

Marine heat wave

In early 2011, sea temperatures along most of the west coast were 2–4°C warmer than usual. Changes in the local abundance and distribution of seaweeds, sessile invertebrates such as abalone, demersal and pelagic fish were reported, with a shift towards a more tropical fish community. Such extreme climate events are key drivers of change and provide insight into future long-term change. (*Leeuwin, ENSO, Temperature, Pelagic fish, Seaweeds chapters*)



Observing: Collecting information on changes in the marine environment is needed for developing adaptation responses. National programs for observing the marine environment, such as the Integrated Marine Observing System, help to identify regions and systems most at risk. Biological monitoring is challenging, but where we have time series, dramatic changes are being detected.

Adaptation is the process of responding to changing ocean environments. Both animals and humans can adapt – either autonomously (on their own) or in a directed manner (with human assistance). Scientists, managers and resource users are designing adaptation strategies that reduce the vulnerability of marine species, systems and industries to climate change.

Sea level rise, currently increasing at 3 mm per year, will threaten coastal systems. Most at risk are low-lying estuaries and tidal flats, and beaches where there is insufficient sand for replenishment. In locations where human settlements or structures such as seawalls prevent landward retreat of coastal habitats, 'coastal squeeze' may lead to loss of habitats. (*Mangroves and tidal wetlands chapter*).

The south

Australia has one of the richest and endemic temperate algal floras in the world. In response to warming, macroalgae have retreated 10-50 km per decade south on both sides of the continent. Further, the east-west orientation of Australia's temperate coastline predisposes flora and fauna there to potential species extinctions from southward shifting isotherms. As macroalgae are foundation species that support a myriad of unique marine life, the decline in temperate macroalgae in response to climate change is likely to resonate across entire temperate marine ecosystems. (*Macroalgae chapter*).



Great Barrier Reef

Warming temperatures have been associated with reduced foraging success and chick growth in seabirds, changes in sex ratios of sea turtles, more frequent bleaching of corals because of climate variability superimposed on a warming trend, some increases in abundance of large herbivorous reef fish, and decreases in abundance of coral-dependent fishes. Ocean acidification has led to a potential reduction in coral calcification and thinning of shells and increase porosity of winged snails. (*Coral reefs, Zooplankton, Marine reptiles and Seabirds chapters*).



Marine mammals and seabirds

Increasing water temperatures are likely to have an impact on the distribution of marine mammals and seabirds; ranges of both tropical and temperate species are likely to move southwards. Adaptation options at bird breeding colonies, such as shading of burrows and reducing fire risk, may offset declining breeding performance as temperatures rise, while reducing non-climate stressors can also increase resilience of marine mammals to climate change. (*Marine mammals and Seabird chapters*).



South-east Australia is a global warming hotspot. The warm East Australia Current is extending southward, leading to fast warming. Southward range extensions have been documented for seaweeds, phytoplankton, zooplankton, and demersal and pelagic fishes. Declining recruitment for rock lobster has been observed. Fisheries and aquaculture businesses are already adapting to these changes. (*EAC, Temperature, Phytoplankton, Zooplankton and Temperate fish chapters*).



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Marine Climate Change in Australia

Impacts and Adaptation Responses 2012 REPORT CARD



This report card summarises our current knowledge of marine climate change impacts for Australia, highlighting key knowledge gaps and adaptation responses

This Report Card summarises present knowledge of marine climate change impacts and identifies knowledge gaps and adaptation responses in Australia. It was produced by an author team representing 34 universities and organisations, a project team from the CSIRO Climate Adaptation Flagship, and a steering group comprising representatives from the partner organisations [NCCARF Marine Biodiversity and Resources Adaptation Network, CSIRO Climate Adaptation Flagship; and the Fisheries Research and Development Corporation (FRDC)].



Further information: detailed assessments for each climate variable or species group, are accessible at www.oceanclimatechange.org.au Contact us via our website or elvira.poloczanska@csiro.au

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Australia's oceans generate considerable economic wealth through fisheries, aquaculture, tourism and mining. Marine ecosystems provide irreplaceable services including coastal defence, oxygen production, nutrient recycling and climate regulation. Unless we adapt and mitigate, climate change will threaten our economic prosperity and social well-being.

Key findings:

- > Climate change is already happening: Widespread physical changes include rapid warming of the southeast and increasing flow of the East Australia Current. Increasing biological impacts include reduced calcification in Southern Ocean plankton and Great Barrier Reef corals from both warming and acidification
- > Scientists, managers and resource users are working to design adaptation strategies that reduce the vulnerability of marine species, systems and industries to climate change
- > We are observing and monitoring key physical and biological variables in the ocean, which is critical to evaluating effective adaptation strategies.
- > Preparation for climate change also involves changes in management or policy arrangements that currently limit adaptation responses.

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What is happening (Confidence =)

What is expected (Confidence =)

What we are doing about it

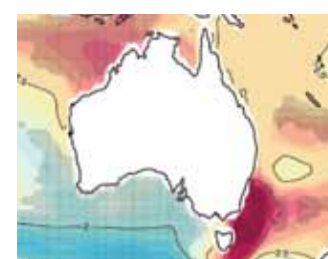
Marine Climate

TEMPERATURE

Ocean temperatures around Australia have warmed by 0.68°C since 1910-1929, with south-west and south-eastern waters warming fastest. The rate of temperature rise in Australian waters has accelerated since the mid-20th century; from 0.08°C/decade in 1910-2011 to 0.11°C/decade from 1950-2011.

New results based on a relatively high scenario for greenhouse gas emissions (RCP8.5) indicate greatest warming in south-east (>3°C) and north-west waters (~2.5°C) by the end of this century.

Investing in regional monitoring as part of the Integrated Marine Ocean Observing System (IMOS) to measure changes in ocean temperatures. Developing ocean models to project changes in coming decades. Ongoing development of seasonal forecasting models and applications to support timely adaptation responses by marine users.



SEA LEVEL

Sea levels are rising around Australia, with fastest rates currently in northern Australia. New analyses of sedimentary records from the east coast of Tasmania confirm slow sea-level change over 1000s of years until the early 20th century, when there was a significant acceleration in the rate of sea-level rise. High sea-level events on annual to decadal timescales have increased by a factor of three during the 20th century.

Sea level will continue to rise during the 21st century and beyond, and result in inundation of low-lying coastal regions and coastal recession.

Satellite altimeters and the Australian Baseline Sea Level Monitoring Array have provided a comprehensive picture of sea level around the Australian coastline since the early 1990s. Adaptation planning will be informed by national and regional assessments of coastal inundation and recession due to future changes in sea level and wave climate.



EAST AUSTRALIAN CURRENT

The intensification of flow and accelerated warming observed in the EAC is also seen in other Southern Hemisphere western boundary current systems, driven by the strengthening and contraction south of Southern Hemisphere westerlies (wind), although regional responses mean rates of warming differ among systems. A range of species, including plankton, fish and invertebrates, are now found further south because of enhanced transport of larvae and juveniles in the stronger EAC and the high rate of regional warming.

EAC flow will increase off south-east Australia with a compensating decrease off north-east Australia.

New observations established as part of IMOS are beginning to provide an integrated view of the EAC. Long-term monitoring at Maria Island (Tas), and Port Hacking (NSW), are being sustained and enhanced as part of a network of National Reference Stations; a new station has also been established at North Stradbroke Island (Qld). IMOS is also supporting the Ships of Opportunity XBT network (provides temperature profiles every 25 km along ship tracks) in the Tasman Sea, which captures key limbs of the EAC system; and is delivering these data in real time.



LEEUWIN CURRENT

Since the mid 1970s, the Leeuwin Current has weakened due to more frequent El Niño events. However, in the past two decades, a strengthening is observed, linked to natural decadal variability not long-term change. Associated with this, there has been a southward range shift in marine biota.

The Leeuwin Current is likely to weaken over the coming century. Despite this, warming will continue to drive southward range shifts in marine biota and there will be more frequent extreme temperature events.

IMOS is monitoring the Leeuwin Current. National Reference Stations at Darwin, Exmouth, Rottnest and Esperance and are providing physical and water quality data. Coastal water temperatures are monitored along the Western Australian coastline by the Department of Fisheries as part of a rock lobster program.

EL NIÑO-SOUTHERN OSCILLATION

While observed El Niño-Southern Oscillation (ENSO) variability is within the broad range of natural variability, the possibility that anthropogenic forcing has influenced ENSO cannot be ruled out.

While the mean climate of the Pacific is expected to change, it is unclear how the amplitude or frequency of ENSO will change (if at all) over the next 100 years.

Investing in Pacific region climate change programs, high quality data collection and monitoring, improving pre-instrumental ENSO reconstructions, process studies to understand mechanisms of variability, and enhancing modelling capabilities.

OCEAN ACIDIFICATION

Most conclusions about biological responses to ocean acidification in Australian waters come from laboratory manipulations rather than observations. However, reduced calcification observed in Southern Ocean zooplankton suggest ocean acidification is already impacting biological systems.

Great Barrier Reef corals and coralline algae will continue to experience reduced calcification rates. Benthic calcifiers, such as molluscs and deep-water corals in Antarctic and southern Australian waters, will show reduced calcification and/or increased dissolution.

Research is underway to improve the methods and equipment used for high-precision carbonate chemistry measurements. Monitoring of carbon chemistry in the open ocean and some shallow coastal systems, including the Great Barrier Reef, has already commenced. Research is underway to investigate effects of ocean acidification on whole coral ecosystems in the Great Barrier Reef.

MANGROVES AND TIDAL WETLANDS

The red mangrove *Rhizophora stylosa* is expanding within its range at its southern limits; the expansion is still to be attributed to climate change however knowledge of thermal limits suggests warming plays a role.

Increasing levels of atmospheric CO₂ will increase tidal wetland productivity over the coming century. Sea-level rise will affect tidal wetlands, however spatial variation in sea-level rise, large and variable tidal ranges, and data gaps for large portions of the Australian coastline reduce our confidence in predictions for some regions.

Systems to monitor surface height have been deployed in Moreton Bay, south-east Qld and in tidal wetlands in southern Australia. The network will provide greater knowledge of possible thresholds of sea-level rise that exceed the adaptive capacity of coastal mangrove and saltmarsh ecosystems to keep pace.

SEAGRASS

A southern range extension of 300 km into Moreton Bay (Qld), of the tropical seagrass *Halophila minor* consistent with a warming and a strengthening East Australian Current.

Declines in seagrass abundance and extent due to sea-level rise and increased storminess. Warming temperatures increase extinction risk for temperate species already considered Vulnerable or Near Threatened under IUCN guidelines. Decline and loss of some species of intertidal seagrass in northern Australia with warmer air temperatures.

Ongoing monitoring and research into the impacts of climate change on seagrass beds, including quantitative modelling at local scales. Investigations into the role of seagrass beds as carbon sinks for CO₂ mitigation.

MACROALGAE

A recent analysis of herbarium records back to the 1940s suggests temperate seaweeds on both east and west coasts of Australia have retreated south 10-50 km per decade as waters have warmed. A recent extreme warming event (marine heatwave) in Western Australia caused substantial changes to seaweed habitats, including a reduction in large habitat-forming species. In eastern Tasmania, a substantial decline in algal habitat is associated with southward expansion of a grazing sea urchin aided by the strengthening of the East Australian Current and warmer temperatures.

Warming will reduce the resilience of macroalgal habitats to other stressors such as pollution. Temperate species will contract their ranges southwards and tropical species expand their ranges further south. Many temperate species, found only in Australia, are at risk of extinction in the next 50-100 years. Extreme events (storms, heat waves, etc) will increase in frequency and magnitude and drive shifts in species' distributions and interactions.

IMOS Autonomous Underwater Vehicle Facility will provide long-term monitoring of water properties and temperate reefs at key locations in Qld, NSW, Tas and WA. Several research projects focusing on climate change and temperate macroalgae are under way. These focus both on establishing the range of impacts as well as the mechanistic relationships which drive impacts of climate change.

MARINE MICROBES

The reporting frequency of microbial-mediated disease outbreaks affecting marine organisms is increasing and could contain a climate change signal. However, disease events (or breakdown in microbial symbioses) in corals, sponges and some other species have been linked with warmer seawater temperatures.

With warmer temperatures in the future, microbial-mediated disease outbreaks or disruptions to symbiosis are likely to become more frequent and wide-spread.

Initiatives are underway for monitoring long-term changes in microbial biodiversity through genomic analysis of water samples. This will allow us to investigate environmental stress thresholds of microbial symbioses of key marine species. Construction of national infrastructure including the SEASim aquarium at AIMS and state-of-the-art facilities at SIMS will increase capacity to investigate changes in community structure and function of marine microorganisms under climate scenarios.

PHYTOPLANKTON

The red-tide dinoflagellate *Noctiluca scintillans* has expanded its range into southern Tasmanian waters and beyond since 1994, associated with warming water and enhanced transport by the East Australian current.

Changes in timing of seasonal phytoplankton blooms may impact marine food webs.

Establishment of IMOS National Reference Stations and AusCPR (Australian Continuous Plankton Recorder) tows are enhancing Australia-wide phytoplankton and biogeochemical data collections for monitoring responses.

ZOOPLANKTON

Decline of cold-water zooplankton and increase in warm-water species with warming off eastern Tasmania from the 1970s to the present. Reduced calcification of pteropod snail shells over the past 40 years in north-east and north-west Australia.

Range shifts toward higher latitudes, earlier zooplankton blooms with warming, changes in nutrient enrichment and thus zooplankton abundance, and reduction in pteropod and foram abundance due to acidification will reorganize foodwebs in time and space and impact fish, seabirds and marine mammals.

Australia is now better placed to track and respond to changes in zooplankton abundance, distribution and timing through the IMOS AusCPR (Australian Continuous Plankton Recorder) survey and National Reference Stations program.

CORAL REEFS

During the past three decades, coral reefs have been impacted by a growing number of thermal bleaching events although their occurrence and severity have varied substantially in space and time. Numerous experimental and observational studies have established a causative link between thermal anomalies (stress) and coral bleaching.

Projected increases in the frequency and severity of thermal stress events will increase the risk of mass coral bleaching events, leading to chronic degradation of most coral reefs by the middle to late parts of the century. Ocean acidification will reduce reef calcification driving a shift from net reef accretion to net erosion of reef structure.

Formal adaptation plans are being implemented to help communities and industries that depend on Australia's coral reefs to deal with the serious impacts of climate change. The Great Barrier Reef Climate Change Adaptation Strategy and Action Plan outlines strategies and measures to support ecosystem resilience, support adaptation by reef-dependent communities and industries, and raise awareness of the importance of urgent action to mitigate climate change if we are to improve the outlook for coral reefs.

TROPICAL FISH

New research suggests that some species have a greater capacity to acclimate to rising temperatures than previously thought; however whether such acclimation capacity is widespread in tropical marine fishes, and whether some critical processes (e.g. reproduction) remain significantly impaired, is unknown.

In addition to effects of habitat degradation, warmer ocean temperatures will cause distribution shifts in some tropical fishes, increasing the geographic ranges of some species and decreasing the ranges of others, including some commercially important species.

Experimental and observational work is underway to investigate the adaptive capacity of tropical fish.

TEMPERATE FISH

Additional evidence and reviews confirm previous reports of southward range extensions for many coastal temperate fishes.

Reduced freshwater flows are likely to have negative effects on estuarine-dependent species, such as bream, and adaptation in relation to water flow management may be needed.

There is ongoing experimental and observational work to understand the environmental tolerances and hence adaptive capacity of temperate fishes.

PELAGIC FISH

Increased reporting of tropical species from southern waters indicates distributions may be expanding south.

Increased occurrence and persistence of tropical species in southern waters as waters warm.

There is increased modelling of distribution and abundance to refine understanding of impacts for tropical species, coastal small pelagic species, and large offshore species, and thus incorporate impacts of climate change into fisheries management.

MARINE MAMMALS

Substantial evidence that sea surface temperature influences foraging locations and reproductive success of marine mammals. However, studies on long-term effects of warming are rare, with only one study providing evidence that dugongs extend their range in warm years.

Warmer water temperatures are likely to have a profound influence on the distribution of marine mammals; the ranges of species currently associated with tropical and temperate waters are likely to expand southwards.

The Australian Animal Tracking and Monitoring System (AATAMS) is using acoustic technology, satellite tags and biologgers to monitor coastal and oceanic movements of marine mammals. This will elucidate links between climate change in Australia's coastal seas and the Southern Ocean, and responses of marine mammals.

MARINE REPTILES

Local declines of sea snakes on coral reefs may be the result of changing environmental conditions. Warming beaches are changing long-term sex ratios of hatchling turtles.

Some turtle nesting beaches will produce more females, but the long-term implications for turtle populations are unknown. Turtle nesting beaches will be lost due to sea-level rise and coastal development.

The Australian Government, together with the WA, NT and Qld Governments are currently supporting a project to monitor sand temperatures on key turtle nesting beaches. Monitoring programs focused on crocodiles and nesting turtles are ongoing.

SEABIRDS

Tropical and subtropical species breeding at Houtman Abrolhos, WA are now experiencing poor breeding success outside of El Niño years linked to warming. Large range extension reported for Bridled Tern in south-west Australia in response to ocean warming.

Warming will impact the timing and breeding success of temperate seabird species. Little penguin breeding is expected to become earlier and more successful to 2030s, but later decline as temperatures warm further. Increases in extreme fire days in southern and eastern Australia will lead to higher risk of injury and death for colonial nesting species, such as penguins.

Implementation of fast-response fire action plans to reduce the risk of fire in seabird colonies close to human settlements or infrastructure. Investigating human adaptation options to increase resilience of conservation-dependent seabirds and marine mammals impacted by climate change