fishing bait, trampling, and pollution from catchment discharges.

The last decade demonstrates the southern reefs of Port Phillip Bay are healthy – with the exception of decreasing numbers of seastars. The numbers of western blue groper, which used to be abundant at Nepean Bay and Point Lonsdale, are increasing.

The subtidal and deep reefs (including the deep canyon reef at Port Phillip Heads) are important ecological assets of Port Phillip Bay, providing valuable ecosystem services for Victorians.

Most reefs in the north of Port Phillip Bay have been permanently changed by native urchins and the highly-invasive Japanese kelp *(Undaria pinnatifida)* which 'takes advantage' of the disturbance caused by the urchins.

Introduction

Parks Victoria monitors subtidal and intertidal reefs in Port Phillip Bay, but research on reefs outside marine protected areas (MPAs) has been fragmentary, and there is little information about the drivers influencing these reef communities and how they differ from the open coast.

This chapter examines the recent findings about subtidal and intertidal reef research in Port Phillip Bay. It also recommends developing a program that addresses the limited knowledge of these important natural assets.

This chapter considers the following reefs:

- sheltered, subtidal, shallow reefs of Port Phillip Bay that are never exposed to the air from tidal influences, generally covering depths of 2.5–20 m, and
- intertidal reefs of Port Phillip Bay that are periodically exposed to air at low tide but are submerged or directly influenced by sea water at high tide. Intertidal reefs are also known as rocky shores (figure R.1).

The subtidal and deep reefs (including the deep canyon reef at Port Phillip Heads – see below) are important ecological assets of Port Phillip Bay, providing valuable ecosystem services for Victorians. The south of the bay, together with the entrance, is popular for recreational diving because the water is generally clear and the area contains high quality diving sites associated with the deep canyon in the entrance, marine national parks and shipwrecks.

The Victorian Government and community groups have created artificial reefs for recreational angling in the bay. This reflects the value of these limited resources. Reefs also act as a wave break protecting beaches from erosion, reef-associated algae act as a nutrient sink, and reefs are sites of detritus production that underpins the detrital food chain in soft bottom habitats.[1]

Rocky reefs occupy only a very small part of Western Port, but three areas are notable – Crawfish Rock, an unusual habitat with very high biodiversity; a small reef near San Remo that is significant for its opisthobranchs; and intertidal reefs along the south western coast, particularly Honeysuckle Reef, that have a high biodiversity. Intertidal reefs in Western Port are likely to be very vulnerable to sea level rise.[2]

The chapter includes a summary of key knowledge gaps for further research. Potential initiatives include:

- conducting biotope mapping of reefs
- improving deep reef research in Port Phillip Bay
- understanding intertidal reefs in Western Port – particularly their vulnerability to climate change and reduced water quality.

PORT PHILLIP BAY REEFS

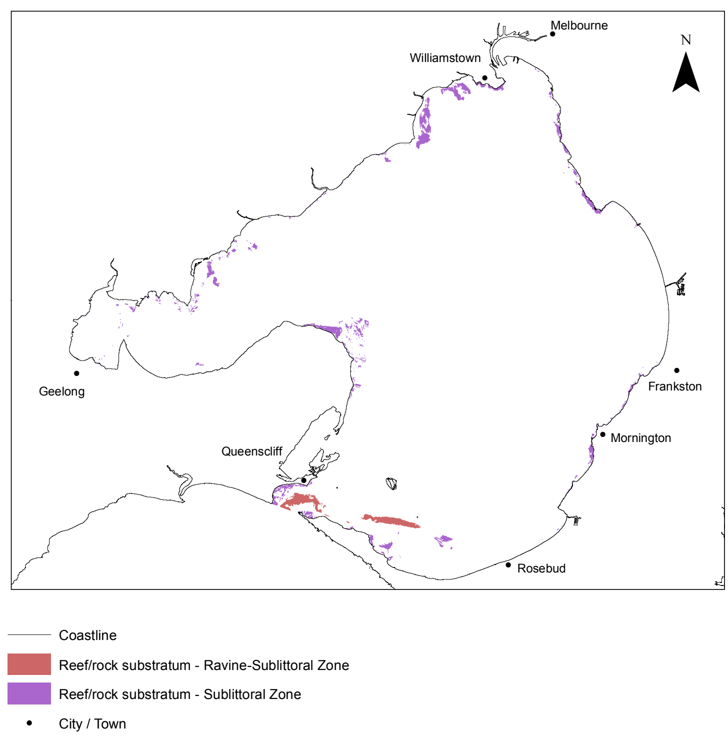

Figure R.1: Reefs of Port Phillip Bay

INDICATOR ASSESSMENT: REEF HABITATS AND DEPENDENT SPECIES

Legend

Status

Unknown	Data is insufficient to make an assessment of status and trends.
Poor	Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.
Fair	Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.
Good	Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear

↘ Deteriorating

→ Stable

↗ Improving

Data quality

Poor	Evidence and consensus too low to make an assessment
Fair	Limited evidence or limited consensus
Good	Adequate high-quality evidence and high level of consensus

Status of Subtidal Reefs

Indicator

Macroalgae dominated beds

Region

Port Phillip Bay

Measures

Cover of canopy and non-canopy species

Metric

Change in percentage cover, diversity of macroalgae

Thresholds

Parks Victoria has control charts[3]

Data custodian

Parks Victoria and Reef Life Survey

Summary

Port Phillip Bay north Most reefs in the north are low-wave energy and have been permanently changed by native urchins and the highly-invasive Japanese kelp (*Undaria pinnatifida*) which exploits the disturbance caused by the urchins. The ecological status is highly variable. Trends are currently unknown. Longer-term monitoring is necessary to identify patterns.

There are six monitoring sites in the north of the bay. Abalone counts are conducted frequently, but the ecosystem component is qualitative, based on observations by contract abalone divers. It does not include detailed information about habitat condition.

Port Phillip Bay south Subtidal Reef Monitoring Program (SRMP) monitoring in the past decade demonstrates the southern reefs are healthy – with the exception of decreasing numbers of seastars.

Anecdotally, *Undaria* and kelp dieback disease is an increasing risk in the south – and potentially other pests and diseases. *Undaria* is a particular concern because monitoring is not undertaken in the cooler months when *Undaria* is at its most abundant.[4]

Status and trends

	UNKNOWN	POOR	FAIR	GOOD
North			? (Fair, Unclear)	
South				↘ (Good, Deteriorating)

DATA QUALITY NORTH

Poor

DATA QUALITY SOUTH

Good

Status of Subtidal Reefs

	Summary	Status and trends
Indicator Fish **Region** Port Phillip Bay **Measures** (i) Census and size estimates of fish species (with sex included for selected species*) (ii) Calculations of biomass using standard length to weight ratios for relevant species **Metric** Change in abundance, diversity and size class distribution (and calculated biomass) of reef associated fish species **Thresholds** Parks Victoria has control charts[5] **Data custodian** Parks Victoria and Reef Life Survey	***Port Phillip Bay north*** Numbers of reef fish are generally low but variable. The exception to this is snapper, which is declining. Limited monitoring occurs in the north. ***Port Phillip Bay south*** The health of reef fish communities in the south of the bay is very good. Pope's Eye has been protected from all forms of fishing since the Harold Holt Reserve was established in 1978. Pope's Eyes is the most popular dive site in Victoria and demonstrates great fish density and diversity. Reflecting the improving health of the ecosystem, western blue groper numbers, which used to be abundant at Nepean Bay and Point Lonsdale, are increasing. There have been persistent sightings for the last six years.[6] Stereo baited camera monitoring (see the **Fish** chapter) could fill spatial and temporal gaps in reef fish data. * Sex ratios are not assessed because it is too variable and non-linear in scale. Sex of key species can be monitored separately – but only after long time series because numbers are low and variable.	UNKNOWN POOR FAIR GOOD North: Unknown South: Good DATA QUALITY NORTH Poor DATA QUALITY SOUTH Good

Status of Subtidal Reefs

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Mobile megafaunal invertebrates **Region** Port Phillip Bay **Measures** Census of mobile invertebrate species, with size estimates of selected species **Metric** Change in abundance, and change in size–class distribution of selected species **Thresholds** Parks Victoria has control charts[7] **Data custodian** Parks Victoria and Reef Life Survey	***Port Phillip Bay north*** Conditions have been highly variable due to drought and *Undaria*. Studies suggest urchins pose the biggest threat to reefs in the bay. The last SRMP surveys in the sanctuaries were conducted in 2015. Megafaunal invertebrates are very diverse in the north, in part due to the additional nutrients from the Western Treatment Plant (WTP), Yarra River and Kororoit Creek inflows. Urchin barrens and sessile sponge and coral communities benefit from the carpets of *Caulerpa*, sediment-covering brown algae, and the diversity of red algae. Monitoring regimes exist for abalone and urchins (Fisheries Victoria surveys six sites each year, while Parks Victoria surveys six sites every two years). However, sessile invertebrates (sponges and coral) are not included in the surveys. ***Port Phillip Bay south*** Across Victoria, seastar numbers have fallen over the past decade, with very low numbers recorded for the past seven years. The cause of this decline is unknown. The last survey of seastars at Port Phillip Heads revealed some sea star communities were diseased (necrosis). Greenlip abalones are recovering in terms of abundance and size – both in the MPAs and at the reference sites outside these areas.[8]	DATA QUALITY Good
Indicator Sea urchins **Region** Port Phillip Bay **Measures** Census of urchins **Metric** Urchin density[9] **Thresholds** Urchin densities ≥8 m[2] are sufficient to overgraze kelp and maintain urchin barrens Kelp can survive and grow at urchin densities ≤4 m[2] **Data custodian** Parks Victoria and Reef Life Survey Melbourne University and Fisheries Victoria also undertook a one-off snapshot monitoring exercise (2014)	Urchins are abundant in the bay's south. However, they are overabundant in the north and numbers are increasing. Parks Victoria monitors numbers as part of its SRMP. Monitoring in the south is better than in the north.[10]	North South DATA QUALITY NORTH Fair (good spatially but no time series) DATA QUALITY SOUTH Good

Status of Intertidal Reefs

	Summary	Status and trends
Indicator Macroalgae **Region** Port Phillip Bay (includes Mushroom Reef Marine Sanctuary) **Measures** Cover of macroalgae (by point intersection within quadrat) and presence/absence of indicator species in quadrat if not detected by intercept (*Ulva spp*, *Cladophora subsimplex*, *Capreolia implexia*, *Ceramium flaccidum*, *Corallina officinalis*, *Hormosira banksii*) **Metric** Change in percentage cover, diversity and extent of macroalgae **Thresholds** Parks Victoria has control charts[11] **Data custodian** Parks Victoria IRMP (and SeaSearch / Museum of Victoria ad hoc surveys)	*Hormosira banksii* (Neptune's necklace) is an intertidal algal that forms large beds. It provides habitats for other flora and fauna including macroinvertebrate grazers, predators, scavengers and microfauna that live on the algae. Data for macroalgae, sessile and mobile invertebrate indicators from the Intertidal Reef Monitoring Program (IRMP) indicates these reef communities have remained in good condition since 2003 with *Hormosira* cover increasing steadily since 2009. Water quality is an issue for intertidal habitats near Point Cook, close to the WTP and storm water inflows.[12]	UNKNOWN / POOR / FAIR / GOOD: Good (improving) DATA QUALITY OVERALL Fair DATA QUALITY (RICKETTS POINT AND POINT LONSDALE) Good Lack of bay-wide monitoring

Status of Intertidal Reefs

	Summary	Status and trends
Indicator Sessile invertebrates **Region** Port Phillip Bay (includes Mushroom Reef Marine Sanctuary) **Measures** Cover of sessile invertebrates (by point intersection within quadrat) and presence/absence of indicator species in quadrat if not detected by intercept (tubeworm) **Metric** Change in percentage cover, total diversity of sessile invertebrates and extent of sessile invertebrates **Thresholds** Parks Victoria has control charts[13] **Data custodian** Parks Victoria IRMP (and SeaSearch / Museum of Victoria ad hoc surveys)	Sessile invertebrates such as bryozoans, tubeworms, mussels and barnacles provide habitats for other invertebrates, like limpets. They also provide feeding areas for predatory gastropods. Data for macroalgae, sessile and mobile invertebrate indicators from the IRMP indicates these reef communities have remained in good condition since 2003.[14]	UNKNOWN / POOR / FAIR / GOOD: GOOD (stable) DATA QUALITY OVERALL Fair DATA QUALITY (RICKETTS POINT AND POINT LONSDALE) Good Lack of bay-wide monitoring

Status of Intertidal Reefs

Indicator

Mobile invertebrates

Region

Port Phillip Bay (includes Mushroom Reef Marine Sanctuary)

Measures

Census (count) of mobile invertebrates, and shell length of indicator species (abundant gastropods such as *Cellana tramoserica, Siphonaria spp., Austrocochlea porcata, Nerita atramentosa, Bembicium melanastoma, Dicathais orbita* and *Cominella lineolate* are the indicator species used – these are a mix of targeted and 'control' species)

Metric

Change in percentage cover, total diversity of mobile invertebrates and extent of mobile invertebrates

Thresholds

Parks Victoria is developing control charts[15]

Data custodian

Parks Victoria IRMP (and SeaSearch / Museum of Victoria ad hoc surveys)

Summary

Data for macroalgae, sessile and mobile invertebrate indicators from the IRMP indicates these reef communities have remained in good condition since 2003.

Humans illegally collecting sea snails as a food source is putting pressure on mobile invertebrates. Education is required that collecting sea snails from the intertidal zone around the bays is prohibited.[16]

Status and trends

UNKNOWN POOR FAIR GOOD

DATA QUALITY OVERALL

Fair

DATA QUALITY (MARINE PARKS)

Good

Lack of bay-wide monitoring

Reef habitats and dependent species: knowledge gaps

The following research program is proposed to address critical knowledge gaps about reefs in Port Phillip Bay and Western Port.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

CONDUCT BIOTOPE MAPPING OF REEFS

New mapping and monitoring arrangements for reefs in Port Phillip Bay and Western Port is recommended. Understanding the underlying systems and dynamics of marine environments across the two bays is universally important, but it is particularly relevant to reef ecosystems.

Depth, geology, geomorphology, sediment and wave exposure are critical for reef development. New technology for monitoring reefs can revolutionise how reefs (and other habitats) are mapped, understood and managed. The new technologies describe the biotopes of the reefs and adjacent areas. It improves monitoring into the future but also allows us to reclassify old video footage to provide better trend and historical data.

Examples of emerging technology include: automated underwater vehicles (AUVs), drones, 3D mosaic mapping, and bathymetric LiDAR and multi-beam sonar (for characterising the geophysical structure of reefs, biota and seabed in general).

Biotope mapping is the conventional approach in terrestrial ecosystem monitoring, so these advances will align marine monitoring with terrestrial maps and modelling. Survey sites can be reassessed based on biotopes, generating more meaningful data. Biotope mapping is also significantly cheaper and allows more frequent monitoring than traditional human-diving monitoring.[17]

It is recommended that biotope mapping be developed based on a hierarchical framework, aligning it with a national program and ensuring it is comparable across systems.

BETTER INTEGRATION OF RESEARCH

Critically, more coordinated field research is needed to understand all reef dynamics and their impacts on the ecosystem services of reefs. Coordinated research requires comparable methods of analysis and studies that complement each other. Otherwise excellent research is sometimes undermined by a lack of integration with pre-existing sites and data. As a first step, academic institutions could collaborate more closely to overcome these inefficiencies.

Generally, surveys are not frequent enough to track trends over time and confirm the changes, and their significance, to the ecosystem health of the reefs. Important assemblage transitions may be missed – such as *Undaria*, sponge communities and/or the seaweed *Caulerpa*. Further, frequency will become increasingly important as the value of 'blue carbon' and the role of reefs in carbon sequestration become significant.

Further studies that research the interaction between reefs, other marine systems and human settlements is also required to improve management outcomes.

IMPROVE DEEP REEF RESEARCH

Knowledge of the deep reefs is very limited and a considerable gap in Victoria's ability to effectively manage the bays (see figure R.1). The deep reefs are a critical component of Port Phillip Bay and Victoria. The social and economic value of these deep reefs is significant. They are tourist and recreational attractions – the most visited diving sites in Victoria – and the deep reefs lie on the edge of the shipping lanes. The deep reefs also impact on broader ecological processes in the region.

Possible research includes understanding how sponge communities maintain water quality through filter feeding. These communities are primarily filter feeders with the potential to remove large amount of organic material from the water, but the extent of this process is currently unclear.

UNDERSTAND INTERTIDAL REEFS IN WESTERN PORT

Understanding intertidal reefs in Western Port is a knowledge gap, particularly:

- assessing the risks from sea level rise
- improving our knowledge about the sediment-based water quality threshold for algae on reefs in the North Arm. These thresholds do not need to be resolved immediately, because seagrasses will be more susceptible to light reduction, and improvements to seagrass habitat will flow through to improvements to reef algae.[18]

The western side of Port Phillip Bay provides a significant proportion of the bay's fisheries production, reflecting higher areas of seagrass in Corio Bay and Swan Bay regions. Small areas of productive seagrass also fringe the northern shoreline of Port Phillip Bay (figure R.2 and figure R.3).

PORT PHILLIP BAY & WESTERN PORT BLUE CARBON

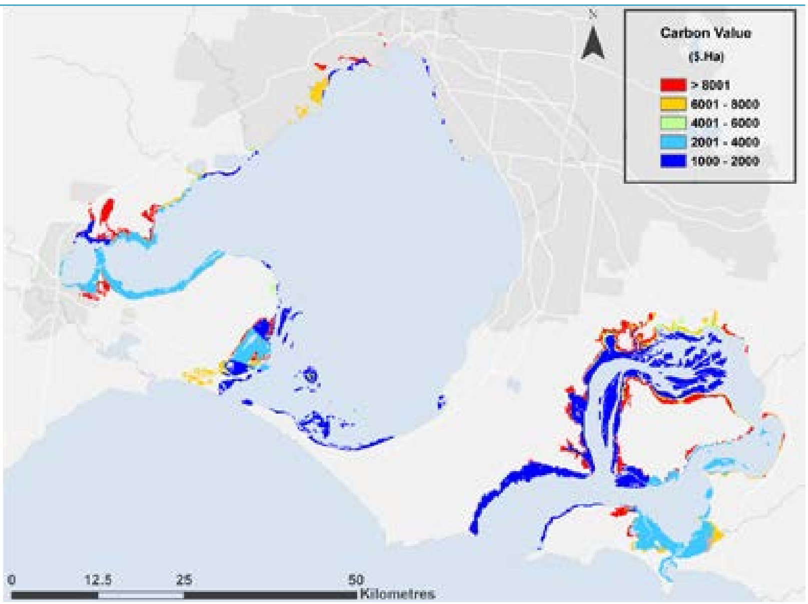

Figure R.2: Blue carbon service map for Port Phillip Bay and Western Port

PORT PHILLIP BAY & WESTERN PORT FISHERIES

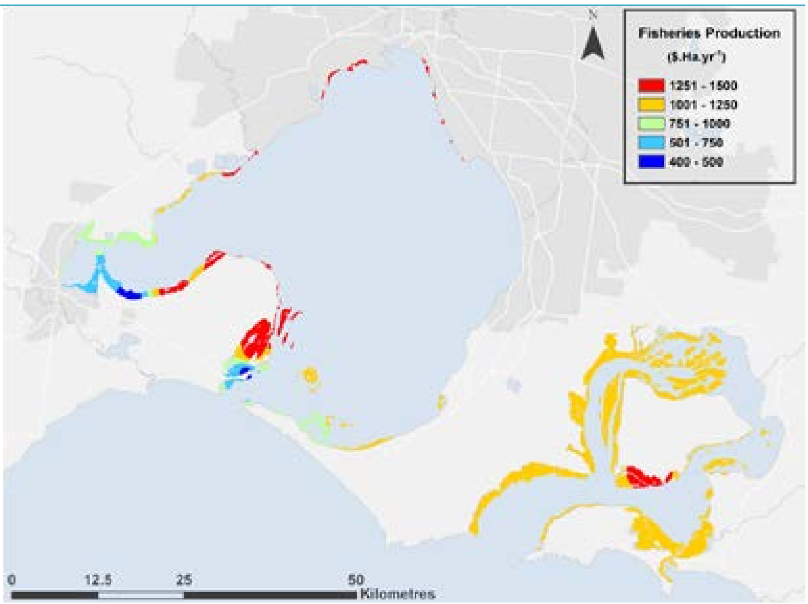

Figure R.3: Fisheries production in Port Phillip Bay and Western Port

Reef habitats and dependent species: the science stocktake

SUBTIDAL REEF HABITATS OF PORT PHILLIP BAY

The sheltered, subtidal, shallow reefs of Port Phillip Bay generally cover depths of 2.5–20 m.

Shallow reef habitats cover extensive areas along the Victorian coast. The majority of reefs are exposed to strong winds, currents and large swell. Shallow reefs in Victoria are predominantly composed of kelp and a high diversity of smaller seaweeds.[19] Seaweeds provide important habitat structure for other organisms on the reef.

The habitat structure provided by seaweeds in shallow reefs varies considerably, depending on the type and diversity of seaweed species present. Giant kelp creates tall vertical structures in the water column, which can form a dense layer of fronds floating on the water surface. Other species with large, stalk-like stipes, such as *E. radiata, P. comosa* and *D. potatorum*, form a canopy 0.5–2 m above the rocky substratum. Lower layers of structure are formed by a variety of other algae from thallose macroalgae (10–30 cm high) to the pink coralline algae that form encrusting layers on the seabed. The nature and composition of the habitat structure also varies considerably within and between reefs, depending on the biogeographic region, depth, exposure to swell and waves, currents, temperature range, water clarity and the presence or absence of deposited sand.

Grazing and predatory motile (mobile) invertebrates are the predominant animal inhabitants of shallow reefs. Common grazers include blacklip and greenlip abalone *(Haliotis rubra* and *Haliotis laevigata)*, warrener *(Lunella undulatus)* and sea urchins *(Heliocidaris erythrogramma, Holopneustes spp* and *Amblypneustes spp.)*. The grazing invertebrate species are crucial to the health of a shallow reef ecosystem and influence the growth and survival of habitat forming organisms. The grazing actions of abalone and sea urchins often prevent sponges and foliose seaweeds from growing on encrusting coralline algae surfaces, for example.

Predatory invertebrates include dogwhelks *(Dicathais orbita)*, southern rock lobster *(Jasus edwardsii)*, Maori octopus *(Octopus maorum)* and a wide variety of seastar species. Other large reef invertebrates include motile filter-feeding animals such as feather stars *(Comanthus trichoptera)* and sessile (attached) species such as sponges, corals, bryozoans, hydroids and ascidians.

Fish are also a prominent component of shallow reef ecosystems – in terms of both biomass and ecological function. Reef fish include roaming predators such as blue throat wrasse *(Notolabrus tetricus)*, herbivores such as herring cale *(Olisthops cyanomelas)*, planktivores such as sea sweep *(Scorpis aequipinnis)* and picker-feeders such as six-spined leatherjacket *(Meuschenia freycineti)*. The type and abundance of each fish species varies considerably depending on exposure to swell and waves, depth, currents, reef structure, seaweed habitat structure and many other ecological variables. Many fish species are critical to the functioning and forming of the reef ecosystem. The feeding activities of fishes such as scalyfin *(Parma victoriae)* and magpie morwong *(Cheilodactylus nigripes)* promote open algal turf areas, free of larger canopy forming seaweeds, for example.

Victoria's subtidal, shallow reefs are a very important ecological component of the marine environment because of their high biological complexity, species diversity and productivity. Shallow subtidal reef habitats also have important social and economic benefits, through commercial fishing of reef species such as wrasses, morwong, rock lobster, abalone and sea urchins, as well as recreational fishing, diving and other tourism activities.

Sponge gardens in the deep reef at Port Phillip Bay[20]

WHAT ARE SPONGE GARDENS?

At the heads in Port Phillip Bay sits a canyon that is thought to mark the historical course of the Yarra Valley. The walls consist of sheltered caves, ledges and overhangs. The colourful sponges, fish and encrusting algae provide spectacular scenery and are popular dive sites.

Situated in this canyon is an immobile invertebrate community known as 'sponge gardens'. The area derives its name from the spectacular and diverse sponges found there, but the gardens also host branching soft corals, stalked ascidians and carpets of colourful anemones.[21]

Marine scientists refer to this sponge community as 'the Entrance Deep Community' and its importance to Victoria's rich biota is well recognised.

WHY ARE THE SPONGES AT PORT PHILLIP HEADS IMPORTANT?

Sponge gardens contain a high diversity of marine life, including filter feeding invertebrates in many colours, shapes and forms.[22] The animals that make up the sponge gardens strategically habituate the main flow of current that passes through The Rip, to feed on the plankton that circulates in the passing water.

It has a high species richness compared with other known Australian communities. Over 271 validated species of sponges have been collected from Port Phillip Heads, a substantial proportion of Victoria's 523 known species and of Australia's 1,416 valid species. Importantly, 115 of the sponge species collected at Port Phillip Heads are presently known only from that area.

The unique environment at the heads creates a structure and species composition that has not been identified anywhere else, as yet. The diversity is significant given the extent of the sponge gardens community is limited to 120 ha.

The sponge community lies directly below a major shipping channel and is vulnerable to a significant shipping accident as well as other changes to the seabed. Future dredging at the heads and in some parts of the shipping channel also poses a risk to some of these communities through rock fall, smothering etc.

SUBTIDAL REEF MONITORING IN PORT PHILLIP BAY

Subtidal reefs are a critical habitat with significant ecological attributes relating to key species and interacting communities. We have considerable time series data for the subtidal reefs of Port Phillip Bay (see **Indicator assessment** above). The assessment is based principally on the following current or recent subtidal reef projects for Port Phillip Bay:

1. Subtidal Reef Monitoring Program (SRMP) by Parks Victoria, since 1998[23]
2. Reef Life Survey (in the south of Port Phillip Bay only) by the Reef Life Survey Foundation, since 2008[24]
3. REEF Evaluation Study by University of Tasmania and the University of Melbourne, 2012–14[25], and
4. Abalone industry-independent surveys and research by Fisheries Victoria, since 1994.[26]

Parks Victoria's SRMP adopted an indicator and condition reporting framework using reef habitat and dependent species data for its MPAs estate which may be applied more broadly.[27] The framework uses functional life history traits of species (for example, body size and biomass of fish species, trophic structures, and successional states) rather than traditional diversity measures, which better detect biological change and therefore better indicate ecological status.[28]

The Reef Life Survey data has been analysed to assess the effect of pollution on reef biodiversity in the south of Port Phillip Bay.[29] The presence of heavy metals and the distance to sewage outfalls explain some variations in reef fauna composition. Lower fish species richness and biomass, but higher invertebrate abundance, is evident for reef communities near sewage outfalls, for example.

The REEF evaluation survey determined that species' community assemblages and the ecosystem health of reefs vary regionally within Port Phillip Bay (generally, northern and western reefs are considered to have diminished quality). The survey includes data on the status of sea urchins (see **Indicator assessment** and detailed discussion below) and their relationship with reef habitats. This survey also explores the ecosystem health of the reefs and the effects of sediment, nutrient and sea urchins as drivers, as well as connectivity and genetic dispersal. The other three projects listed above provide additional urchin census data and evidence on the relationships between urchins and the cover and abundance of reef macrophytes and other organisms.

THE IMPACT OF NATIVE SEA URCHINS

Researchers first noticed the northern Port Phillip Bay sea urchin infestation during the Millennium drought (1997–2009). There is less sediment and nutrients in drought conditions, so hungry urchins turned to algae as a primary food source. Deteriorating macroalgae allowed the introduced Japanese kelp *(Undaria pinnatifida)* to get a foothold – the *Undaria* is very resilient and can create communities on any type of surface.

Urchins will eat anything – algae, drift weed and even sand is often found inside dissected urchins. The urchins that dominate Port Phillip Bay will preferentially feed on drift algae[30] – which can float on to, and smother, the reef and sustain urchins. The western area of the bay has experienced urchin barrens since the mid-1980s, but urchins have few predators now. We know little about what eats small urchins or urchin eggs. Urchins are prey for mobile predators (crabs), but micro-species may also eat urchins (although this has not been observed in studies).

The density of native sea urchins is a critical pressure on subtidal reefs in Port Phillip Bay. Overgrazing by urchins leads to loss of larger macroalgae cover and density (which is critical for fish mortality[31]), and creates intense competition for abalone. Removal of fish grazers and predators by fishing has also altered the trophic balance, which reduces urchin control.

Urchin barrens are a significant threat to all subtidal reefs in Port Phillip Bay; not only directly, but also because barrens allow *Undaria* to invade a reef. *Undaria* dominated reefs are clearly less desirable than those dominated by native algae for several reasons. First, *Undaria* dies back completely for six months or more, so any habitat for fish and invertebrates disappears for half the year (native algae species senesce as well, but not as dramatically). Second, *Undaria* dominated reefs are also likely to be considerably less diverse in terms of algal species.[32]

Intertidal reef habitats of Port Phillip Bay

Rocky intertidal reefs are restricted to a narrow fringe between fully terrestrial environments on land and fully submerged subtidal environments further offshore. Intertidal reefs in Victoria are generally restricted to points and headlands, and are often isolated from each other by stretches of sandy intertidal habitats.[33]

Victorian intertidal reefs vary in structure from steep sloping rock faces to relatively flat or gently sloping boulder fields and rock platforms. Geomorphology, variations in substrate (for example, basalt, limestone) and weathering create features on intertidal reefs including cobble fields, vertical steps, undulations in the reef, crevices, sand patches and rock pools. The influence of the twice daily semi-diurnal tide is the most important determinant of the types of biota inhabiting rocky reefs. Intertidal reefs tend to experience rapid and extreme changes in environmental conditions including temperature, salinity and desiccation stress through exposure to air.

Common algae on intertidal reefs include the mat-forming brown algae Neptune's necklace *(Hormosira banksia)* and the green algae *(Ulva spp.)*. Other small turfing species are also often present. Less conspicuous is a thin layer of microscopic algae growing directly on the surface of the reef, which is an important food source for species of grazing molluscs.

Molluscs tend to be the dominant fauna on intertidal reefs. Herbivorous species include the limpet *(Cellana tramoserica)*, as well as top shells *(Austrocochlea spp.)* and conniwinks *(Bembicium spp.)*. Molluscan predators include *Cominella lineolata* and *Lepsiella vinosa*. The small mussel *Limnoperna pulex* and tubeworms such as *Galeolaria caespitosa* create encrusting mats on the surface of the reef. Other invertebrates on intertidal reefs include small crustaceans such as crabs, as well as sessile (sedentary) animals including anemones. Fishes frequent the reefs as the tide rises and can be important structuring components of intertidal reef communities.

Intertidal reefs are the most accessible component of marine environments and consequently these habitats have important social and cultural values. Due to their accessibility, intertidal reefs are sometimes subject to human pressures, including collecting animals for food and fishing bait, trampling, and pollution from catchment discharges. To help effectively manage and conserve these habitats, the Victorian Government, through Parks Victoria, established the IRMP.

Citizens get involved in Sea Search

Marine ecosystems worldwide are under increasing pressure from population expansion, illegal fishing, pollution, urban development, marine pests and climate change. Many of these threats also affect Victoria's marine environment and protected areas.

Sea Search is a Parks Victoria program that encourages and provides opportunities for community participation in marine data collection and surveillance within Victoria's MPA system, focusing on marine national parks and marine sanctuaries. The program provides opportunities for volunteers with varying interests and skill levels.

THE COLLABORATIVE EFFORT OF CITIZEN SCIENCE

While Parks Victoria conducts its own significant marine monitoring and research program, community participation in gathering information adds enormous value. Sea Search helps Victorians improve our understanding of natural assets and processes, detect change and identify threats. It also allows citizens to help manage the MPAs.

Participation by local communities in monitoring further promotes stewardship and helps to build community connections, as well as broadening a local understanding and appreciation of marine values.

HOW TO MEASURE PROGRESS

To measure progress against protection goals, Sea Search provides up-to-date information on the abundance, distribution and health of marine plants and animals, as well as information about threats to the natural values of these areas.

Parks Victoria can better make informed and effective management decisions about MPAs.

INTERTIDAL REEF MONITORING IN PORT PHILLIP BAY

Intertidal reefs are a critical habitat with key ecological attributes relating to individual species and community assemblages.
The **Indicator assessment** (above) is based principally on the following current programs with regular time series for Port Phillip Bay and Mushroom Reef:

1. Intertidal Reef Monitoring Program undertaken at Jawbone, Ricketts Point and Point Cooke marine sanctuaries by Parks Victoria, since 2003[34]
2. community monitoring of intertidal reefs conducted by Sea Search, which is sponsored by Parks Victoria (see box).[35]

Parks Victoria's IRMP monitors important fluctuations in the abundance of indicator species: *Ulva spp., Cladophora subsimplex, Capreolia implexia, Ceramium flaccidum, Corallina officinalis, Hormosira banksii* and the tubeworm *Boccardia proboscidea*, which respond to change in nutrients and freshwater inputs.

In addition, O'Hara et al. (2010) sampled 65 intertidal reefs across Victoria (with some sites at Port Phillip Bay and Western Port), as part of a state-wide biodiversity assessment.[36]

Supporting the growth of the native flat (*Angasi*) oyster and shellfish reef restoration

Shellfish reefs are complex, three-dimensional living structures made up of high densities of oysters, mussels and other shellfish. They have two key ecological functions: to provide food, shelter and protection for invertebrate and fish species; and to facilitate an infrastructure that helps reduce coastal erosion and improve water clarity.

Before the 20th Century, shellfish reefs dotted the coastline around both tropical and temperate Australia and were an important food source for Aborigines.

Early maritime explorers such as Cook, Flinders, Eyre and Vancouver reported extensive shellfish reefs in their voyage reports around Australia. From early European settlement of Australia, vast quantities of oysters and mussels were harvested for food to support the growing colonies. Early settlers also used the shell as a source of lime for to construct roads and buildings.

Researchers believe shellfish reefs were commercially harvested during the 1800s and early 1900s in over 150 locations across Australia, including Port Phillip Bay. Many are now 'functionally extinct' habitats with only a handful of reefs still in existence.[37]

CONSERVATIONISTS AND INDUSTRY WORK TOGETHER TO RESTORE OYSTER POPULATIONS

Following the sharp decline of the previously abundant native flat oyster, *Ostrea angasi* (known as the flat oyster, Port Lincoln oyster, mud oyster or *'Angasi'*), the Pacific oyster *(Crassostrea gigas)* was introduced in 1947 to support the Tasmanian industry.

Recently, conservationists and oyster growers have partnered to revive the native flat oyster industry and to restore natural reefs. As part of the repair process for *Angasi* reefs, oyster spat (baby oysters) sourced from commercial hatcheries and the oyster leases 'kick start' natural reproduction and boost oyster numbers.

Hatcheries gain a commercial benefit, reducing the cost of producing *Angasi* spat for commercial growers. Oyster growers share their animal husbandry and reproduction experience with restoration practitioners to improve restoration techniques. And growers can use information from ecological studies of natural and restored reefs to improve farming practices.

TOWARDS THE RECOVERY OF SHELLFISH REEF HABITATS

Shellfish reefs clean water by removing nutrients and sediments, promote abundant fish, sequester carbon and defend against sea level rise. Establishing these reefs around aquaculture zones (where practical) can help offset impacts to existing benthic habitats, and reduce nitrogen and particulate organic matter.

In 2014, The Nature Conservancy partnered with the Victorian Government and the Albert Park Yachting and Angling Club to initiate Australia's first shellfish reef restoration project in Port Phillip Bay. Since then, other shellfish reef restoration projects have been established across Australia.

THE IMPACT OF RECOVERY ON COAST AND COMMUNITY

Partnerships among shellfish aquaculture industry, recreational fishers, Indigenous groups, government and not-for-profits are particularly well-suited to provide the resources, knowledge and community ownership required to sustain large-scale restoration efforts.

Industry and conservationists can share the cost of researching mutually beneficial topics such as disease prevention, preferred environmental conditions and diet, accelerating growth in both sectors. Such mutually beneficial partnerships can be extended to help recover other shellfish reef-forming species such as the Sydney rock oyster *(Saccostrea glomerata)* and blue mussels *(Mytilus (edulis) galloprovincialis)*.

Rebuilding native shellfish reefs and other marine habitats is 'jobs intensive', with over 17 full-time and part-time jobs created for every $1 million spent.[38] Further, restoration work can generate new jobs in marine engineering, construction, science, recreational fishing tourism and ecotourism.

Shellfish reefs are also considered to be fish factories – helping grow and augment recreationally and commercially important fish species such as snapper, bream and King George whiting.

For further information on shellfish reef restoration in Australia or to join the Shellfish Reef Restoration Network, visit: http://www.shellfishrestoration.org.au

Reef habitats of Western Port

Western Port's evidence base on shallow reefs is not as robust as that available for Port Phillip Bay.

Rocky reefs occupy only a very small part of Western Port, but three areas are notable — Crawfish Rock, an unusual habitat with very high biodiversity; a small reef near San Remo that is significant for its opisthobranchs; and intertidal reefs along the south western coast, particularly Honeysuckle Reef, that have high biodiversity. Parks Victoria also monitors Mushroom Reef Marine Sanctuary, which is just outside Western Port between Flinders and Stony Point.

Intertidal reefs in Western Port are likely to be very vulnerable to sea level rise. A loss of diversity is evident at Crawfish Rock, most likely a result of high turbidity in the North Arm.[39]

SRMP surveys a small reef near San Remo off Phillip Island, because San Remo is a listed reef community under the *Flora and Fauna Guarantee Act 1998*. These surveys revealed a new species of opisthobranchs.[40]

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Platycephalus bassensis
Sand flathead

HABITATS AND THEIR DEPENDENT SPECIES

FISH

Anchovy and pilchards are important prey items for little penguins. Port Phillip Bay and Western Port are important spawning areas for anchovy. Port Phillip Bay currently supports the largest commercial anchovy net fishery in Victoria. Commercial catches have declined, following the steady decline in fishing effort (that is, total days fished), rather than changes to anchovy abundance.

Research indicates that sand flathead recruitment in Port Phillip Bay is heavily influenced by climatic variability.

Sand flathead stocks in Port Phillip Bay declined by 80–90% between 2000 and 2010. The magnitude of this decline was directly linked to the prolonged severity of Victoria's most recent drought.

Due to its critical importance as a juvenile nursery habitat for King George whiting, reductions in the area and condition of seagrass beds in Port Phillip Bay is an ongoing threat for fish stocks and ecosystem health.

Research is ongoing to understand the relative contributions of fishing pressure, nutrient inputs, water quality, food availablility (particularly in the larval and juvenile stages), and habitat availability in shaping patterns of survival and recruitment in early life-history stages of snapper.

Declines in snapper adult catch rates over the past three years are evident for both the commercial and recreational fisheries in Port Phillip Bay. The decline should stabilise as the fishery transitions to a new wave of recruitment.

King George whiting has shown a long-term increase in numbers in Port Phillip Bay since 1978–79.

Introduction

Port Phillip Bay and Western Port support many fish species with geographic distributions that extend across temperate marine waters of south eastern and southern Australia. The marine environments in each of these bays can be broadly divided into several habitats used by fish[1] including rocky reefs and macroalgal-dominated communities, seagrass beds, unvegetated sediments (such as sands and muds) and open water (pelagic) habitats.

Reef and seagrass habitats in temperate marine waters are dominated by three particularly diverse families: the wrasses *(Labridae)*, leather jackets *(Moncanthidae)* and morwong *(Cheilodactylidae)*. Fishes characteristic of soft-bottom habitats include flounders, flatheads *(Platycephalidae)*, gurnards, rays and skates. Coastal open water fish include several larger species such as Australian salmon *(Arripis spp.)*, barracouta *(Thrysites atun)*, short-fin pike *(Sphyraeana novaehollandiae)* and silver trevally *(Pseudocaranx dentex)*. Smaller, schooling open water species include several families including the sardines and sprats *(Clupeidae)*, anchovies *(Engraulidae)*, scads and jack mackerel *(Carangidae)*, and hardyheads and silversides *(Atherinidae)*.

A high proportion of Victoria's recreational fisheries catch is sourced from Port Phillip Bay and Western Port. Historically the commercial fishery in the bays was the largest commercial bay and inlet fishery in Victoria. Commercial net fishing was removed from Western Port in 2007. In April 2016 the number of commercial fishing licences was reduced by a buy-out scheme from 43 to 10 under a Government policy to remove netting from Port Phillip Bay by 2022. From 2022, eight licences will be permitted to fish commercially in Port Phillip Bay using hook methods only. Important commercial and recreational species include: King George whiting (*Sillaginoides punctatus*), snapper *(Chrysophrys auratus)*, flathead species, Australian salmon, Australian anchovy *(Engraulis australis)*, pilchards *(Sardinops sagax)*, yellowtail kingfish *(Seriola lalandi)*, silver trevally *(Pseudocaranx georgianus)*, garfish (*Belone belone*) and gummy sharks *(Mustelus antarcticus)*.[2]

This chapter focusses on King George whiting, snapper and sand flathead as key species that indicate the health of fish in the bays more generally, as well as other processes (for example, seagrass health, snapper as an important predator etc.). It also discusses pelagic fish and the fish of Western Port more generally.

It is important to consider this chapter in the context of changing commercial fishing arrangements. Historically, the Port Phillip Bay commercial fishery was a multi-species, multi-gear fishery and Victoria's largest commercial bay and inlet fishery. Fishers operate under the Western Port/Port Phillip Bay Fishery Access Licence. Since netting was removed from Western Port in 2007, over 99% of the catch by weight under this licence has come from Port Phillip Bay. In April 2016, the number of licences fell from 42 to 10 via a buy-out scheme. This change reflected Government policy to stop net fishing in Corio Bay from 2018 and to remove all netting from Port Phillip Bay by 2022. From 2022, eight licences will be permitted to fish commercially in Port Phillip Bay using hook methods only.

The chapter includes a summary of key knowledge gaps for further research. Potential initiatives include:

- understanding how climate change may affect snapper, King George whiting and sand flathead recruitment
- understanding how recreational fishing will affect fish stocks now that commercial net fishing is being phased out in Port Phillip Bay
- improving our knowledge of pelagic fish and the significant role they play in our bays.

FISH: INDICATOR ASSESSMENT

Legend

Status

Unknown
Data is insufficient to make an assessment of status and trends.

Poor
Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.

Fair
Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.

Good
Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear

↘ Deteriorating

→ Stable

↗ Improving

Data quality

Poor
Evidence and consensus too low to make an assessment

Fair
Limited evidence or limited consensus

Good
Adequate high-quality evidence and high level of consensus

	Summary	Status and trends (UNKNOWN / POOR / FAIR / GOOD)
Indicator King George whiting **Region** Port Phillip Bay **Measures** i) Relative abundance of juvenile (post-larval) King George whiting in seagrass from ongoing annual scientific netting survey ii) Commercial catch rates of sub-adult King George whiting iii) Recreational catch rates of sub-adult King George whiting iv) Angler Diary Program (CPUE) **Metric** i) Mean number of individuals per standardised net haul ii) Catch per unit effort for the commercial haul seine fishery in (kg/net haul) iii) Catch per unit effort for recreational angler surveyed at boat ramps (number of retained fish/angler hour) **Data custodian** Fisheries Victoria	Relative abundance of juvenile King George whiting cycles over time with no clear trend (figure F.1). Commercial haul seine (dragnet) catch rates of King George whiting show a long-term increasing trend since 1978–79. In addition, three periods of higher catch rates (1984–90, 1996–2001 and 2006–13) indicate cyclic variability in abundance of King George whiting. Catch rates increased in 2015–16, after a recent low between 2013 and 2015 (figure F.2). Recreational catch rates have not been published for Port Phillip Bay since 2010, but the data are available and will be assessed in early 2017.[3]	Status: GOOD ↗ DATA QUALITY Good No trend shown, trend cycles over time.

	Summary	Status and trends UNKNOWN POOR FAIR GOOD
Indicator Snapper **Region** Port Phillip Bay **Measures** i) Relative abundance of juvenile (less than one year old) snapper from annual scientific trawl surveys ii) Commercial catch rates of adult snapper iii) Recreational catch rates adult snapper iv) Angler Diary Program (CPUE) adults and juveniles (1–3 year olds) **Metric** i) Number of individuals/1,000 m^2 of bottom trawled ii) CPUE for the long-line fishery in kg/200 hook lifts iii) CPUE for recreational anglers surveyed at boat ramps from October–December (number of retained fish/angler hour) **Data custodian** Fisheries Victoria	Juvenile trawl surveys in Port Phillip Bay indicate good juvenile recruitment rates over the past 12 years, which are expected to maintain a healthy stock in coming years (figure F.3). Adult catch rates declined over the past three years for both commercial and recreational fisheries in Port Phillip Bay (figure. F.4 and figure F.5). The decline should stabilise as the fishery transitions to a new wave of recruitment from the six average-to-above-average recruitment events that have occurred over the past 12 years. None of the catch rate data show long-term sustained declines.[4]	DATA QUALITY Good

	Summary	Status and trends
Indicator Sand flathead **Region** Port Phillip Bay **Measures** i) Relative abundance of juvenile (less than one year old) sand flathead from annual scientific trawl surveys ii) Commercial catch rates of adult sand flathead iii) Recreational catch rates adult sand flathead **Metric** i) Number of individuals/1,000 m^2 of bottom trawled ii) Catch per unit effort (CPUE) for the long-line fishery (kg/200 hook lifts) iii) CPUE for recreational anglers surveyed at boat ramps from October–December (number of retained fish/angler hour) **Data custodian** Fisheries Victoria	Trawl surveys of juvenile sand flathead show recruitment in Port Phillip Bay continues to remain poor when compared with levels recorded in the late 1980s and 1990s (figure F.6). Recruitment over the past five years (2011–16) remains well below the long-term average, with the most recent year recording one of the lowest amounts. Commercial long-line catch rates are currently below the 10-year and long-term average. Catch rates declined by 89% between 1999–2000 and 2009–10. Further, catch rates have improved only slightly since 2009–10. Figure F.7 show that current catch rates remain below the long-term average for both the recreational and commercial fisheries.[5]	UNKNOWN POOR FAIR GOOD Status: POOR, trend: declining DATA QUALITY Good

KING GEORGE WHITING, SNAPPER AND SAND FLATHEAD STATUS SUMMARY

The following figures show data informing the status summary for King George whiting, snapper and sand flathead above.

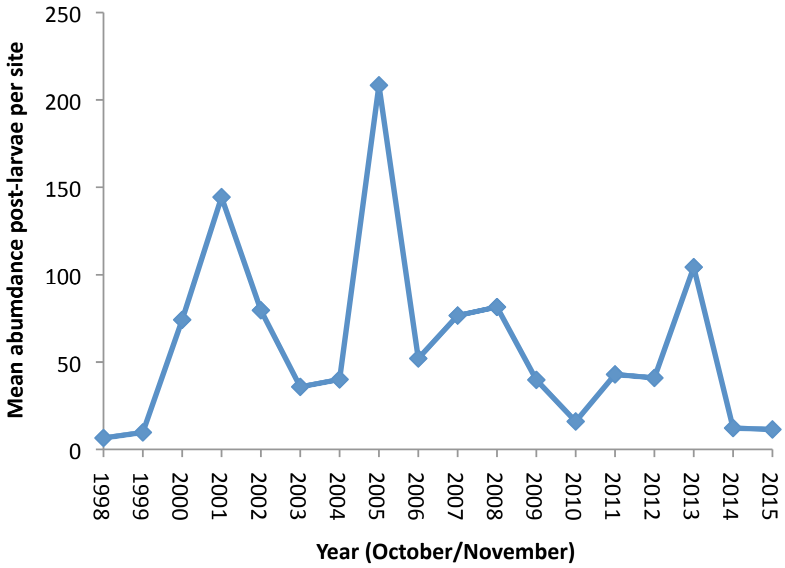

Figure F.1: Juvenile King George whiting – relative abundance of post-larvae in Port Phillip Bay (scientific seine net survey)

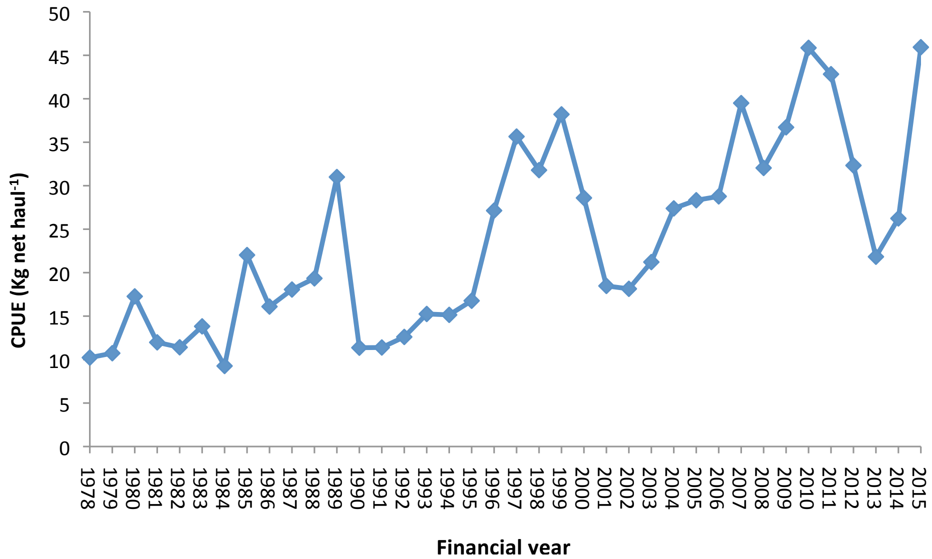

Figure F.2: King George whiting – commercial haul seine catch rate in Port Phillip Bay

KING GEORGE WHITING, SNAPPER AND SAND FLATHEAD STATUS SUMMARY

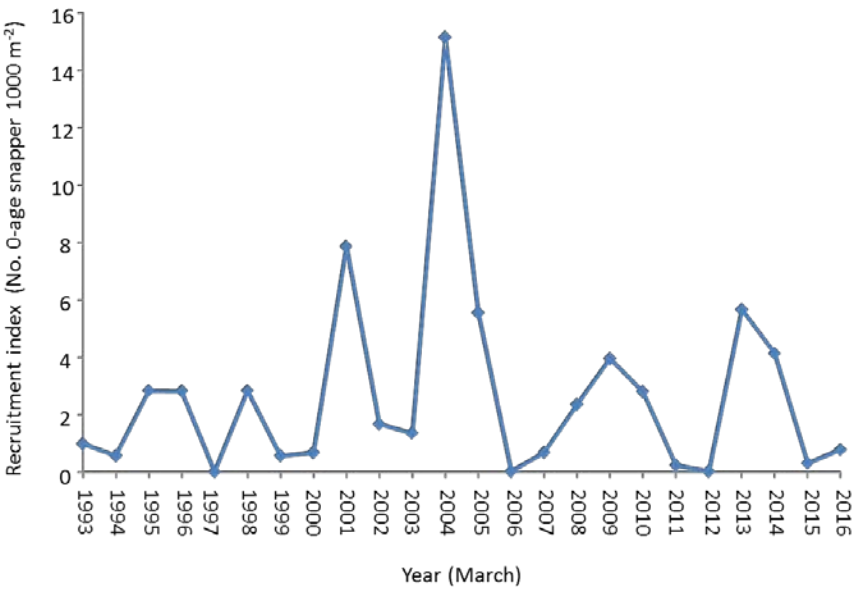

Figure F.3: Snapper – relative abundance of 0-age snapper in Port Phillip Bay (scientific trawl survey)

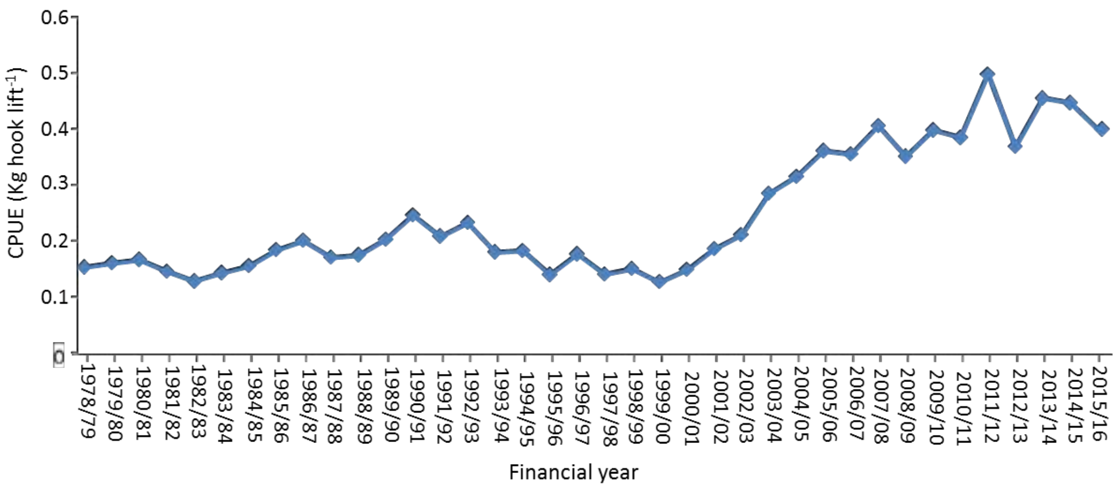

Figure F.4: Snapper – catch rates from commercial long-line fishery

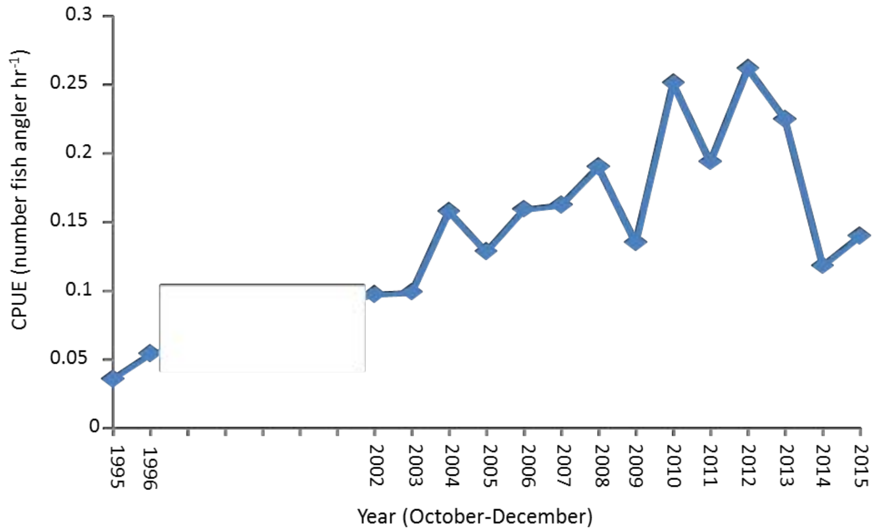

Figure F.5: Snapper – recreational catch rates from boat ramp surveys in Port Phillip Bay during October-December (adult snapper fishing season)

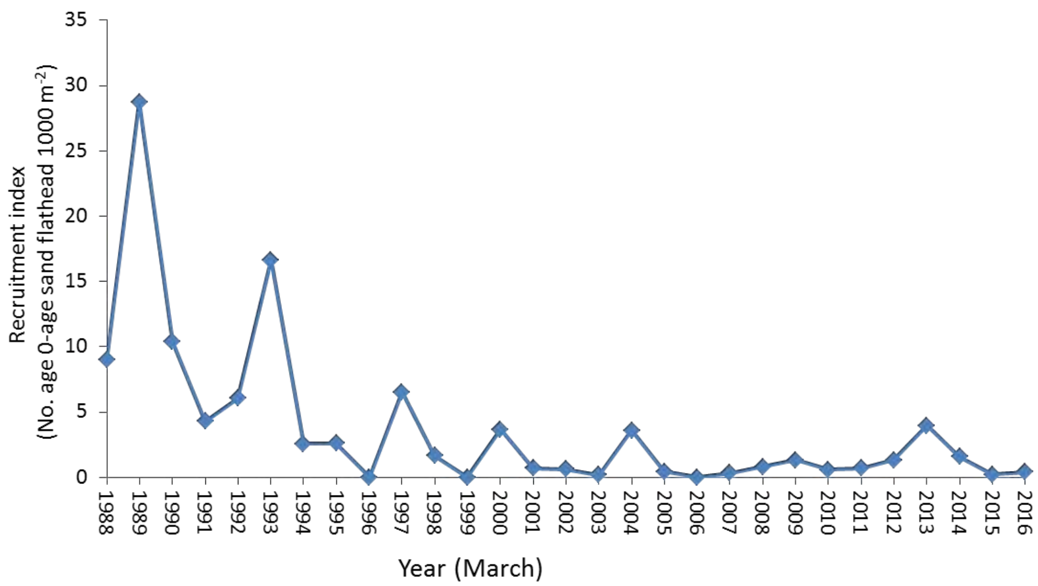

Figure F.6: Juvenile sand flathead – relative abundance of 0-age sand flathead in Port Phillip Bay (scientific trawl survey)

KING GEORGE WHITING, SNAPPER AND SAND FLATHEAD STATUS SUMMARY

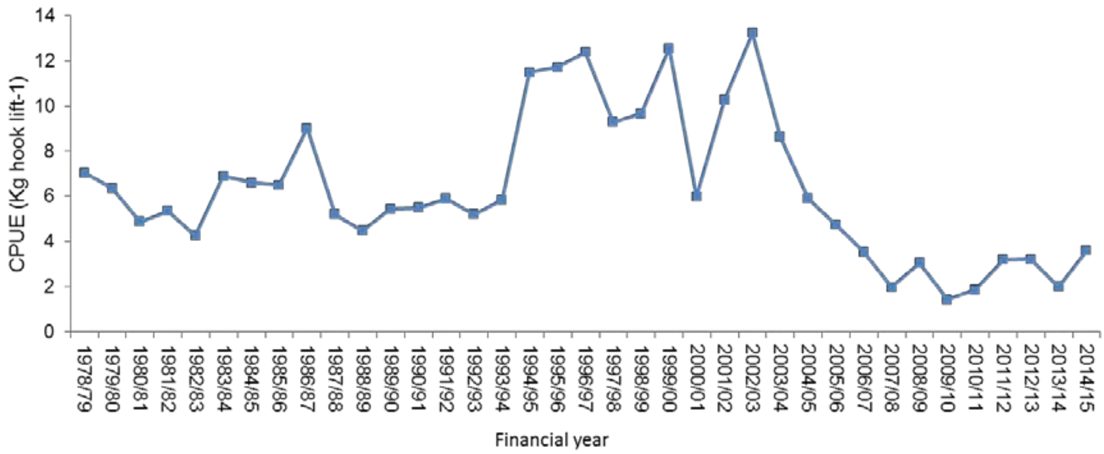

Figure F.7: Sand flathead – commercial long-line catch rates from Port Phillip Bay

SAND FLATHEAD PORT PHILLIP BAY RECREATIONAL CATCH

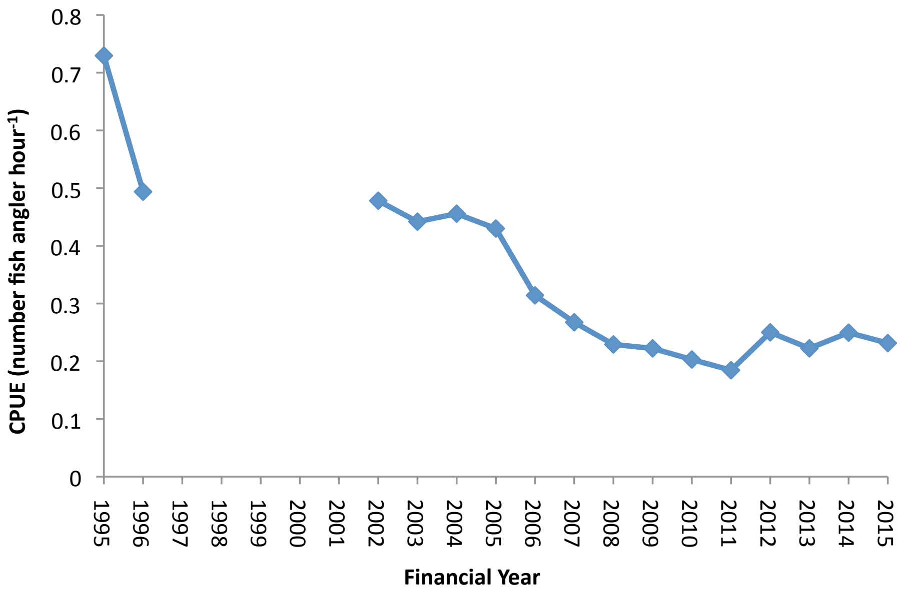

Figure F.8: Sand flathead – recreational catch rates from boat ramp surveys in Port Phillip Bay

Fish: knowledge gaps

Fish are a vital aspect of the marine ecosystems of Port Phillip Bay and Western Port, and yet many knowledge gaps still exist in our understanding of fish communities.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

UNDERSTAND THE IMPACT OF SEA SURFACE TEMPERATURE ON RECRUITMENT VARIABILITY FOR KING GEORGE WHITING

A number of areas of research could help inform climate change prediction and its impacts on King George whiting. Understanding how sea surface temperatures (SSTs) in Bass Strait influences whiting recruitment is an important knowledge gap, but first it is important to clarify the spawning sources for King George whiting in central Victoria, as well as movement and migration patterns.

UNDERSTAND THE IMPACTS OF CLIMATIC AND ENVIRONMENTAL VARIATION ON RECRUITMENT VARIABILITY FOR SNAPPER AND SAND FLATHEAD

Several key knowledge gaps exist in our understanding of pressures on the recruitment of snapper and sand flathead:

- the role of freshwater and nutrient inputs into the bays in relation to plankton productivity and recruitment
- the role of temperature in spawning periods, larval survival and recruitment, and
- the links between nutrient inputs, benthic productivity, and juvenile and adult populations of sand flathead.

UNDERSTAND THE ROLE OF FISHING IN SPECIES RECOVERY

Research is critical to understand the role of recreational fishing in preventing population recovery of sand flathead. This information is even more important now commercial netting is being phased out in Port Phillip Bay (see below) and the numbers of recreational anglers is expected to rise. Further studies should address the impact of recreational fishing on both bays and include a broader range of species. This effort requires a fish monitoring regime in Port Phillip Bay and Western Port to integrate the diverse monitoring currently undertaken into a strategic system for different outcomes (for example, fisheries management, catchment management).

The potential of citizen science (especially ReefWatch) to perform a critical role in the new monitoring regime should be assessed.

Monitoring in a post commercial fishing world[6]

Victoria's marine and estuarine finfish fisheries are complex multi-species and multi-method fisheries that are subject to competing consumptive and non-consumptive uses. More recently, and in future, fisheries access and impacts are becoming increasingly weighted towards the recreational sector. However, data from areas with a small commercial sector and a large recreational sector is generally inferior to data from fisheries dominated by the commercial sector.

Fisheries Victoria recognised phasing out commercial fishing activities would reduce in the quantity and quality of data.

NEW MONITORING METHODS

Fisheries Victoria developed goals and objectives for managing wild fisheries and implemented scientific programs to collect and assess fisheries data, including data targeted at recreational fishers. The overarching objective of the marine and estuarine finfish science program is to maintain sustainable levels of fish.

The methods used to monitor and determine if a fish stock is overfished, or is at risk of overfishing and the appropriate management response alternatives, varies. It ranges from using simple empirical data, such as catch and effort monitoring, to complex stock assessment models that integrate several data types.

ANGLER DIARY PROGRAM

Increasing numbers of recreational fishing participants, and policymakers appreciating the social and economic benefits of recreational fishing, means resources have been reallocated to the recreational sector. Removing commercial fishing from estuaries, small inlets and inland waters across Victoria creates a need for alternative sources of fisheries monitoring data.

The Angler Diary Program provides time series data on catch rates, catch length, frequency and catch age-frequency composition for key target species in selected Victorian recreational fisheries.[7] Since the Angler Diary Program started in 1997, anglers have recorded 35,000 trips.

Fisheries Victoria administers the program as a research initiative that facilitates public participation in science, and harnesses the expertise, experience, and enthusiasm of recreational fishers to collect information needed to support robust fisheries management decisions.

RESULTS

Port Phillip Bay – The majority of fish species data is on snapper, which represents an overall preference by anglers. The second most common fish was King George whiting, though a lower catch rate overall correlates with a decline in its abundance. Flathead is viewed as a species of low value – a bycatch, though its numbers are stronger than that of whiting.

Western Port – King George whiting is the most heavily represented species for data collection in Western Port, followed by snapper and gummy shark.

IMPROVE MONITORING OF PELAGIC FISH

Developing indicators for pelagic fish status (anchovy or pilchard recruitment/growth) is required. This is important for both bays and has implications for other species including seabirds.

Other priorities are understanding actual measures of bay-wide productivity (or better proxies), and better understanding how variation in pelagic production drives cycles of fisheries productivity in Port Phillip Bay and how this may be influenced by climate change.

UNDERSTAND THE IMPACT OF MARINE PESTS AND TOXICITY ON FISH IN THE BAYS

It is important to improve knowledge of ongoing impacts of introduced species (for example, highly abundant introduced yellowfin goby) on fish communities in Port Phillip Bay and the role that litter, microplastics and toxins have on fish in the bays (especially pelagic fish). This work could build on recent studies such as Parry and Hirst (2016).[8]

Fish: the science stocktake

KING GEORGE WHITING (*SILLAGINODES PUNCTATUS*) IN PORT PHILLIP BAY

Data about King George whiting comes from two main sources:

- an annual survey of seagrass areas in Port Phillip Bay, which focuses on early life-history (20–30 mm length) stages associated with seagrass beds. From 1998 to the present, researchers have collected data from several sites around the bay in October and November every year (figure F.8). These data provide an index of King George whiting settlement in Port Phillip Bay, and
- data on catch rates and CPUE provide information on stock abundance.

Overall, data from these collections suggest the numbers of King George whiting have increased in Port Phillip Bay.

The first collection focuses on seagrass, which is an important habitat for King George whiting following settlement from the larval life stage (early post-settlement). King George whiting spawn in ocean waters during the late autumn and early winter. After a long period of larval drift (up to 150 days), they enter Port Phillip Bay (and other bays and estuaries throughout Victoria) during the spring as small larvae (about 20 mm in length) and settle into the bays' fringing seagrass beds – their primary nursery habitat. These recently settled fish are termed 'post-larvae'.

Seagrass provides a refuge from predation and physical disturbance (for example, from wave energy), food and shelter. The newly-settled fish take about two and a half years to grow to a size where they can be legally caught. By about four years of age, they leave the bay to complete their adult life in coastal waters and never return.

Because it is critically important as a juvenile nursery habitat for King George whiting, any change in the area and condition of seagrass beds in Port Phillip Bay is likely to affect fish stocks and ecosystem health. The increase in seagrass cover in Port Phillip Bay over the past half century is likely to have contributed to rising King George whiting stocks in the bay (although seagrass cover has declined in some sites in the past decade).

Juvenile King George whiting are not sampled in Western Port or Corner Inlet, but fish abundance and community structure have been estimated using the same sampling equipment (that is, beach seine net) in the past.

The second collection focuses on fisheries-dependent CPUE data. These data show King George whiting catch and CPUE have been increasing in recent decades in Port Phillip Bay, but decreasing in Western Port. Trends in Western Port were similar to Port Phillip Bay until the major seagrass loss occurred in the mid-1970s after which the trend was downward.[9]

PORT PHILLIP BAY SEAGRASS AREAS

Figure F.9: Seagrass areas in Port Phillip Bay sampled by seine net (Inset – post-larval King George whiting)

Sea surface temperature off Portland (western Victoria) was significantly correlated with the number of young juveniles entering Port Phillip Bay, and also with CPUE approximately three years later.[10] Increased SST off Portland is thought to be related to King George whiting abundance in two ways:

- by promoting increased larval growth and survival rates, and/or
- by signifying the influence of a strong Leeuwin current,[11] transporting larvae to central Victorian bays. The strength of westerly winds during winter and early spring influences larval supply to Port Phillip Bay; eggs and larvae are planktonic and drift in ocean currents from South Australia and far western Victoria before entering Port Phillip Bay and settling into seagrass beds.

Predicting the future trend in King George whiting under climate change depends on several competing factors. If rising SST promote larval growth and therefore survival, then climate change may have a positive effect. However, if rising SST leads to less favourable currents (including weakening the Leeuwin current) then climate change may have a negative effect.

Similarly, climate change may have a negative effect on King George whiting stocks by reducing seagrass cover in Port Phillip Bay. It decreases light, increases desiccation stress due to higher summer air temperatures, and increases storm intensity and water temperature. Shallow seagrass beds are expected to be most affected, and a pilot study showed juvenile whiting were strongly associated with shallow beds.

Snapper *(Chrysophrys auratus)* in Port Phillip Bay

Snapper spawn in Port Phillip Bay over the late spring and throughout summer.[12] Port Phillip Bay is the main spawning and nursery area for snapper in central and western Victoria. This region is referred to as the Western Stock, which incorporates the coastline between Wilsons Promontory and south east South Australia, including Western Port. Snapper migrate between Port Phillip Bay and coastal waters and Western Port.

Juvenile snapper in Port Phillip Bay are sampled in late March or early April each year with a small beam trawl at nine sites. The survey, which has been running since 1993 to the present, focuses on snapper juveniles less than five months of age (and less than 15 cm total length). These fish are called '0+ age' or 'young-of-the-year'.[13] Researchers count and measure all snapper and sand flathead. Catch rates are standardised to number of individuals per 1,000 m^2 of bottom trawled.

The survey is timed to measure the relative abundance of new recruits derived from the previous spring and summer spawning seasons, thereby providing an annual index of year-class strength. The survey does not measure total abundance or biomass; it uses catch rates (that is, number of fish per unit of bottom area covered by each trawl) as an index of abundance. The survey indicates spawning success and future replenishment of snapper in the bay. Fisheries Victoria uses the data to predict future fisheries production, in stock assessments and assessment models, and to study relationships between environmental and climate variables and recruitment.

Port Phillip Bay provides the majority of the catch of snapper in Victoria and is also the primary spawning and juvenile nursery area. Catch and CPUE of snapper declined in recent decades but increased again since the late 1990s, apparently reflecting a sequence of strong recruitment events. Catches and catch rates peaked in 2010–11 and have declined in recent years.[14]

The available time series of recruitment for snapper shows highly variable recruitment among years, but no obvious long-term trends. Much of the inter-annual variation is related to environmental influences on survival of the early life stages (that is, river flow, nutrient supply, plankton food chain dynamics). Snapper experience high variation in juvenile recruitment, which is closely related to variation in larval abundance.[15] Increased availability of crustaceans *(Copepod nauplii)* prey and higher temperatures best explained the inter-annual variation in larval growth.[16]

There is also evidence that links larval survival with the amount of flow and nutrients delivered into the Carrum Bight spawning grounds, with the Yarra River being the main source. High and low flows in the spring seem to lead to poor survival and intermediate flows are more likely to produce higher survival. Over the past decade, 0+ age snapper recruits collected in the pre-recruit survey showed a positive correlation with freshwater flow in October, and a negative relationship with water temperature in spring of the year of spawning.

These findings suggest that the relationship with flow is complex – high spring flows and low spring flows are not as conducive to high recruitments as intermediate flows, but the timing and dynamics of flows is also likely to be critical in relation to the optimal water temperature window for egg larval survival. Snapper eggs and larvae require water temperature in the range 18–22°C for optimal survival. Climate change forecasts for SSTs in Port Phillip Bay suggest the availability of this temperature window may change, which may affect the reproductive success of snapper in Port Phillip Bay.[17]

These correlations are likely to be relevant in the future; the present dry conditions are similar to what is predicted under climate change. However, the recent strong recruitment that occurred under these conditions highlights the need to better understand the processes driving snapper recruitment, which are most likely to relate to variation in plankton production over the spawning season. Larval feeding success and growth directly relate to survival and recruitment. Evidence clearly links this success to nutrients and temperature – but the exact form of the relationships requires more work (see **Knowledge gaps** below).[18]

Sand flathead *(Platycephalus bassensis)* in Port Phillip Bay

Sand flathead *(Platycephalus bassensis)* was once both a significant commercial fishery and the largest recreational fishery in Port Phillip Bay. Sand flathead stocks in Port Phillip Bay declined by 80–90% between 2000 and 2010 (figure F.9), but had recovered to 30% of 1990s levels, and 50% of 1980s levels, by 2012–13.[19] Stock exploitation was stable between 2000–01 and 2006–07 (at 15–30% of the stock biomass) despite the decline.[20]

Sand flathead spawn in Port Phillip Bay over the late spring and early summer and most larvae occur in the water column during November–December. Sand flathead settle out of the plankton from January to March. Sand flathead juveniles of less than one year age (referred to as '0+ age' or 'young-of-the-year'), and less than 15 cm total length, are sampled from the same survey as snapper (see above for survey design detail). The survey occurs in late March or early April each year.

Sand flathead are considered to have a largely resident, isolated stock within Port Phillip Bay – with limited exchange with the coastal population. Therefore the survey indicates replenishment of the bay's population only.

A comprehensive review concluded declining recruitment from the mid-1990s onwards led to the decline of sand flathead stocks from 2000 (figure F.6).[22] It coincided with a period of prolonged drought in Victoria from 1997–2009, which was characterised by substantially lower rainfall and river flows. Sand flathead recruitment in Port Phillip Bay from 1988–2013 was significantly correlated with Yarra River flows during November and December, when the majority of sand flathead larvae occur in the water column.

PORT PHILLIP BAY SEAGRASS AREAS

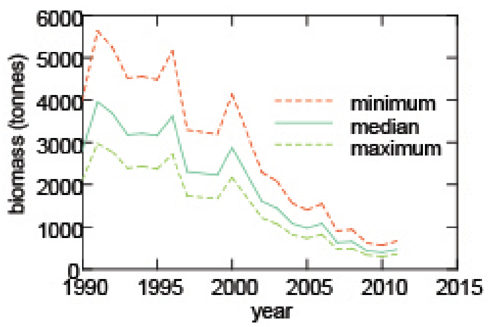

Figure F.10: Trends in sand flathead stock biomass (tonnes) in Port Phillip Bay for different trawl net efficiencies, 1990–2011[21]

The relationship between flow and recruitment was positive up to 3,000 ML/day, but negative for flows in excess of 3,000 ML/day. That is, recruitment was lowest in years when flows were either very low or very high and highest in years with intermediate flows of 1,000–3,000 ML/day. Almost all low flow years during the drought corresponded with low recruitment. By contrast, there is little evidence that sand flathead growth was affected by the introduction of the exotic seastar *Asterias amurensis* in the late 1990s.[23]

This research suggests sand flathead recruitment in Port Phillip Bay is heavily influenced by climatic variability, which is consistent with our understanding of the processes that drive cycles of productivity for other fisheries in Port Phillip Bay.[24] However, the magnitude of this decline is unprecedented for sand flathead since catch and effort records began in 1978, and there is little evidence of declines of a similar scale among commercial catches recorded since 1914. Further, sand flathead recruitment has recovered little since the drought ended in 2010. Low stock abundance may be currently impeding population recovery in the bay.

Interestingly, sand flathead in Port Phillip Bay grow more slowly and reach a smaller maximum size than sand flathead collected from Bass Strait and south-east Tasmania.[25] The reasons for this are unclear, but may reflect differences in the benthic productivity of the environments the fish live in or genetic changes to the Port Phillip Bay sand flathead population.

The abundance of a range of other benthic fish species (including rays, stingarees and gurnards) also declined substantially during the drought, although the mechanisms for these declines are less clear.[26] The greatest declines occurred in the deeper, central parts of the bay where the impact of the drought was likely to be most pronounced. However, research suggested the abundance of some species may also have been affected by the introduction of seastar *(Asterias amurensis)*. Researchers recorded sharp declines in the biomass of three species with a high dietary overlap with *A. amurensis*. This decline coincided with the peak abundance of *A. amurensis* in 2000 in the deeper regions of the bay.[27]

Another unresolved question regarding flathead in Port Phillip Bay has been the decline of toothy flathead (from 0.3 tonnes to 22 kg), and the relative increase of yank flathead (from 0.2 tonnes to 0.57 tonnes), in the scientific trawl surveys that occurred between 1970–76 and 1990–2007.[28]

Pelagic fish

Pelagic fish are an important link between planktonic productivity and predators such as squid, fish and seabirds in Port Phillip Bay and Western Port. Anchovy and pilchards are important prey items for little penguins, for example.[29] Little penguins feed mostly on juvenile pilchards from spring to summer, and anchovy from autumn to winter, reflecting changes in the availability of preferred prey.[30] The decline in the pilchard population in the mid to late 1990s has likely increased the ecological importance of anchovy in Port Phillip Bay.[31] Seabirds that formerly depended on pilchards as a major food source have switched to diets of other pelagic species, including anchovy, for example.[32]

Port Phillip Bay and Western Port are important spawning areas for anchovy.[33] Adult anchovy migrate into the bays between October and December to spawn and return to Bass Strait between February and May. Juvenile anchovy remain within the bays for up to two years after hatching, before migrating offshore to join the adult population. This life-history strategy is likely to have evolved to maximise egg, larval and juvenile survival in anchovies.[34]

Juvenile pilchards also use Port Phillip Bay as a nursery, entering the bay as mostly 0+ and 1+ juveniles in late spring/early summer, but do not attain sexual maturity within the bay.[35] Unlike anchovy, pilchards spawn primarily in offshore coastal shelf waters[36] and rarely in Port Phillip Bay.[37] Ward et al. (2001) suggested the spatial segregation of spawning areas for anchovy and pilchards in South Australian coastal waters may have evolved as a result of competition avoidance between these two species.[38]

Anchovy populations in Port Phillip Bay exhibited consistent recruitment in each year from 2008 to 2011.[39] The relative size of the 0+ age cohort in each year was similar to or larger than the existing juvenile cohort (comprising mostly 1+ fish) recruited in the previous year, suggesting the biomass of the over-wintering population of juvenile anchovy remained relatively stable. Port Phillip Bay supported the largest commercial anchovy fishery in Victoria before commercial fishing began to be phased out in 2016.[40] Despite falling commercial catches, catch rates (per unit effort) have remained relatively stable since 1995–96.[41]

Fish in Western Port

Fishing as a form of harvesting was identified as a high priority research area in the Western Port Science Review.[42] The recreational fishing research data obtained from boat ramp interviews over 15 years produced detailed information on numbers and lengths of species caught, as well as location, depth and habitat of capture. Jenkins and Conron (2015) analysed the data, to better understand the ecology and biodiversity of key fish species in Western Port. The results also form the baseline information for a stock assessment of important recreational fishing species in Western Port to be conducted in phase two of the project.[43]

The spatial distribution of catch rates (an indicator of abundance) was visualised using geographical information system (GIS) mapping for key species, and supplemented with data on habitat and depth fished. Some species, such as King George whiting, southern calamari *(Sepioteuthis australis)* and southern sea garfish *(Hyporhamphus malnochir)* had higher catch rates (indicating greater abundance) in areas of higher seagrass cover. Fishing for these species tended to be in relatively shallow depths and habitats that included seagrass. By contrast, species such as snapper and gummy shark had higher catch rates in the deeper reef habitats of the Western Entrance Segment and the Lower North Arm.

Rhyll Segment was an area of high catch rates for most species; it is a broad subtidal sedimentary plain with habitats such as seagrass, macroalgae and sedentary invertebrate isolates. The Rhyll Segment is also strongly influenced by water quality and sedimentation entering the bay's north east from the catchment; so catchment management to maintain water quality entering the bay is likely to be critical to maintaining fish biodiversity and sustaining recreational fishing.

In terms of changes to catch rates and length distributions over the survey period, several species demonstrated a common pattern of strong fluctuations over a few years. For species such as King George whiting and snapper, these fluctuations reflected recruitment variations driven by environmental fluctuations.

For other species, the survey suggested long-term trends. Snapper showed an increasing trend that was most likely related to a series of successful recruitment years in Port Phillip Bay in the 2000s, following poor recruitment in the 1990s. Flathead showed a slightly decreasing trend in catch rate that may be related to the much more significant decrease in sand flathead catch rates in Port Phillip Bay over the same period. This decline is likely to reflect a period of poor recruitment related to environmental conditions. Catch rates of elephant fish *(Callorhinchus milii)* were relatively stable across the survey period, but the spatial distribution of the catch rates contracted to the Rhyll Segment. This result may be a cause for concern because decline in the population is masked by increased aggregation.

Overall the study provided new information on the spatial distribution and habitat use of important fish populations in Western Port. This information will help manage the marine environment in relation to catchment inputs, coastal development, recreational fishing and marine protected areas. The results suggested variation in catches by recreational fishers was primarily influenced by the environmental drivers of recruitment of young fish to the Western Port ecosystem.

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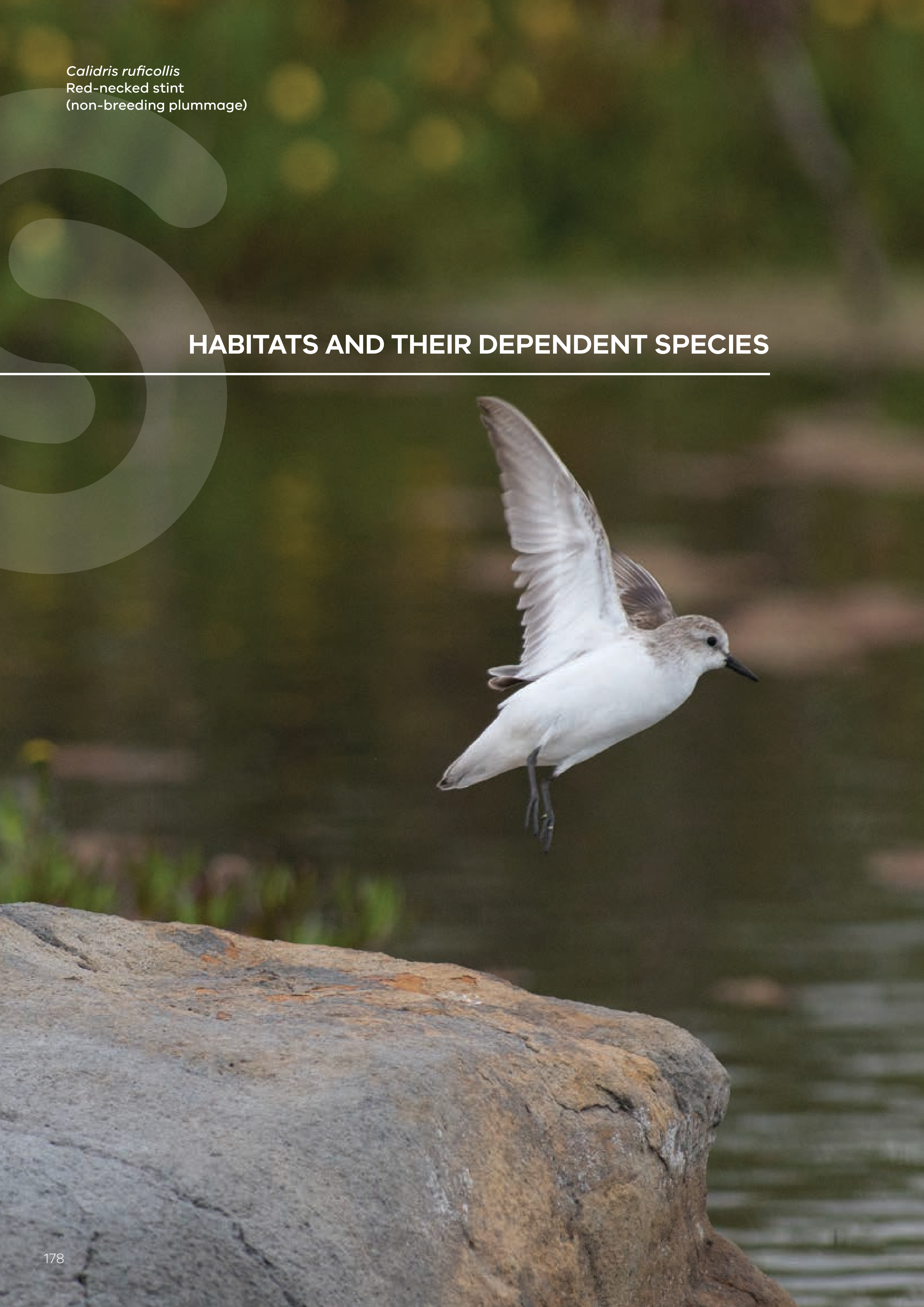

Calidris ruficollis
Red-necked stint
(non-breeding plummage)

HABITATS AND THEIR DEPENDENT SPECIES

MARINE-DEPENDENT BIRDS

Red-necked stint, curlew sandpiper and sharp-tailed sandpiper are the three key species of roosting shorebirds for Port Phillip Bay. Shorebirds in Port Phillip Bay are declining in line with populations throughout the world in the last 20 years.

Terns, cormorants and the Australian pelican are decreasing at Western Port, but increasing at West Corner Inlet. Falling tern numbers account for most of the decline in piscivorous birds in Western Port. This result suggests feeding conditions for terns (and to a lesser extent for cormorants and pelicans) in Western Port have deteriorated compared with feeding conditions in West Corner Inlet.

Several species of water birds in Western Port recorded serious declines, and very few are increasing. Species at the highest risk of further declines are trans-equatorial migrants, nomadic or dispersive, local breeders or largely piscivorous (fish-eating) species.

The Phillip Island little penguin colony declined between 1980 and 1985. The population increased until 1995, when a significant decline in pilchards impacted penguin numbers. Penguin numbers have increased again and have been stable in recent years. The most recent breeding year (2015–16) was the most productive in the last 48 years.

For 16 migratory shorebird species examined at Port Phillip Bay and the Bellarine Peninsula Ramsar site, 10 species (62%) had significantly declined since 1981, with curlew sandpipers and lesser sand plovers showing particularly strong declines.

The impacts of climate change on penguins will be complex – warmer sea surface temperatures will increase breeding productivity and first-year survival, but increased frequencies of fire, higher temperatures and drought will threaten adult penguin survival.

Introduction

This chapter explores the role of marine-dependent birds in the ecosystems of Port Phillip Bay and Western Port. Information is available on the health of a range of waterbirds in Western Port – including fish-eating birds – while the Port Phillip Bay analysis is restricted to roosting shorebirds.[1] There is also a discussion of the little penguin colonies at Phillip Island and St Kilda.

Shorebirds are declining around the world, including populations that spend the non-breeding period in Australia. Migratory shorebird conservation involves identifying important shorebird habitat, and monitoring changes in shorebird populations to inform management interventions.

Annual summer count data of shorebirds was collected at key sites in the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site from 1981–2010 (figure B.2 and figure B.3). For 16 migratory shorebird species examined, 10 species (62%) had significantly declined since 1981, with curlew sandpipers and lesser sand plovers experiencing particularly strong declines.[2]

PORT PHILLIP BAY AND WESTERN PORT FLYWAYS

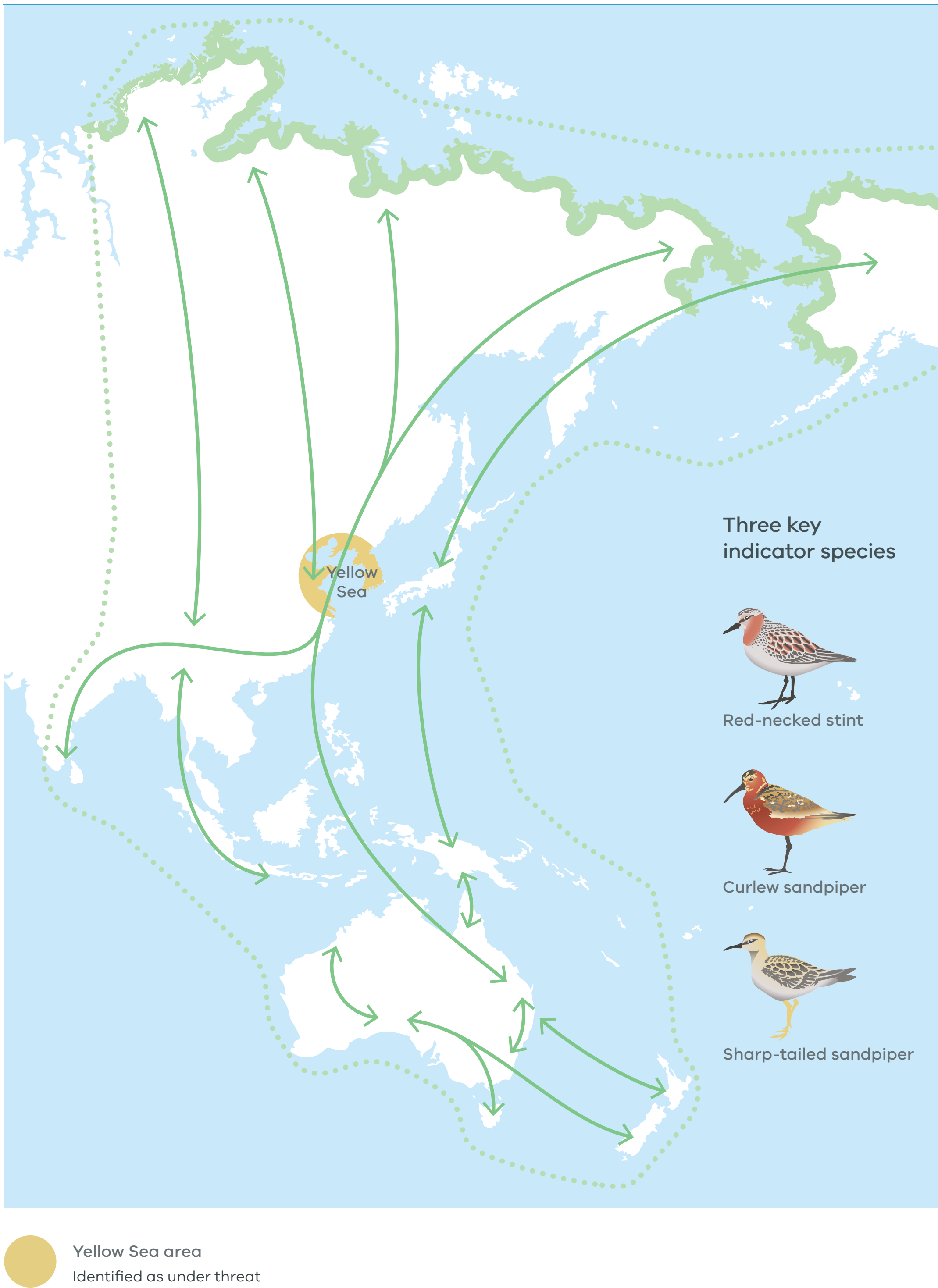

Figure B.1: Flyways of key migratory bird species for Port Phillip Bay and Western Port

RAMSAR MIGRATORY SHOREBIRD COUNT DATA

Species	Estimated flyway population	1% of flyway population	Count data for years 2006–2010				
			2006	2007	2008	2009	2010
Bar-tailed godwit	325,000	3,250	1,551	22	179	458	456
Black-tailed godwit	160,000	1,600	10	0	10	20	9
Common greenshank	60,000	600	381	314	399	242	256
Common sandpiper	25,000–100,000	250–1,000	2	4	3	1	1
Curlew sandpiper	180,000	1,800	6,380	5,525	6,794	3,081	3,551
Eastern curlew	38,000	380	104	74	7	37	35
Great knot	375,000	3,750	16	3	12	16	15
Grey plover	125,000	1,250	41	4	14	52	49
Grey-tailed tattler	50,000	500	6	1	3	4	5
Lesser sand plover	140,000	1,400	0	1	4	1	4
Marsh sandpiper	100,000–1,000,000	1,000–10,000	202	279	179	99	127
Pacific golden plover	100,000	1,000	123	37	87	38	60
Red knot	220,000	2,200	220	125	70	20	109
Red-necked stint	325,000	3,250	19,121	20,682	14,500	17,606	14,644
Ruddy turnstone	35,000	350	75	25	38	35	30
Sharp-tailed sandpiper	160,000	1,600	9,699	4,957	7,471	6,547	7,652
					>1% of flyway population		

Table B.2: Migratory shorebird count data for the Ramsar site for the years 2006-2010 inclusive, in relation to species' estimated flyway population and international significance.

SUMMARY OF SHOREBIRD TRENDS AT FIVE MAJOR AREAS

Species	Major shorebird area					
	Laverton-Altona	Werribee-Avalon	Moolap Salt Works	Swan Bay & Mud Islands	Lake Connewarra Area	Overall Trend
Latham's snipe	n.a.	n.a.	n.a.	n.a.	n.a.	_
Black-tailed godwit	n.a.	↓	n.a.	n.a.	n.a.	↓
Bar-tailed godwit	n.a.	_	n.a.	_	n.a.	_
Eastern curlew	n.a.	↓	n.a.	_	_	↓
Marsh sandpiper	_		_	_	_	↑
Common greenshank	↓	_	↓	↓	_	_
Grey-tailed tattler	n.a.	n.a.	n.a.	↓	n.a.	↓
Ruddy turnstone	n.a.	n.a.	n.a.	↓	n.a.	↓
Great knot	n.a.	n.a.	n.a.	↓	n.a.	↓
Red knot	n.a.	_	n.a.	↓	n.a.	↓
Red-necked stint	_	↑	↓	_	_	_
Sharp-tailed sandpiper	↓	_	_	_	_	_
Curlew sandpiper	↓	↓	↓	↓	_	↓
Pacific golden plover	_	_	n.a.	↓	n.a.	↓
Grey plover	n.a.	n.a.	n.a.	↓	n.a.	↓
Lesser sand plover	n.a.	n.a.	n.a.	↓	n.a.	↓
Masked lapwing	↓	_	↑	↓	_	_
Australian pied oystercatcher	n.a.	_	↑	↓	n.a.	_

↓ significant decrease

↑ significant increase

n.a. count data insufficient for trend analysis at the shorebird level

_ no significant trend

Table B.3: Summary of shorebird trends at the five major shorebird areas and overall trend for 16 migratory species and two resident species

Similarly, several species of waterbirds in Western Port experienced serious declines, and very few are increasing. Species at the highest risk of further declines are trans-equatorial migrants, nomadic or dispersive, local breeders or largely piscivorous (fish-eating) species. Despite these falls, piscivorous bird numbers are increasing at West Corner Inlet. This result suggests feeding conditions for terns (and to a lesser extent for cormorants and pelicans) in Western Port have deteriorated compared with feeding conditions in West Corner Inlet.

The Phillip Island little penguin breeding population doubled between 1984 and 2011. However, climate change will be a critical and complex pressure on penguin communities. Sea level rise, decreased rainfall and humidity, increasing air temperatures and increased sea surface temperatures (SSTs) in Bass Strait are likely to affect a number of aspects of the biology of penguins. However, the impacts will be complex – warmer SSTs will increase breeding productivity and first-year survival but increased frequencies of fire, higher temperatures and drought will threaten adult penguin survival rates.

Other threats to penguins include the impact of winds, the southern oscillation index, increased ocean acidification, factors that affect food supply (fishing, fish recruitment), human interference (plastics and pollution), and nest predation by corvids.

Knowledge gaps include improving Port Phillip Bay monitoring activities, to bring them into line with activities in Western Port, and integrating current bird research. Other gaps include understanding the impacts of fish food stocks on birds and improving the accuracy of penguin counts.

Legend

Status

Unknown	Data is insufficient to make an assessment of status and trends.
Poor	Environmental condition is under significant stress, OR pressure likely to have significant impact on environmental condition/ human health, OR inadequate protection of natural ecosystems and biodiversity.
Fair	Environmental condition is neither positive or negative and may be variable across Victoria, OR pressure likely to have limited impact on environmental condition/ human health, OR moderate protection of natural ecosystems and biodiversity.
Good	Environmental condition is healthy across Victoria, OR pressure likely to have negligible impact on environmental condition/ human health, OR comprehensive protection of natural ecosystems and biodiversity.

Trend

? Unclear ↘ Deteriorating → Stable ↗ Improving

Data quality

Poor
Evidence and consensus too low to make an assessment

Fair
Limited evidence or limited consensus

Good
Adequate high-quality evidence and high level of consensus

Summary

Indicator
Status of roosting shorebirds

Region
Port Phillip Bay

Measures
Number of individuals (counts) of migratory and resident species

Metric
Number of individuals at high tide

Thresholds
International agreed thresholds on numbers apply to the shorebird significant site network.

Data custodian
Arthur Rylah Institute/Birdlife Australia

All shorebirds are counted at high tide during roosting, twice a year since 1981. Roosting shorebirds are monitored at eight coastal sites.

Red-necked stint, curlew sandpiper, sharp-tailed sandpiper are the three key species of roosting, migratory shorebirds for Port Phillip Bay. Numbers of roosting shorebirds are declining in line with populations throughout the world over the past 20 years.

The impact of sea level rise on tidal flats is probably an important pressure.[3]

Status and trends

UNKNOWN POOR FAIR GOOD

Status: Fair, trend: Deteriorating

DATA QUALITY

Good

Indicator

Status of waterbirds

Region

Western Port

Measures

(i) Number of individuals (counts) of migratory and resident species at two hours either side of high tide over 40-year period

(ii) Extent and topography of intertidal habitat

Metric

(i) (a) Total counts (means, standard deviations and ranges) Count data time series analysed using autoregressive integrated

(b) Moving average (ARIMA) models

(ii) Extent in m² of habitat and relative elevation height and emersion time of this habitat in relation to the low tidal range

Thresholds

International agreed thresholds on numbers apply to the shorebird significant site network.

Data custodian

Birdlife Australia (Western Port Waterbird Survey) / DELWP

Summary

All shorebirds are counted at high tide during roosting, three times a year since 1973.

A broad suite of species recorded serious declines, and very few are increasing. Species at the highest risk of further declines are trans-equatorial migrants, nomadic or dispersive, local breeders or largely piscivorous species.

Thirty-nine species were recorded often enough to analyse trends over time. Twenty-two species had declined, including four species of duck, five species of piscivorous bird (including cormorants, terns and pelicans), one species each of grebe, gull and heron, and 10 species of shorebird. Only two species (Australian pied oystercatcher *Haematopus longirostris* and straw-necked ibis *Threskiornis spinicollis*) increased significantly over the same period.

Patterns of decline in non-migratory waterbirds may reflect drought, diminishing wetland availability, local reductions in fish prey, increased predation pressure and changes in inland wetland resources. Declines in migratory shorebirds are most likely related to loss of habitat elsewhere in their trans-equatorial migration routes.[4]

A good monitoring regime is in place, but it depends heavily on volunteers and is difficult to maintain indefinitely.

Status and trends

UNKNOWN | POOR | FAIR | GOOD

Status: FAIR (deteriorating)

DATA QUALITY

Good

	Summary	Status and trends
Indicator Status of piscivorous (fish-eating) birds (terns, cormorants and Australian pelican) **Region** Western Port **Measures** Number of Individuals (counts) over 38 years (summer (February) and winter (June–July) **Metric** Total counts (means, standard deviation and ranges)	Menkhorst (2015) evaluated trends in numbers of piscivorous waterbirds in Western Port since 1974 (and in West Corner Inlet since 1987).[5] The study identified opposing population trends for each location (terns, cormorants and the Australian pelican decreasing at Western Port, but increasing at West Corner Inlet). Most of the decline in piscivorous birds in Western Port is due to a decline in terns. About 70% of the decline in tern numbers is associated with the crested tern, with the fairy tern accounting for most of the remainder (most likely due to their reduced use of Western Port for feeding, since breeding numbers increased substantially at the western entrance to Western Port). The results suggest that feeding conditions for terns (and to a lesser extent for cormorants and pelicans) in Western Port have deteriorated compared with feeding conditions in West Corner Inlet.[6]	UNKNOWN POOR FAIR GOOD Status: GOOD (trend deteriorating) Trend deteriorating but no significant concern to species as they are relocating where fish stocks are available DATA QUALITY Good

	Summary	Status and trends
Indicator Status of little penguins **Region** Port Phillip Bay and Western Port **Measures** (i) Numbers of individuals (ii) Breeding success (iii) Body weight (male & female) **Metric** (i) Mean number of individuals recorded in standardised counts at the Penguin Parade each night, and mean numbers occupying burrows (ii) Number of chicks fledged per breeding female/ pair (iii) Weight in grams and exponentially weighted moving average (EWMA) of the de-seasonalised weight to a control limit, set at 2.5 standard deviations below the long-term target average **Thresholds** EWMA long-term target average for Phillip Island penguins of 1,141g for females and 1,275g males; the lower control limit of 955g for females and 1,069g for males **Data custodian** Phillip Island Nature Park/Earthcare St Kilda	The Phillip Island little penguin colony declined between 1980 and 1985. The population increased until 1995, when a significant decline in pilchards reduced numbers. Penguin numbers have been increasing again in recent years – most recent breeding data is the highest in 48 years of collecting data (per female rather than breeding pair). Researchers suspect severe drought and higher than average temperatures in 2006–09 contributed to a lower breeding success rate at St Kilda compared with Phillip Island.	UNKNOWN / POOR / FAIR / GOOD GOOD: PPB WP DATA QUALITY (PHILLIP ISLAND) Good DATA QUALITY (ST KILDA) Fair

Marine-dependent birds: knowledge gaps

The following research program is proposed to address critical knowledge gaps and to better understand the role of the marine-dependent birds in the health and sustainability of the marine ecosystems of Port Phillip Bay and Western Port.

The studies proposed below should be considered and/or conducted within the scope of an integrated research framework for the marine and coastal systems of Port Phillip Bay and Western Port.

Litter and accumulation of microplastics are a critical threat to birds, so the **Water quality** chapter addresses improving knowledge of the impacts of litter.

IMPROVE MONITORING OF SHOREBIRDS IN PORT PHILLIP BAY

Presently, there is good data on terns and gannets in Port Phillip Bay. However, the complete suite of species – pelicans, cormorants, herons, egrets, ducks and swans – are not studied as rigorously in Port Philip Bay as they are in Western Port.

Establishing a better monitoring regime for the western shore of Port Phillip Bay has already been recommended in the **Seagrass and dependent species** chapter. However, this chapter suggests that the regime must also better monitor birdlife activity, especially because most of the bay's shoreline is a Ramsar site and/or an Important Bird and Biodiversity Area.

The Geelong Field Naturalists have long-term data for many bird species and further studies could help them broaden their monitoring to better understand bird populations on the bay's western side.

UNDERSTAND IMPACTS OF FISH FOOD STOCKS ON BIRDS

Generally, a decline in waterbirds indicates birds are migrating elsewhere to improve their access to food stocks. A critical knowledge gap about piscivorous waterbirds is understanding the role of fishing regimes on fish stock health – particularly small fish such as anchovies, which are a more important food source than larger fish (particularly for crested terns and penguins).

There is a demonstrable and considerable decline in the threatened fairy terns in both Port Phillip Bay and Western Port (and more broadly across Victoria) over the past 50 years, while cormorants and pelicans have remained stable.

The reasons for this decline are unclear but researchers consider recreational fishing is having an impact. Further study of fish takes and fish stocks is required.

INTEGRATE RESEARCH

Critically, a more coordinated field research and meta-analysis to understand the collective research impact of multiple studies is recommended. Coordinated research requires comparable methods of analysis and undertaking studies that complement each other. Academic institutions could collaborate more closely to overcome these inefficiencies.

Marine dependent birds: the science stocktake

SHOREBIRDS IN PORT PHILLIP BAY[9]

Shorebirds are declining around the world, including populations that spend the non-breeding period in Australia.[10] Most migratory shorebirds spend the non-breeding period in sub-tropical and temperate regions, and breed in the arctic tundra. Shorebirds that breed in western Alaska and eastern Siberia, and spend the non-breeding season in Australia (and New Zealand), migrate along the East Asian-Australasian Flyway (figure B.1).

Conserving migratory shorebirds involves identifying important shorebird habitat, protecting it from detrimental change and monitoring changes in shorebird populations. Annual summer count data of shorebirds were collected at the following key sites in the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site from 1981 to 2010:

- Laverton-Altona
- Werribee-Avalon
- Moolap Salt Works
- Lake Connewarre Area
- Swan Bay and Mud Islands.

Several minor shorebird areas are also monitored on the Bellarine Peninsula, but these areas are not within the Ramsar site boundary.[11]

Count data revealed the following results:

- Three shorebird species – red-necked stint *(Calidris ruficollis)*, curlew sandpiper *(Calidris ferruginea)*, and sharp-tailed sandpiper *(Calidris acuminate)* – were regularly recorded in internationally significant numbers in the Ramsar site between 2006 and 2010.
- Of the 16 migratory shorebird species examined, 10 species (or 62%) recorded significant declines in numbers during annual February counts since 1981, with curlew sandpipers and lesser sand plovers experiencing particularly strong declines.
- Numbers for five species varied greatly between years, with no apparent overall trend.
- Marsh sandpiper *(Tringa stagnatilis)* numbers significantly increased during the monitoring period.
- Grey-tailed tattler *(Tringa brevipes)* numbers dropped dramatically between 1990 and 1991, then remained stable at very low levels from 1991 to 2010.
- Two resident shorebird species, masked lapwing *(Vanellus miles)* and Australian pied oystercatcher, showed different trends at different major shorebird areas. Masked lapwing numbers decreased significantly at Laverton-Altona and Swan Bay and Mud Islands, but increased significantly at the Moolap Salt Works. Similarly, Australian pied oystercatcher numbers decreased significantly at Swan Bay and Mud Islands and increased significantly at Moolap Salt Works. Neither resident species changed significantly overall when their annual count data from the five major shorebird areas were combined.

Given the declines detected in annual count data of migratory shorebird species in the Ramsar site, researchers expected fewer species to be present in recent years compared with the count data from the early 1980s. The 1980s count data was used to derive the levels of international significance for migratory shorebirds when the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site was designated in 1982.

Why it's important to protect our Ramsar sites of significance

WHAT IS THE RAMSAR CONVENTION?

The Convention on Wetlands of International Importance, also called the Ramsar Convention, is an intergovernmental treaty adopted on 2 February 1971 for, 'the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world'. Australia is host to many Ramsar sites, including Western Port and Port Phillip Bay.

To date, over 160 nations have joined the convention as contracting parties, representing more than 2,200 wetlands around the world and covering over 215 million hectares.

MIGRATORY BIRDS

Experts estimate the wetlands around the world have declined by 64–71% in the 20th Century, and wetland losses and degradation continue.[12] Furthermore, 'The decline of migratory shorebirds is related to the deterioration of stopping sites (including staging and stopping sites) in the Yellow Sea, including loss of intertidal wetlands, spread of invasive smooth cordgrass *Spartina* alterniflora on intertidal flats, an increase in pollution, and an increase in human disturbance'.[13] Migratory shorebirds require stable wetlands for breeding, as well as non-breeding and staging areas on migration.

In Australia, urban development is encroaching on essential habitat for migratory shorebirds including the red-necked stint, curlew sandpiper, and sharp-tailed sandpiper.

Like other migratory birds, the curlew sandpiper breeds in Siberia during June and July and then migrates to the southern Victorian bays in November/December for the Australian summer.[14]

Research shows that '... populations of the eastern curlew *(Numenius madagascariensis)* and the curlew sandpiper have declined by more than 80% in the last 50 years, and seven of Australia's 37 migratory wader species are edging towards extinction.'[15]

For the curlew sandpiper, identified threats to their habitat include coastal development, land reclamation (particularly on migration routes), construction of barrages and stabilisation of water levels that destroy feeding habitat.

The Australian Government has listed the curlew sandpiper as critically endangered in Victoria. The importance of protecting these shorebirds is internationally recognised.[16]

THE IMPORTANCE OF GANNETS

Gannets are an important, iconic species in the bays and a top predator. The gannets in Port Phillip Bay represent a large biomass and are an important indicator of the health of the bay. The total number of gannets breeding within the bay has not been surveyed for several decades and this species remains an important knowledge gap. However, several other studies have been published about gannets in recent years.[17]

Angel (2015a), for example, discovered that during the breeding season, seabirds adopt a central place foraging strategy. Their foraging range is restricted by the fasting ability of their partner and/or chick(s) and the cost of commuting between the prey resources and the nest. Because of the spatial and temporal variability of marine ecosystems, individuals must adapt their behaviour to increase foraging success within these constraints.

The authors determined the at-sea movements, foraging behaviour and effort of the Australasian gannet *(Morus serrator)* over three sequential breeding seasons of apparent differing prey abundance to investigate how the species adapts to inter-annual fluctuations in food availability. Interestingly, neither males nor females increased the total distance travelled or duration of foraging trip in any breeding stage despite apparent low prey availability. However, the energy expenditure of the gannets was greater in years of poorer breeding success (increased by a factor of three to eight), suggesting birds were working harder within their range. Additionally, both males and females increased the proportion of a foraging trip spent foraging in a poorer year. Individuals may be limited in their ability to extend their range in years of low prey availability due to competition from nearby colonies and, consequently, increase foraging effort within their restricted foraging area.

Marine-dependent birds in Western Port

Western Port has considerable biodiversity value.[18] At least 253 bird species have been recorded in Western Port, including 102 species of waterbird and 151 other species, including bush birds (passerines), raptors, cockatoos and parrots, pigeons, cuckoos and quail.[19]

Importantly, it is one of Victoria's most important sites for waterbirds, regularly supporting over 10,000 shorebirds from 37 species and over 10,000 waterfowl.[20] Before and during the 1980s, it regularly supported over 5% of the known Victorian population of eight species of migratory shorebird.[21] It has long been recognised as a wetland of international significance for migratory shorebirds – it's listed under the Ramsar Convention (1971), and it's included in the East Asian–Australasian Shorebird Site Network.[22]

In 2010, Western Port was also listed as an Important Bird Area (BirdLife International) because it regularly supports more than 1% of the global population of eastern curlew, red-necked stint and Australian pied oystercatcher numbers. It also hosts declining numbers of two threatened species, the fairy tern and the orange-bellied parrot.

Waterbirds are an important component of any wetland or estuarine system because they rely on the resources in these environments. Changes affecting the quality and availability of these resources affect the birds. In Western Port, the presence of important estuarine and marine resources like fish, seagrass, saltmarsh and mangrove communities, and near-coastal wetlands, affect the diversity of bird populations. Waterbirds, by virtue of their visibility and conspicuousness, can provide useful indicators of the 'health' of these resources.

Since the Shapiro Report (1975) was published, we have accumulated a large body of information about waterbirds (particularly shorebirds) in Western Port, including count data and mark–recapture studies, largely organised and conducted by volunteers. Hansen (2015) recently analysed a 40-year time series (since 1973) of waterbird observational data from various localities around Western Port.[23]

The study found numbers of many waterbird species are declining in Western Port, and very few are increasing. Data suggests long-term declines in the abundance of some species,[24] although trends have not been tested formally recently. Declines may reflect a range of impacts and landscape modifications, including disturbance, loss or degradation of habitat, and food web changes.

Species at the highest risk of further declines are trans-equatorial migrants, nomadic or dispersive, local breeders or largely piscivorous birds. Thirty-nine species were recorded often enough to analyse trends over time. Numbers declined for 22 species, including four species of duck, five species of piscivorous waterbird (cormorants, terns and pelicans), one species each of grebe, gull and heron, and 10 species of shorebird. Only two species (Australian pied oystercatcher and straw-necked ibis) increased significantly over the period.

Patterns of decline in non-migratory waterbirds may reflect diminishing wetland availability, local reductions in fish prey, increased predation pressure and changes in inland wetland resources. Declines in migratory shorebirds are most likely related to loss of habitat elsewhere on their trans-equatorial migration routes. These trends in waterbirds that use Western Port reflect widespread impacts on populations elsewhere in Australia and overseas.[25]

Menkhorst (2015) also evaluated trends in numbers of piscivorous waterbirds in Western Port since 1974 (and in West Corner Inlet since 1987).[26] The study identified opposing population trends for each location (terns, cormorants and the Australian pelican decreasing at Western Port, but increasing at West Corner Inlet). Falling numbers of terns accounted for most of the decline in piscivorous waterbirds in Western Port – crested terns accounted for around 70% of this fall, with the fairy tern accounting for most of the remainder. Interestingly, terns are using Western Port less for feeding, despite breeding numbers increasing substantially at the western entrance to the bay. This result suggests feeding conditions for terns (and to a lesser extent for cormorants and pelicans) in Western Port have deteriorated compared with feeding conditions in West Corner Inlet.

There is no obvious cause for the rising numbers of terns, cormorants and the Australian pelican *(Pelecanus conspicillatus)* at West Corner Inlet. However, the increasing success of commercial fishing (as measured by catch per unit effort) suggests higher fish stocks, which improve foraging conditions. To better understand these changes in piscivorous waterbird numbers, we must first understand the factors affecting the productivity and availability of prey species consumed by piscivorous waterbirds.

Menkhorst (2015) suggest changes in fish trophic relationships in Western Port have reduced the food available for the crested tern. Specifically, fewer Australian salmon *(Arripis trutta)* have reduced the time that schools of small fish spend in surface waters, making them less accessible to bird species that capture small fish by shallow plunge diving, such as terns. For the crested tern, the southern anchovy *(Engraulis australis)* is a particularly important prey species, for example.[27]

Several threats are known to affect waterbirds:

- Waterbirds are sensitive to disturbance by people and their pets, so public access to important roosting and foraging sites may disturb birds using those areas.
- Loss and degradation of shoreline vegetation through inappropriate land use practices reduces both roosting and breeding habitat.
- Erosion of foreshore substrate also reduces available feeding and roosting habitat.
- Sediment exports from the catchment have potentially contributed to past seagrass declines,[28] which affect invertebrate and fish communities and thus, the birds that rely on those marine fauna for prey.

Conserving waterbird habitat and minimising disturbance is impeded by a lack of detailed knowledge among land managers and the public about the location and significance of waterbird foraging habitat. In addition, rising sea levels associated with climate change are predicted to impact waterbirds through loss of habitat.[29]

Little penguins

Little penguins *(Eudyptula minor)*, the world's smallest penguin, occur throughout New Zealand and Australia's southern coast.[30] Up to 1,500 little penguins come ashore each night on Summerland Beach, Phillip Island, at the world famous 'Penguin Parade'. This penguin colony has been carefully monitored and managed for over 40 years to secure the population.[31]

The Penguin Parade is an iconic component of Victoria's tourism industry. In 2010, the site attracted 471,680 domestic and international visitors, providing direct employment to approximately 200 staff and contributing over $100 million in tourism to the region.[32] Therefore a significant fall in the number of penguins (as a result of climate change and other threats, for example) will affect regional tourism revenue.

Climate change affects seabirds directly (for example, heat-related mortality) and indirectly (for example, through the impact of climate on food webs).[33] In Australia, seabird responses to observed climate change vary by location and species:

- Seabird breeding timing and reproductive success has changed,[34] including for the little penguin.[35]
- In Western Australia, breeding distributions of tropical seabirds shifted southward as regional SSTs increased.[36]
- Warmer SSTs associated with the El Niño Southern Oscillation[37] are associated with reduced seabird populations on the Great Barrier Reef.[38]
- Evidence suggests increased SSTs reduce prey availability to seabirds through decreased productivity.[39]
- Strong winds and severe storms also affect seabird breeding participation, success of breeding and mortality.[40]

FORAGING

Satellite tracking by Gormley and Dann (2009) found little penguins at Phillip Island typically engaged in two foraging methods in winter:[41] short trips (1–2 days) near Phillip Island, and longer trips (10–50 days) into Port Phillip Bay and further west.[42] Total trip distances ranged from 19 km up to 1,237 km. A relatively high proportion of tagged penguins (71%) used Port Phillip Bay during foraging, with many spending over 50% of their time there. Areas of high use were between Frankston and St Leonards, Corio Bay, and to the south of the Western Treatment Plant near Werribee.

Kowalczyk (2015a, 2015b) recently determined spatio-temporal variability in foraging activity of little penguins, driven by variations in environmental conditions. These variations include rainfall activity that influences run-off and plumes from the Yarra River that drive local variations in productivity and food supply.[43] Foraging ranges are associated with higher chlorophyll-a, turbidity, temperature and lower salinity than non-foraging ranges. Therefore, links to water quality and climate trend indicators are very important. One of the major drivers of little penguin success is availability of food (pilchards, anchovies), which itself reflects ocean productivity cycles, as well as extrinsic factors such as fishing.

Foraging habits of St Kilda penguins

The little penguin population at St Kilda allows scientists to study the birds' biology. There are very few, if any, penguin colonies around the world of this size so close to a major city. Their significance for research is further compounded because the birds demonstrate signs of being more affected by environmental factors (relating to the proximity of Melbourne) than those at Phillip Island. Further, as little penguins forage at sea but breed on land, they are an excellent indicator species of changes in both the marine and terrestrial environments. The global population of penguins is in decline, so understanding the success of the colony at St Kilda is very important.

Penguins were first spotted at St Kilda in 1974, when there were just a few breeding pairs. As the population grew through the 1980s, long-term research has tracked the basic biology, trajectory and population trend of this particular penguin colony.

Researchers suspect severe drought and higher than average temperatures between 2006 and 2009 contributed to a lower breeding success rate compared with Phillip Island.

ADAPTIVE FORAGING HABITS[44]

Research suggests penguin foraging changes between drought and normal years.

Marine animals forage in areas where there is a high density of prey to maximise their energy input – particularly when they need to return frequently to their colony and feed their young.[45] Research conducted with Phillip Island Nature Parks studied how the St Kilda penguins adapt their foraging habits to counteract intense environmental variability in the area.

The penguins adapt their foraging strategy with changes in outflow of the Yarra River, an important anchovy spawning area. In drought years when river outflow falls, the penguins concentrate their foraging closer to the river mouth to take advantage of the increased fish productivity – a result of nutrients carried by the Yarra. By contrast, when outflow from the Yarra increases, the penguins range more widely in the bay to follow the dispersed nutrients and productivity, probably reflecting the movements and availability of anchovies.

The foraging flexibility is critical to the survival and viability of the little penguins, because the species relies on a key foraging area throughout the year.[46,47] However, researchers found that, despite their ability to modify their foraging ranges and diet, the little penguins displayed high variation in their reproductive success, signalling that the continued monitoring of their foraging ecology is central to their management.

Pilchard mortality and the impacts on penguin colonies

In May 1995, numbers of little penguins coming ashore fell at Phillip Island and St Kilda. This decline coincided with the death of many penguins in western Victoria. Research suggests the deaths were linked to a massive mortality of one of their food species, pilchards, throughout southern Australia.

Of 29 corpses autopsied, at least 26 died of starvation during this period following the pilchard mortality. Egg-laying by penguins in the subsequent breeding season (1995–96) was around two weeks' later than the long-term mean. Further, fewer eggs hatched and first-year mortality increased markedly.

Research suggested a virus that travelled through migratory fish populations caused the pilchard dieoff.[48]

REPRODUCTION AND SURVIVAL

Analysis of time series data from 1993 to 2011 by Afa´n (2015) found local SSTs are a major driver for wider ocean productivity, which then influences the reproductive timing of little penguins.[49] The penguins anticipate the annual peak in surrounding ocean productivity and the accompanying abundance in the food supply.

Examining the impact of climate change, Chambers (2014) forecast little penguins and other species of seabirds more generally in relevant locations will benefit from the warmer oceans projected under some climate change scenarios.[50] Higher SSTs are expected to increase seabird productivity, through earlier breeding, heavier chicks and an increased chance of double brooding (at least in the short term). However, this life history relationship must be balanced with appreciation of how climate interplays with adult survival on land.[51]

Annual adult survival of little penguins is positively associated with humidity during moult and negatively associated with rainfall during moult. Prolonged heat during breeding and moult is negatively associated with annual adult survival. Local climate projections suggest increasing days of high temperatures, fewer days of rainfall that will result in more droughts (and by implication, lower humidity) and more extreme rainfall events. All of these predicted climate changes are expected to negatively affect adult penguin survival.

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Sabella spallanzanii
European fan worm

FUTURE PRIORITIES

The *State of the Bays* report presents 50 assessments against 36 diverse indicators across seven themes, to provide a baseline for understanding the state of the environmental health of Port Phillip Bay and Western Port. It establishes a foundation for future reports on the bays. The report also identifies knowledge gaps for future study that would improve our understanding and build on the existing scientific evidence base.

Building on the indicator assessments contained in this report, and the identified knowledge gaps, this chapter presents the need for a Marine Knowledge Framework for the bays encompassing eight future priorities. These priorities should inform the Government's marine research program and the (i) design of an adaptive management cycle and (ii) assessment of future indicators of the state of the bays.

At the time of writing the Department of Environment, Land, Water and Planning, Victoria (DELWP) confirms that work by CSIRO is underway to develop a provisional set of indicators for future *State of the Bays* reporting. It is anticipated that, these indicators for future reporting will be made available by DELWP, and published on the OCES website, in mid-2017.

It is also anticipated that the release of the Environmental Management Plan (EMP) for Port Phillip Bay (due in mid-2017) – together with the scientific baseline provided by this *State of the Bays* report and the pending, future indicators for reporting – will enable the development of an adaptive management cycle for the bays (see figure FP.1).

ADAPTIVE MANAGEMENT CYCLE

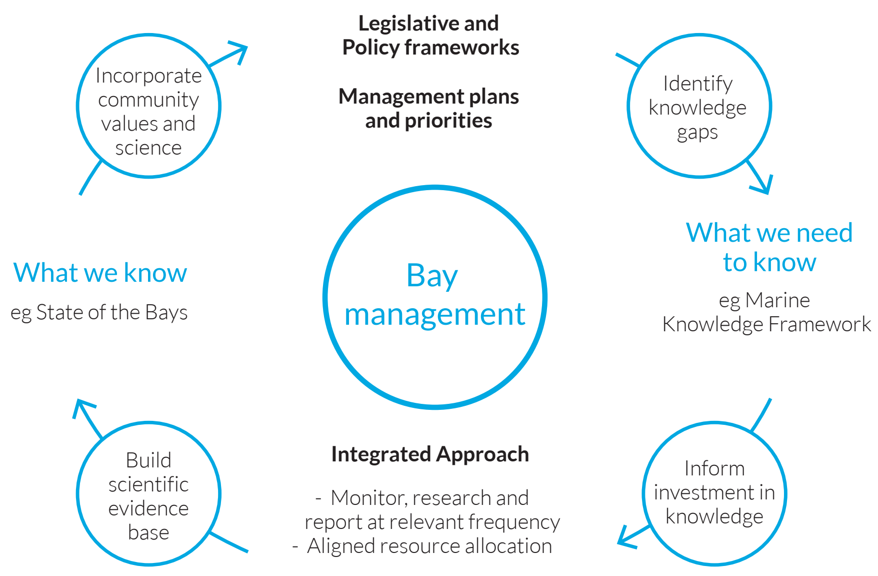

Figure FP.1: Adaptive Management Cycle; managing environmental health of the bays

The figure illustrates the importance of the shift in environmental reporting asserted in the *State and Benefit* framework. The shift from reporting on 'what we know' to 'what we need to know' to make better decisions. Reports like *State of the Bays* provide the evidence base, which, along with community values, inform government decision making and the formulation of management priorities. In turn, those management priorities lead to (i) direct interventions to improve environmental outcomes , and (ii) the establishing of a knowledge framework to address knowledge gaps, reduce uncertainties and form the future evidence base for assessing management interventions and environmental outcomes.

With regard to Port Phillip Bay and Western Port, a Marine Knowledge Framework for the bays (led by DELWP in collaboration with all responsible agencies) would set the agenda for future investment in environmental science. The framework aims to improve the evidence base, which in turn, would be used to implement and assess: management priorities for Port Phillip Bay; the existing strategies for Western Port; relevant State Environment Planning Policies; the Biodiversity Plan (due in 2017); and other related policy commitments.

This Marine Knowledge Framework must have clear objectives including the appropriate funding of critical marine research and a commitment to monitor and report on indicators and targets at relevant frequencies.

It is a priority for the new Marine and Coastal Act (due in 2017) to formalise these arrangements legislatively and to stipulate the requirement for a Marine Knowledge Framework to guide activity and investment to build our knowledge base with ecological, social and economic research that leads to environmental outcomes.

Similarly, the Biodiversity Plan should extend to the protection and conservation of marine as well as terrestrial landscapes and habitats. Marine habitats, particularly the benefits of blue carbon, should also be considered as a part of Victoria's climate adaptation and mitigation strategies.

The future priorities listed below recognise that research outcomes would benefit from better integration and coordination of effort and by embracing new technologies and methods, to enable more frequent and extensive monitoring and ultimately, improve understanding. The strategy to improve our knowledge of the future priorities should be set out in the Marine Knowledge Framework.

Future priorities fall into two categories:

- TOOLS – enabling better tools to improve the monitoring and reporting system – two priorities are listed.
- UNDERSTANDING – addressing critical gaps in understanding the ecological processes of the bays to build the evidentiary base for decision making – six priorities are listed.

MARINE KNOWLEDGE FRAMEWORK

As illustrated in figure FP.1, it is critical to develop a Marine Knowledge Framework for Port Phillip Bay and Western Port to ensure research and monitoring efforts are directed towards management priorities: addressing knowledge gaps, reducing uncertainties and forming the future evidence base for assessing management interventions and environmental outcomes.

The focus of the Framework should initially be the two bays but the scope could be extended to the broader Victorian marine environment in the future.

A coordinated approach to marine research is critical. Currently, marine science tends to be disaggregated, species-specific research, largely reflecting resource constraints. A strategic future program for marine research must understand the key habitats (seagrass, sediment, mangrove, saltmarsh, reef, and water column), and importantly, how the habitats interact. A systems approach to ecosystems will provide the evidence base for improved decision making and management interventions.

The key challenge for designing a Marine Knowledge Framework is the current absence of a management plan for marine environments – especially in Western Port. The Environmental Management Plan for Port Phillip Bay (due in 2017) will address this gap for Port Phillip Bay. But, ultimately, clear government policy and management priorities are needed for all marine assets across Victoria. Once clear management priorities are formalised, the Marine Knowledge Framework becomes an urgent deliverable to acquire the evidence base for assessing progress against the management priorities. It would be anticipated that the Framework would be implemented well before the next *State of the Bays* report to enable assessing the updated suite of indicators.

Coordinated research requires comparable methods of analysis among agencies and researchers, and undertaking studies that complement each other. Otherwise, excellent research is sometimes undermined by a lack of integration with pre-existing sites and data.

The proposed Marine Knowledge Framework would focus on developing the standards and protocols for marine research in the bays. It would emphasise the why and how of marine science and could address a number of the procedural gaps identified in this report, such as:

- meta-analysis of existing studies
- incorporating citizen science (Reef Watch, Sea Search, Birdlife Australia) into digital reporting and integrated monitoring regimes
- connecting marine practitioners (researchers, managers, stakeholders)
- ensuring management and policy outcomes are met through improved information and by identifying opportunities for delivering research to support outcomes
- institutional arrangements.

The approach to addressing the eight future priorities explained in detail below would also be formulated in the Marine Knowledge Framework.

The proposed Framework would build on the strong foundation of the existing monitoring programs of the Marine Protected Areas. It would also provide a strategic vision for integrating diverse research partnerships. Current partnerships such as the Victorian Marine Operational Model (VIC-MOM) and Integrated Marine Observing System (see **Water quality** chapter) are good examples of partnerships integrating marine research.

FUTURE PRIORITIES: TOOLS

MAINTAIN AND EXPAND MAPPING REGIMES

Ongoing marine monitoring of the bays requires periodically mapping habitats (seagrass, mangrove, saltmarsh etc.), to update the benchmark mapping of Boon et al. (2011)[1] and others, and to inform an adaptive management cycle.

The frequency of monitoring and mapping activity should allow researchers to identify natural cycles of habitat loss and recovery, and unnatural changes due to human impact. Mapping and remote sensing will help bay managers to understand the extent of pest invasion, and other threats to habitats, and identify early indicators of those threats.[2]

The proposed Marine Knowledge Framework would identify the critical areas for informing bay management, which could then be prioritised for strategic, frequent mapping. Other regions could be mapped less frequently. The seagrass maps used in this report were compiled over a four-year period (2008–11) and are now over five years old, for example. There is no ongoing mapping of seagrass extent, or monitoring of seagrass condition. This is a critical knowledge gap in our understanding of what drives seagrass health in Port Phillip Bay and Western Port.

Further, technologies like NearMap (already used in Western Port seagrass research) could supplement mapping, by repurposing existing aerial photography for different objectives. Similarly, existing research partnerships such as the CSIRO Landsat mapping of Western Port vegetation could be extended.

A robust marine mapping discipline will improve models of Victoria's marine environments. Higher resolution mapping will enable more complex hydrodynamic modelling, so we can better resolve coastal processes and understand the sensitivities of different marine systems. This modelling would include nutrients, suspended sediments and pollution events, among other things.

A strong mapping regime will enable a better understanding of the interdependencies of different marine ecosystems and their interaction with catchments. It will bring research of the marine environment more into line with studies of the biodiversity of terrestrial landscapes.

IMPROVED MONITORING TECHNOLOGY

Advances in monitoring technology include drones, 3D mosaic mapping, autonomous underwater vehicles (AUVs), bathymetric LiDAR (Light Detection and Ranging) and multi-beam sonar (for characterising the geophysical structure of reefs, biota and seabeds in general). Future monitoring regimes for the bays must consider adopting (or expanding the use of) these technologies that:

- allow for more comprehensive data from across the bays
- are less expensive and safer than conventional monitoring techniques
- provide data faster and at better resolution
- reduce human error
- challenge current monitoring conventions
- increase the scope and immediacy of digital reporting mediums.

A number of the current monitoring sites were established based on constraints such as human access, human resourcing and safety considerations. The emerging technology will allow monitoring to occur at different and more numerous sites and could replace time-intensive techniques such as quadrat monitoring.

Adopting emerging technologies will increase the frequency of reporting and will reduce the possibility that important assemblage transitions may be missed. Further, improved monitoring technology will aid the assessment of 'blue carbon' and the role of habitats in carbon sequestration.

The emerging technology will also enable researchers to reclassify old data and videos in new and dynamic ways, providing better trend and historical data. The improvements in mapping technologies will enable more sophisticated analysis of marine environments, which will improve understanding and management interventions.

FUTURE PRIORITIES: UNDERSTANDING

Understanding Impacts

IMPACT OF CLIMATE CHANGE

On the one hand, climate change will reduce rainfall, but increase the number of intense rainfall events, which in turn will cause higher event-related flows containing nutrients, sediments and other pollutants to the bays. Sea levels are expected to rise, which will affect Port Phillip Bay's extensive coastline and Western Port's gently sloping shoreline. Climate change will also impact catchment discharges, alter bay water chemistry, change sea surface temperature (SST) and influence changes to wind and storm patterns. Increased temperature and evaporation can cause desiccation on exposed mudflats.

On the other hand, EPA modelling[3] suggests sea level rise will reduce pressures from catchments. Specifically, catchment flows will enter a larger volume of embayment water and be diluted/mixed more than they are currently. Under this scenario, coastal processes – sea level rise and winds – will lead to increased wave energy, increased tidal flats exposure, coastal erosion and increased sediment re-suspensions, which in turn will affect the bays' water quality and habitats.

We need a strategic approach to improving our understanding of climate change impacts across all marine habitats. Better knowledge of the bays will help inform management options and create solutions that allow biodiversity to adapt to the changes. It will also help prevent catchment-based pollution, and increase the resilience and health of near-shore waters.

This report explored many examples – from how tidal inundation affects waterlogging and salinity regimes in saltmarshes, to the causal mechanisms of the influence of SST in Bass Strait on whiting recruitment.

The proposed Marine Knowledge Framework should also consider adaptation options – both social adaptation (for example, climate-resistant coastal infrastructure) and environmental adaptation (for example, improving resilience of species). Ultimately, a more nuanced understanding of climate change impacts will also improve the evidence base for system-wide management of landscapes from catchments to coasts.

IMPACT OF MARINE PESTS

Marine pests can affect habitats (particularly reefs) and processes (water quality and nutrient cycle). Denitrification remains potentially vulnerable to introduced marine pests (and some native species), for example.

Marine pests may affect nitrogen cycling by:

1. displacing or consuming the infauna living in the sediment
2. intercepting organic matter before it reaches the sediment (short circuiting denitrification), and/or
3. increasing nutrients in the water column by injecting wastes directly into the water column rather than into the sediment.

More research is required to understand the impact of specific pest species. No recent surveys have been taken of the distribution and abundance of any exotic species in Port Phillip Bay. The effect of future exotic species is also unknown.

IMPACT OF POLLUTION

Better understanding of how pollution affects marine ecosystems and how they recover over time is a key research priority. An example is understanding legacy toxicants in embayment sediments.

Understanding the impacts, extent and source of emerging chemicals (pharmaceuticals from storm waters, micro plastics, litter and toxicants) entering embayment waters and their effects on food webs, fish and marine fauna is particularly important. With better information, we can develop management options (for example, improved technology for litter removal, more sophisticated compliance regimes).

Similar to the research of climate change impacts, understanding pollution impacts will improve the evidence base for system-wide management of landscapes from catchments to coasts.

This research program would build on the VIC-MOM partnership, where relevant.

IMPACT OF FISHERIES, AQUACULTURE AND SHIPPING

Climate change, invasive pests and pollution are threats caused by changes to natural processes and catchment flows. But Victorians also impact on the bays directly through recreational and industrial uses of the bays.

Understanding the impact of recreational fishing on fish populations in the bays is critical. It is even more important now that commercial netting is being phased out in Port Phillip Bay and recreational fishing is expected to increase. Future research would depend on establishing a fish monitoring regime in Port Phillip Bay and Western Port within the proposed Marine Knowledge Framework. This approach would consolidate the current diverse monitoring approaches into a strategic system for different outcomes (for example, fisheries and catchment management). It is also important to understand the system-wide implications of pressures on existing fish stocks, and the implications for habitats and other species. The contribution of citizen science (especially ReefWatch and the Angler Diary Program) to this effort should also be assessed.

Understanding the impact of shipping and port infrastructure is also important. As population increases so will these activities, and continued diligence in monitoring and understanding the impact of shipping is required. Some of the deep reefs of Port Phillip Bay (such as the popular Cathedral Reef) are located on the edges of the shipping lanes.

Fishing and shipping also contribute to the threat of pollution directly through tackle line litter and oil spills.

Understanding Marine Systems

UNDERSTANDING THE INTERTIDAL SYSTEM

The intertidal system is a critical ecosystem within the marine environment, particularly in Western Port (see **Intertidal habitats and dependent species**). Understanding the interaction between seagrass, soft sediments, mangrove, saltmarsh and the water column habitats is critical for maintaining system health.

Research priorities for vegetated soft sediments include:

- understanding vegetated intertidal soft sediments, and establishing indicators based on seagrass, shorebirds and fish
- monitoring species, because the bays are home to rare species that have not been found elsewhere
- a survey to compare current biodiversity of soft sediments in Western Port with past records and adjacent bays. Researchers could also use this information to assess various disturbances and invasive species.
- understanding the functional roles of benthic organisms[4]
- exploring the sediment delivery to mangrove and saltmarsh
- examining the impact of elevated nutrients on vegetation structure.[5]

Further studies on how birds (and bats) use the intertidal habitats are also important. An estimated 30–40 species of birds inhabit the intertidal habitats of Port Phillip Bay and Western Port. These species are distributed across the habitats. Some are attracted to the exposed soft sediments, others to the fresh water inputs or the open saltmarsh (like the endangered orange-bellied parrot), and others to the ponding water, both fresh and salt.

The intertidal habitats are the most 'visible' marine environments, located adjacent to human population, but also the most vulnerable to development and other threats. Given this, further studies should consider coastal dynamics such as the link between sediment delivery and surface elevation, and erosion patterns in the bays, to improve coastal management and protection.

Erosion is complex and different erosion types have different effects. There needs to be better understanding of the role of elevation, erosion, sediment provenance (the original source of sediments being deposited), sedimentation rates, and the impacts of storm surges in intertidal habitats in the bays, as sea level rise impacts these ecosystems.

UNDERSTANDING THE SUBTIDAL SYSTEM

The current CSIRO study to propose future indicators for the bays (due in 2017) has provisionally recommended the following assessments for subtidal systems to improve management outcomes:

- For unvegetated subtidal soft sediments: indicators of ecosystem health based on nitrogen gas, ammonia in the sediment, and oxygen are the priority.
- For vegetated subtidal soft sediments: indicators of ecosystem health based on *Zostera* seagrass, epiphytic algae, and juvenile fishes are the priority.
- For vegetated subtidal rocky reefs: indicators of ecosystem health based on reef fish, urchin grazing pressure, and canopy forming algae are the priority.

There is very limited knowledge of the deep reefs, reducing the potential to effectively manage the bays. The social and economic value of these deep reefs is significant. They are tourist and recreational attractions – the most visited diving sites in Victoria – and some of the deep reefs lie within the shipping lanes. The deep reefs also impact on broader ecological processes in the region.

Possible further research includes understanding how sponge communities maintain water quality through filter feeding.

Endnotes

1 Boon PI 2011, 'Saltmarsh', in ***Understanding the Western Port environment: a summary of current knowledge and priorities for future research***, Melbourne Water, Melbourne, pp. 116–33.

2 Saintilan N, Rogers K and Tomkins K (in press), ***Mangroves, saltmarshes, sedimentation and sea level***, Macquarie University and University of Wollongong.

3 Yeates, P. and Okely, P. (2016) ***Western Port SEPP Loads Modelling Strategy, Development and Scenarios***, Report by Hydronumerics for EPA Victoria.

4 Melbourne Water 2011, ***Understanding the Western Port environment: A summary of current knowledge and priorities for future research***, Melbourne.

5 Saintilan N, Rogers K and Tomkins K (in press), ***Mangroves, saltmarshes, sedimentation and sea level***, Macquarie University and University of Wollongong.

6 DELWP advise that work undertaken by CSIRO has confirmed a provisional set of indicators for future *State of the Bays* reporting. These indicators will be published on the OCES website in 2017.

Aracana ornata
Ornate cowfish

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Spatial data is sourced from the Victorian Spatial Data Library.

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