IMOS

Integrated **Marine Observing** System

State and Trends of Australia's Oceans

Report

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Australia's Integrated Marine Observing System (IMOS) is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

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Introduction

Marine assessments are important tools for examining the state and trends of marine systems at regional, national, and global scales. The most robust assessments are data-driven and underpinned by time series of internationally accepted ecosystem indicators, based on measurement of physical, chemical, and biological variables. The collating, synthesising, and reporting of meaningful indicators of marine ecosystem health provides information in a clear way to a broad, and often non-scientific audience.

The Integrated Marine Observing System (IMOS) is uniquely positioned to provide time series data that can underpin assessments of Australia's vast and valuable marine estate (see "Australia's Integrated Marine Observing System (IMOS)" below).

The national State of the Environment Report, global World Ocean Assessment, and regional Great Barrier Reef Outlook Report are examples of regular reporting and assessment tools that require time series data collected at the scale of IMOS. The State and Trends of Australia's Oceans Report (2019) is intended to provide a baseline for contribution to all such marine assessments into the future.

It is not the role of IMOS to undertake marine assessments. The role of IMOS as a national research infrastructure is to build large datasets and long time series for use and reuse. The process to produce this report is designed to ensure that datasets and time series available within Australia are organised, analysed, and interpreted so that they can be used in relevant assessment and reporting processes as required. Making our datasets and time series 'assessment ready' is part of the IMOS strategy to plan for impact. This includes data collected by IMOS facilities as well as additional data contributed by partners through the Australian Ocean Data Network (AODN).

IMOS
Integrated **Marine**
Observing System

Australia's Integrated Marine Observing System (IMOS)

The Integrated Marine Observing System (IMOS): IMOS is a national research infrastructure funded under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS). Since 2006, IMOS has been routinely operating a wide range of observing equipment throughout Australia's coastal and open oceans, making all of its data accessible to the marine and climate science communities, and other stakeholders and users. Significant co-investment is provided by institutional partners, other Australian Government programs, State and Territory Governments, the private sector, and international collaborators. Co-investment comes in the form of cash and in-kind contributions, including provision of additional data accessible through the IMOS-operated Australian Ocean Data Network (AODN). IMOS is a regional alliance of the Global Ocean Observing System (GOOS) and works with many nations to improve the quality, consistency and availability of ocean observations globally.

About this report

The process to develop this report involved over 70 scientists from 16 institutions working with available datasets, mostly of ten years length or longer. New analyses were undertaken to produce scientifically robust information about the state and trends of ecosystem indicators relevant to the Australian marine environment and its bioregions (see “Australian marine bioregions”, p 8).

A total of 27 time series datasets were assessed as being appropriate for inclusion in the State and Trends of Australia’s Oceans Report (2019). They are grouped into four themes covering indicators of the physical and chemical environment, biological productivity, water quality and marine animals (zooplankton, fish, sharks and marine mammals).

All the time series used are of variables in the water column of the ocean, known as the pelagic zone (see “The pelagic zone”, p 9). Before IMOS was established there was no systematic and sustained collection of data in the pelagic zone of Australia’s marine environment, limiting our ability to understand the state and trends of key ecosystem indicators. The 2019 report begins to address this huge gap. No variables from the seafloor (benthic zone) are included in this report, though an expanded scope could be considered in the future.

The four themes were not predetermined at the start of the process. Identification of the 27 time series included in the 2019 report was inevitably based on availability of data and willingness of subject matter experts to make time available for analysis. As the editorial team went through the process of synthesising outputs into a single report, this four-theme structure emerged. Different thematic structures could evolve in response to user and stakeholder feedback.

The report contains succinct documents (of 4-6 pages) for each time series that are written in a common format by a group of subject matter experts. There is a Rationale and a section on Implications for people and ecosystems. The analysis Methods used are explained. Results and Interpretation are provided through a combination of brief narratives and downloadable graphs and maps. Data Sources are acknowledged, and References to relevant scientific literature are provided. Each time series document has been assigned its own digital object identifier (DOI).

The goal has been to ensure that the report will be relevant to national, global, and regional marine assessments and therefore useful to the scientific community, government managers and policy makers, and marine industries. The intention has been to establish a process that is repeatable, efficient, and can be timed to feed into future assessment and reporting cycles and take advantage of new data and methods as they become available.

A list of the four themes and 27 time series included in this report is shown below. A summary of key findings is provided in the next section.

Time Series themes

1

Physical & chemical environment

2

Biological productivity

3

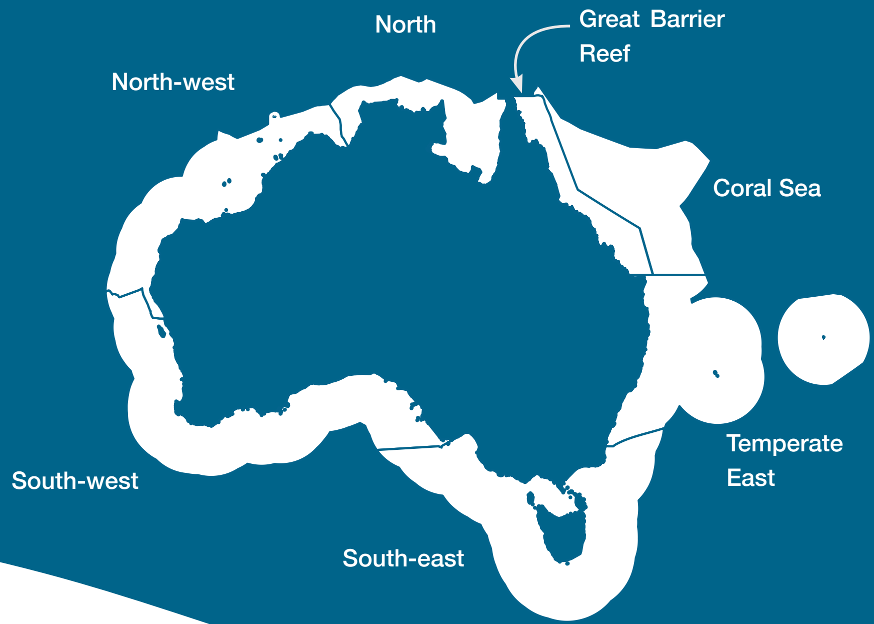
Water quality

4

Marine animals

Australian marine bioregions

Australia's ocean territory has been classified into six marine bioregions – South-east, Temperate East, South-west, North-west, North and Coral Sea. Marine bioregional plans have been developed by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) to improve the way Australia's oceans are managed so they remain healthy and productive.



The time Series

1. Physical and chemical environment Time Series

- 1.1 Long-term changes in temperature around Australia
- 1.2 Sea Surface Temperature Variability
- 1.3 East Australian Current Variability
- 1.4 Variability in ocean currents around Australia
- 1.5 Spatial and temporal trends in concentrations of nutrients
- 1.6 Ocean acidification

2. Biological Time Series – Productivity

- 2.1 Spatial and seasonal trends in Chlorophyll a
- 2.2 Spatial and seasonal and trends in net primary production
- 2.3 Contrasting trends of Australia's plankton communities
- 2.4 The seasons of phytoplankton around Australia
- 2.5 Indicators of depth layers important to phytoplankton production
- 2.6 Picophytoplankton: harbingers of change in our coastal oceans
- 2.7 Status of Australian marine microbial assemblages

3. Biological Time Series – Water quality

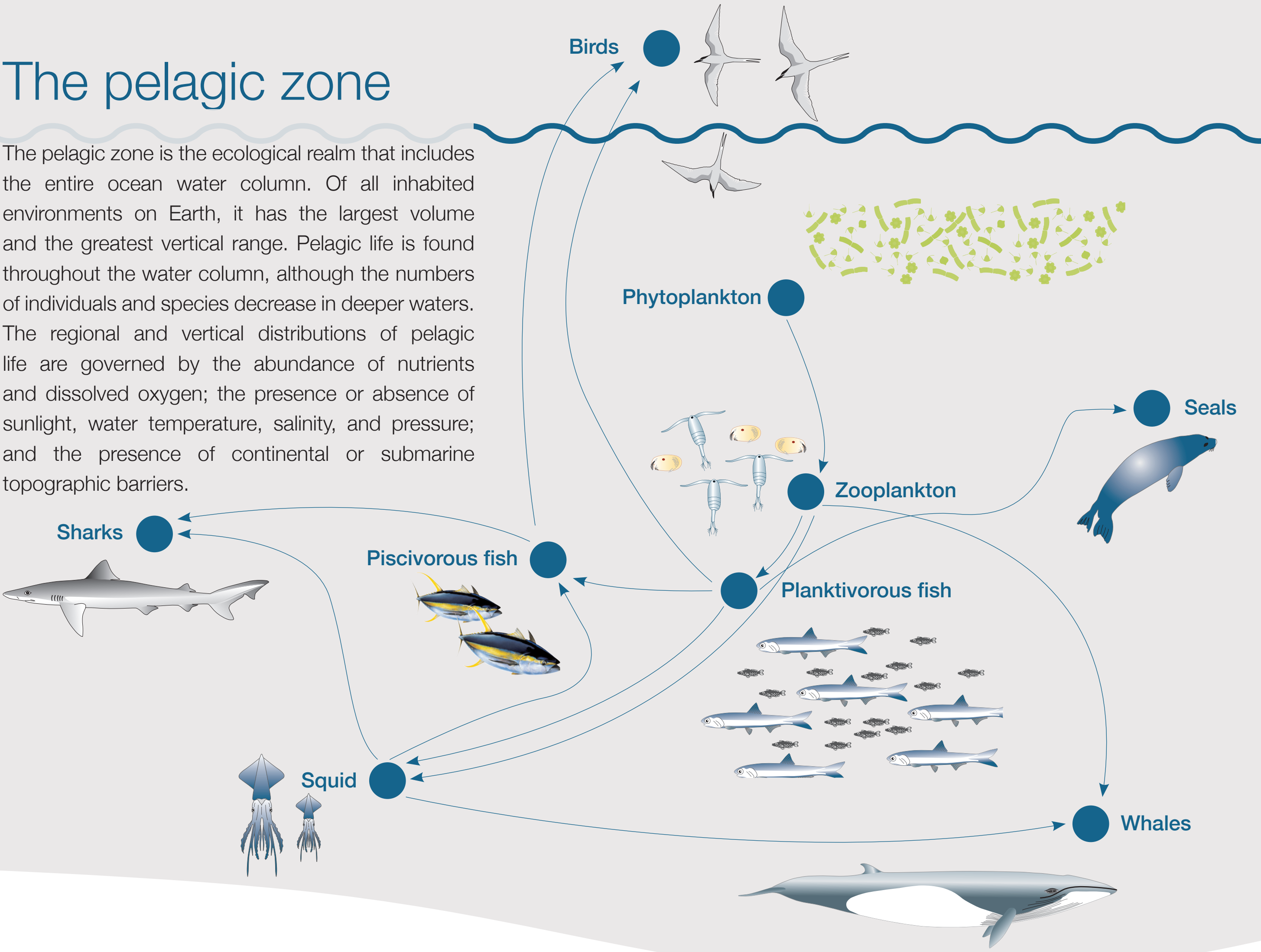
- 3.1 Water clarity around Australia – satellite and in situ observations
- 3.2 Spatial and seasonal trends in *Trichodesmium*
- 3.3 *Tripos* dinoflagellates as indicators of Australian marine bioregions
- 3.4 Harmful Algal Blooms and the shellfish industry
- 3.5 Harmful Algal Blooms in New South Wales
- 3.6 Range expansion of the red tide dinoflagellate *Noctiluca scintillans*

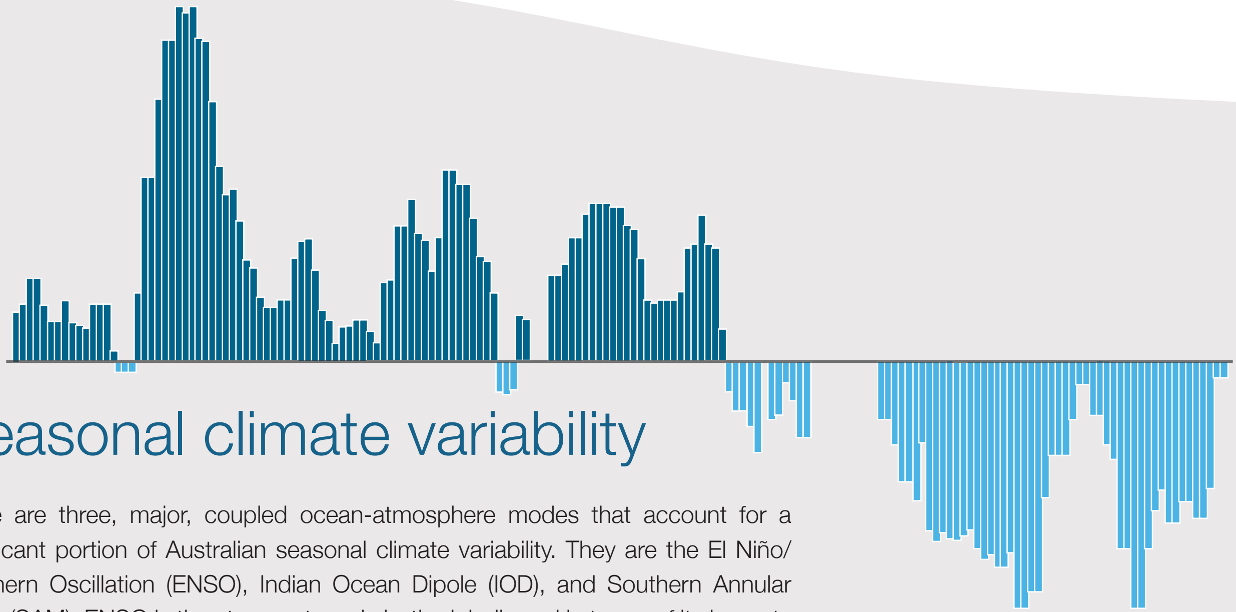
4. Biological Time Series – Marine animals

- 4.1 The response of the copepod community to long-term warming along the east coast of Australia
- 4.2 The impact on Zooplankton of the 2011 heatwave off Western Australia
- 4.3 Use of Zooplankton communities to estimate the relative strength of the East Australian Current
- 4.4 Ocean acidification and calcifying zooplankton
- 4.5 Sounding out life in Australia's twilight zone
- 4.6 Temporal and spatial changes in larval fish
- 4.7 Continental scale-shark migrations
- 4.8 Tracking elephant seal population trends in the Southern Ocean

The pelagic zone

The pelagic zone is the ecological realm that includes the entire ocean water column. Of all inhabited environments on Earth, it has the largest volume and the greatest vertical range. Pelagic life is found throughout the water column, although the numbers of individuals and species decrease in deeper waters. The regional and vertical distributions of pelagic life are governed by the abundance of nutrients and dissolved oxygen; the presence or absence of sunlight, water temperature, salinity, and pressure; and the presence of continental or submarine topographic barriers.





Seasonal climate variability

There are three, major, coupled ocean-atmosphere modes that account for a significant portion of Australian seasonal climate variability. They are the El Niño/ Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Southern Annular Mode (SAM). ENSO is the strongest mode both globally and in terms of its impacts on Australian climate. A characteristic of ENSO is the associated pattern of sea surface temperature (SST) variation in the eastern tropical Pacific Ocean, which alternates between a warm phase (El Niño) and a cold phase (La Niña). ENSO has a strong influence on regional rainfall patterns across much of Australia. El Niño are events associated with droughts and La Niña events associated with heavy rainfall.

Key findings

The 27 individual time series include results, interpretations, and implications that will be of use to anyone interested in the variables being observed. Bringing all of these time series together into a single State and Trends of Australia's Oceans Report (2019) creates the potential to get a much more integrated and comprehensive view of what is happening across Australia's marine environment.

It is now possible to do this because of sustained investment in a nationally integrated marine observing system (IMOS) and a national ocean data network (AODN). This report is intended to add value to these investments by providing additional scientific analysis to make available research data more useful to marine assessments that inform government managers and policy makers and marine industries responsible for sustainable development of Australia's marine environment.

Key findings of the State and Trends of Australia's Oceans Report (2019) are summarised below.

1 Physical and chemical environment

Time series of the physical environment (1.1) show steady warming of Australia's oceans over the last century, with some regional variation. Regional variation is strongly influenced by the major ocean currents that flow around the Australian continent (see "Boundary currents around Australia", p 12).

Warming has been fastest in the south, particularly in the South East and Temperate East bioregions. High variability between years, called interannual variability, is also observed (1.2, 1.3, 1.4). This can be related to the major modes of seasonal climate variability impacting the Australian region (see "Seasonal climate variability", p 9). Consistent with global climate models, seasonal, high-temperature extremes called 'marine heatwaves' can now be observed. Marine heatwaves appear to be increasing in frequency and intensity, with implications for marine ecosystems (1.4, 2.6, 4.2).

Bringing these time series together enables investigation of connections between the physical environment, chemical environment, and biological productivity.

Along with rising temperature, increasing acidification of the ocean is observable at a global scale. Time series of chemical variables within the Australian marine environment (1.6) show large decreases in pH of seawater and in concentration of dissolved carbonate ions. These are the internationally accepted measures of ocean acidification. Regional data show interannual variability driven by the combination of seasonal climate and boundary currents. There is no evidence of decline in the abundance of calcifying organisms over the last decade (4.4).

2 Biological productivity

Consistent with ocean warming, there is evidence of declining biological productivity of surface waters across the Australian marine environment. This can be seen in time series of chlorophyll a (2.1), net primary production (2.2), and phytoplankton abundance (2.3). Regional variation can be explained by physical factors e.g. incursion of nutrient-rich sub-Antarctic surface waters in the South East bioregion. Seasonal cycles of productivity are shown to follow latitudinal bands that are temperature dependent (2.4). It is noted that these findings relate to surface waters only, and the importance of sub-surface productivity also needs to be considered in assessing the biological productivity of Australian waters (2.5).

Time series of the biomass and abundance of marine animals that undertake secondary production (called zooplankton) are increasing (2.3), in contrast to the decline in primary production. Possible explanations for this increase include changes to community structure and changes to rates of top-down predation by fish. This interesting finding highlights the value of undertaking integrated analysis of datasets and time series to inform the focus of future research.

Molecular tools have been applied to IMOS sampling programs since 2012 and it is now possible to produce time series of Australian marine microbial assemblages (2.7). As this work matures under the Australian Microbiome Initiative the utility of molecular tools in monitoring, forecasting and managing marine environments will be further investigated.

3 Water quality

Most of Australia's offshore marine environment has relatively high water clarity, with some regional variation but no evidence of long-term change (3.1). The distribution and abundance of microorganisms with the potential to have harmful effects on people, fish, and shellfish is of significant interest to scientists, government managers and policy makers, marine industries, and the community at large. These include various species of dinoflagellates, diatoms, and bacteria.

Time series show changes in distribution and abundance of key species consistent with the physical and chemical effects of ocean warming (3.2, 3.6) and extreme events (3.5). The abundance of major harmful algal bloom species is typically below trigger levels, with some exceptions, though there is evidence that abundance of some key species is increasing (3.4).

A feature of the time series used in this section is the significant contribution of data collected outside of IMOS, by university researchers, State Governments, and the private sector. It is hoped that this report will help to motivate other data custodians to make more marine data findable, accessible, interoperable, and reusable (FAIR) through the AODN so that it can contribute to our collective understanding of the Australian marine environment.

4 Marine animals

Zooplankton are small marine animals that drift with ocean currents. They play a key role in marine food webs as consumers of phytoplankton and other food sources and as a resource for fish and other consumers at higher trophic levels. Time series show zooplankton communities responding to ocean warming, with increased abundance of warm-water taxa and decreased abundance of cold-water taxa (4.1). Marine heatwaves are shown to substantially reduce total zooplankton biomass, abundance, and size, while increasing diversity (4.2). Zooplankton communities have bounced back quite quickly after marine heatwaves, though the effects on higher trophic levels of reduced food availability during these events are currently unknown. Zooplankton community composition is also shown to change in response to variability of the East Australian Current (4.3).

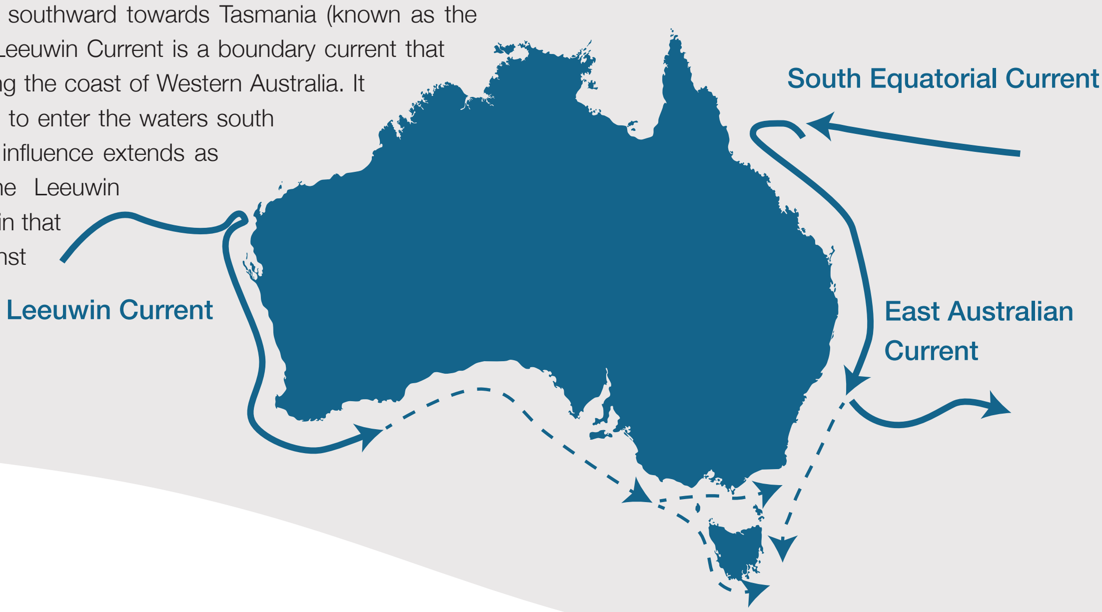
An estimate of the density of smaller fish and larger zooplankton (e.g. squid and jellyfish) that live in the intermediate depths of the ocean (called the mesopelagic zone) can be developed using data from echosounders on fishing vessels and research vessels. Basin-scale time series have been established in the Indian Ocean, Southern Ocean, and Tasman Sea. The data show a significant increasing trend in the Tasman Sea and Southern Ocean (4.5). Further research is required to validate these estimates and understand the mechanisms at play.

The eggs and larvae of most marine fish inhabit surface waters of the ocean as planktonic organisms (called ichthyoplankton). Larval fish data for both the east and west coasts (4.6) show a strong latitudinal gradient for most of the year, with higher diversity and abundance in tropical northern regions and a steep decline below 30°S. Over the last two decades however, this gradient appears to have weakened along the east coast. Larval fish assemblages at northern and southern latitudes have become more similar. This is consistent with southward extension of warm EAC waters, shifting tropical/sub-tropical species poleward. Increased abundance of warm-water larval fish at southern latitudes is also consistent with the trend observed in other zooplankton (see 4.1, above).

Understanding movement and connectivity of larger marine animals (fishes, sharks, marine mammals) is increasingly important as human use and environmental change alter ocean ecosystems. Identifying movement patterns is particularly important for species that move long distances, and animal tracking technologies provide an effective and efficient means to build time series of species distribution. Previously unknown migration of bull sharks between Sydney Harbour and the Great Barrier Reef has been revealed by analysis of data from the continental-scale acoustic telemetry network (4.7). Time series of environmental data collected from satellite tags on elephant seals in the Southern Ocean have been used to describe the water masses in which the animals are feeding, helping to resolve questions about population trends (4.8).

Boundary currents around Australia

The main, large-scale influences on the ocean around Australia arise from the South Pacific basin in the east and the Indian Ocean basin in the west. Australia is therefore influenced by two major ocean current systems at the boundaries of these basins. The East Australian Current (EAC) is a southward-flowing boundary current that is formed by the South Equatorial Current (SEC) crossing the Coral Sea and reaching the coast of Australia off north Queensland. As it flows southward, it splits from the coast just north of Sydney. The majority of the EAC flow moves eastward across the Tasman Sea towards New Zealand, with the remainder flowing southward towards Tasmania (known as the EAC extension). The Leeuwin Current is a boundary current that flows southwards along the coast of Western Australia. It rounds Cape Leeuwin to enter the waters south of Australia where its influence extends as far as Tasmania. The Leeuwin Current is anomalous in that it flows poleward against the prevailing winds.



The next steps

The State and Trends of Australia's Oceans Report (2019) is a pilot product.

The concept emerged from within the IMOS community, and preparation of the report has been facilitated through one-off funding of an IMOS Task Team.

It is envisaged that updates of the State and Trends of Australia's Oceans Report would be produced every two years, on a biennial cycle, timed to optimise potential for contribution to major reports and assessments carried out regularly at national, regional and global scales.

Feedback on the first report from the Australian marine management and policy communities is therefore critical to determining next steps. The provision of feedback on this report will be facilitated by the IMOS Office, and stakeholders are encouraged to engage in helping to develop the concept.

For example, the next Australian State of the Environment (SoE) Report will cover the five-year period from 2017 to 2021. Whether or not data and analysis from the State and Trends of Australia's Oceans Report series are used in SoE 2021 will provide one indication of utility.

The large team of over 70 scientists involved in preparing the report found it an interesting and useful process. Many lessons were learnt along the way and any future reports will benefit from this experience. We are confident that the resources required to produce these reports on a routine basis could be marshalled if there is sufficient user and stakeholder demand for the product.

Summary

The time series in this report provide scientifically robust information on state and trends of pelagic ecosystem indicators for Australia's vast and valuable marine estate. Many of these indicators have not been previously available.

Against a background of long-term global ocean warming and acidification, regional variations are elucidated and the influences of seasonal climate variability (e.g. ENSO) and boundary current variability (e.g. EAC) are shown. There is evidence of extreme events (e.g. marine heatwaves) increasing in frequency and intensity.

Importantly, numerous biological responses to change and variability in the physical/chemical environment are shown. Many of these have potential socio-economic and policy implications which are outlined in each of the time series' "implications for people and ecosystems" sections.

There is evidence of declining biological productivity of surface waters across the Australian marine environment. Sub-surface productivity is also shown to be important, though it is currently less well understood at large scale. Decline in primary production is not reflected in time series of secondary production, which is increasing. Explanations for this interesting result are hypothesised and could inform the focus of future research.

Distribution and abundance of harmful algal bloom species is changing. The abundance of major harmful algal bloom species is typically below trigger levels, with some exceptions, though there is evidence that abundance of some key species is increasing.

Communities of microscopic marine animals (e.g. zooplankton) are changing, with evidence of increased abundance of warm-water taxa and decreased abundance of cold-water taxa as the oceans warm. Poleward shifts of tropical/sub-tropical species are also observed. In deeper, colder waters of the Tasman Sea and Southern Ocean, density of larger zooplankton and fish appears to be increasing. New insights into movement patterns of larger marine animals (e.g. bull sharks, elephant seals) are provided, with evidence of patterns changing in response to environmental conditions.

The improved understanding of connections between physical, chemical, and biological variables provided in the State and Trends of Australia's Oceans Report (2019) is a significant step in describing these links and the ongoing changes they face. This in turn increases our confidence in modelling of future states across the Australian marine environment, to inform government managers and policy makers, and marine industries, in the context of sustainable development.

The data behind the Time Series

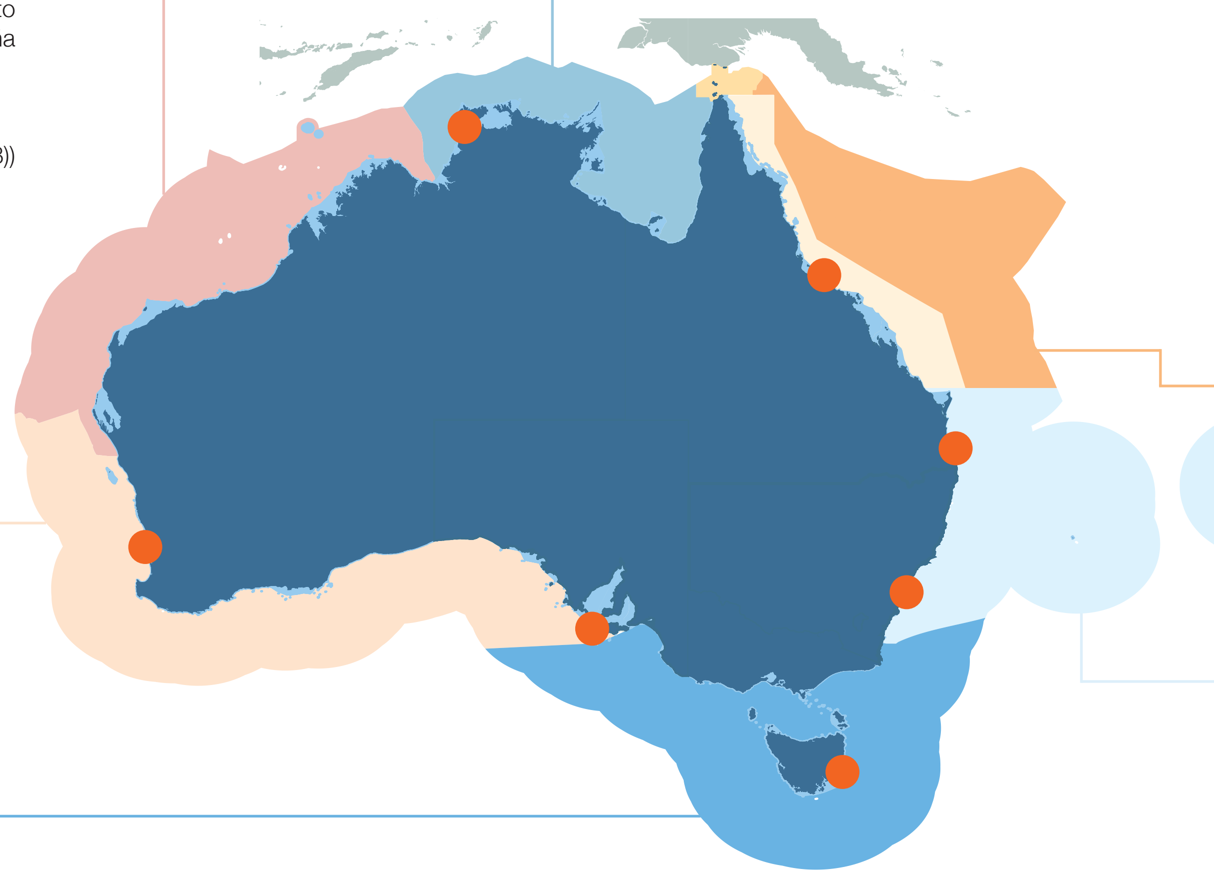
	Ships of Opportunity	Satellite Remote Sensing	National Mooring Network	Animal Tracking	Deep Water Moorings	Australian Ocean Data Network	Ocean Radar
1. Physical and Chemical Time Series							
1.1 Long-term changes in temperature around Australia		●	●				
1.2 Sea Surface Temperature Variability		●					
1.3 East Australian Current Variability		●			●		●
1.4 Variability in ocean currents around Australia		●					
1.5 Spatial and temporal trends in concentrations of the nutrients N, P, Si			●				
1.6 Ocean acidification			●				
2.Biological Time Series - Productivity							
2.1 Spatial and seasonal trends in Chlorophyll a		●					
2.2 Spatial and seasonal and trends in net primary production		●					
2.3 Contrasting trends of Australia's plankton communities			●				
2.4 The seasons of phytoplankton around Australia		●					
2.5 Indicators of depth layers important to phytoplankton production			●				
2.6 Picophytoplankton: harbingers of change in our coastal oceans			●				
2.7 Status of Australian marine microbial assemblages			●				
3. Biological Time Series - Water Quality							
3.1 Water clarity around Australia – satellite and in situ observations		●	●				
3.2 Spatial and seasonal trends in *Trichodesmium*	●		●				
3.3 *Tripos* dinoflagellates as indicators of Australian marine bioregions	●		●			●	
3.4 Harmful Algal Blooms and the shellfish industry						●	
3.5 Harmful Algal Blooms in New South Wales						●	
3.6 Range expansion of the red tide dinoflagellate *Noctiluca scintillans*	●		●				
4. Biological Time Series - Marine Animals							
4.1 The response of the copepod community to long-term warming along the east coast of Australia	●		●				
4.2 The impact on Zooplankton of the 2011 heatwave off Western Australia			●				
4.3 Use of Zooplankton communities to estimate the relative strength of the East Australian Current	●	●					
4.4 Ocean acidification and calcifying zooplankton			●				
4.5 Sounding out life in Australia's twilight zone	●						
4.6 Temporal and spatial changes in larval fish	●		●				
4.7 Continental-scale shark migrations				●			
4.8 Tracking elephant seal population trends in the Southern Ocean				●			

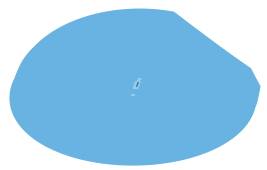
State and Trends of Australia's Ocean Report

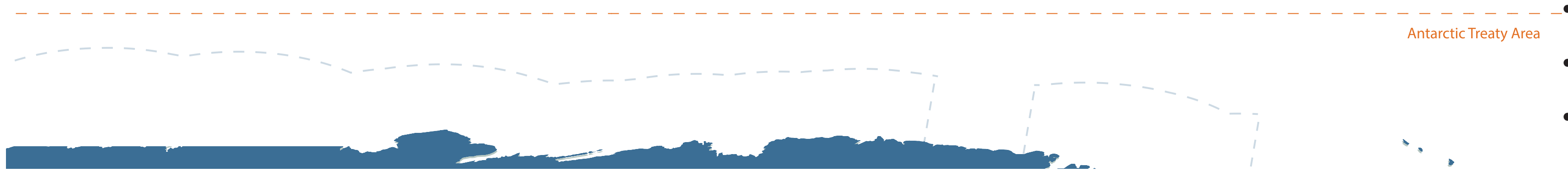
Marine Bioregional Summary

IMOS National Reference Station

Coastal Waters







North-west Marine Region

- Ocean warming (~0.6°C century^{-1}) (Time Series 1.1)
- Many increases/decreases in mean monthly SST by up to 2°C at inter-annual scales, mainly associated with La Niña events (Time Series 1.2)
- Significant decline in Chlorophyll ***a*** from 2002-2019 (Time Series 2.1)
- Decline in net primary production (-10.2% (2002-2018)) (Time Series 2.2)

South-west Marine Region

- Warming (~0.99°C century^{-1}), with up to ~1.50°C century^{-1} at Rottnest Island (Time Series 1.1)
- At Rottnest Island there is no discernible trend in surface nitrate. Surface phosphorous and surface silicon are declining (Time Series 1.5)
- Decline in net primary production (8.6% (2003-18)) (Time Series 2.2)
- Phytoplankton biovolume declining at Rottnest Island, but zooplankton abundance increasing (Time Series 2.3)
- Unseasonal appearance of tropical *Prochlorococcus* at Rottnest Island during 2011-2012 marine heatwave (Time Series 2.6)
- High water transparency (Time Series 3.1)
- The 2011 WA marine heatwave led to a substantial decline in zooplankton biomass, abundance and size, and an increase in diversity at Rottnest Island (Time Series 4.2)

South-east Marine Region

- Fast warming (~1.1°C century^{-1}) with up to ~2°C at Maria Island, Tasmania (Time Series 1.1)
- At Maria Island, surface nitrate is rising, contrary to warming trend, and due to winter mixing and incursion of sub-Antarctic surface waters; surface phosphorous and surface silicon is declining (Time Series 1.5)
- Relatively low net primary production (423 mg C m^{-2} d^{-1}) (Time Series 2.2)
- Zooplankton abundance and biomass increasing at Maria Island (Time Series 2.3)
- Summer peaks of tropical *Prochlorococcus* and sub-tropical *Synechococcus* at Maria Island indicate prolonged exposure to warmer waters via EAC extension (Time Series 2.6)
- Low water transparency (Time Series 3.1)
- Presence of warm-water *Tripos paradoxides* increases in winter (Time Series 3.3)
- Abundance of HABs is typically below trigger levels, with some exceptions. There is however evidence that abundance is increasing (Time Series 3.4)
- Range expansion of *Noctiluca scintillans* into Tasmania (1994) and the Southern Ocean (2010, 2013) (Time Series 3.6)
- Warm water copepod species increased in abundance at Maria Island, while cold water species decreased (Time Series 4.1)
- Some evidence that calcifying zooplankton may be sensitive to falling aragonite saturation (Time Series 4.4)
- North/south shift in latitudinal trend of larval fish assemblages below 35°S (Time Series 4.6)

North Marine Region

- Ocean warming (~0.74°C century^{-1}) (Time Series 1.1)
- High Chlorophyll ***a*** (0.537 mg m^{-3}) (Time Series 2.1)
- North bioregion had the greatest primary production at 324 gC m^{-2} y^{-1} (Time Series 2.2)
- Relatively high net primary production (888mg C m^{-2} d^{-1}) (Time Series 2.2)
- Phytoplankton abundance declining at Darwin, but zooplankton abundance and biomass increasing (Time Series 2.3)
- Lowest water transparency and most opaque waters (Time Series 3.1)
- Modest increases in calcifier abundance (Time Series 4.4)

Coral Sea Marine Region

- Warming (~0.8°C century^{-1}) (Time Series 1.1)
- Low Chlorophyll ***a*** (0.084 mg m^{3}) (Time Series 2.1)
- Decline in net primary production (9.1% (2003-2018)) (Time Series 2.2)
- Highest water transparency (Time Series 3.1)

Temperate East Marine Region

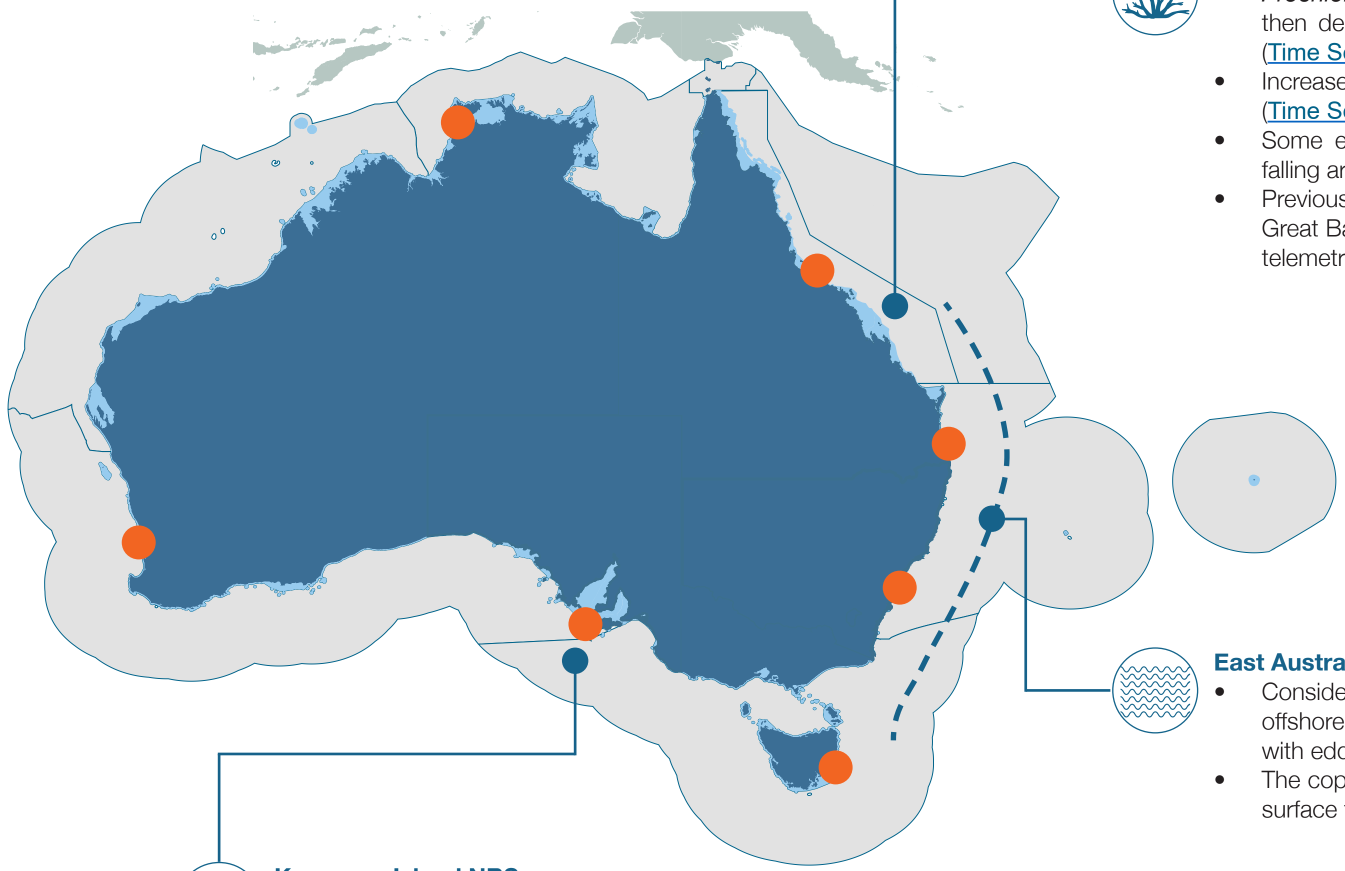
- Fast warming (~0.93°C century^{-1}), with up to ~1.50 °C century^{-1} at Port Hacking (Time Series 1.1)
- Linear increase in sea surface temperature along the east coast over 1993-2016 (Time Series 1.2)
- At Port Hacking, surface nitrate is declining - consistent with warming trends and is increasing at depth due to stratification. Surface phosphorous and surface silicon are declining (Time Series 1.5)
- Decline in net primary production (12.9% (2003-2018)) (Time Series 2.2)
- Phytoplankton biovolume and abundance declining significantly at North Stradbroke Island and Port Hacking, and zooplankton biomass declining at North Stradbroke Island (Time Series 2.3)
- Molecular data suggest that strains of *Synechococcus* increase in abundance and those of *Prochlorococcus* decrease in response to coastal upwelling at Port Hacking (Time Series 2.7)
- High water transparency. Validated by North Stradbroke Island NRS (Time Series 3.1)
- Significant decline in abundance of *Trichodesmium* at North Stradbroke Island (Time Series 3.2)
- Abundance of HABs is typically below trigger levels, with some exceptions. There is, however, evidence that abundance is increasing (Time Series 3.4)
- Harmful algal blooms on NSW beaches are seasonal and episodic nature (Time Series 3.5)
- Warm water copepod species increased in abundance at Port Hacking, cold water species decreased (Time Series 4.1)
- North/south shift in latitudinal trend of larval fish assemblages below 35°S (Time Series 4.6)

State and Trends of Australia's Ocean Report

Regional Summary

IMOS National Reference Station

Coastal Waters



Australian Region/EEZ

- Steady warming since 1920, particularly in the south (Time Series 1.1)
- The Leeuwin and East Australian Currents demonstrated strong seasonable and inter-annual variability linked to El Niño and La Niña events (Time Series 1.4)
- Large decreases in both aragonite saturation rate and pH between 1870-99 and 2000-09 (Time Series 1.6)
- Low average Chlorophyll ***a*** (0.25 mg m^3) typical of healthy tropical/ sub-tropical oceans. The average is declining, by 8% in the period 2003-19 (Time Series 2.1)
- Low average net primary production (551 mg C m^{-2} d^{-1}) typical of healthy tropical/sub-tropical oceans. Average declining by 12% in the period 2002-2019 (Time Series 2.2)
- Seasonal cycle of phytoplankton follows latitudinal bands, except in the Leeuwin Current and northeast Indian Ocean (Time Series 2.4)
- Deep chlorophyll maxima deeper than mean mixed layer depths indicating that sub-surface production is important (Time Series 2.5)
- Average Secchi disk depth is 24m (Time Series 3.1)
- Majority of Tripos species exhibit broad temperature range (10-25°C). Restricted group of warm water species identified to enable monitoring of any future range expansion (Time Series 3.3)
- No evidence of decline in calcifying zooplankton at National Reference Stations (Time Series 4.4)

Great Barrier Reef

- *Prochlorococcus* most abundant at Yongala in spring and summer, then decline rapidly with drop in salinity due to seasonal rainfall (Time Series 2.6)
- Increase in abundance of *Trichodesmium* at Yongala (Time Series 3.2)
- Some evidence that calcifying zooplankton may be sensitive to falling aragonite saturation (Time Series 4.4)
- Previously unknown migration of Bull Sharks between NSW and the Great Barrier Reef revealed by the IMOS continental scale acoustic telemetry network (Time Series 4.7)

East Australian Current

- Considerable variability dominated by movement of the EAC on and offshore. Eastward displacement every 65-100 days associated with eddy shedding (Time Series 1.3)
- The copepod composition index is positive related to trends in sea surface temperature anomaly (2010-2018) (Time Series 4.3)

Kangaroo Island NRS

- Inter-annual variability at Kangaroo Island driven by variability in Leeuwin and Flinders Currents associated with El Niño-Southern Oscillation (Time Series 1.6)
- Phytoplankton biovolume and abundance declining significantly at Kangaroo Island, but Zooplankton abundance and biomass increasing (Time Series 2.3)
- Euphotic depth is 41m deeper than mean mixed layer depth, pointing to a large volume of sub-surface water in which irradiances are high enough for photosynthesis (Time Series 2.5)

Southern Ocean and Tasman Sea

- Increasing trend in acoustic backscatter in Southern Ocean (77% (2010-2018)) and Tasman Sea (44-105%), likely to reflect change in mesopelagic communities (Time Series 4.5)
- IMOS satellite tagging of elephant seals in the Southern Ocean revealing physical drives of population change (Time Series 4.8)