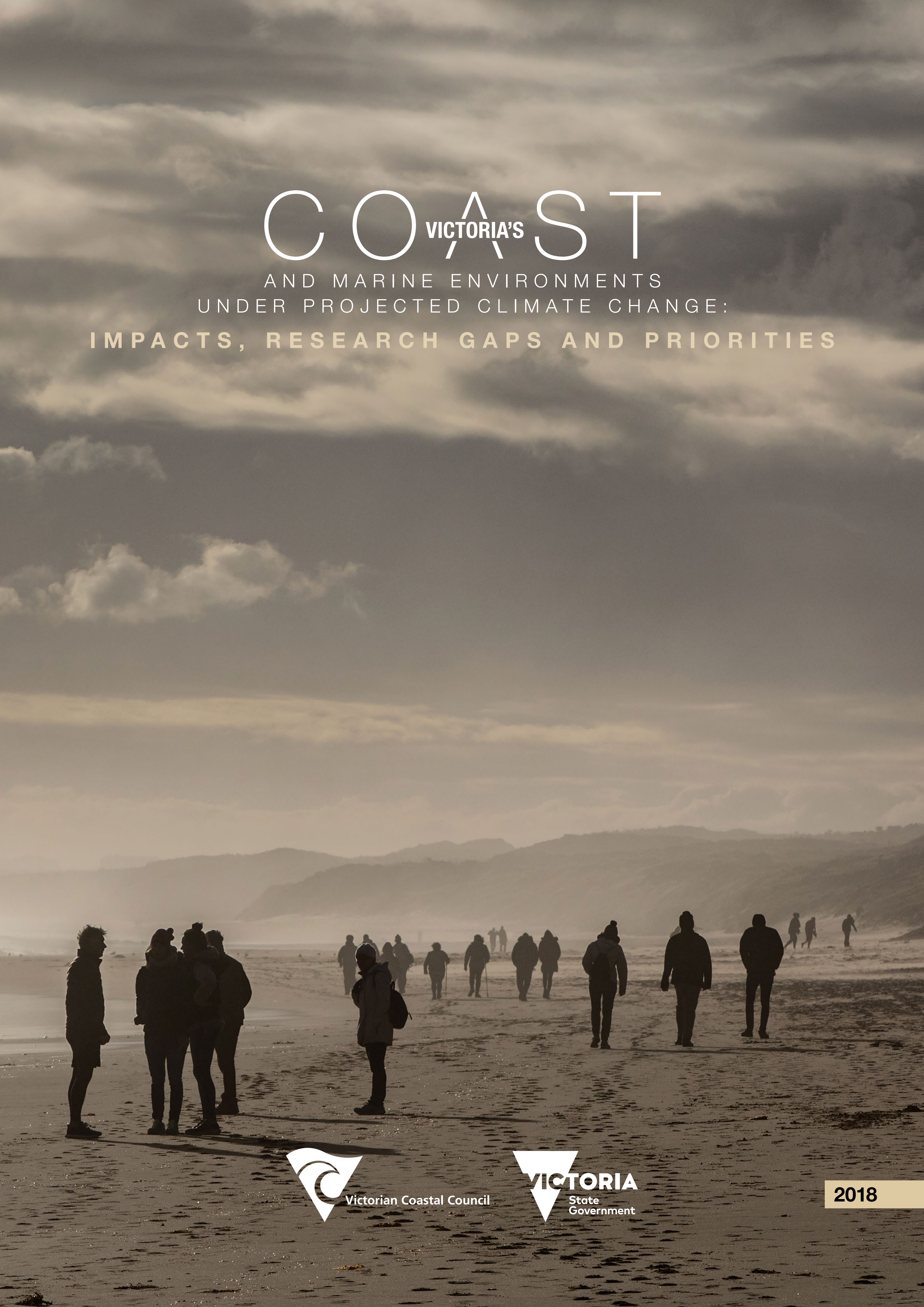
# VICTORIA'S COAST AND MARINE ENVIRONMENTS UNDER PROJECTED CLIMATE CHANGE:

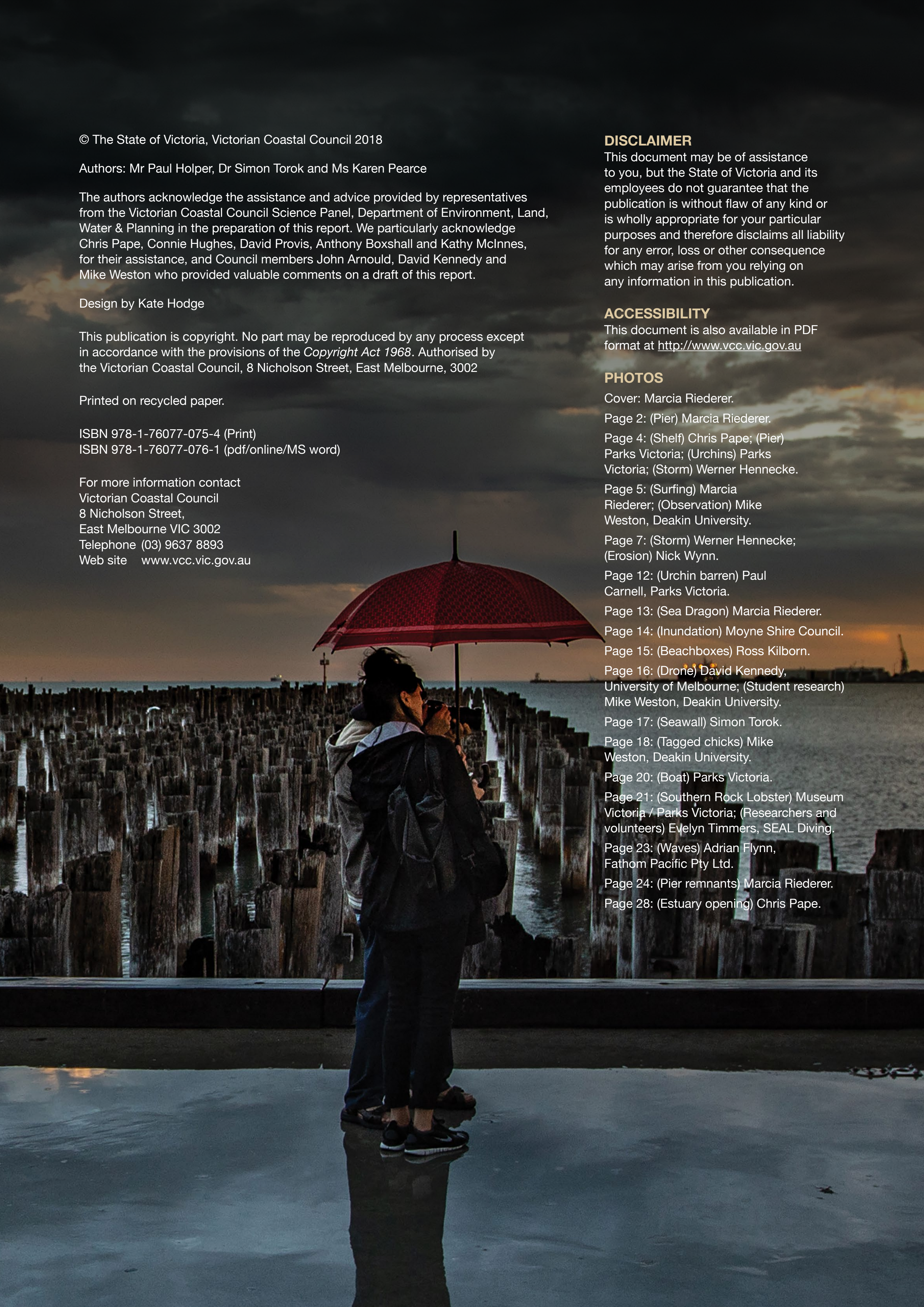
## IMPACTS, RESEARCH GAPS AND PRIORITIES



Victorian Coastal Council

VICTORIA State Government

2018





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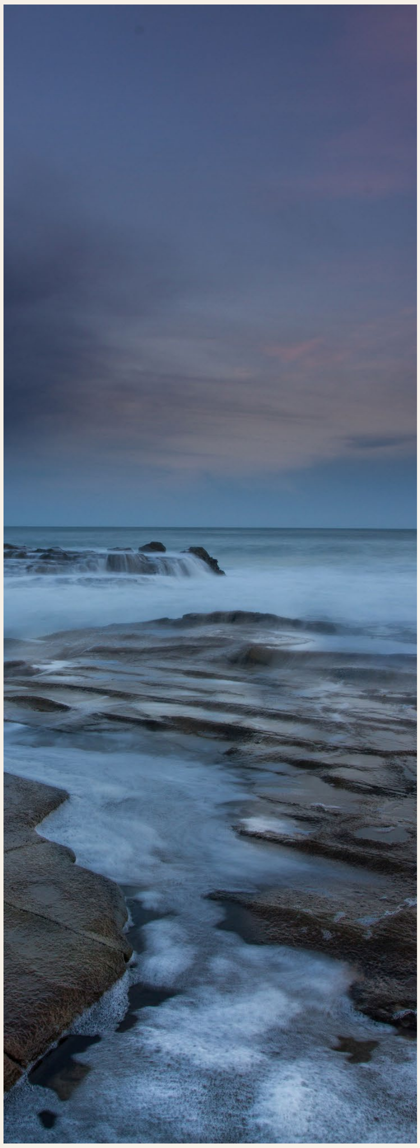


In October 2017, the Victorian Coastal Council (VCC) Science Panel held a workshop to examine Victoria's coastal and marine environment under future climate change. This report summarises and extends the workshop findings and forms part of the VCC's handover to the new Marine and Coastal Council (MACC).

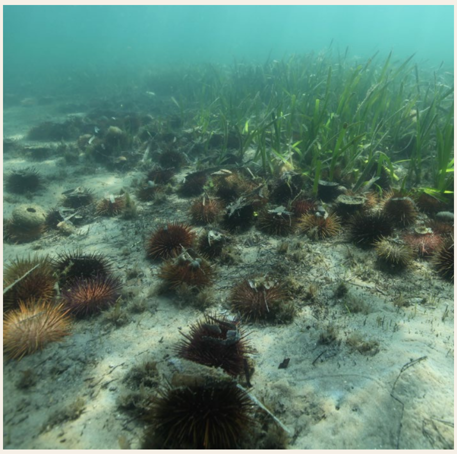
In future, Victoria's coastal regions are expected to have a warmer climate year-round, more hot days and warm spells, harsher fire weather and longer fire seasons, less rainfall in winter and spring, more frequent and more intense downpours, rising sea level, increased frequency and height of extreme sea-level events, increased wave height in winter, increased frequency of easterly winds, and warmer and more acidic oceans.

Climate change is likely to have considerable impacts on marine life, habitats, ecosystems and landforms, with flow-on effects to society and the economy. Impacts of sea-level rise are likely to include more frequent and extensive inundation of low-lying areas, and erosion of cliffs, beaches and foreshores. Changes in wave direction will cause realignment of beaches. Ocean acidification impedes the ability of calcifying organisms to form their skeletons and the ability of some reef fish to avoid predators. Higher temperatures, as well as changes in ocean currents, are likely to lead to continued species distribution shifts, and spread of invasive species and diseases.

The report identifies 'hot spots', or significant likely impacts of climate change, that include more frequent and extensive inundation of low-lying areas, shoreline realignment and changed estuaries. The report also identifies 'sentinels', or changes that could imply thresholds or tipping points. Examples of these include species distribution shifts and spread of invasive species and diseases.

There is much known about the general extent and likely impacts of climate change, but there are major gaps in knowledge, especially relating to coastal regions. The report identifies some such gaps, including the need for detailed regional coastal-climate projections and better information about biological impacts.

Based on the workshop findings, expert interviews and a literature review, the report concludes with a list of recommended research projects.



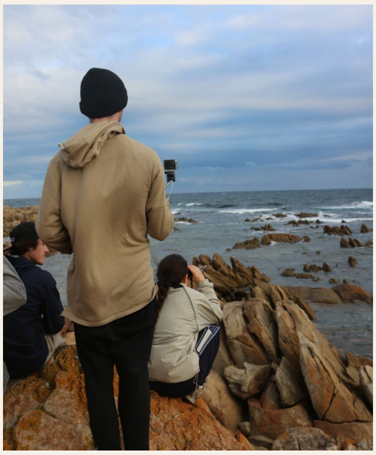
# Background to this report

The Victorian Coastal Council (VCC) is a statutory body advising the Minister for Energy, Environment and Climate Change on coastal issues in Victoria. The VCC convenes a Science Panel to provide scientific advice about Victoria's coast.

In December 2017, the Victorian Government introduced a bill to establish a new Marine and Coastal Act. Along with the bill, the Department of Environment, Land, Water and Planning (DELWP) released *Strengthening Victoria's Marine and Coastal Management: a proposed transition plan*, which outlines the policy and practical 'on ground' actions that are being delivered to support these reforms, as well as other measures to help transition and implement the new approach.[1] Under the Act, the VCC will be replaced with a new Marine and Coastal Council (MACC), tasked with a range of functions including advising the Minister on the development and implementation of the Marine and Coastal Policy and the Marine and Coastal Strategy.

The proposed transition plan outlines the functions of an improved marine and coastal management system. The first of these is improving the extent of knowledge of the condition of the marine and coastal environment and using that knowledge to inform decision-making and evaluate the effectiveness of those decisions.

In October 2017, in light of new peer-reviewed research suggesting physically plausible scenarios of global sea-level rise between 2.0 and 2.7 metres by the year 2100,[2] the VCC asked the Science Panel to review how this new global information changes what is known in the Victorian context. Due to the suspected knowledge gaps in the literature, the Panel used a two-step expert elucidation process to refine the inputs for this report. Initially, the Science Panel held a workshop to examine Victoria's coastal and marine environments under future climate change scenarios. The findings from the workshop were included in a draft report, which was provided to the workshop participants for review and critique. This process enabled the Panel to provide their expertise, identify relevant research publications, add expert opinion, and later review the final product for accuracy. This is a common process to gather expert opinion in the absence of detailed published information in the scientific literature, or where there are known knowledge gaps.[3]



At the initial workshop, following a presentation on climate science and projections provided by Dr Kathy McInnes from CSIRO, attendees participated in a series of activities aimed at capturing:

- predicted coastal and marine impacts under two climate change scenarios: 'Paris' (Paris agreement achieved) and 'Business as usual' (no mitigation)
- indicators or changes in condition that suggest system departures from natural variability
- implications for knowledge, monitoring and management (participants identified specific monitoring or research tasks that would fill important knowledge gaps that currently hinder effective planning and management).

The Workshop process enabled participants with particular expertise to have input and to comment on opinions expressed by others, thereby providing real-time 'peer-review'.

This report summarises and extends the workshop findings, and forms part of the VCC's handover to the new MACC. Objectives of this report include to:

- summarise the latest science, projections and impacts of climate change on Victoria's coasts
- suggest and highlight key areas of focus and advocacy for the new MACC
- inform development of projects under the proposed transition plan accompanying the passing of the Marine and Coastal Act
- identify future areas of research (gaps and needs) and monitoring priorities that will assist coastal managers in a practical way.

# Climate observations and projections

## Observed changes

The global concentration of atmospheric carbon dioxide passed 403 parts per million in 2017.[4] This is much higher than the natural variations between 172 and 300 parts per million that occurred for hundreds of thousands of years prior to the industrial revolution, and probably the highest it has been for more than two million years.

Seventeen of the world's 18 hottest years on record have occurred in the 21st century. Globally, 2017 was the third-warmest year on record since 1850, and the warmest non-El Niño year.[5] It follows the world's warmest year in 2015, and second warmest year in 2016.

The oceans have absorbed more than 90 per cent of the climate system's increase in energy, raising their temperature. Coastal sea-surface temperatures have been increasing at a faster rate than ocean temperatures.[6]

Additionally, the oceans have absorbed about 30 per cent of the extra carbon dioxide emitted through human activities over the past 200 years, leading to ocean acidification. Ocean pH has fallen 0.1 units, representing an increase of approximately 30 per cent in the hydrogen ion concentration of sea water.[7]

Victoria's climate is warmer and drier than in previous decades, and the rate of warming has increased since 1960. Average rainfall has declined since the 1950s, especially in autumn. Sea level has risen by about 22.5 cm since 1880, the impacts of which are more profound during extreme events.[8]

## Climate change projections

Climate projections are based on sophisticated national and international global climate models. These models use the physical laws that govern the Earth system to simulate the climate. The models run on some of the world's most powerful supercomputers, and successfully represent the important features of today's climate as well as those of the past.

Population growth, energy consumption, economic changes and technology will all affect future greenhouse gas emissions and, hence, atmospheric greenhouse concentrations. To cover a range of possibilities, scientists use emissions scenarios called Representative Concentration Pathways (RCPs) to develop climate projections. These projections describe various emission futures.[9]

The most extreme scenario considered by scientists, called RCP 8.5 (relating to the resulting level of greenhouse-gas radiative forcing by 2100, measured as 8.5 watts per square metre, or W/m$^2$), represents fast population growth to 12 billion, a low rate of technological development and high energy use. For over a decade, the world has tracked at this rate, so this scenario is sometimes associated with 'business as usual' (although equating these is not technically correct[10]). By the year 2100, RCP 8.5 is likely to lead to about 4.9 °C of global warming, with carbon dioxide equivalent concentrations (that is, including carbon dioxide, other greenhouse gases, and aerosols) of approximately 1370 ppm.[11]

The lowest emissions scenario, called RCP 2.6 (greenhouse-gas radiative forcing by 2100 of 2.6 W/m$^2$) leads to about 1.5 °C of global warming, and would see carbon dioxide equivalent concentrations reach about 490 ppm.

At the 21st Conference of the Parties in Paris in 2015, agreement was reached under the United Nations Framework Convention on Climate Change for countries to take action to keep global average temperature increase to well below 2 °C and pursue efforts to keep warming below 1.5 °C above pre-industrial levels. To meet the Paris Climate Agreement, the world needs to be on at least an RCP 4.5 pathway (forcing by 2100 of 4.5 W/m$^2$).[12]

The projections in the following infographic cover the range between a high emissions future (RCP 8.5) and a mid-range emissions future (RCP 4.5; which approximates meeting the Paris Climate Agreement[13]).[14,15,16,17]

The threats from climate change may be underestimated, and greater than commonly reported through assessments such as those of the Intergovernmental Panel on Climate Change (IPCC). A US National Oceanic and Atmospheric Administration (NOAA) report in 2017 on global and regional sea-level rise scenarios stated that 'projections and results presented in several peer-reviewed publications provide evidence to support a physically plausible global mean sea-level rise in the range of 2.0 to 2.7 metres, and recent results regarding Antarctic ice-sheet instability indicate that such outcomes may be more likely than previously thought.' The NOAA report recommends a revised 'extreme' upper-bound scenario for global mean sea-level rise of 2.5 metres by the year 2100.[18] The report notes that while this is unlikely (0.1% under RCP 8.5) there are known and possible pathways for this outcome.

In addition to the changes listed in the infographic *per se*, there is potential for the confluence of compounded events (for example, rainfall, river flooding, and storm surge) to have even greater impact under climate change. Furthermore, there may be more severe changes at the boundaries of changing atmospheric circulation patterns,

## Our future climate

In future, Victoria's coastal regions are expected to have:

- a warmer climate year-round, with an increase in temperatures of between 0.6 °C and 1.3 °C by 2030, and between 1.1 °C and 3.2 °C by 2070 (relative to the climate of 1986 to 2005)
- more hot days and warm spells
- fewer frosts
- harsher fire weather and longer fire seasons
- less rainfall in winter and spring
- more frequent and more intense downpours
- rising sea level of between 8 and 20 cm by 2030 and between 20 and 59 cm by 2070 (relative to the 1986–2005 level), with higher levels should there be greater melting of the Antarctic ice sheet
- increased frequency and height of extreme sea-level events
- an increase in wave height in winter
- warmer oceans, with sea-surface temperatures rising by between 1.1 and 2.5 °C by 2070
- more acidic oceans.

leading to shifts in erosion and accretion patterns, rotation of beaches and a less stable coastline.[19] For example, a belt of high pressure systems called the subtropical ridge greatly influences Australia's climate and is moving southwards due to climate change. This could lead to a change in the wind regime along the southeast coast of Victoria – this region is dominated by westerly winds, but with the movement of the subtropical ridge there could be an increase in easterlies, leading to westward transport of sediment and potential changes in beach alignment.[20]

Table 1 lists climate projections for Victoria's coast for the years 2030 and 2090 as presented at the workshop by Dr Kathy McInnes.

Predicting biological changes at the state level is difficult, and so in addition to these physical projections there is a high likelihood of ecological surprises.[21] Moreover, human activities on the coast can mask and accelerate impacts and even override them.[22]

*Table 1 Summary of marine and coastal climate projections for Victoria (Source: Kathy McInnes, VCC workshop, 2017)*

| VARIABLE | LOCATION/ SOURCE | SCENARIO: RCP 2.6 (MITIGATION) | | SCENARIO: RCP 8.5 (BUSINESS-AS-USUAL) | |
|---|---|---|---|---|---|
| *Changes relative to 1985-2005 | | 2030 | 2090 | 2030 | 2090 |
| Sea surface temperature (K) | Stony Point/ NRM Marine Explorer | 0.5 (0.3 to 0.8) | 0.5 (0.3 to 0.9) | 0.6 (0.3 to 0.9) | 2.3 (1.9 to 3.8) |
| Ocean pH | Stony Point/ NRM Marine Explorer | -0.07 (-0.07 to -0.06) | -0.07 (-0.07 to -0.06) | -0.08 (-0.09 to -0.08) | -0.3 (-0.3 to -0.3) |
| Aragonite saturation | Stony Point/ NRM Marine Explorer | -0.28 (-0.29 to -0.25) | -0.28 (-0.29 to -0.21) | -0.34 (-0.36 to -0.26) | -1.1 (-1.2 to -1.0) |
| | | 2030 | 2100 | 2030 | 2100 |
| Sea-level rise (m) | Warrnambool/ CoastAdapt | 0.12 [0.07-0.16] | 0.42 [0.24-0.61] | 0.13 [0.08-0.17] | 0.70 [0.45-0.98] |
| | Westernport/ CoastAdapt | 0.11 [0.07-0.16] | 0.41 [0.23-0.59] | 0.12 [0.08-0.17] | 0.69 [0.44-0.96] |
| | East Gippsland/ CoastAdapt | 0.12 [0.08-0.17] | 0.41 [0.23-0.60] | 0.13 [0.08-0.17] | 0.73 [0.49-1.00] |
| Other projections | | Notes | | 2090 | |
| Waves | Southern Ocean/ Hemer et al 2013 | Wave climate model run with wind forcing from several climate models. New simulations with latest climate models yield similar results | | Future increases in Southern Ocean wave height and wave period | |
| Storm surge | South Coast/ Colberg and McInnes 2012 | Hydrodynamic model run with wind and pressure forcing from several climate models. New simulations with latest climate models yield similar results | | Small decline in extreme sea levels (~cm) owing to southward movement of weather patterns. | |
| Storm surge + waves | Gippsland O'Grady et al 2015 | Analysis of consistent wave and hydrodynamic model projections on nearshore wave-induced and wind-induced nearshore transport | | Increased transport to the west along Ninety Mile beach in summer due to southward movement of the subtropical ridge creating more frequent easterlies | |
| Sea-level rise | Australia Zhang et al, 2017 | Potential to analyse model output for shelf-scale sea level, temperature, Ocean pH, salinity etc | | Greater resolution of shelf-scale sea level rise. | |

# Impacts of climate change on Victoria's coast

More than a decade ago, Australian researchers reported that climate change was likely to have considerable impacts on marine life, habitats, ecosystems and landforms, with flow-on effects on society and the economy.[23]

In 2007, the VCC reported:

*One important effect of climate will be a shift in the factors that cause environmental change – the "drivers". The current drivers of environmental change are immediate human activities, such as coastal development, discharge of waste, fishing, etc. This may continue for the next few years, but within a decade, the physical (climatic) environment will become a major driver. Climate change may also have important synergies with other drivers, such as eutrophication, habitat loss, etc., which have eroded coastal marine ecosystem resilience to climate change.*

*Climate change is now a focus of attention for coastal managers, and the first steps focus on changes to average states – changes to average temperatures, mean sea level, wave action, etc. However, a key feature of climate change is not just "average" changes but increases in climatic variability. For coastal environments, this variability may be reflected in changes to rates of opening and closing of estuaries, increased variability in river flows, and changes to frequency of storm waves and other severe weather events.*[24]

Although some work has been done to address these, most of the impacts identified in 2006 by the first broad synthesis of climate change impacts on Australian marine life have not been addressed and are reiterated in this 2018 report.[25]

Outside of climate change impacts, human activity affects marine biodiversity, often through impacts on water quality and habitat quality, as well as resource use. The Victorian Coastal Strategy, published in 2014, acknowledges that both the natural and built environments on the coast are under pressure from a range of threats including population growth, the competing demands placed on a limited resource, a changing climate and ageing infrastructure.[26] Other pressures include input of nutrients, toxins, sediment, exotic species, physical changes to habitats and overuse.

Table 2 lists the likely impacts of climate change on Victoria's coast, presented graphically in Figure 1. Detailed explanations follow.

## Physical and chemical impacts

### Sea-level rise

Impacts of sea-level rise are likely to include more frequent and extensive inundation of low-lying areas, and erosion of cliff, beach and foreshore. Cliff, beach and foreshore erosion, as well as the loss of saltmarsh and mangrove habitats, results in the loss of natural coastal defence, which is an important ecosystem service provided by these habitats. There will be more damage to coastal infrastructure, including seawalls, jetties, roads and walking tracks, and to private property.[27]

Rising sea levels will increase tidal ranges in locations like Port Phillip Bay where there is a constricted opening and lead to shorter water resident time in the Bay.[28]

### Wave and wind changes

Changes in wind climate, especially in direction, can have significant impacts on the coast. A change in wind direction may result in a change in wave direction. A change in the strength and location of major storms in the Southern Ocean may result in a change in the level and direction of wave energy reaching the west coast of Victoria. Sandy coastlines tend to align perpendicular to the average direction of incoming wave energy. If the average wave direction changes, there is a likelihood of changes to the alignment of sandy coasts with potential loss – or gain – of coastal land. An increase in wave energy may result in changes in beach slope and potential erosion of sandy beaches, as well as impacts on cliffy shorelines.

Long-period swells can travel vast distances from the weather systems that create them. They carry a lot of energy. As they approach shallow water, the wave height increases. Long-period swells can cause significant flooding of coastlines through wave set-up and run up.[29,30] Predicted increases in storm activity in the Southern Ocean would lead to increases in swell height and period along the Victorian coast.

### Storms

More frequent and extreme storms will cause greater flooding of land and buildings on the coast, loss of and damage to private and public property and infrastructure, and beach, foreshore and cliff erosion (Figure 2). There is a risk of pollution from sewer overflows and inundation of low-lying coastal areas.[31]

### Rainfall changes

Despite an overall trend of declining rainfall, more of the rain that does fall will be in increasingly extreme downpours. This is likely to lead to changed salinity, nutrient and sediment flows, changed estuaries, greater extremes of high and low fresh water input and reduced water clarity. Drier conditions will create increased frequency and intensity of fires on land, with impacts in the coast and marine environment.[32,33]

*Table 2 Summary of the potential impacts of climate change on Victoria's coast (this table extends information from the 2014 Victorian Coastal Strategy[34]). Yellow circles (●) indicate 'hot spots', representing changes that have significant impacts. Blue squares (■) indicate 'sentinels', representing changes that could imply thresholds or tipping points. While impacts have been assigned to particular measures likely to have the strongest relationships, impacts can occur due to multiple measures.*

| MEASURES | IMPACTS |
|---|---|
| Sea-level rise | ● More frequent and extensive inundation of low-lying areas<br>● Loss of coastal habitat, such as roosting and nesting sites for shorebirds and seabirds<br>● Cliff, beach and foreshore erosion<br>● Altered saltmarsh and mangrove habitats<br>■ The Hooded Plover, which suffers direct impacts such as nest flooding<br>• Declines in seagrass abundance and extent<br>• Increased tidal ranges in locations such as Port Phillip Bay where there is a constricted opening<br>• Damage to infrastructure, such as seawalls, jetties, roads, walking tracks, beach access, dune fencing, navigation aids and drainage systems<br>• Loss of, and damage to, private property, and changes to land use<br>• Altered intertidal areas, saltmarshes and coastal wetlands<br>• Loss of significant heritage sites<br>• Loss of coastal Crown land for tourism and recreation |
| Wave and wind changes | ● Realignment of shorelines<br>● Changed beach profile and orientation |
| Ocean current changes | ● Impacts on the diversity, distribution and abundance of species |
| Rainfall changes | ● Changed estuaries<br>• Changed salinity, nutrient and sediment flows<br>• Greater extremes of high and low fresh water input<br>• Reduced water clarity<br>• Changes in water quality, in particular due to changes in stormwater runoff<br>• Increased frequency and intensity of fires, with impacts beyond the coast |
| More frequent and extreme storm events | ● Intense and destructive flooding of land and buildings on the coast and in areas where drainage systems lose their functionality<br>● Inundation of low-lying coastal environments<br>● Beach, foreshore and cliff erosion<br>• Loss of, and damage to, private and public property and infrastructure<br>• Pollution from sewer overflows |
| Higher sea temperatures | ■ Species distribution changes<br>■ Spread of invasive species and diseases<br>■ Changes in recruitment patterns, flowering, breeding and migration, including phytoplankton blooms<br>• Altered ocean currents |
| Changed patterns of wet and dry periods | • Changed salinity, nutrient and sediment flows<br>• Changed estuaries, greater extremes of high and low fresh water input<br>• Reduced water clarity<br>• Increased frequency and intensity of fires, with impacts beyond the coast<br>• More people visiting the coast in hot, dry periods |
| Ocean acidification | ● Impacts on early life stages of species, particularly larvae and plankton<br>■ Loss of plankton base for food webs<br>■ Changes to ecological cycles<br>• Damage to reef-building communities, such as molluscs, polychaetes (worms), corals and sponges<br>• Damage to infrastructure |

## Likely changes to Victoria's coast caused by climate change

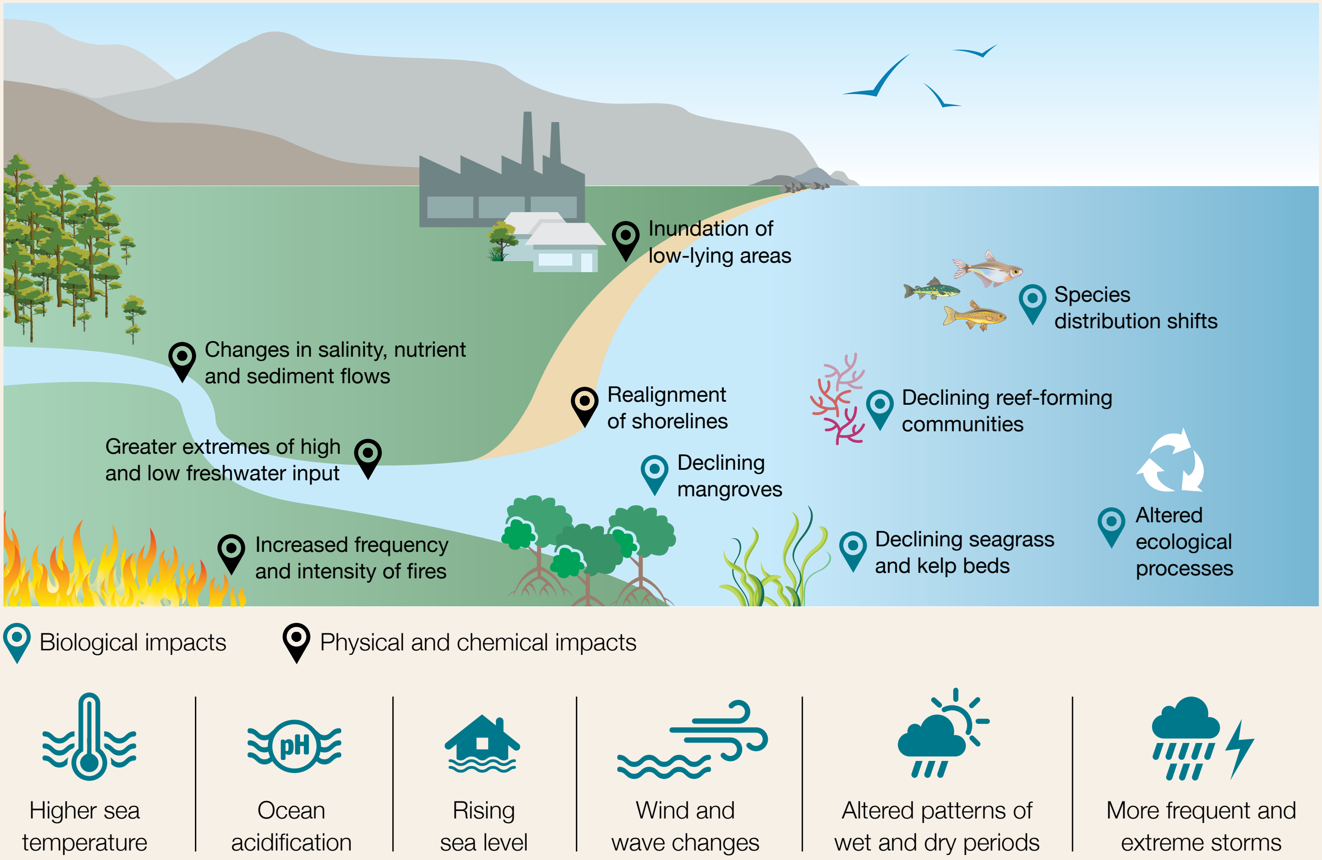



*Figure 1*

## Schematic of the surf zone showing principal contributors to the coastal water level

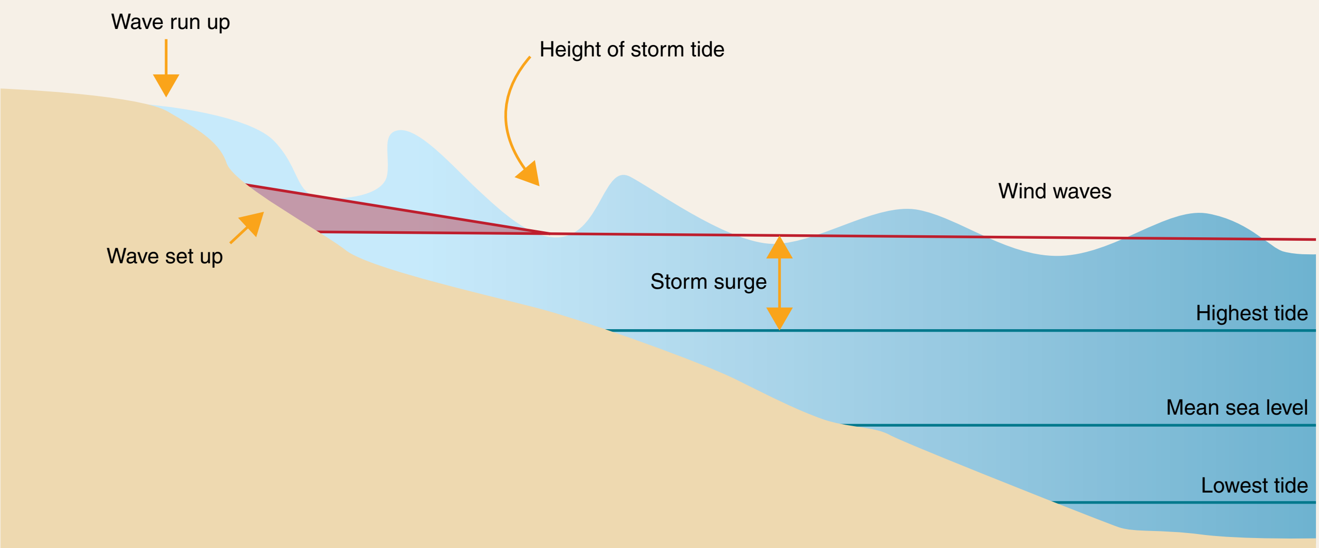



*Figure 2*
*(Source: Victorian Department of Sustainability and Environment 2012.[35])*

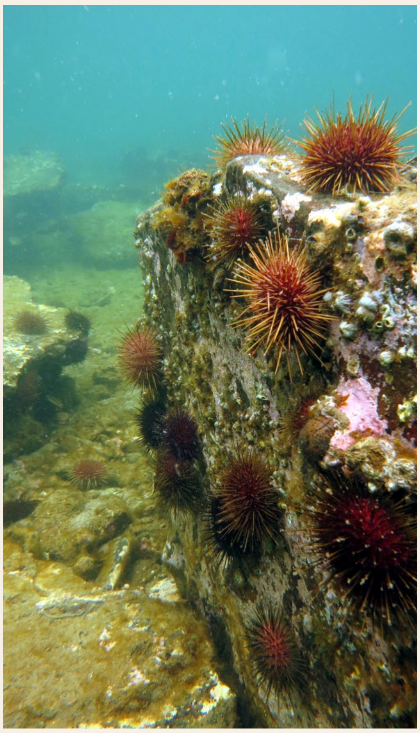
### Nitrogen cycle

Global warming and eutrophication in fresh and coastal waters may mutually reinforce the symptoms they express and thus the problems they cause.[36]

The Port Phillip Bay Environmental Management Plan 2017–2027 Supporting Document[37] states: 'Managing catchment inputs is as important as managing discharges from the Western Treatment Plant. The efficiency of the nitrogen cycling process across the Bay is impacted more by changes in Yarra/Maribyrnong flows than discharges from the Western Treatment Plant. This is because the process can be impacted by changes in climatic conditions, phytoplankton dynamics and other factors that affect benthic microbial processes. Loads from rivers are also highly variable in comparison to treated wastewater discharges. Monitoring of nitrogen cycling in Hobsons Bay has shown that the efficiency of the process is reduced following high flow events. When this occurs, there is increased likelihood of algal blooms'.

### Ocean acidification

Acidification may increase the rate of degradation of coastal infrastructure.[38]



## Biological impacts

### Biological changes due to ocean acidification

Ocean acidification impedes the ability of calcifying organisms to form their skeletons.[39] Formation of shells or skeletons of calcium carbonate by organisms such as shelled plankton, polychaetes (worms), coralline algae, corals and molluscs will decrease. Many reef-building/forming organisms will take longer to build reefs, which are likely to be more fragile and vulnerable to erosion.

Increased ocean acidity impairs the ability of some reef fish to avoid predators. Conversely, other species such as non-calcifying algae may benefit from increased oceanic carbon dioxide concentrations. The ability of reef-forming organisms to provide ecosystem habitats, protect coastal regions from storms and support tourism and fisheries is likely to decline.

Victorian waters are home to many reef-forming organisms, including many inside marine national parks and sanctuaries.[40] Acidification is already affecting reef-forming organisms and other marine organisms. Impacts are likely across the entire marine food web.[41]

### Species and habitat changes

Higher temperatures, as well as changes in ocean currents, are likely to lead to continued species distribution shifts, and spread of invasive species and diseases.[42] There will be changes in the recruitment patterns of marine organisms, as well as flowering, breeding and migration patterns.[43]

Recent research suggests rising temperature will have a greater impact on fish and crustaceans than increasing ocean acidification.[44]

Climate change is moving phytoplankton southwards off eastern Australia, with rising sea-surface temperatures and the southward flow of the East Australian Current likely to drive phytoplankton species further southwards in future.[45]

Warmer waters are causing replacement of small cool-temperate species in southern waters by subtropical and tropical species.[46] Impacts on Victoria's coast and marine environments include the southerly migration of species of sea urchins into eastern Victoria and new fish species in Port Phillip Bay.[47]

Warming seas off Portland are likely to increase the growth and survival rates of King George whiting with the currents transporting larvae to central Victorian bays. However, reductions in the area and condition of seagrass beds in Port Phillip Bay (see below) threaten fish stocks and ecosystem health.

Sand flathead birth rate in Port Phillip Bay is heavily influenced by climate variability. A decline in birth rate coincided with a period of prolonged drought in Victoria from 1997–2009, characterised by substantially lower rainfall and river flows. Sand flathead recruitment has not fully recovered since the drought ended in 2010. Low stock abundance may be currently impeding population recovery in the bay.[48]

Changes to ocean currents, winds and temperature can have significant cumulative impacts on ecosystems. In particular, such changes can have cascading effects on higher predators through the alterations in the diversity, distribution and abundance of their prey. Victoria's offshore islands are home to more than 70 per cent of the Australian fur seal population, the largest colonies of little penguins and large numbers of short-tailed shearwaters. The massive biomass consumption represented by fur seals and shearwaters means that they represent sentinels of climate change impacts.[49]

### 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. Over the past 20 years, shorebirds in Port Phillip Bay have declined in line with global population reductions[50] due to a number of complex reasons. Aside from directly affecting the communities, climate change reduces the capacity for these communities to recover from the declines.

Resident beach-nesting species, especially the obligate hooded plover, are arguably even more sensitive than migrants to coastal changes caused by climate change.[51]

There has been a shift in dune floral communities. This is likely to be having a significant impact on shorebirds, through reducing the width of the beach and steepening the foredune.[52]

### Seagrass

Seagrass delivers a diverse range of ecosystem services that provide benefits to the economy and the community. These benefits include water filtration, sediment stabilisation, maintenance of nursery populations and habitat, and carbon sequestration and storage.

Port Phillip Bay seagrass ecosystems provide important habitats for a number of fish species including Australian anchovy, southern sea garfish and King George whiting. The ecosystems support recreational fishing, aquaculture, recreation and amenity. Seagrass provides climate change mitigation through carbon sequestration.[53]

Scientists have projected declines in seagrass abundance and extent due to sea-level rise, increased storminess resulting in increased sediment infiltration and reduced light levels and higher temperatures.[54]

### Mangroves and saltmarshes

Ecosystem impacts of sea-level rise will include altered saltmarsh and mangrove habitats and loss of coastal habitat for biodiversity, such as roosting and nesting sites for shorebirds and seabirds. There will be impacts on intertidal areas, saltmarshes and coastal wetlands.

Mangroves are predicted to decline due to ‘squeeze’ associated with coastal development. However, higher temperatures would see a southward migration of mangroves.[55] Along with seagrass, mangroves act as important natural coastal defences.

### Kelps

Seaweed forests are comprised of large brown algae called kelps. The plants attach themselves to solid structures such as rock. The plants create habitat for smaller algae and animals that either live attached to the rocks beneath the kelps, on the kelps themselves or in the sheltered waters between individual plants. Victoria has impressive kelp forest communities throughout the state. They are the basis of diverse ecological communities as well as dampening wave energy where present as forests on the outer Victorian coast. [56]

Sea-level rise, rising sea-surface temperatures, and increasing ocean acidity threaten kelps[57] and hence the ecosystem services they offer.

### Terrestrial vegetation

Invasive exotics now dominate much of the coast. Marram grass, sea spurge and sea rocket are displacing native spinifex.[58]

## Regional impacts

Different zones of Victoria are likely to experience different impacts.[59]

Offshore, an increase in temperature may lower nutrient levels, decrease oxygen in the water for fish and lower fishery production, while acidification may also decrease fishery production. Larger waves offshore would affect oil and gas field infrastructure and potentially increase maritime incidents such as oil spills and vessel strandings. Conversely, larger waves could provide opportunities for ocean renewable energy. An extension of the East Australian Current could lead to more harmful algal blooms and a shift in fish and invertebrate species to eastern Victoria offshore.

Near the shore, there could be loss of intertidal habitat and potential changes to species composition with 'tropicalisation' of groups of species and extensions to the range of northern species, with indirect effects due to changes in food webs.

Rocky-shore fishing is likely to become more dangerous due to increased wave heights. Rocky-coast fish species may shift to southerly or more wave-exposed shores. Acidification may lead to decreases in some species, especially echinoderms and molluscs, which are important in rock shore ecology. Increased sea-level rise and storms would increase under-cutting of soft-rock cliffs.

In estuaries, higher sea levels may lead to closure of river mouths through greater sedimentation, loss of salt-intolerant vegetation, and increased flooding (exacerbated by increased wave energy in winter destroying barriers). There may be changes to important chemical cycles, declines in waterbirds and fish, rising coastal water tables undermining structures, and increases in algal blooms and more fish kills.

Significant impacts in and around Victoria's bays and built shorelines include stormwater affecting beaches, greater sediment transport, more jellyfish swarms, loss of wetlands, harm to recreational fishing from increasing temperatures and ocean acidification, properties increasingly vulnerable to sea-level rise, undermining of seawalls and a loss of jetties and associated structures.

# Knowledge gaps

In most cases, it is possible to predict the direction of future changes. However, it is not yet possible to predict when the changes will occur and their extent. Experts can provide a good estimate of the range of some of the changes, but, especially in the case of ecological processes, the follow-on effects on ecosystems and species cannot yet be quantified.

Physical impacts are more readily measurable and visible than biological impacts, which are more complex and have greater uncertainty (although there are good baseline data for birds and seagrass).[60]

Hobday *et al*. noted that the lack of long-term data collection in Australian waters made evidence of climate change impacts sparse and lamented the lack of computer modelling of future changes in Australia's marine ecosystems.[61] These critical gaps identified 12 years ago are yet to be addressed sufficiently.

Hobday *et al*. posed the following questions relating to biological systems, all of which are relevant to Victoria today[62]:

- How will the distribution and abundance of marine species and communities alter with climate change?
- Which species are candidate indicators for climate change impacts? (Effective 'sentinels of climate change impacts', or 'canaries in the coalmine', are corals and kelp, which provide structural integrity of habitat, or other species with important key ecological roles, such as phytoplankton, which drive food chains.)
- Within large marine domains, where are areas sensitive to change? (The Tasman Sea in the south-east and the east coast of Australia, both relevant to Victorian environments, are such examples.)
- How will ocean productivity alter with climate change? (Australia's productivity, already low, is likely to further decrease.)

- How would reduction in non-climate related stressors increase ecosystem resilience to climate change? (The paper recommends a reduction in stressors that aren't related to climate, such as extractive or polluting activities, to build climate resilience in ecosystems and species.)
- To what extent will marine climate change impacts affect socially and economically important uses of Australian marine ecosystems? (The paper concludes that Australia's fisheries and tourism industries are likely to be the most affected by climate change.)[63]

Understanding what the appearance of Victoria's coastline during past periods of higher sea level would help us appreciate the likely impacts of higher sea level in future. Such an assessment of the past cannot be undertaken using today's shoreline maps as they do not account for past landform dynamics.[64]

Another significant gap in our knowledge relates to the age and sediment dynamics of our coast – we barely know where sediment is coming from or going to. Another fundamental gap is the bio-geomorphic response of systems. For example, a marram dune responds very differently to a spinifex dune, which means modelling cannot be conducted on a whole landform system.[65]

## Regional coastal climate projections

There needs to be improved understanding about the likely changes from the continental shelf edge to the Victorian shore to determine effective management strategies. While much research has been done on 'downscaling' (making the models higher resolution and covering smaller areas) terrestrial climate projections (e.g. Climate Change in Australia[66]), coastal climate projections are relatively new and underdeveloped.[67]

Coastal managers need detail at the estuary level and local coastline, but coastal projections need to be first done at a state level. Updated projections of physical ocean variables such as sea-level rise, wind, ocean currents and circulation patterns, storm surge and waves (height, period and direction) will demonstrate the compound impacts from interactions of these variables and coincident extremes. Some of these variables are available in some parts of the coast, so need to be identified, updated and downscaled. Such information will support research aimed at determining how climate change will affect Victoria's coastal flora and fauna, and importantly, which sentinel flora and fauna, or ecological processes, to target for further understanding.

Regional coastal climate projections will identify regions of more rapid change, which can then inform the establishment of monitoring programs to identify changes in hotspot areas.

Downscaled climate models will help support investigations of the impact of changing prey fields under climate change scenarios on pelagic fish distribution and abundance, and how fishers might respond.[68] Fishery management plans to conserve stocks and assist fishers in adapting to changes in species' abundances and distributions will be well served by localised climate change projections.[69]

### Wave and wind information

Waves contribute considerably to sea-level extremes. Near-shore wave statistics are required to project such extremes and their likely impacts, including realignment of beaches. Downscaling of the outputs from global and regional wave modelling under climate change scenarios would be a readily accessible source of predicted changes in the nearshore wave climate. Such information would underpin coastal climate adaptation programs.[70]

### Shelf-scale models

New models and simulations could provide additional information on coastal climate change at the shelf scale, which could pinpoint where more detailed monitoring or development of projections are needed.[71]

### Beach-dune interactions during high energy events

Beach and dune system changes occur during storm events. The zone of adjustment extends from the first set of dunes to water depths of over 20 metres on the Victorian coast. With climate change affecting storm frequency and intensity, understanding how beaches respond to large events is critical in predicting habitat change. In Victoria the changing vegetation ecology on the dunes greatly impacts this dune response but is largely unknown.

It is therefore critical to measure the current active storm zone of the coast and contemporary sediment flows. Such measurements will permit differentiation between 'normal' erosion and what is driven by climate change, as well as identifying thresholds and tipping points in the geomorphic system. Change will not be gradual, so understanding landscape resilience is key.[72]

## Biological systems

### Intertidal system interactions

The intertidal system is a critical ecosystem within the marine environment, particularly in Western Port. Understanding the interaction between seagrass, soft sediments, mangroves, saltmarshes and the water column habitats is critical for maintaining system health.[73] Understanding how, and if, rocky intertidal habitats and communities can adapt to rising sea level is also crucial.

### Seagrass stocktake

Researchers have documented a pattern of frequent, localised and small-scale fluctuations in seagrass across Port Phillip Bay as part of a comprehensive assessment.[74] Given the importance of seagrass, and the extensive list of ecosystem services they provide, a stocktake of seagrasses, their value and the likely impacts of climate change is warranted. Included should be an assessment of thermal tolerances and the likely impacts of coastal catchment runoff under changing climate and responses to increasing rates of habitat fragmentation.[75] Attention should be given to the coastal defence role that seagrasses offer as an ecosystem service.

### Fish assessments

Scientists know little about the spawning sources, movement or migration patterns of the King George whiting so it is difficult to predict how rising temperatures will affect them.[76]

The development of indicators for open sea fish status in both Port Phillip Bay and Western Port based on anchovy or pilchard birth rate and growth is required.[77]

Victoria's marine data collection regime is more complete within the Marine Protected Areas of Port Phillip Bay than in other regions.[78]

### Invasive species surveys

More research is required to understand the impact of specific pest species. No recent surveys have been taken of the distribution and abundance of exotic species in Port Phillip Bay.[79]

## Climate change adaptation

The most effective approach to adaptation to inevitable climate change involves collaboration and joint planning. For example, a council acting to restrict development on flood-prone land will benefit power suppliers and insurance companies. Management actions that result in coordinated adaptation will increase the likelihood of sound adaptation activities.

Some coastal areas may become untenable as they are currently used. There are a variety of strategic approaches, including financial ones, to achieve successful resettlement or other forms of adaptation.[80]

The 2014 Victorian Coastal Strategy[81] states: 'If the coastal resources that maintain biological diversity such as saltmarshes and mangroves are to adapt to the impacts of sea-level rise and urban encroachment, outlays to 'buy-back' land will be required. Also, in some circumstances incorporation of private land, to replace eroded public land, may be warranted to ensure community access to parts of the beach'. The strategy states that 'Financing of coastal infrastructure in the short, medium and long term will require a range of options and may involve both public and private entities. Options to be investigated could include development contributions, charges and levies or a dedicated long-term fund'.

## Other environmental pressures

A range of human activities affect Victoria's coast, including population growth, overuse and competing demands on resources, climate change, ageing infrastructure,[82] input of nutrients and toxins, introduction of exotic species, and habitat change. Better understanding of the relative importance of these impacts along Victoria's coast would provide a clearer basis for refining catchment management priorities to promote ecological resilience under climate change scenarios.

# Priorities

This report presents information about observed and projected climate change, and the impacts those changes are having on Victoria's coastline, and are likely to have in future. There is much information available about both the projections and the impacts. However, there are also extensive gaps in our knowledge. These gaps are briefly described here.

Determining research priorities to fill these gaps is no easy task. There is almost no end to the amount of useful information that could be collected and analysed. The question is: what are the most urgent tasks that will result in findings that can be readily applied to protect the state's coastal resources.

Physical scientists present cogent arguments in favour of monitoring and modelling variables such as sea-level rise and tidal changes. Biologists urge investigations of life cycles of important species, such as seagrass and kelp, or fundamental ecological cycles such as denitrification. With limited funding available, what areas of research will give Victorians the greatest benefits and focus for management action?

One tactic for such decision making is to ask, 'what is it that we care about?'. With that value established, the next step is to determine what is known, and identify what needs to be measured and the priorities for doing so.

The October workshop of the VCC Science Panel suggested two possible approaches:

- Identify what we most care about; look for a link to something measurable; go out and measure looking for a change that triggers management action.
- Identify the parameters we care about; determine what changes are likely for these parameters; decide whether existing modelling or data be used to predict these expected changes. Use this information to explore or trigger management action.

Workshop participants and Science Panel members identified a range of factors that they considered to be important indicators of climate change or sources of information meriting investigation. They included (not in any order):

- shifts in abundance of species
- loss and gain of species with important or critical functions in food web
- fish catch data
- seagrass mapping
- extent and permeability of mangrove habitats along the coast
- aerial photograph analysis as monitoring tool for seagrass
- changes in area/extent of intertidal platform
- measure and predict the migration of intertidal flora and fauna
- historical bird data
- ocean pH levels
- Eastern Australian Current penetration into Bass Strait, and changes to coastal upwelling, especially in Western Victoria
- historic tide gauge data
- sea-surface temperatures
- wave data
- aerial images to allow determination of natural variability and long-term trends
- understanding sand dune bio-geomorphic dynamics
- berm dynamics at estuary entrances
- beach-storm dynamics
- age of the coast and position of last higher sea level shoreline.

With the paucity of standardised and accepted indicators of climate change impact on the coasts, each of the above points have merit. Each indicator will link to a specific management action or set of actions. Any have been, and can be, used to differing extents based on data availability. All have known data gaps, some of which are significant.

What gaps are filled, and what should be monitored as indicators of coastal climate change impact, may not be driven by science alone. The Science Panel acknowledges that the decision about 'what is it that we care about' is not a scientific decision alone. It should be strongly influenced by expert knowledge on what is tractable, more likely to be early warnings of change and scientifically robust. However, the question of what we value is driven by influences other than science.

Another important question to address is determining which species are candidate bio-indicators of the impacts of climate change.[83]

Hobday *et al*. suggested strategies to increase the resilience of marine ecosystems to help minimise the impacts of climate change.[84] Also in 2006, the VCC Science Panel made recommendations for action, published in the subsequent year,[85] in response to emerging scientific issues. In 2011, the panel updated the recommendations.[86] The three recommendations from 2011 hold true in 2018; little research has been completed into these areas during the past seven years. The 2011 panel recommendations were:

**1. Understanding the effects of increased climatic variability**

Impacts cannot be predicted accurately from changes to average climate alone. The Science Panel strongly encourages the development of the scientific understanding and tools needed (including monitoring) and better harnessing of existing data and information to predict local responses of coastal ecosystems and landforms to changes in climatic variability including extreme events, taking into account synergies between climate drivers.

**2. Understanding the importance of links between catchments, estuaries and broader coastal waters for maintaining marine ecosystem health**

Catchments are a major source of sediments, nutrients, and a wide range of chemicals, which move into estuaries and potentially out into oceanic waters. An important scientific question is how do estuaries influence marine environments along the coast and how does climate change affect this.

**3. Understanding the cumulative ecological consequences of coastal development to meet human needs**

Understanding the cumulative ecological impacts of coastal development is important for informed planning decisions, and it will become increasingly so as we adjust our plans for new climates.

The Science Panel also noted that failing to develop basic scientific understanding about the Victorian coast limits our ability to manage coastal and marine environments. Scientific understanding depends on the collection of appropriate data and the existence of a skill base to interpret information and provide independent scientific advice in Victoria. While there have been some significant advances in consolidating marine and coastal data and information since 2011[87,] there remains a serious and considerable task of bringing together the right data with the right expertise and skill base for Victorian coastal and marine managers to access and make appropriately evidence-based decisions.

In 2017, Hobday *et al*. published the *National Adaptation Research Plan for Marine Biodiversity and Resources*.[88] Their priority research questions for marine biodiversity and conservation were:

- What are the critical thresholds (e.g. warming, acidification) to ecosystem change and how close might any ecosystems be to a potential 'tipping point'?
- Which ecosystems and species of conservation priority require adaptation management and supporting research, based on their status, value, vulnerability to climate change, and what are the feasible adaptation options? How can a risk-based approach inform this prioritisation?
- How can the barriers, limits and costs to implementing adaptation policy be overcome?
- How should conservation managers and planners modify their practices to reduce or manage climate change risks and enhance adaptation options?

Many of the knowledge gaps identified by the VCC Science Panel in 2017 mirror these, especially the first and second priority questions.

## Coordination and resourcing

A coordinated approach to marine research is critical. Marine science tends to be disaggregated, species-specific research, largely reflecting resource constraints, and the interests of experts. A strategic future program for marine research must understand the key habitats (seagrass, sediment, mangrove, saltmarsh, rocky reefs and water column) and how the habitats interact, as well as the key processes. A systems approach to ecosystems will provide the evidence base for improved decision-making and management interventions.[89]

There is an urgent need to establish – and consolidate existing – long-term monitoring programs with adequate funding and resources. Long-term data are needed to understand and predict how climate change will affect marine and coastal resources.

In 2016, the Commissioner for Environmental Sustainability called for a Marine Knowledge Framework focused 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 procedural gaps identified in her *State of the Bays report*[90], such as:

- meta-analysis of existing studies
- incorporating existing citizen science that occurs on Victoria’s coastline (Reef Watch, Sea Search, Birdlife Australia) into digital reporting and integrated monitoring regimes
- initiating new citizen science projects to fill gaps in observations and to inform management action required and help track progress; an example is Redmap (Range Extension Database & Mapping project), which invites the Australian community to spot, log and map marine species that are uncommon along particular parts of our coast
- connecting marine practitioners (researchers, managers, stakeholders).


## Recommended research projects

The above list of potential research activities includes physical science projects that can practically contribute to coastal management and decision-making, and biological projects that build towards a better understanding of how changing conditions influence ecological processes.

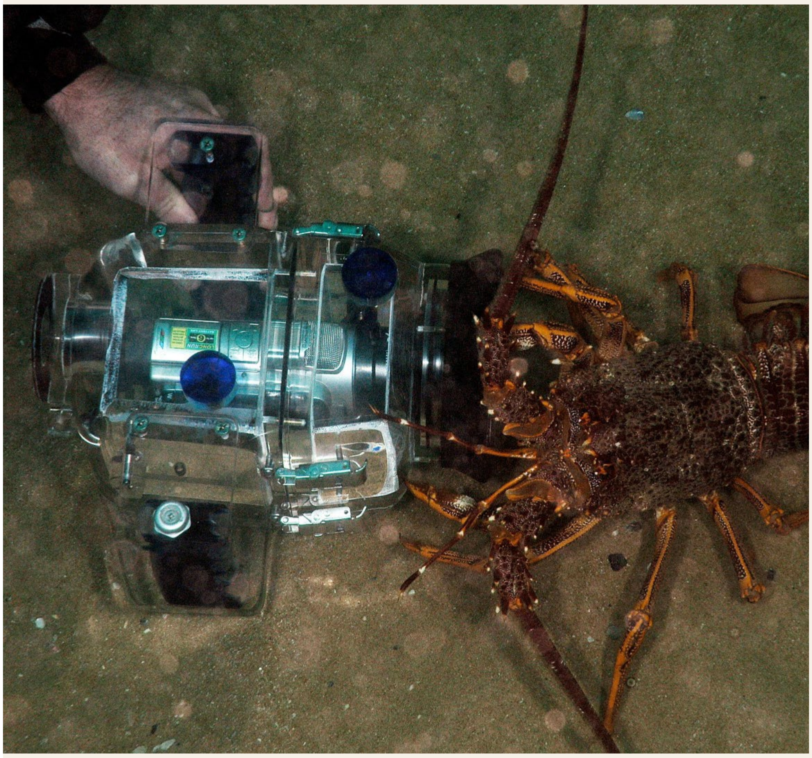
The following projects represent discrete, manageable pieces of work that can significantly develop our understanding and capacity to manage the impacts of climate change on Victoria’s coast.

### General projects

- Establish a working group to collate and interpret data and information in support of effective management of Victoria’s coastline, especially in response to the impacts of climate change
- Implement activities to provide practical advice and support for conservation managers and planners to modify their practices to reduce or manage climate change risks and enhance adaptation options
- Embed a practice that enables the Science Panel to maximise the impacts of its findings on decision-makers
- Promote learning-by-doing climate change adaptation activities. This could include using adaptive management interventions and actively assessing the effectiveness to alter the intervention. These ‘act, check and change’ approaches are management interventions that act like trials or pilots for new ways of managing. They are well suited to interventions in areas where there is no strong scientific evidence suggesting the appropriate interventions. Local communities would need to be included with these types of adaptive management approaches.

### Physical science projects

- Monitor ocean pH levels
- Monitor and model changes to wave direction and strength, and their impacts
- Analysis of available sea-water temperature data to provide a baseline at local scales in Victoria



- Digitise and analyse historic tide gauge data to determine trends in sea-level rise, storm surge and storm tide
- Collate and analyse photogrammetry to provide baseline data on shoreline position
- Conduct regular surveys to determine beach profile, bathymetry and elevation
- Determine the extent of Eastern Australian Current penetration into Bass Strait, and changes to coastal upwelling, especially in Western Victoria
- Determine projected changes in coastal currents in hydrodynamic models linked to climate models
- Harness existing data and information to predict local responses of coastal ecosystems and landforms to changes in climatic variability including extreme events
- Conduct research into linkages between catchments, estuaries and broader coastal waters and their roles in maintaining marine ecosystem health to determine the roles that estuaries play in influencing coastal marine environments

**Biological projects**

- Conduct a meta-analysis of existing studies
- Determine the critical thresholds (e.g. warming, acidification) to ecosystem change
- Establish which species are candidate bio-indicators of the impacts of climate change
- Determine invaders of concern (i.e. new species to Victoria) under climate change and likely early signals
- Determine shifts in abundance of species
- Establish likely impacts on the food web
- Determine population and community level impacts from likely changes
- Determine how ecosystem function changes when key species are affected by climate change impacts (especially sea level rise, changes in sea surface temperatures or ocean acidification)
- Determine relevant processes, especially those fundamental to maintaining ecological resilience
- Determine interventions that would promote natural system resilience
- Consolidate historical bird data (to influence decision-making)
- Combine the findings from existing citizen science projects that occur on the coastline
- Initiate new citizen science projects to fill gaps in observations
- Determine the major marine and coastal ecosystem services at risk from impacts from climate change impacts

**Geomorphological projects**

- Map the past higher sea level shoreline
- Consolidate all past historical shoreline mapping
- Consolidate current citizen science data collection into a single platform
- Determine the geomorphic sensitivity of key landforms
- Quantify the current active beach envelop

## Effectiveness and ease of research projects

Participants in the October 2017 VCC Science Panel workshop determined the most tractable research projects likely to give the most useful answers for coastal and marine managers, by assessing how effective particular research would be in addressing gaps or monitoring changes to the Victorian coast and then weighing this assessment of effectiveness against the difficulty of completing such projects. While the Science Panel was of a view that all the projects were priorities, there is an explicit cost-benefit analysis in the opinion of the panel's 'effectiveness' assessment. While most, if not all, of the projects considered would be 'effective' *per se*, they may not give the most useful immediate answers to coastal and marine managers requiring an evidence-base for action. Note that for the priority biological projects, the Panel identified a natural sequence in the priorities.

Figure 3 and Figure 4 summarise the workshop participants' consideration of effectiveness versus ease, for physical science projects and biological science projects. For example, a physical science project involving analysis of downscaled wave climate to predict waves was considered as relatively easy to complete and effective in identifying potential changes to Victoria's coast. Hence this project appears in the top right quadrant. Conversely, undertaking regular surveys for beach profile, where there is little or no baseline data, was deemed to be difficult, and less effective than other projects. Hence, it appears in the bottom left quadrant and represents the least tractable project to commence first.

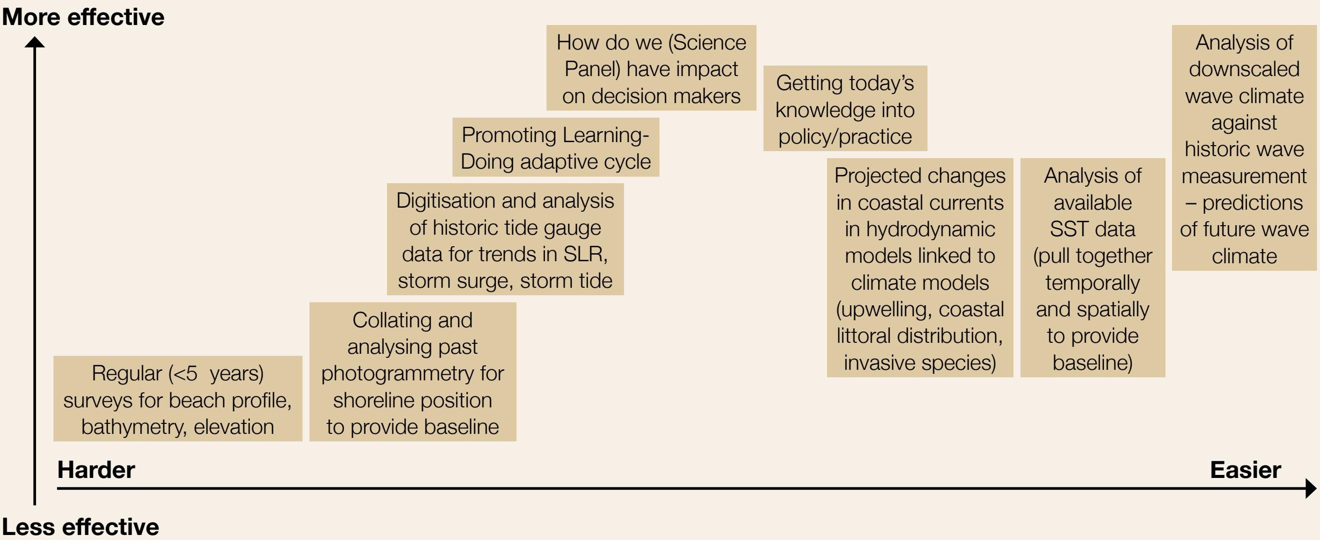



*Figure 3 'Effectiveness' of physical science research projects versus the ease of completing such projects. (SLR is sea level rise; SST is sea surface temperature.) (Source: VCC workshop, 2017).*

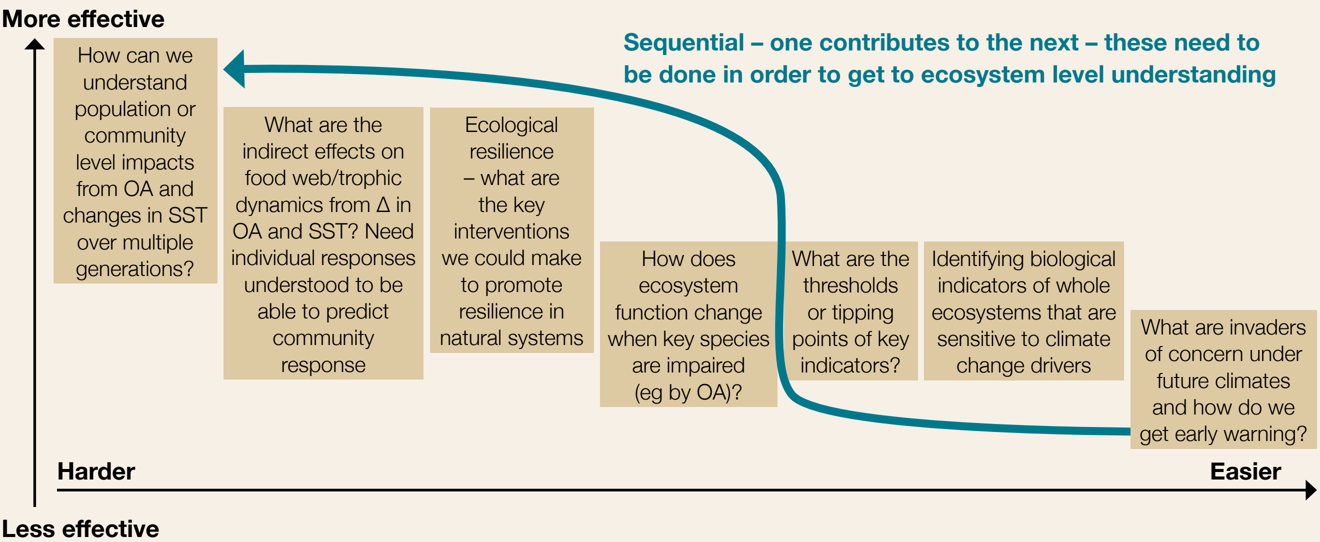



*Figure 4 'Effectiveness' of biological science research projects versus the ease of completing such projects. (SLR is sea level rise; SST is sea surface temperature) (Source: VCC workshop, 2017)*

# Conclusions

Victoria's coastal regions are expected to have a warmer climate year-round, more hot days and warm spells, harsher fire weather and longer fire seasons, less rainfall in winter and spring, more frequent and more intense downpours, rising sea level, increased frequency and height of extreme sea-level events, increased wave height in winter, increased frequency of easterly winds, and warmer and more acidic oceans.

These changes are likely to have considerable impacts on marine life, habitats and ecosystems, with flow-on effects to society and the economy. This report identifies significant likely impacts of climate change, that include more frequent and extensive inundation of low-lying areas, shoreline realignment, changed estuaries and altered ecosystems. The report also identifies changes that could imply thresholds or tipping points. Examples of these include species distribution shifts and spread of invasive species and diseases.

The following list of recommended research projects is based on the workshop findings, expert interviews and a literature review. All of them would add considerably to the information available to support sound management of Victoria's coastline. The most readily achieved research projects that are likely to translate into use by coastal and marine managers are:

## General projects

- Implement activities to provide practical advice and support for conservation managers and planners to modify their practices to reduce or manage climate change risks and enhance adaptation options.
- Embed a practice that enables the Science Panel to maximise the impacts of its findings on decision-makers.

## Physical science projects

- Monitor and model changes to wave direction and strength, and their impacts.
- Analyse available sea-surface temperature data to provide a baseline at local scales in Victoria.
- Determine projected changes in coastal currents in hydrodynamic models linked to climate models.

## Biological projects

- Determine invaders of concern under climate change, and the likely early signals.
- Establish which species are candidate bio-indicators of the impacts of climate change on Victorian coastal and marine ecological communities.
- Determine the critical thresholds (e.g. warming, acidification) to ecosystem change.
- Determine how ecosystem function changes when key species are affected by climate change impacts (especially sea level rise, changes in sea surface temperatures or ocean acidification).

Each of the above priorities is designed to lead to ready action by the relevant coastal and/or marine manager or regulator. Each will require collaboration across marine and coastal science disciplines. Additionally, each will require active translation of the outcomes by researchers into the day-to-day decision-making of coastal and marine managers.


PHOTOS

# Key resources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# Workshop participants

Here is list of participants in the October 2017 workshop ordered alphabetically.

Dr Anthony Boxshall, University of Melbourne, Victorian Coastal Council

Mr Gerry Byrne, Vantree Pty Ltd

Dr Perran Cook, Monash University

Assoc. Prof. Rob Day, University of Melbourne

Prof. Peter Gell, Federation University

Prof. Michael Keough, University of Melbourne

Prof. Spas Kolev, University of Melbourne

Dr Randall Lee, Environment Protection Authority Victoria

Mr Andrew Longmore, University of Melbourne

Dr Peter Macreadie, Deakin University

Dr Andrew McCowan, Water Technology Pty Ltd

Dr Kathleen McInnes, CSIRO

Dr David Provis, Cardno, Victorian Coastal Council

Assoc. Prof. Ian Rutherford, University of Melbourne

Assoc. Prof. Stephen Swearer, University of Melbourne

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