

# Plankton 2015

## State of Australia's oceans

Linking science and policy: an assessment  
of our oceans using plankton indicators of  
ecological change



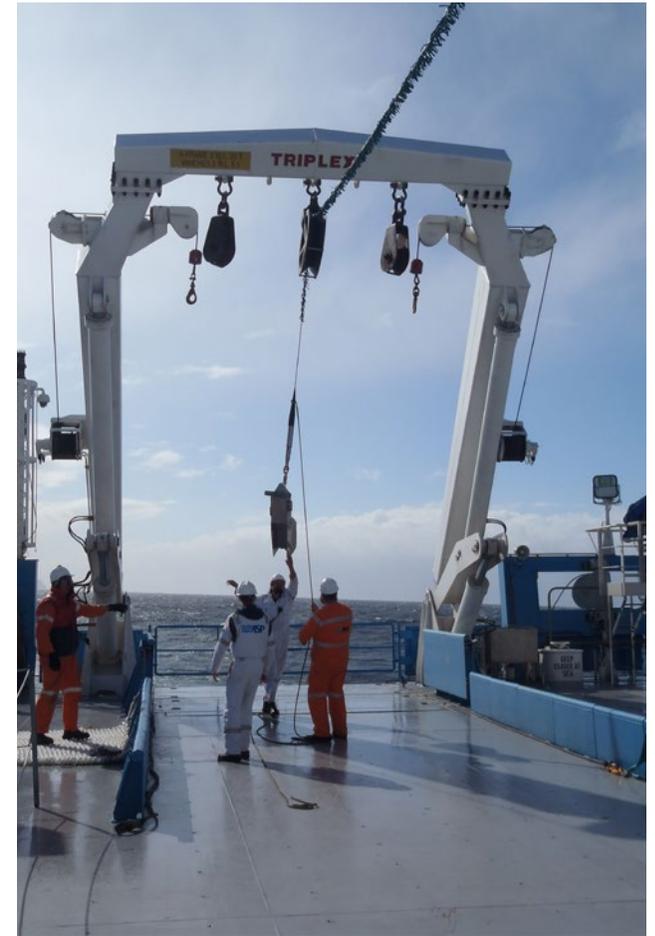
# What is Plankton 2015?

Plankton is the foundation of the marine food web and supports nearly all life in our oceans. Plankton 2015 is an assessment of the state of the oceans around Australia using plankton as indicators of ecological change.

It is based on plankton data from the Australian Integrated Marine Observing System (IMOS) and supplemented by data from historical and contemporary sources. We have organised this report around a series of management issues – climate change, ocean acidification, productivity supporting fisheries, biodiversity and ecosystem health – and suggested ecological indicators where appropriate.



It is hoped that Plankton 2015 will inform marine managers, scientists and the public of changes at the base of the marine food web and their potential implications for higher trophic levels and ourselves. Plankton 2015 will be updated and evolve as time series grow longer, and as we develop and refine ecological indicators.



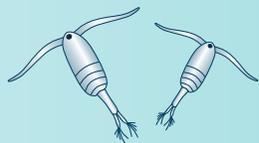
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 IMOS Integrated Marine Observing System



## SUMMARY FOR POLICY MAKERS

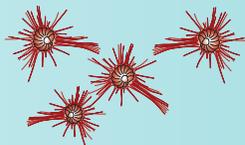
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**Climate change: Range shifts**  
*Climate change is altering plankton distributions*

- A general shift southward by 300 km off the east coast of 15 common phytoplankton species since 1990
- Increased abundance of warm-water copepod species and decline in cold-water species off eastern Tasmania
- In 2010, the generally warm-water red tide species *Noctiluca scintillans* was observed for the first time blooming in the Southern Ocean
- With further warming, there is likely to be more tropical species expanding into temperate and polar waters, which could lead to smaller plankton and reduced food for higher trophic levels

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**Ocean acidification**  
*Evidence of ocean acidification impacting calcifying plankton in Australia is equivocal*

- Potential thinning and increased porosity of shells of pteropods in northern Australia over past 30 yrs with increased acidity
- No decrease in calcifier abundance at IMOS National Reference Stations
- As oceans become more acidic over coming decades, the abundance of some calcifiers is likely to decline, impacting their predators

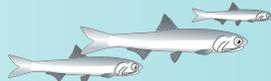
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**Biodiversity**  
*IMOS is providing the first Australia-wide view of plankton biodiversity*

- A decrease in phytoplankton and zooplankton biodiversity from the subtropics to the Southern Ocean is evident, driven by a decrease in temperature towards the pole
- Distinct zooplankton communities at each of the National Reference Stations highlight the importance of continued continental-scale monitoring

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**Productivity supporting fish**  
*Spawning and recruitment of fish are dependent upon the amount, composition, and timing of plankton*

- Marked seasonal and inter-annual changes in zooplankton biomass change the amount of food available for fish
- Trial surveys of larval fish abundance at NRS have found many commercial and recreational species that will shed new light on spawning and recruitment patterns

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**Ecosystem health**  
*HABs, jellyfish, and marine pathogens are common in Australia and IMOS is providing long-term datasets*

- Harmful Algal Blooms have significant health, economic and social impacts, although environmental conditions that trigger them are unclear; National Reference Stations and Continuous Plankton Recorder data show periodic blooms with high concentrations of potentially toxin-producing species
- Jellyfish are not increasing at the National Reference Stations. There were few major jellyfish sting events in tropical Australia in 2014/2015, but an unusually late Irukandji sting event at Ningaloo in June 2015
- The massive dust storm in 2009 caused a bloom of the fungus pathogen *Aspergillus sydowii* off SE Australia; ecosystem repercussions are unknown
- The presence of *Vibrio* spp. that grow on copepods and cause cholera is being assessed using molecular tools

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**Management applications**  
*Increasing opportunities for uptake of IMOS plankton data in ecosystem assessments, bioregional planning, and modelling*

- Plankton data are being used in regional and global assessments of ecosystem health
- IMOS is collecting plankton data regularly within or near areas of high conservation value, including protected areas such as the Commonwealth Marine Reserves, the Great Barrier Reef Marine Park and Key Ecological Features
- There is growing interest in using IMOS plankton data in ecosystem models

# What is plankton?

The ocean is teeming with microscopic drifting primary producers<sup>1</sup>. These are the phytoplankton, and they are grazed by animals known as zooplankton. The word plankton derives from the Greek *planktos* meaning “to drift”, and although many of the phytoplankton move (by flagella or cilia) and zooplankton swim, none can progress against currents. Most plankton is microscopic, but some such as jellyfish can be 2 m in diameter. Plankton communities are highly diverse, with members from almost all phyla.

## WHY IS PLANKTON IMPORTANT?

Plankton dominates the biomass of marine systems (Figure 1). Each day, phytoplankton perform nearly half of the photosynthesis on Earth, fixing 100 million tons of carbon dioxide and producing half of the oxygen we breathe. The most common zooplankton, the copepods, are the most abundant animals on Earth, even outnumbering insects<sup>2</sup>. The carrying capacity of marine systems – the biomass of exploited fish, squid and shellfish, the numbers of charismatic marine mammals, seabirds and sea turtles, and the diverse bottom-dwelling communities of crabs and fish – are determined by the biomass, growth, timing, and composition of the plankton.

Plankton impacts human health. Some phytoplankton species produce toxins and form large harmful algal blooms or red tides, which can contaminate shellfish and cause a suite of poisoning syndromes and death in humans. Some zooplankton is venomous, such as the box jellyfish *Chironex fleckeri* and Irukandji species, which close beaches in northern Australia and can cause severe pain and death.



Plankton influence the pace and extent of climate change. Many phytoplankton species produce chemicals that evaporate from the ocean, helping to form clouds, which cause rain and reflect solar radiation back to space. Plankton also shunts carbon from the surface to the deep ocean by fixing carbon through photosynthesis. This carbon is transferred to zooplankton grazers, sinking to the ocean floor as faeces or dead carcasses, where it can be removed from the atmosphere for thousands to millions of years – a process known as the biological pump (Figure 2). The type of phytoplankton present can have a significant influence on the efficiency of carbon export, as larger species sink more quickly. Movement of carbon to the deep ocean by plankton has contributed to the ocean uptake of 40% of the carbon dioxide produced by people – it would be much warmer if this carbon had not been taken up by the ocean. Over geological time, the accumulation of carbon from plankton on the seafloor has formed the oil and natural gas deposits we use today.

Without plankton, the Earth would be warmer and devoid of large fish and charismatic animals.

In fact, much of the economic value of the oceans, estimated at US\$21 trillion per annum and similar to the global gross national product<sup>3</sup>, is provided by plankton through fishery production, nutrient cycling, gas production and climate regulation.

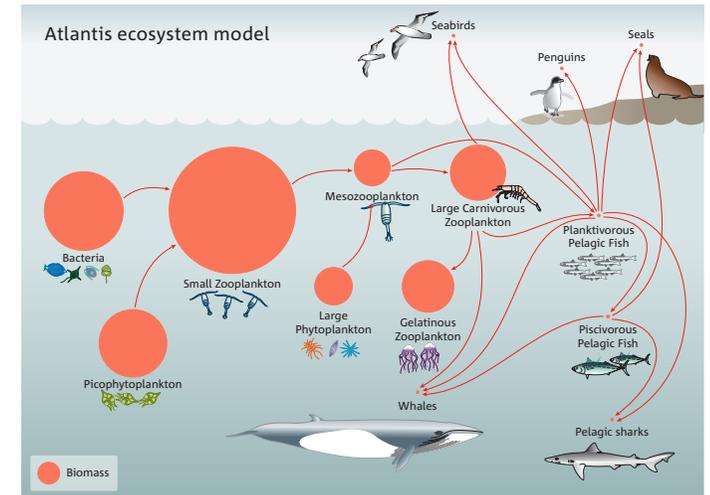


Figure 1. Diagram of a marine foodweb off SE Australia, with the size of spheres representing the biomass of each group.

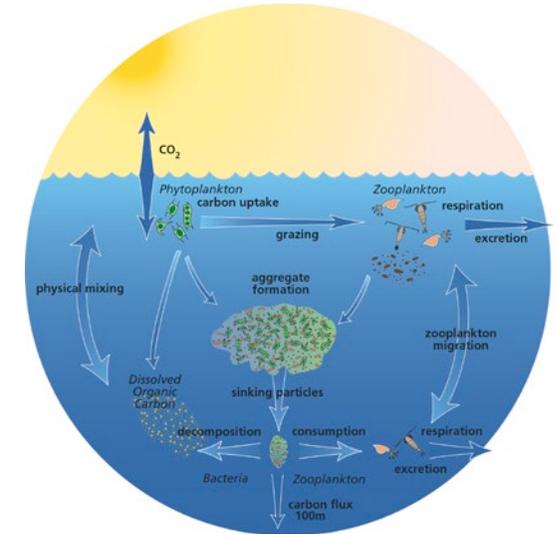


Figure 2. Plankton is critical to the “biological pump”, which removes carbon from the atmosphere and stores it in the deep ocean (image US JGOFS)

# Plankton as ecological indicators

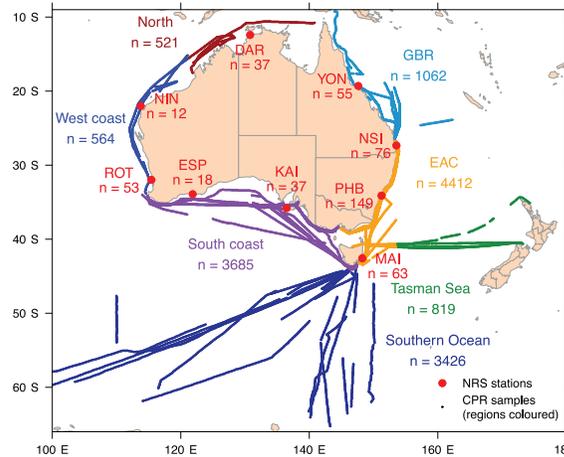
Indicators are simple measures of the state of a system. Plankton provides ideal indicators of ecosystem health and ecological change because it is abundant, short-lived, not harvested, and sensitive to changes in temperature, acidity and nutrients. Plankton has thus been used as indicators for climate change, eutrophication, fisheries, invasive species, ecosystem health and biodiversity<sup>4</sup>. Here, we have used the term ecological indicator as a measure of ecosystem state without considering a threshold level that triggers management intervention as in fisheries management.

## PLANKTON OBSERVATIONS

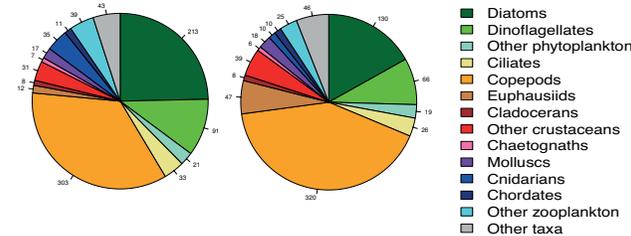
The Integrated Marine Observing System (IMOS) is a national ocean observing system measuring the physical, chemical and biological environment. It is one of the national research infrastructure capabilities currently supported under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS). IMOS has been awarded \$144M of Australian Government funding over 10 years (2006-2016), with matching co-investment of \$200M. Plankton observations within IMOS are provided by the Australian Continuous Plankton Recorder survey (AusCPR) and the National Reference Stations (NRS) program.

AusCPR samples are collected using a CPR towed behind commercial ships and then returned to the laboratory for counting. The AusCPR survey has analysed 15,196 samples (Figure 3) and recorded 770 plankton taxa (Figure 4). NRS samples are collected monthly at seven (originally nine) locations around Australia. The NRS program has analysed 1,000 samples (Figure 3) and recorded 864 plankton taxa (Figure 4). We have also included historical plankton

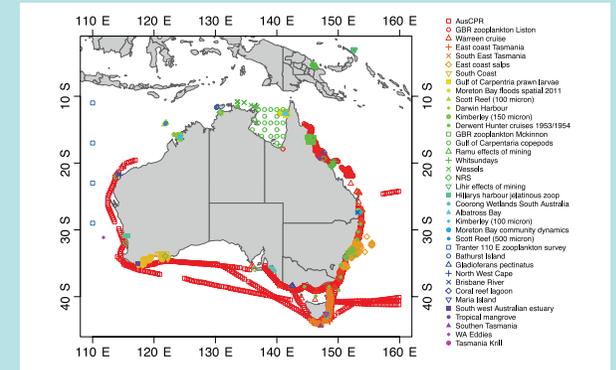
observations from the Australian Phytoplankton and Zooplankton Databases, IMOS physical data and published papers.



**Figure 3. Map of AusCPR and NRS plankton samples 2007-2015.** DAR=Darwin; YON=Yongala; NIN=Ningaloo; NSI=North Stradbroke Island; ROT=Rottneest Island; PHB=Port Hacking B; KAI=Kangaroo Island; MAI=Maria Island; ESP= Esperance.



**Figure 4. Number of plankton taxa counted in the IMOS NRS program (left) and IMOS AusCPR survey (right).**



## Improving access to Australian plankton data

There have been two compilations of plankton data collected by Australian researchers over the past 100 years. These compilations are being made publicly available through the Australian Ocean Data Network.

The Australian Zooplankton Database contains data on the abundance of marine zooplankton species in Australian waters<sup>5</sup>. It includes data from IMOS, papers, reports, unpublished data and theses. The compiled dataset has 98,676 records from 38 projects and includes >1,000 taxa.

The Australian Phytoplankton Database is currently being compiled and will make freely available phytoplankton abundance and chlorophyll data from Australian waters. The Australian Phytoplankton Database includes biovolume estimates for species in the dataset.

A new Australian Research Council Discovery Project investigates *The missing link in our oceans: how zooplankton size spectra couple phytoplankton with fisheries*. It will create a freely-available archive of zooplankton size spectra. This project is led by Iain Suthers and colleagues at University of New South Wales, University of Queensland and CSIRO. It investigates the size distribution of zooplankton, which is related to ecosystem productivity, carbon sequestration, and the efficiency of energy transfer to fish.

# Climate change: Range shifts off Australia's east coast

Temperature regulates plankton physiology (e.g. metabolism, reproduction, ingestion) and influences species interactions (e.g. competition, predation, disease). Warmer temperatures thus alter species' ranges (generally poleward), timing of blooms (generally earlier), diversity (higher), composition (more gelatinous and omnivorous), and size structure (smaller). This is why plankton species are sensitive indicators of climate change.

## INCREASE IN WARM-WATER COPEPODS OFF TASMANIA

Water temperature off Maria Island (east coast of Tasmania) has warmed by 1.5°C since 1944 (Figure 5), and is a consequence of global warming and its influence on the intensification of the warm, poleward-flowing East Australian Current (EAC)<sup>6</sup>. The EAC now makes more incursions into Tasmanian waters than previously<sup>7,8</sup>. The increase in strength of the EAC is likely to be a response to climate change<sup>9</sup>, and has contributed to ocean warming off Australia ~3–4 times the global average<sup>7</sup>.

Work by Craig Johnson and co-authors<sup>6</sup> has described the ecosystem response to warming. Off Maria Island, there is a decline of copepod species with preferences for colder water and an increase in those that prefer warmer water (Figure 6). This response to warming is consistent with other changes including a decline in the cold-water giant kelp *Macrocystis pyrifera*, the expansion of the long-spined sea urchin *Centrostephanus rodgersii*, and increasing numbers of warm-water inshore fish species<sup>6</sup>.

Changes in zooplankton ranges in response to warming are consistent with what is happening in other systems including the North Sea<sup>9</sup>, Northeast Atlantic<sup>10-12</sup> and Northwest Atlantic<sup>13</sup>. Range shifts exhibited by zooplankton in response to global warming can be 100s of kms per decade, and are among the largest of any taxa<sup>14</sup>.

Such a change from cold- to warm-water zooplankton species off eastern Tasmania is likely to have repercussions for higher trophic levels, as warm-water species are generally smaller and inferior food for fish, seabirds and marine mammals<sup>15</sup>.

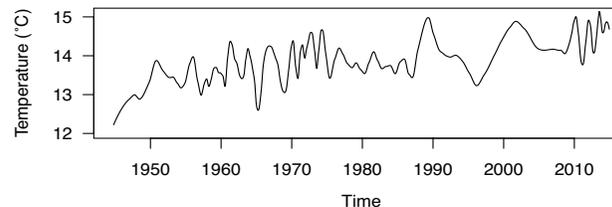


Figure 5. Standardised water column temperature (0–50 m) off Maria Island (1944–2014). Data from historical CTD casts (1944–2008), IMOS NRS water quality meters (2008–2014), and IMOS NRS CTD casts (2009–2014). All data obtained from IMOS Ocean Portal <https://imos.aodn.org.au/imos123/>

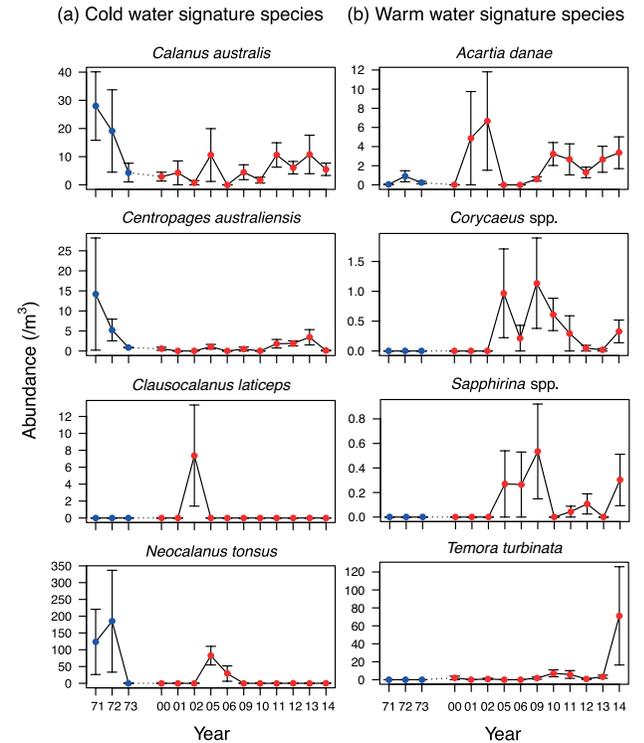


Figure 6. Zooplankton abundance (mean±SE) in NRS samples off Maria Island for (a) cold-water species and (b) warm-water species. Data from Kerrie Swadling (University of Tasmania) for 1971-2006 and from IMOS (2009-2014).

# Climate change: Range shifts in the Southern Ocean

## RANGE EXPANSION OF THE RED TIDE SPECIES *NOCTILUCA SCINTILLANS*

Work by Dave McLeod (CSIRO) and co-workers suggests that the range of *Noctiluca* is expanding as waters warm<sup>16</sup>. *Noctiluca scintillans* is a conspicuous, predatory dinoflagellate that commonly forms red tides. It was first documented in Australian waters in Sydney Harbour in 1860 (Figure 7a). It expanded its distribution off SE Australia in 1980-1993 (Figure 7b). It was first observed in Tasmania in 1994 (Figure 7c), apparently carried by the EAC, and has since established overwintering populations<sup>17</sup>. In 2008, IMOS sampling found it in Queensland, Western Australia and South Australia, and in 2010 in the Southern Ocean for the first time, the most southerly record globally (Figure 7d). It appeared to be transported south by a warm-core eddy, a likely consequence of the increased poleward penetration of the EAC. As the EAC is projected to continue to strengthen and transport more warm-water eddies further south<sup>7,9</sup>, *Noctiluca* may be able to establish in the Southern Ocean, leading to competition with copepod grazers for phytoplankton. In 2014, IMOS data reported *Noctiluca* for the first time from Darwin Harbour, potentially transported there through ballast water.

The continued range expansion and increase in abundance of *Noctiluca* Australia could have negative impacts on aquaculture and fisheries. *Noctiluca* has been implicated in the decline of fisheries in the Indian Ocean<sup>18</sup> and impacts caged fish production<sup>19</sup> through de-oxygenation of the water and as a result of a build-up of toxic ammonia within its cells. There is anecdotal evidence of shellfish turning pink after ingesting *Noctiluca*. Sustained and spectacular blooms of *Noctiluca* were observed around Hobart in May/June 2015, providing a beautiful display of bioluminescence for many weeks (Figure 8).

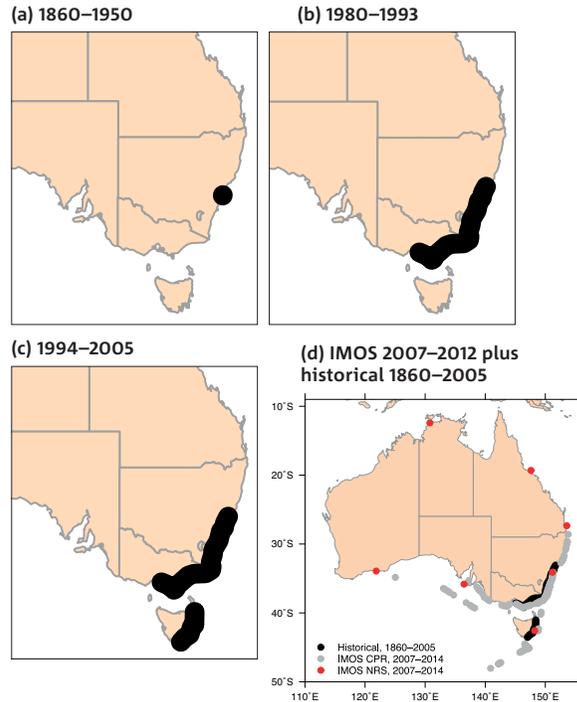


Figure 7. Expansion in the distribution of *Noctiluca scintillans* in Australian waters from 1860-2014.



Figure 8. Bioluminescence from an extensive *Noctiluca scintillans* bloom, near Hobart in May/June 2015.

# Phytoplankton on the move as oceans warm

Work by Alexandria Coughlan (University of Queensland) and colleagues suggests phytoplankton species are shifting southwards along the east coast of Australia with climate change<sup>20</sup>. They collated data on the presence of phytoplankton species in the region, including data from the IMOS NRS and AusCPR databases. The dataset comprised 21,343 species records spanning >60 years (Figure 9). To investigate whether their distribution had shifted, the mean latitude for each of the 15 most common species was calculated for pre- and post-1990, the time categories used by the Intergovernmental Panel on Climate Change. They found a southward shift of the phytoplankton community since the pre-1990 baseline, equating to a movement of ~300 km (Figure 9).

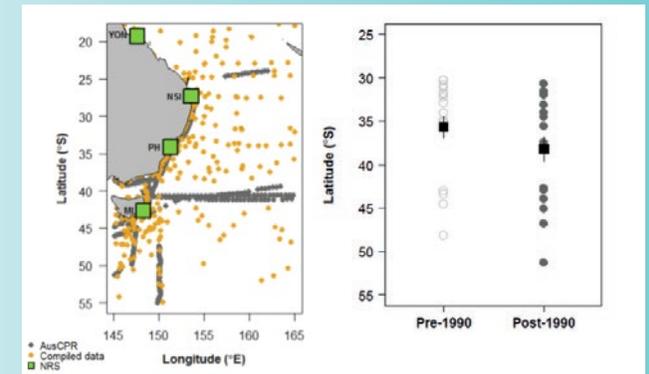


Figure 9. Left. Phytoplankton presence data from 1950s onwards. Right. Mean latitude of the 15 most common phytoplankton taxa (*Ceratium carriense*, *Climacodium frauenfeldianum*, *Ceratium vultur*, *Ceratium pentagonum*, *Ceratium tripos*, *Ceratium macroceros*, *Ceratium trichoceros*, *Ceratium furca*, *Ceratium fusus*, *Gymnodinium catenatum*, *Fragilariopsis kerguelensis*, *Emiliania huxleyi*, *Gonyaulax spinifera*, *Calcidiscus leptoporus*, *Proboscia alata*) showing a southward movement.

# Ocean acidification

A consequence of elevated carbon dioxide levels in the atmosphere is that more carbon dioxide dissolves in the ocean. This alters the carbonate balance, releasing more hydrogen ions into the water and lowering pH. There has been a drop of 0.1 pH units since the Industrial Revolution, representing a 30% increase in hydrogen ions<sup>21</sup>. This partially dissolves calcium carbonate structures of animals and plants, increasing maintenance costs and reducing growth. Among marine organisms with calcium carbonate shells, those with the aragonite form of calcium carbonate are more susceptible to acidification than those with calcite.

## CALCIFERS AT THE NRS

A Principal Components Analysis of the abundance time series of calcareous organisms at the NRS shows that there is no overall decline in abundance (Figure 10). These calcareous organisms include echinoderm larvae (starfish and sea urchins that have calcite structures with magnesium, which makes it 30 times

more soluble than calcite alone<sup>21</sup>), bivalve larvae (that have shells of aragonite and calcite), Cavoliniids (aragonite shells) and other shelled gastropods (*Limacina* spp. and Prosobranchs). As the time series grow, it will be clearer whether calcifying organisms are being impacted by ocean acidification.

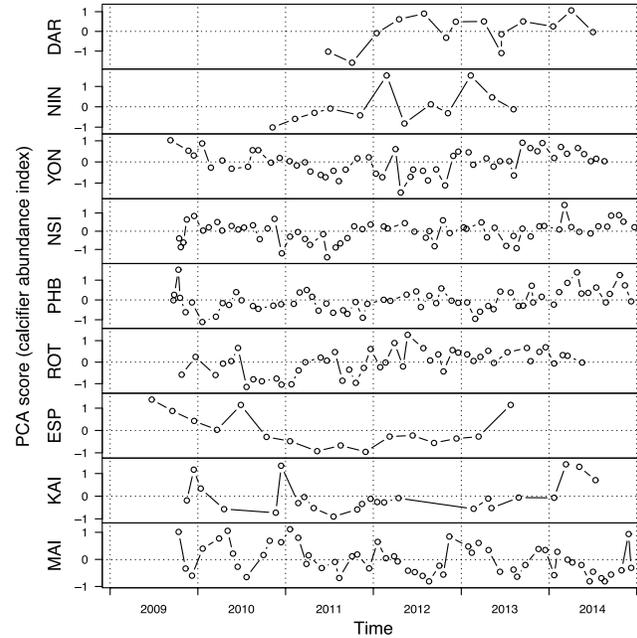
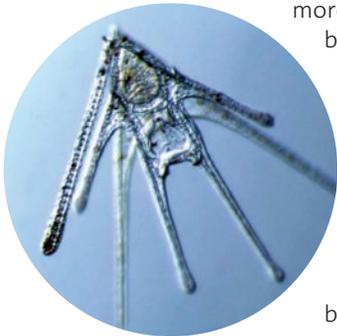


Figure 10. Principal Components Analysis showing time series of calcifiers (echinoderm larvae, bivalve larvae, Cavoliniid gastropods, and other shelled gastropods) at the National Reference Stations. For abbreviations and their locations, see Figure 3.

## IMPACTS OF OCEAN ACIDIFICATION ON SEA BUTTERFLIES

Work by Liza Roger (University of Western Australia) and co-workers suggests we might be seeing an effect of ocean acidification on sea butterflies (pteropods) in tropical Australia<sup>22</sup>. The aragonite saturation level (related to pH) of tropical waters has declined by 10% from 1963 to 2009 (Figure 11). Over this period, the shell structure of two aragonite-producing sea butterflies, *Creseis acicula* and *Diacavolinia longirostris*, was analyzed<sup>22</sup> (Figure 11). There was a thinning of shell thickness of both species (*C. acicula* by 4.43  $\mu\text{m}$ , *D. longirostris* by 5.37  $\mu\text{m}$ ) and an increase in shell porosity (*C. acicula* by +1.43%, *D. longirostris* by +8.69%), consistent with acidification eroding the shell. This work, although not conclusive because of irregular sampling, suggests sea butterflies off tropical Australia may have been negatively affected by ocean acidification.

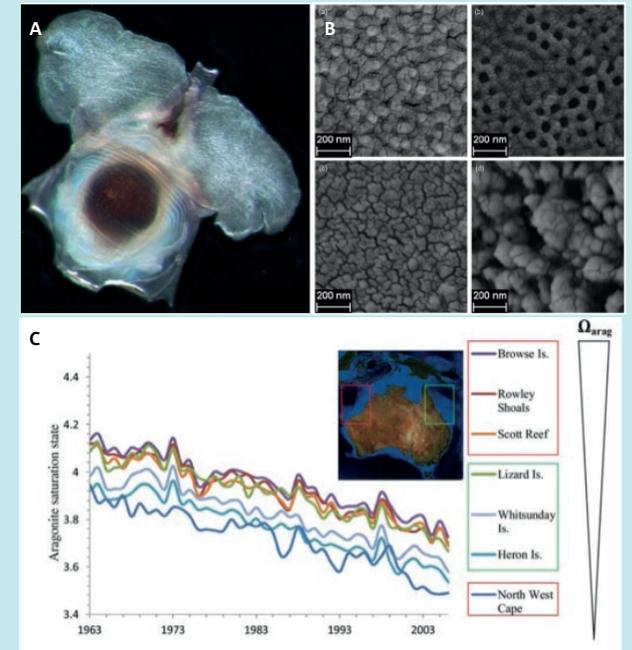


Figure 11. A. *Diacavolinia longirostris* under the light microscope. B. Scanning electron micrograph images showing change in shell porosity of *Creseis acicula* (top) and of *Diacavolinia longirostris* (bottom) from 1985 (left) to 2009 (right). C. Decline in aragonite saturation state over the past few decades in northern Australia.

# Biodiversity

Biodiversity sustains healthy ecosystem function and provides goods and services we depend on. Globally, biodiversity is in decline because of human modification of Earth's systems. This period since the Industrial Revolution has been termed the Anthropocene. The taxonomy of smaller organisms is less studied and their abundance rarely monitored compared with larger marine life. IMOS has helped fill this gap.

## LARGE-SCALE BIODIVERSITY PATTERNS

There is a large-scale pattern in biodiversity from the tropics to the poles in both the dinoflagellates (based on 46 species) and copepods (based on 236 species), from 3,657 CPR samples (Figure 12). This decrease is typical of many terrestrial and marine groups and is related to temperature. These data provide important baselines to assess changes in biodiversity against. Another way to view biodiversity patterns is to assess how different communities are around Australia<sup>23</sup>. Based on a Principal Components Analysis of 183 copepod species from 244 samples from the NRS, there are clearly differentiated communities (Figure 13). The first axis (PC1, representing 14% of the variation) ordered stations from cool, temperate waters in the south (Maria Island) to warm, tropical waters of the north (Darwin and Yongala). The second axis (PC2, 7% of the variation) separated south-western



stations (Rottneest and Esperance) from other subtropical stations on the east coast (Port Hacking and Stradbroke Island). All NRS have different copepod communities, suggesting no stations are redundant.

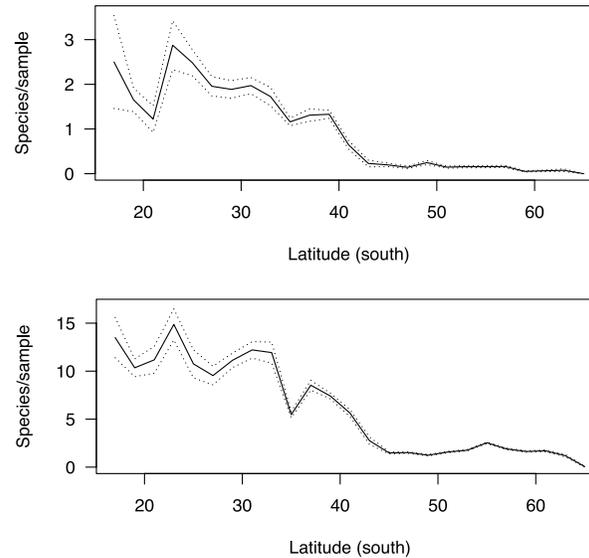


Figure 12. The pattern of biodiversity across 50° of latitude (from AusCPR and SO-CPR data off the east and west coasts of Australia and the Southern Ocean) for dinoflagellates (Top) and copepods (Bottom).

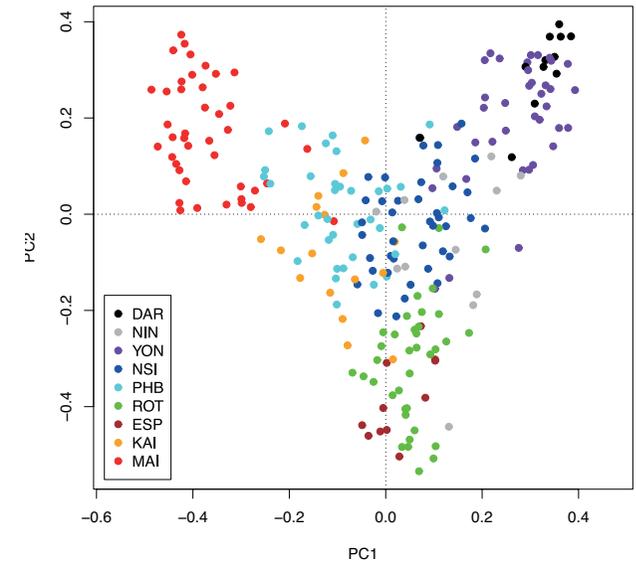


Figure 13. Principal Component Analysis sample scores for copepods. Samples are coloured by National Reference Station<sup>23</sup>. For abbreviations and their locations, see Figure 3.

# Unusual biodiversity records

There have been a number of new records and unusual plankton occurrences. In 2014, the dinoflagellate *Ceratoperidinium falcatum* was observed in significant numbers at Port Hacking, reported for the first time in this region.. The taxonomy of this genus has recently been clarified by a team including Miguel de Salas (University of Tasmania)<sup>24</sup>, The rarely reported “shade flora”, dinoflagellate species such as *Tripes gravidus* and *Tripes horridus* var. *claviger* found at the deep chlorophyll maximum (100-200 m depth) in the tropical ocean were encountered in September 2014 in plankton net samples off North Stradbroke Island, indicating intrusion of deep oceanic water onto the shelf.

The small copepods *Oncaea zernovi*, *O. vodjanitskii*, *O. atlantica*, *Spinoncaea* sp., *Triconia umerus* and *T. denticula* were documented from Australian waters for the first time in 2013. Unusually, the cold-water/upwelling copepods *Euchirella rostromagna*, *Neocalanus tonus* and *Calanoides carinatus* were found between Sydney and Melbourne in September 2014. Other notable observations in recent years include the first records in Australia for the copepods *Scaphocalanus brevicornis* (seen in June 2012 off

Tasmania), *Paraeucalanus sewelli* (seen in December 2011 between Brisbane and Sydney), *Euchirella rostrata* (seen in August 2010 off Brisbane) and *Euchirella rostromagna* (seen in October 2010 near Sydney).

Jellyfish are an under-studied zooplankton group. Lisa Gershwin is describing many new species and distribution records, including two new species of Irukandji from Western Australia – *Malo bella* (from Exmouth Gulf in July 2013) and *Keesingia gigas* (from Shark Bay in December 2012)<sup>25</sup>. *Keesingia gigas* is the largest known Irukandji (with a body 0.5 m long) and it has stung several people in the Ningaloo region (Figure 14). These two species bring the total number of species thought to cause Irukandji syndrome to 16. There was also a new species of box jellyfish from the Gold and Sunshine Coasts that was found in 2014 – it is the first Chirodropid resident in southeast Queensland. It is small and not deadly.

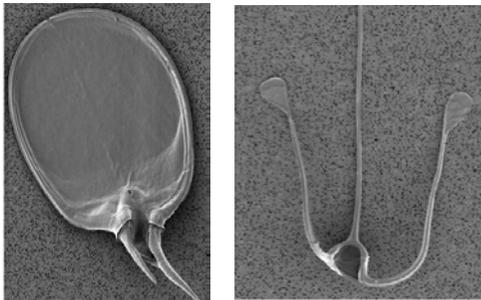


Figure 14. The tall jellyfish on the right is *Keesingia gigas* – newly described and the largest Irukandji jellyfish.

## A new species of ciliate discovered by IMOS

The large diatom *Palmerina ostenfeldii* looks like a sliced orange with pips (Figure 15 left). Julian Uribe-Palomino (CSIRO), Gustaaf Hallegraeff (UTas) and the IMOS team have found this diatom in SE Qld following the major flood in summer 2010/2011. This is the southernmost record (27°S) for this tropical species. It was noted that *P. ostenfeldii* has folds, typically housing 6–12 individuals of a previously undiscovered ciliate. This ciliate is currently being described using molecular and SEM techniques. The ciliates attach without perforating the cell wall of the diatom and is thus not parasitic. The diatom provides support and protection for the ciliate, and the ciliate provides rotational movement of the large diatom cells, moving them into areas of new nutrients. As many species of ciliates on diatoms are host-specific, the current work highlights the often-missed biodiversity at a microscopic level.

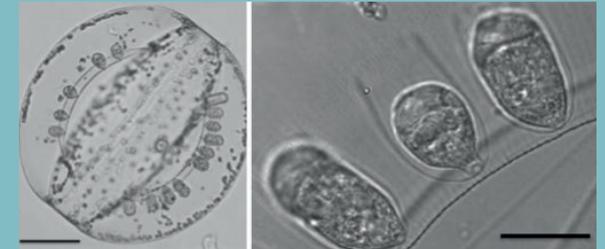


Figure 15. Left. *Palmerina ostenfeldii*. Right. Close up of the new species of ciliate within the fold in *P. ostenfeldii*.

# Productivity supporting fish: biomass and hotspots

The carrying capacity of marine ecosystems (the mass of fish resources) and recruitment of individual stocks is strongly related to plankton abundance, timing and composition. Productivity hotspots (e.g. Eden, Bonney) have high densities of plankton and are important for fish and whales alike. Links between plankton productivity and feeding, spawning and recruitment success have rarely been studied in Australia.

Fisheries in SE Australia account for 50% of our catch. The main fishery by tonnage is for sardine (which feeds on plankton), which is then food for larger fish such as tuna. We provide three indicators of zooplankton that represent the carrying capacity of these waters (Figure 16). The first is total copepod abundance; copepods make up >80% of the

zooplankton abundance. There is considerable variation in copepod abundance, with generally higher values in 2010 and 2013 and higher during winter and spring than summer and autumn. The second is mean size of copepods – the larger the copepods the better the food environment for fish feeding success. The third is a biomass index (calculated from size and abundance), which predominantly reflects the abundance. These large interannual changes, greater than an order of magnitude, are likely to influence the spawning and recruitment of fish species in the region.

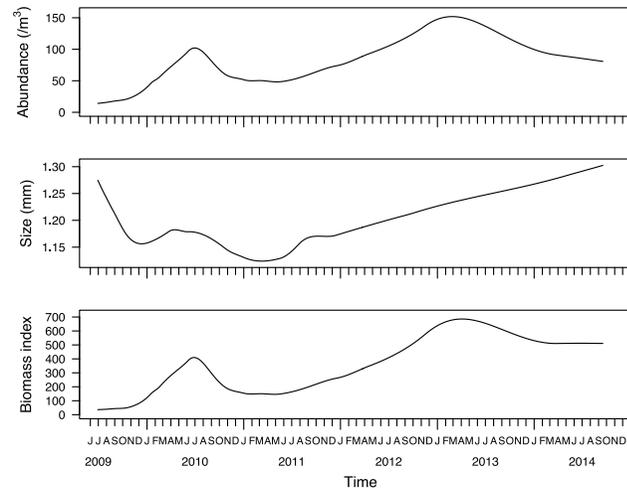


Figure 16. Time series of copepod abundance (top), mean size (middle) and biomass (bottom) from 2009-2014 from Sydney to Melbourne. A spline smoother has been used between sampling dates.



## A PILOT STUDY SAMPLING FISH LARVAE AT THE NATIONAL REFERENCE STATIONS

Fish larvae are part of the zooplankton, but poorly captured in current IMOS sampling. A pilot study is underway since the beginning of 2015 to sample fish larvae monthly at three NRS (North Stradbroke Island, Port Hacking, Maria Island). This work has been undertaken by a consortium led by Ana Lara-Lopez (University of Tasmania) and Iain Suthers (University of New South Wales). The aim of this study is to provide information on the spawning and inter-annual changes in abundance of commercial and recreational fish species. Samples are collected with a large (85-cm diameter) ring net with 500  $\mu\text{m}$  mesh towed near surface at 1.5 knots for 5-10 minutes. This pilot study has found a mix of species that are important commercially, recreationally or as food for other species (Figure 17). The highest diversity of fish larvae has been found off North Stradbroke Island, and includes important commercial and recreational species such as trevallies, tunas, snappers, tailors, flatheads and sweetlips. Off Port Hacking, the major commercial and recreational fish larvae found include trevallies, flatheads, whittings and rockcods. Off Maria Island, the key commercial species found include jack mackerel, sardines and whittings. Time series of larval abundance will provide new insights into the seasonal and inter-annual dynamics of key fish species. It is hoped that this pilot study will be continued in the future. This pilot project has recently attracted funding from the Australian Fisheries Management Authority.

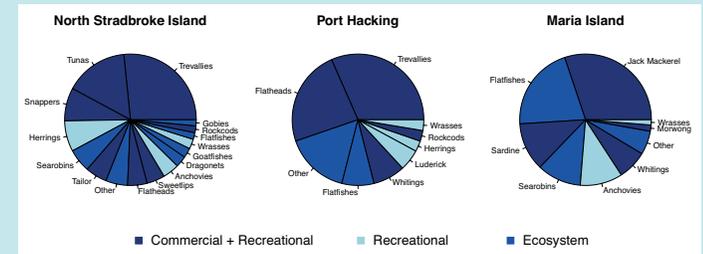
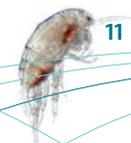


Figure 17. Abundance of fish larval taxa from three NRS showing Commercial plus Recreational, Recreational, and Ecosystem species.



# Productivity supporting fish: mesopelagics and megafauna

## Mesopelagics and plankton in the Tasman Sea

Within IMOS, Rudy Kloser (CSIRO) estimates mesopelagic fish and squid density using bioacoustics. There have been four cross-Tasman transects with both acoustic and CPR data collected and these have provided new insights into trophic connectivity (Figure 18). In August 2010, fish density was greatest in the western Tasman Sea and this corresponds with the highest

phytoplankton abundance, but not zooplankton. However, mesopelagic fish and squid biomass showed strong diel vertical migration, moving closer to the surface at night. These fish and squid closely followed the vertical migration of their zooplankton prey, such as the large copepod *Pleuromamma* spp.

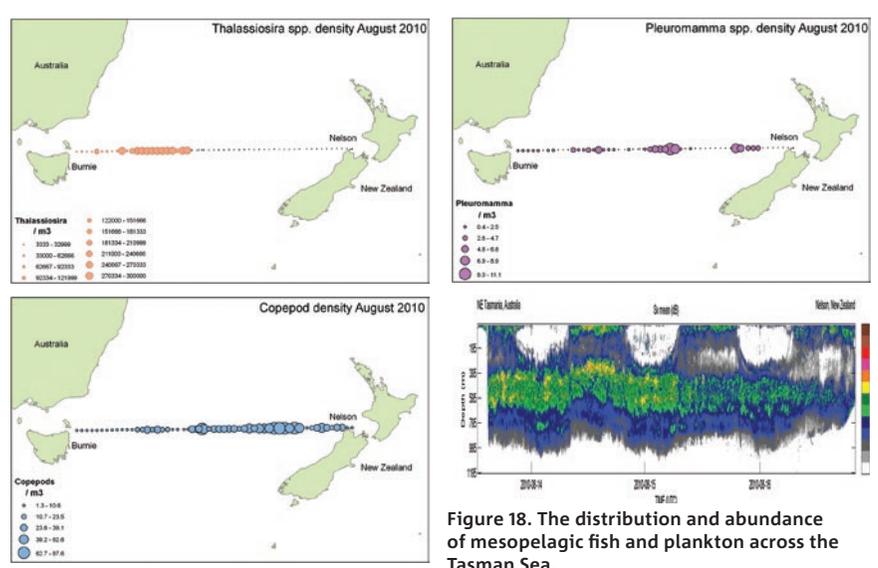


Figure 18. The distribution and abundance of mesopelagic fish and plankton across the Tasman Sea.

## Manta rays and zooplankton off North Stradbroke Island

The manta ray *Manta alfredi* feeds on high densities of zooplankton. Project Manta, a research project conducted by University of Queensland researchers Mike Bennett, Kathy Townsend, Scarla Weeks and Anthony Richardson has shown that manta rays migrate from the Great Barrier Reef in winter to southeast Queensland and northern

NSW in summer. North Stradbroke Island is a key feeding site in summer, when the food quantity and quality is high (Figure 19). Mooring data at the NRS show that subsurface upwelling is common at that time, promoting plankton productivity.

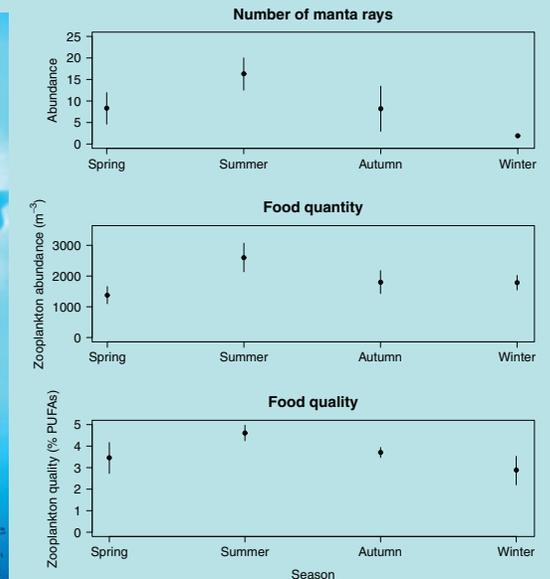
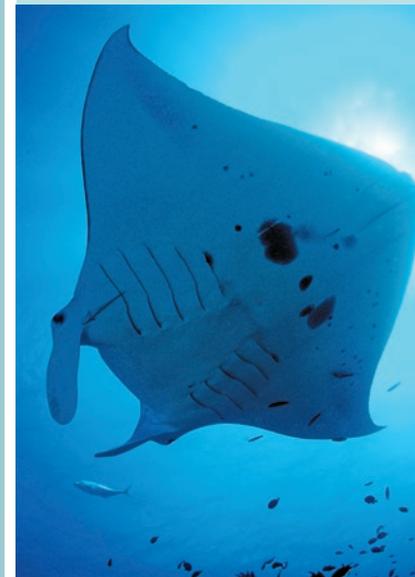
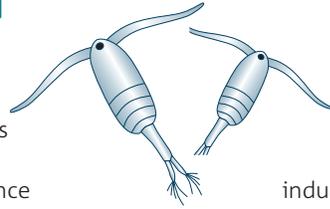


Figure 19. The number of mantas, food quantity and food quality off North Stradbroke Island.

# Ecosystem health



The notion of ‘health’ is generally applied to the vigour of people, but has been extended to describe ecosystems in response to the accumulating evidence that humans are causing them major negative impacts<sup>26</sup>. A healthy ecosystem is stable and sustainable, maintains its organization and functions over time, and is resilient to stress. Here we assess three aspects of ecosystem health: harmful algal blooms, jellyfish blooms and pathogens.

## HARMFUL ALGAL BLOOMS

Phytoplankton bloom naturally, with numbers increasing rapidly to more than a million cells/L, providing sustenance for zooplankton grazers and the wild fisheries that depend upon them. However, under some circumstances, particular phytoplankton species can produce toxins and proliferate, discolouring the water (see Table 1). This bloom phenomenon is called a Harmful Algal Bloom (HAB) and can have serious economic, health and environmental impacts. In Australia, HABs have resulted in toxin accumulation in oysters, mussels, abalone, scallops, clams and rock lobster, although few cases result in human health impacts due to strict monitoring programs and harvesting restrictions. One recent HAB in Tasmania had an economic impact of \$23 million<sup>27</sup>. Some HABs are non-toxic, but are so abundant that they can irritate fish gills, or can kill fish when the bloom decays and the water is depleted of oxygen.

Whilst some HAB species are native, others are associated with introductions through ballast water (e.g. *Gymnodinium catenatum*) or have significantly increased their range in Australia (see Range expansion of the red tide *Noctiluca scintillans* on Page 7). Analysis of CPR and NRS data can

help managers identify temporal and spatial patterns in HAB species that can be identified by light microscopy, providing supplementary background information to industry-specific monitoring programs and risk assessments. There are monthly data on HABs since 2009 at five NRS. *Dinophysis* spp. produce the toxin responsible for Diarrhetic Shellfish Poisoning, which causes a gastrointestinal illness in humans (Table 1). *Dinophysis* spp. bloom in summer at Port Hacking and Maria Island (Figure 20). The genus *Pseudo-nitzschia* can cause gill clogging and irritation in fish, and some species are also implicated in Amnesic Shellfish Poisoning through the toxin Domoic Acid (Table 1). There are large blooms of *Pseudo-nitzschia* spp. at Port Hacking and Maria Island, particular during spring and summer (Figure 20). CPR data show that there are extensive blooms of these species along the east and south coasts of Australia (Figure 21). *Pseudo-nitzschia* species require electron microscopy and molecular sequencing for conclusive identification, but this can be achieved from archived CPR silks.

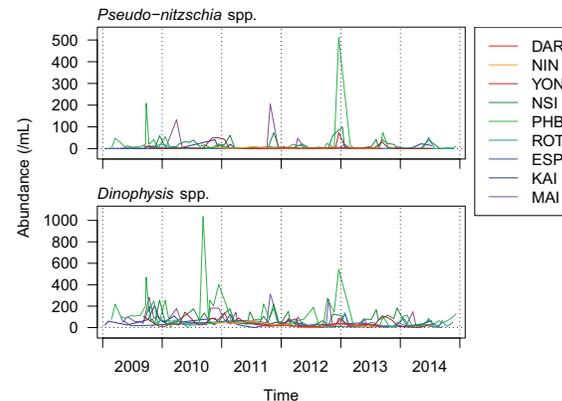


Figure 20. Time series of harmful algal blooms at the National Reference Stations: (Top) *Pseudo-nitzschia* spp. and (Bottom) *Dinophysis* spp. For abbreviations and their locations, see Figure 3.

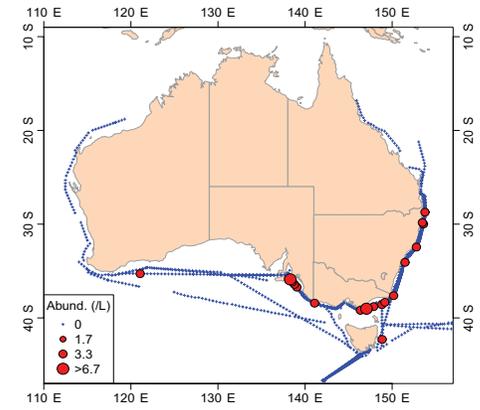
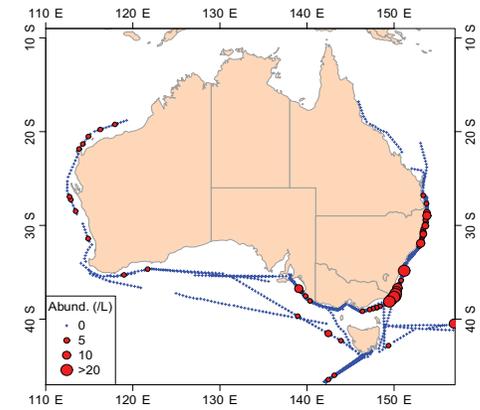
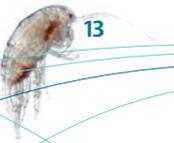


Figure 21. Distribution of *Pseudo-nitzschia* spp. (top) and *Dinophysis* spp. (bottom) from 2009-2014.



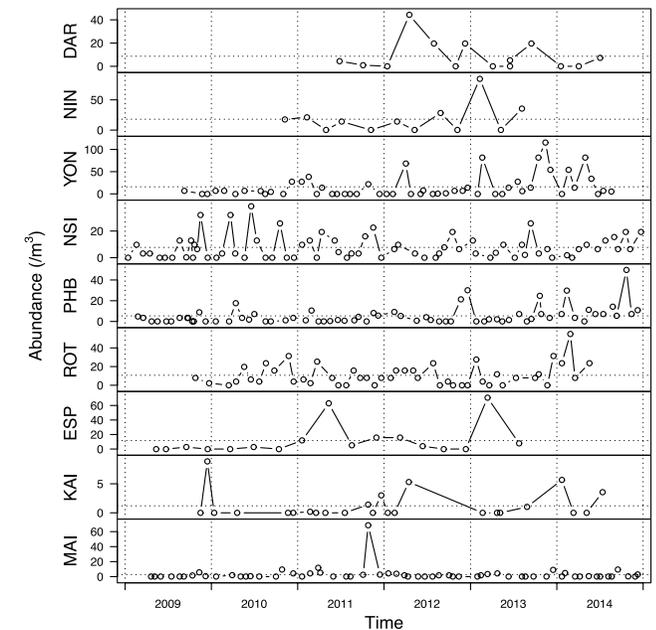
**TABLE 1. SUMMARY OF HARMFUL ALGAL BLOOM SECTORS AFFECTED, CAUSES AND IMPACTS, SPECIES RESOLVED IN NRS/CPR/SAMPLES**

SECTOR AFFECTED	CAUSES AND IMPACTS	SPECIES RESOLVED IN NRS/CPR
Shellfish industry	Accumulation of toxins in cultured (and wild) shellfish, resulting in human health impacts if contaminated shellfish consumed. Native birds or marine mammals may also be affected. Shellfish can also develop a bitter taste, or die.	<ul style="list-style-type: none"> <li>• <i>Pseudo-nitzschia seriata</i> &amp; <i>P. delicatissima</i> groups (Amnesic Shellfish Poisoning*)</li> <li>• <i>Dinophysis fortii</i>, <i>D. acuta</i>, <i>D. acuminata</i>, <i>D. caudata</i>, <i>Prorocentrum lima</i> (Diarrhetic Shellfish Poisoning*)</li> <li>• <i>Gymnodinium catenatum</i>, <i>Alexandrium</i> spp., <i>Anabaena</i> spp. (Paralytic Shellfish Poisoning*)</li> <li>• Neurotoxic Shellfish Poisoning.* Causative species are generally poorly preserved with Lugols, and therefore not clearly resolved in NRS samples. Includes <i>Karenia brevis</i></li> <li>• <i>Rhizosolenia chunii</i> (bitter taste)</li> </ul>
Finfish industry	Fish-killing species, which act by production of toxins, deterioration of water quality (e.g low DO), or physical irritation leading to poor health or death in farmed fish.	<p><i>Fish killing species</i></p> <ul style="list-style-type: none"> <li>• Generally poorly preserved with Lugols and may not therefore be clearly resolved in NRS samples, but better in formalin-preserved CPR samples</li> </ul> <p><i>Physical damage leading to fish death</i></p> <ul style="list-style-type: none"> <li>• Barbed <i>Chaetoceros</i> species including <i>C. peruvianus</i>, <i>C. convolutus</i>, <i>C. concavicornus</i></li> <li>• Clogging of fish gills and asphyxia also associated with blooms of <i>Cerataulina pelagica</i> and <i>Pseudo-nitzschia</i> groups</li> </ul>
Recreational water quality	“Red” and “brown tides”.	<ul style="list-style-type: none"> <li>• Any algal species that bloom in large enough concentrations to cause water discoloration, odours due to decomposition, oil formation, foam production and other aesthetic issues</li> <li>• Examples include <i>Noctiluca scintillans</i>, <i>Phaeocystis</i> spp., <i>Ceratonies closterium</i>, <i>Pseudo-nitzschia</i> spp.</li> <li>• “Swimmers itch” is associated with <i>Lyngbya majuscula</i></li> </ul>

\* Human health syndromes

## JELLYFISH BLOOMS

Although jellyfish blooms are natural, there is evidence that some jellyfish species could be increasing in abundance, in areas stressed by overfishing or eutrophication<sup>28,29</sup>. The NRS show that there is considerable variation of jellyfish abundance within and among years, but there is no evidence for jellyfish increases (Figure 22).

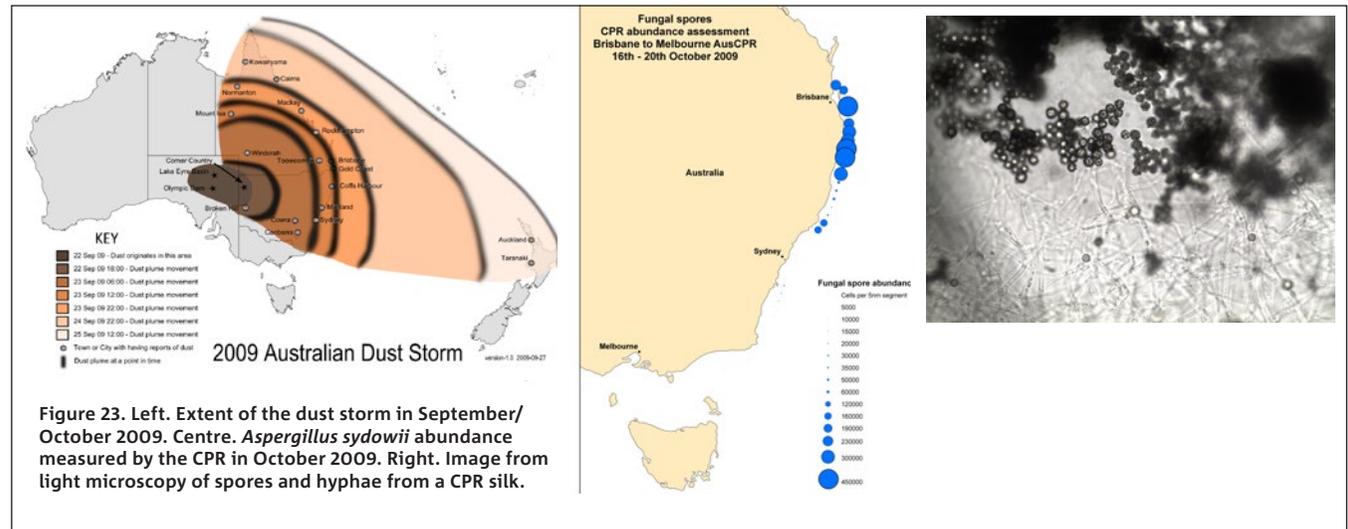


**Figure 22. Time series of jellyfish abundance at the National Reference Stations. For abbreviations and their locations, see Figure 3.**

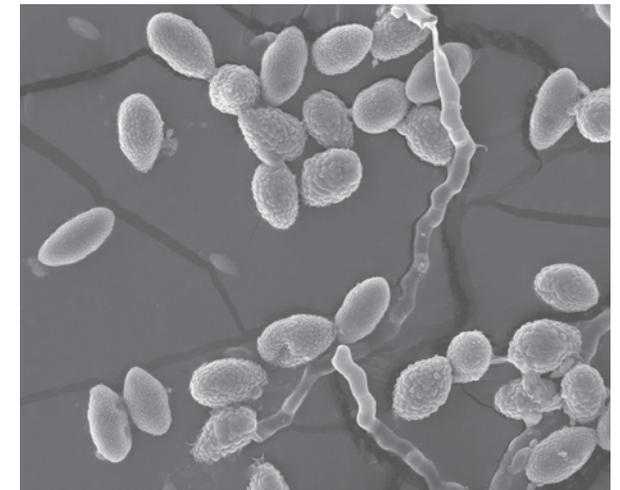
# Pathogens

Pathogens cause disease and include bacteria, viruses, protozoa and fungi. Work by Gustaaf Hallegraeff at the University of Tasmania and colleagues has shown pathogens can be monitored using plankton data<sup>30</sup>. A massive central Australian dust storm in September 2009 transported 75,000 tonnes per hour of dust across the NSW coast, traversing the Tasman Sea and reaching New Zealand (Figure 23). Three weeks after the event, CPR samples between Brisbane and Sydney had abundant, fungal spores and hyphae (Figure 23). Using scanning electron micrographs, molecular tools, and (remarkably!) culturing from formalin-preserved samples, spores were identified as *Aspergillus sydowii*. This is a terrestrial fungus, but salt-tolerant and capable of growing in the sea. Spores were likely to have originated from Lake Eyre, were then blown into the ocean 1000s of kms away, deposited with nutrient-rich floating dust slicks, and then grew rapidly. *A. sydowii* causes a variety of lung diseases in humans and infects sea fans. Surprisingly, there were no recorded human health or marine ecosystem impacts associated with this event. Australian fungal cultures were non-toxic to fish gills, but affected motility of the dinoflagellate *Symbiodinium*, a common coral symbiont. These observations raise the possibility of future marine ecosystem pathogen impacts from similar dust storms harbouring more pathogenic strains. This is the only time this fungus has been observed in CPR samples anywhere in the world in the past 70 years.

Other pathogens are also present in CPR samples. A subset of samples are being analysed molecularly for the bacterium *Vibrio*, by Luigi



Vezulli, University of Genoa. He recently analysed CPR samples from the North Sea, showing that *Vibrio* spp. have increased since the 1960s as waters have warmed<sup>31</sup>. *Vibrio* spp. grow on chitinous plankton such as crustaceans and cause human diseases such as cholera and seafood-associated gastroenteritis and shellfish-associated death.



# Potential management applications

## USE OF PLANKTON DATA IN ECOSYSTEM ASSESSMENT REPORTS

Plankton indicators are fundamental in many ecosystem assessments. The Ecosystem Health Monitoring Program in Southeast Queensland began in 2000 and was the first ecosystem report card in the world. This program produces an easy-to-understand report card that informs councils, managers and the general public on current ecosystem health and evaluates the effectiveness of management actions. A key ecological indicator of the ecosystem response to nutrient input (eutrophication) in the report card is phytoplankton biomass measured as chlorophyll-a.

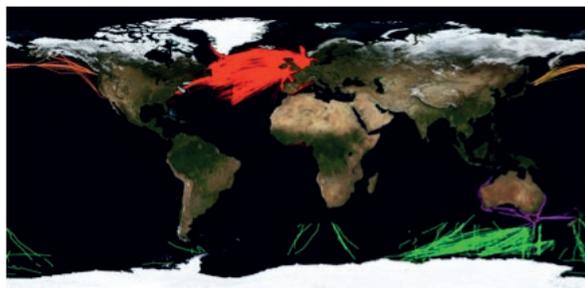
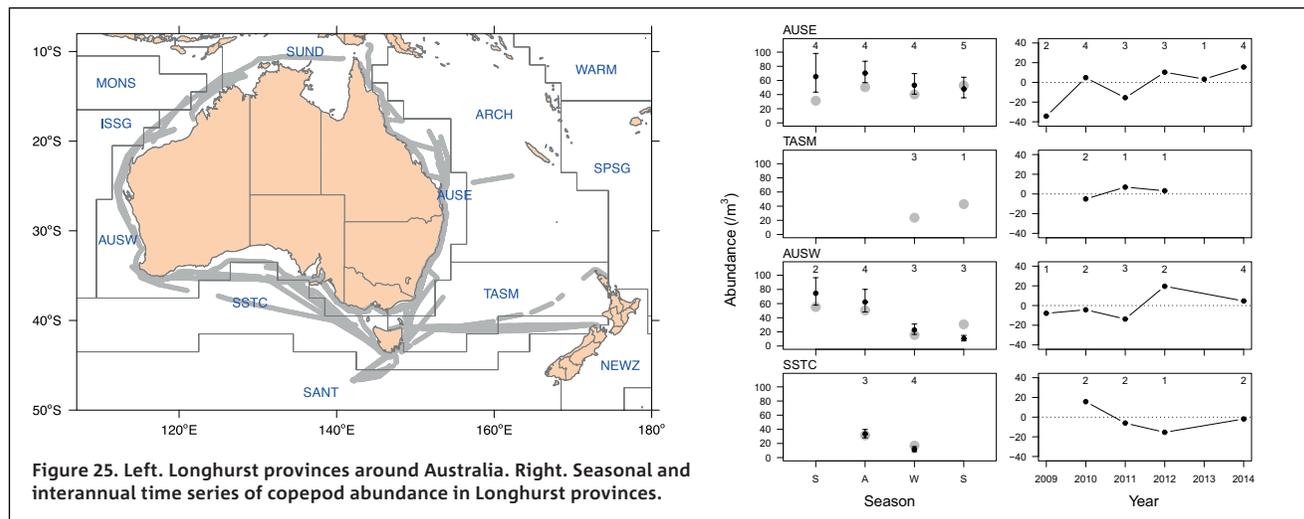


Figure 24. Global map of CPR surveys.

Plankton data from Australia contribute to a semi-annual Global Marine Ecological Status Report based on CPR data from around the world (Figure 24). This report is produced by the Global Alliance of CPR Surveys (GACS) – a global network established in 2011 with the vision of developing a global CPR database, ensuring common methods amongst surveys, facilitating new surveys, and producing a global



status report. As a founding member of GACS, the IMOS AusCPR survey reports on seasonal and interannual changes in zooplankton abundance in Longhurst biogeochemical provinces in Australian waters (Figure 25). As the time series in Australia grow, our knowledge of baseline conditions improves, allowing better assessment of long-term changes.

State of Environment (SoE) reporting is a process of presenting key information about environmental condition, pressures driving it, and management effectiveness. A national SoE Report is produced every 5 years, and most states and territories also produce their own reports. There are extensive opportunities for including IMOS ecological indicators series into SoE reporting, including those representing primary and secondary productivity, ecosystem health, climate change and ocean acidification (Figure 26).

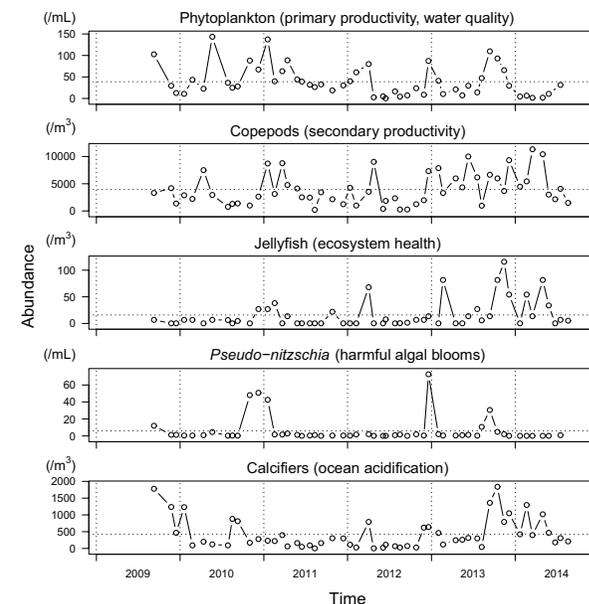


Figure 26. Time series of key ecological indicators at Yongala (off Townsville).

## USE OF PLANKTON DATA IN MARINE BIOREGIONAL PLANNING

IMOS plankton data provide a cost effective means of monitoring key habitats (Figure 27). Plankton diversity and abundance are available within or near areas of conservation values such as key ecological features and protected areas such as the Commonwealth Marine Reserves and the Great Barrier Reef Marine Park. Key ecological features (KEFs) are habitats regionally important for maintaining biodiversity or ecosystems. Plankton data are available for several KEFs including the East Australian Current, Canyons of the Eastern Continental Slope and Shelf Edge, East Coast Humpback Whale Aggregations, and Kangaroo Island Canyons and Adjacent Shelf Break.

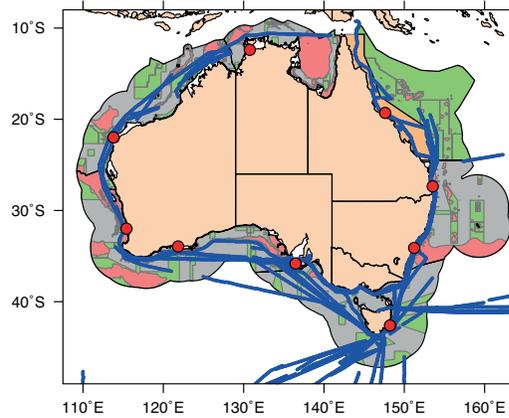
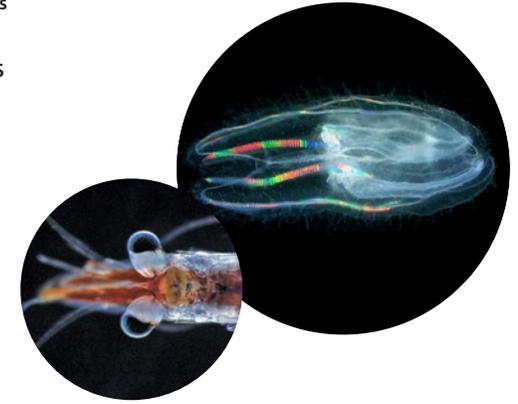


Figure 27. Bioregional planning units that conserve ecological features require regular monitoring of biodiversity – IMOS AusCPR and NRS programs can help achieve this.

• AusCPR  
• NRS

■ CMR  
■ GBRMP

■ KEF  
■ Region



## USE OF PLANKTON DATA IN MODELS

IMOS has convened the Zooplankton Ocean Observations and Modelling (ZOOM) Task Team. Its aim is to incorporate zooplankton observations from multiple sources (nets, CPRs, optical counters) into biogeochemical and ecosystem models. Zooplankton are nearly always poorly constrained in models due to limited data. Observations by scientists within IMOS and elsewhere provide an opportunity to bring together complementary observations at multiple scales for use in ecosystem models. There are several models at CSIRO and at universities in Australia that will benefit from improved zooplankton data: the CSIRO Environmental Modelling Suite (eReefs, south east Tasmania); WOMBAT (global runs); Atlantis (many regional applications in Australia); Ecopath with Ecosim (many regional applications); MICE (Model of Intermediate Complexity for Ecosystem assessments); and ROMS biogeochemistry (GAB, WA, NSW). ZOOM will assess the strengths and weaknesses of zooplankton data types, increase use of zooplankton data in models, improve parameterization of zooplankton processes, and enhance collaboration between the zooplankton observational and modelling communities.

## Forecasting models of venomous jellyfish for public health

Work by Lisa Gershwin and colleagues at CSIRO have developed a predictive model of Irukandji stings<sup>32</sup>. Irukandji jellyfish hospitalise 50–100 people per year, and their financial impact on tourism can be enormous – costs of cancelled tourism bookings following two fatalities on the Great Barrier Reef in 2002 were ~\$US65M. Using collated medical records of stings and local weather conditions, it was found that Irukandji sting events off Cairns coincide with relaxation of the prevailing southeasterly trade winds (Figure 28). This predictive model provides a basis for designing management interventions that have the potential to eliminate the majority of stings and increase public safety.

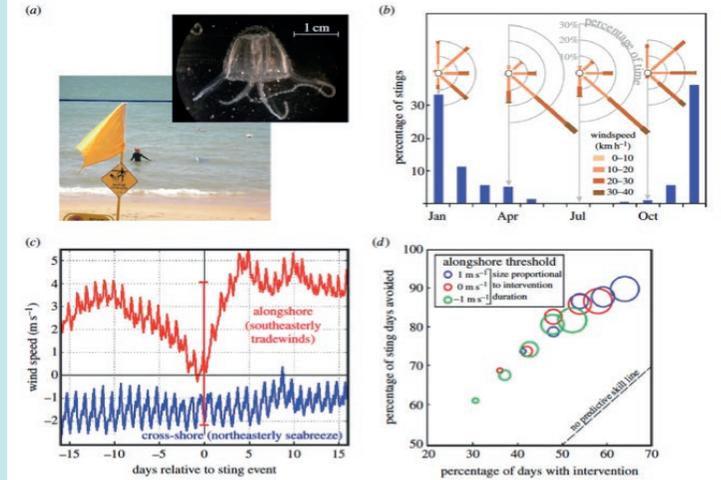


Figure 28. (a) Irukandji and bather. (b) Average seasonal distribution of stings (bars, monthly) and wind roses. (c) Average across all sting events of alongshore and offshore wind speeds as a function of days before stings. (d) % of sting days avoided versus % of days affected by proposed interventions. Results are shown for three alongshore wind trigger points (1, 0, -1 m. s<sup>-1</sup> where positive values are from the southeast) and five different time intervals over which each proposed intervention was maintained (1, 2, 3, 4 and 5 days indicated by increasing symbol size). Values are well above the threshold for no predictability.

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