CHAPTER 9.

Seas and coasts

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Key messages

- Australia's marine biodiversity is globally distinctive but its dimensions are still being discovered. New scientific techniques are helping to describe marine biodiversity and manage it.
- It is hard to work out the biological processes taking place in the sea, but understanding marine connectedness is important for understanding the outcome of management. New automated sampling, monitoring and tracking, combined with large-scale managed intervention, provide the best opportunities for improved understanding.
- There are two big challenges in managing marine biodiversity: the scientific challenge of providing appropriate information, and the societal challenge of clarifying goals for management.
- Australia has developed a science-based participatory process for fisheries management within a clear legislative framework.
- Collaboration between scientists, managers and society is needed in order to manage biodiversity within the context of sustainable development.
- Australia is a respected participant and science collaborator in international marine management – for southern bluefin tuna, the management of Antarctic marine living resources, and the identification of ecologically significant areas on the high seas.

THE SCIENTIFIC CHALLENGES OF MARINE BIODIVERSITY

Australia has the third-largest Exclusive Economic Zone (the area extending 200 nautical miles from our coastline for which Australia has jurisdiction over economic and resource management) and extended continental shelf in the world (Figure 9.1). Our ocean territory contains a mega-diverse biota. In the north, Australian waters are adjacent to the Coral Triangle, the epicentre of marine biodiversity, and in the south the coastal waters contain species found nowhere else in the world's seas, with as many as 90% of some groups of organisms being endemic.

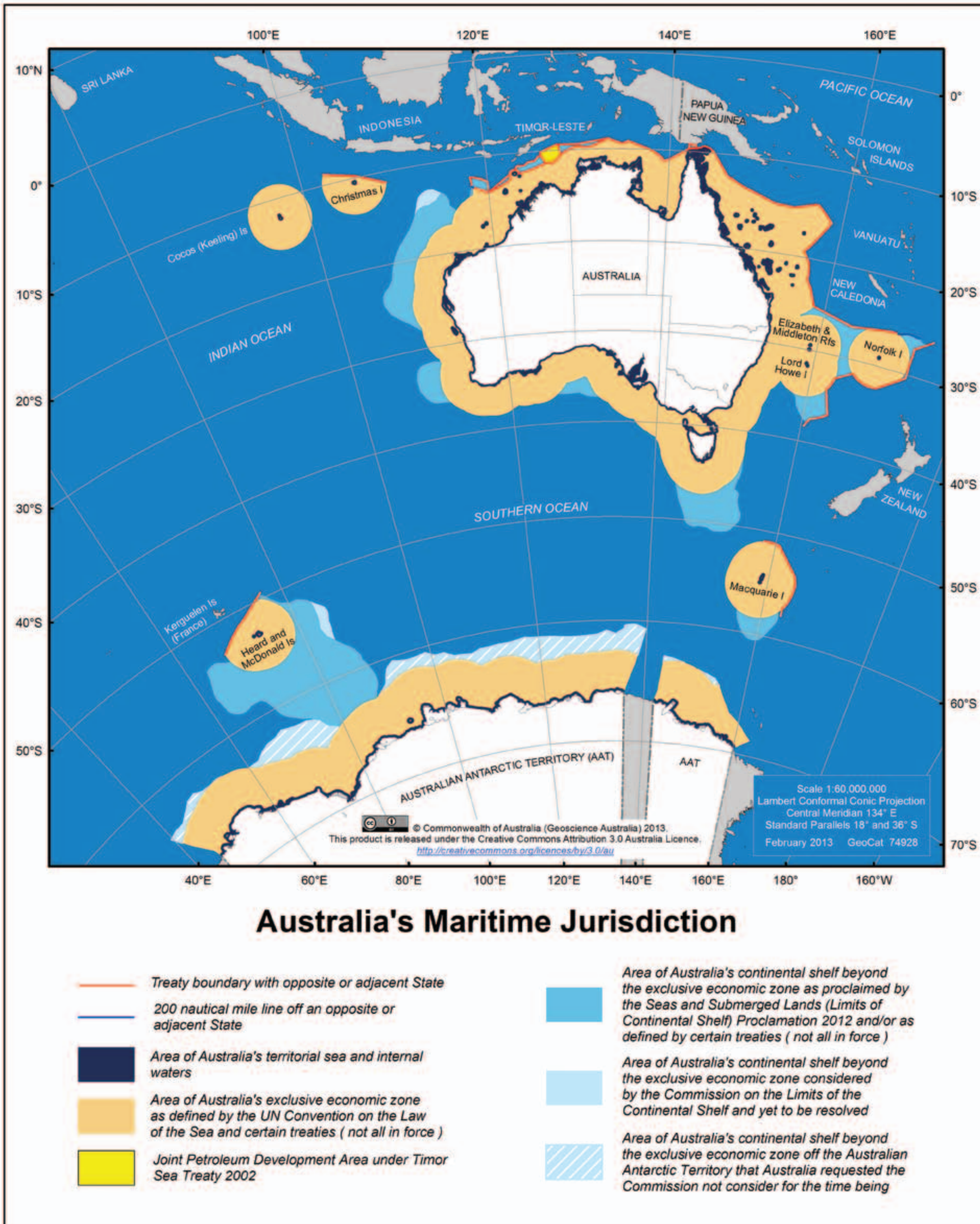
Exploration of Australia's marine biodiversity has been limited mostly to the margins of the continent, on the continental shelf and the upper continental slope. Even near the continent, some 50–70% of the species found in recent surveys have never previously been seen by scientists. Life originated in the oceans 3–5 billion years ago and even now 20 of the 33 animal phyla (the highest groupings within the animal kingdom) remain confined to them. The oceans are rich indeed, and Australian waters are among the richest.[1] Marine systems are distinctive, and so they often require different management and scientific approaches from terrestrial systems.

Discovering our biodiversity is exciting and absorbing, yet it is only a beginning if we are to understand what is going on in the seas. When we need to understand the ecological dynamics of the system, or even something as simple as how an organism grows and matures, then scientists need to go back to the same places more than once. Only recently has the technology become available to allow scientists to revisit a precise location a kilometre or more beneath the ocean's surface. Worldwide there are, not surprisingly, big gaps in our understanding of the oceans compared with the land.

Australian scientists are working broadly on two fronts to address these gaps. The first is to develop smarter ways of detecting and measuring biodiversity; the second is to improve our use of surrogates – things that are easier to measure than the species we really want to know about, but which still provide insight into the plant or animal of interest.

Smarter techniques

In the sea we explore biodiversity using many tools. Among them are robots – moored sampling devices, Argo floats and gliders (Box 9.1). These have revolutionised our physical understanding of the oceans, and now biological sampling capacity is being added to these robots by fitting cameras and other biological sensors. An even more exciting aspect of sampling in the sea (and elsewhere) is to examine the genome of a whole group of organisms at once – a process called metagenomics. This is especially valuable – and virtually the only way – when it comes to micro-organisms. Genomic techniques can tell us not only about diversity in organisms too small to see, but also about diversity in ecological processes. As one example, scientists are defining the roles of different kinds of micro-organisms in nutrient cycles in tropical estuaries, which in turn affect



▲ ***Figure 9.1***: *Depiction of the various zones and limits, under the United Nations Convention on the Law of the Sea, that comprise Australia's marine jurisdiction. Source: Geoscience Australia.*

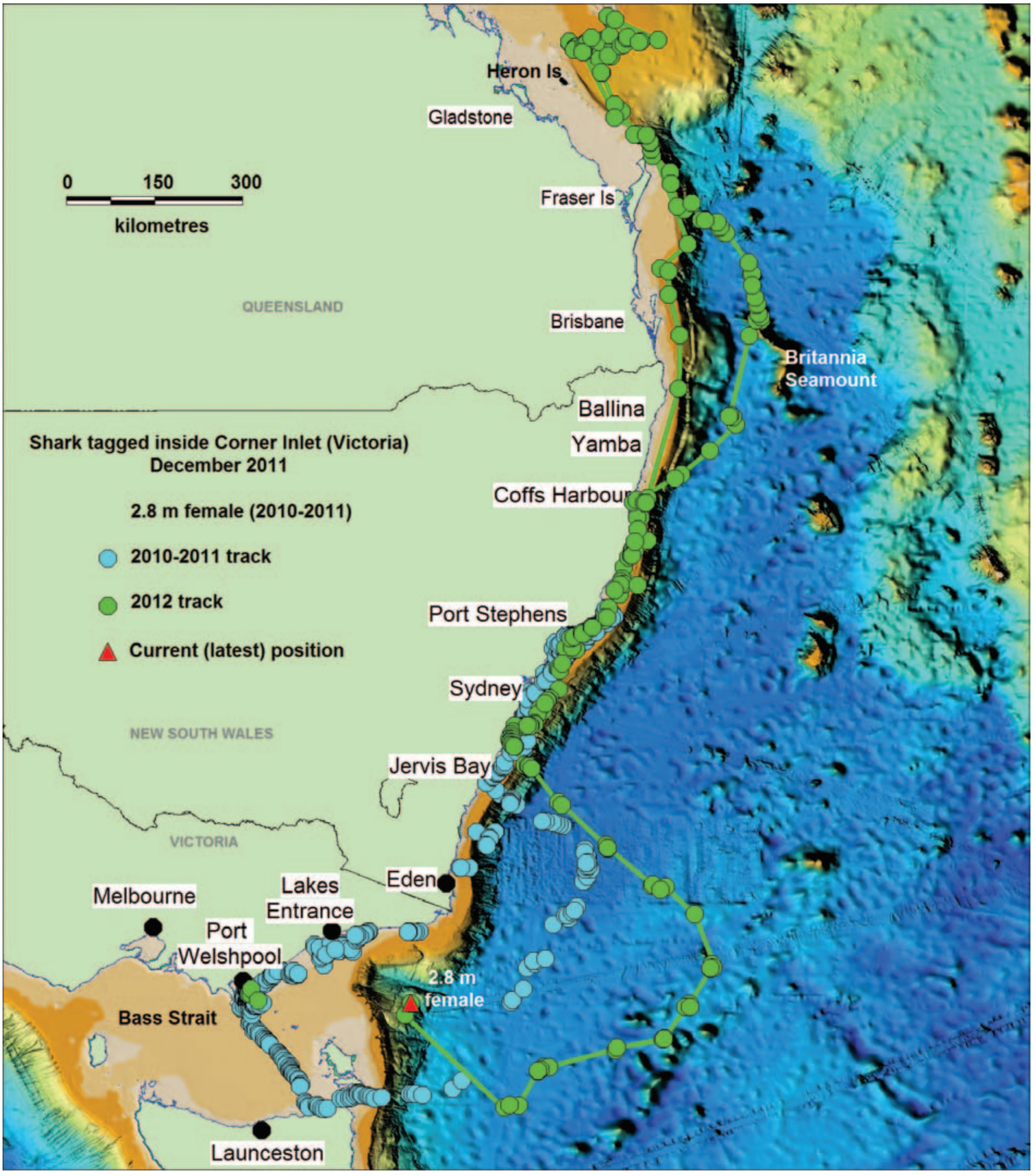
the amount of nutrients washing out onto coral reefs. They find a high diversity of microbial types but, unlike the picture for more complex organisms, genomics suggests that the micro-organisms in Australian waters tend to be similar to those found elsewhere in the world.

To unravel how diversity relates to ecological function, much broader coverage is needed, but the difficulty is to obtain enough genomic samples. Ship-based, manual sampling is expensive; robots would reduce sampling and assay costs. There are several engineering challenges to be overcome to make and miniaturise such devices, but we anticipate that these will be solved in the next few years.

Older technologies such as acoustics (what used to be called echo-sounding or sonar) continue to evolve to make increasingly sophisticated measurements. Another powerful example is the technology of global positioning systems. Animals can now be tracked across expanses of ocean, the tracking devices even reporting back the conditions as they travel (Figure 9.2).[2]

Scientists are also producing better products from their data to facilitate management and public understanding. For example, ocean currents around Australia are now routinely predicted and made publicly available by BLUElink.[3] Furthermore, the southern boundary of the east coast long-line fishery is determined weekly using these data, to reduce by-catch (the organisms caught unintentionally while fishing for other species). Also, the introduction of the Integrated Marine Observing System (Box 9.1) has greatly enhanced Australia's marine data collection, management, and dissemination.

Releasing a great white shark from the sling after tagging. A blue satellite tag is visible on the dorsal fin; there is a conventional plastic 'spaghetti' tag on the flank (which cannot be seen), and the shark also has a long-life acoustic tag (battery life about seven years), which has been surgically implanted under its skin. Photo: Justin Gilligan.



▲ ***Figure 9.2**: Track of a 2.8 m great white shark,* Carcharodon carcharias, *tagged in Corner Inlet, Victoria, over two years. Source: CSIRO.*

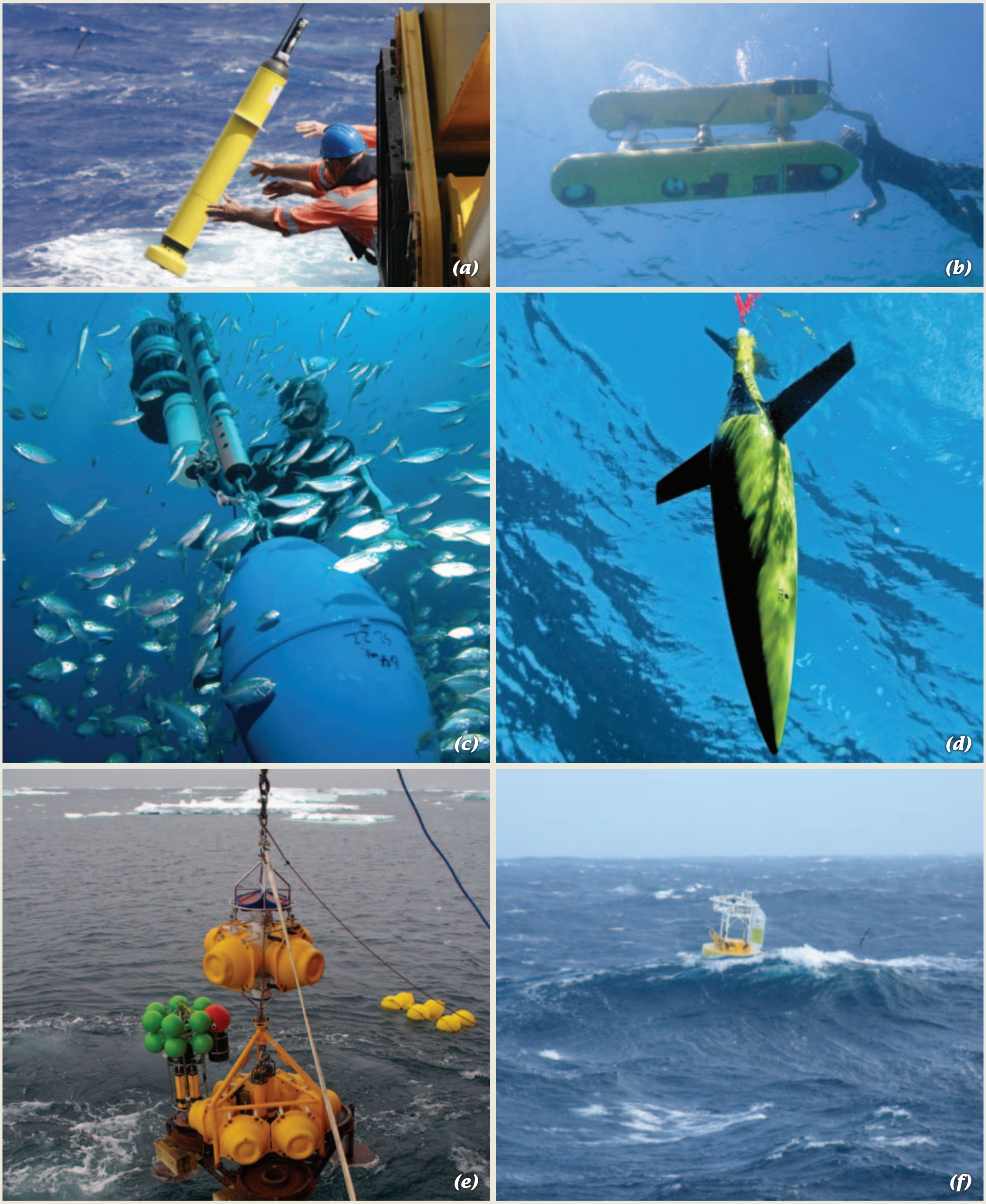
Box 9.1: Australia's Integrated Marine Observing System

The introduction of Australia's Integrated Marine Observing System (IMOS) is an especially exciting development.[4] In just a few years, IMOS has established a network of observations – mainly physical but increasingly biological as well – around the nation's oceans, and a system for managing and making available the huge amount of information (Figure 9.3).

▲ ***Figure 9.3**: An illustration of the data streams being collated by IMOS. Yellow dots, Argo floats; pale blue lines, ships of opportunity (i.e. commercial vessels carrying freight or passengers but which take scientific measurements); dark, olive and white lines, research vessel tracks; orange lines, elephant seal tracks. Source: IMOS.*

At the IMOS web-portal you can find data using a map interface, or by searching the database.[5] For example, the latest seal-tracking results are available; associated with those tracks are data on temperature, salinity and depth, as well as the animal's location and time. From the tags we learn amazing amounts about the biology of the seals – how deep they dive, how far they travel, where they feed. As a bonus, because they go regularly to places we find difficult, such as under the Antarctic sea-ice, we get valuable data for the physical oceanographers. You can also find the tracks of robotic devices called 'ocean gliders' – these are already measuring some aspects of biology as well as a suite of physical measurements, and more biological results will surely come. These are a few examples; we now have a wide range of new tools, and marine ecology is just starting the sort of revolution that has made so much difference to other fields of endeavour, such as physical oceanography and climate science, in recent decades.

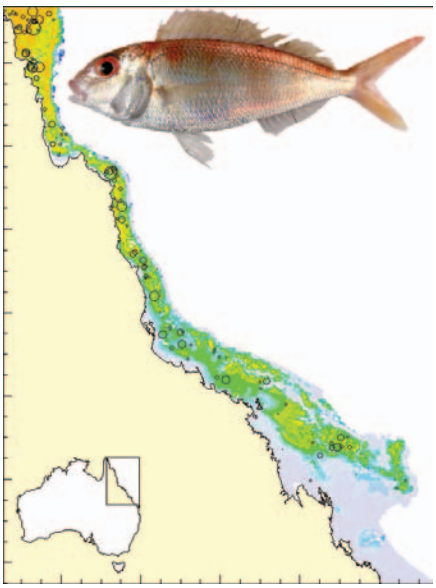
Elephant seal, Mirounga leonina, *with a conductivity–temperature–depth tag. As well as learning about the biology of the seals we are getting more data from inaccessible places, such as under the sea-ice in Antarctica, than ever before. Photo: Chris Oosthuizen, IMOS.*



Sampling devices used within the Integrated Marine Observing System. ***(a)*** *Argo float deployment;* ***(b)*** *autonomous underwater vehicle;* ***(c)*** *acoustic receiver mooring;* ***(d)*** *ocean glider;* ***(e)*** *polynya ocean monitoring;* ***(f)*** *Southern Ocean flux station buoy. Photos: (a) Alicia Navidad, CSIRO; (b) Kim Brooks, AIMS; (c) Rob Harcourt, Macquarie University; (d) Daniel Wisdom, AIMS; (e) Steve Rintoul, CSIRO; (f) Eric Schulz, Bureau of Meteorology.*

Surrogates

Planning and management of the marine environment and biological discovery must work hand-in-hand. Some of the sea's physical features – depth, bottom hardness, water temperatures and nutrient concentrations – can be mapped relatively rapidly at a scale of square kilometres or more. We already have more detailed information about some organisms (such as fishes) than about others (e.g. bryozoans). To get around the knowledge gaps, scientists are developing biodiversity surrogates. Can the patterns in the distributions of fishes indicate the sorts of patterns found in some kinds of invertebrates? And can some clever combination of physical variables at a particular place – depth, temperature, current velocity, or type of sediment – predict the sorts of organisms that would be expected there? Sophisticated statistics on large data sets suggest that the answer is 'yes, but …'. These approaches can work under specific conditions and scales, with an important aspect of uncertainty and probability in the predictions. But surrogates are just that, and do not directly mimic the biology of organisms or measure their abundance. Surrogates might predict where conditions are suitable for a particular fish, but they won't tell you if the fish are suffering from over-fishing, or a disease, or are absent due to some other as yet unknown ecological factor (Figure 9.4). Surrogates also miss historical or evolutionary factors, such as why penguins don't occur in the Arctic.



▲ ***Figure 9.4**: Distribution of rosy threadfin bream,* Nemipterus furcosus*, on the Great Barrier Reef shelf of north-eastern Australia. The black circles show abundance as measured from fishing samples. The colours show predicted distribution of threadfin bream, with blues and greens indicating low, yellow indicating medium, and red indicating high biomass. Ecological explanations for these patterns are still developing. Source: CSIRO.*

Surrogates have been important in the design of the recently proposed Commonwealth Marine Reserve network. While they offer exciting possibilities, surrogates cannot replace direct knowledge of an ecosystem. Surrogates can be used to predict and map how the present environment affects the distribution of organisms and how those distributions might change in the future, but they cannot provide the basis to measure real distributions and determine changes over time – actual field observations are required for this.

THE DYNAMIC NATURE OF MARINE BIODIVERSITY

Biodiversity is dynamic – it's a set of processes as well as being a list of species, genes or ecosystems. Despite the technical difficulties, we are learning a lot about these processes in the sea, and some highlights are mentioned here, concentrating on the idea of 'connectivity'.[6]

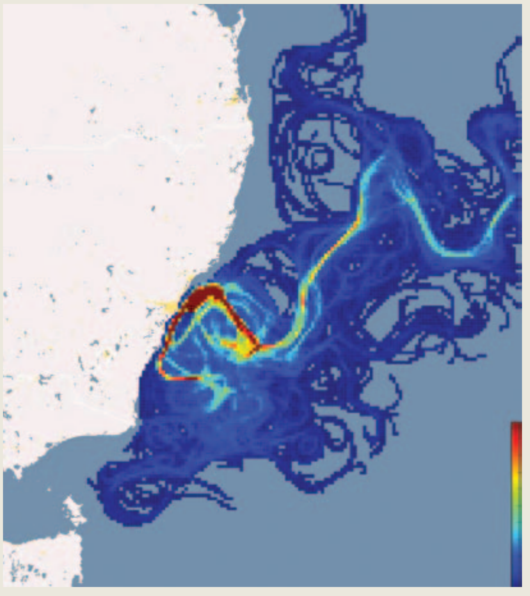
The oceans are well connected. Ocean currents move water, oxygen, nutrients, heat and species continuously around the globe. Connectivity is an ecologically complex concept (see Chapter 5) but connectivity in the sea has many advantages: biodiversity depleted in one area may be recolonised with offspring from another; point-source pollution like oil spills can be mobilised by the energy in the oceans, diluted by the movement of the oceans and finally broken down by the organisms that live there; animals that are stationary as adults can filter food particles from the moveable feast that bathes them; while animals that are mobile can take advantage of different habitats at different times in their lives.

Some areas of the sea are disconnected, however; low connectivity allows pollution and nutrients to concentrate and may lead to 'dead zones' in the oceans where oxygen is consumed as soon as it arrives. Some potentially mobile species are highly restricted: some shallow-water skates have been restricted to small 'habitat islands' for hundreds of thousands of years. Less mobile species are more vulnerable and are increasingly experiencing competition and predation from more mobile species that are responding to the warming ocean waters.

Animals that ride the currents have to deal with speeds of flow and directions that can change daily, seasonally and between years, making it uncertain whether they will ever make it back home. That is why almost all the offspring of the majority of marine species die, leaving the continuation of the species to depend on the very rare offspring (or two) that make it back to where their parents started the process. This leads to great variability in the number of animals produced each year – a real challenge for fishery managers (Box 9.2).

Box 9.2: Connectivity and biological variability

Physical and biological oceanographers work together to understand patterns of water movement in the oceans and their effects on biology. For example, the tropical rock lobster in Queensland and Torres Strait, *Panulirus ornatus*, circumnavigates the Coral Sea as a series of larval stages, carried by the currents. The variable behaviour of the currents makes a big difference to lobster recruitment (the number of young animals joining the fishery each year). There have been serious recruitment failures in recent years for the western and southern rock lobsters, *Panulirus cygnus* and *Jasus edwardsii*, leading to severe reductions in the catch. The lobster's life-cycle is so complicated that no one is sure of the reason for the recruitment failure, but it probably has something to do with ocean currents.[7] Biologists and physical oceanographers are working together to model the movements of ocean currents and, hence, how they might carry larvae. You can find, and use, an example called Connie at www.csiro.au/connie2/ (Figure 9.5).



▸ ***Figure 9.5**: Output from the connectivity modelling system Connie, showing predicted movement over 60 days of particles released 40 km east of Sydney. This illustrates how broadly organisms that drift as plankton can disperse with the currents. Colours indicate percentage of particles that passed through each point (scale max. 20%, min. 0%). Source: CSIRO.*

Shifting baselines: a complex game with changing rules

With climate change, the ocean environment isn't stationary. There have always been, of course, short-term changes and cycles – storms and calms, El Niño and La Niña years – but longer-term changes are now evident, both in physical environment and in biological interactions. Weather patterns are changing, ocean acidity is increasing, ocean currents are changing, and (to cite an example from only one part of the Australian coast) many species of macroalgae, microalgae, zooplankton, invertebrates and fish are extending their ranges southward down the east coast (Box 9.3).[8,9,10] But ecosystems don't move as a collective; rather, different species move at different rates and in different directions, and the complex interactions in ecological communities are frequently unpredictable.

The concept of 'novel ecosystems' is increasingly discussed (see Chapter 4). All ecosystems are now to some degree new due to the effects of climate change and invasive species. More than 170 introduced marine species have colonised Australian waters. In heavily used locations such as Port Phillip Bay, non-native invasive species are now more abundant than natives. Non-native species arrive via oil rigs, commercial shipping, recreational yachts and fishing nets, and most established species are here to stay. An estimated 10 000 species are in transit in ships' ballast water around the world at any one time. With more than 5000 international ship visits to Australia per year, a number projected to double by 2020, this will continue to be a challenge to managers. The reality of shifting baselines has important implications for setting goals and objectives.

Box 9.3: The long-spined sea urchin in south-eastern Australia

The New South Wales sea urchin, *Centrostephanus rodgersii*, has been extending its range down the east coast for some years and is now established off Tasmania, where it is having major effects. The complex story is not yet fully understood, but contains these elements.[6,7]

- Larval urchins float in the East Australian Current, which is now carrying warm water further south, allowing adult urchins to arrive in Tasmania.
- Urchins eat kelps, and can change the habitat to 'barrens' dominated by encrusting coralline algae.
- Abalone (important seafood #1) eat kelps, either directly or by catching drifting algal fronds, and don't do very well if there are extensive barrens.
- Large rock lobsters (important seafood #2) can eat urchins and may be effective in keeping urchin numbers down, but large lobsters are being selectively fished out of the system.

There is a good deal of research being done on this problem, including management of the fishery for lobsters in the hope that they will reduce urchin numbers. But the problem is complex, and there will be many others like it in the future.

DECIDING WHAT MATTERS AND WHAT TO DO ABOUT IT – A SOCIAL CHALLENGE

The first strength of science lies in describing the state of things and what is causing change. Science can also describe management possibilities. In the end, though, looking after 'ecosystem health' can only be achieved in the context of societal goals. Deciding what matters ultimately requires stakeholders, managers and scientists working closely together and communicating with the general public, to decide what in the oceans is important to us humans.[11] The challenges in understanding and caring for marine biodiversity may now be summed up as follows:

- The scientific challenge of providing appropriate information under conditions of uncertainty
- The societal challenge of clarifying goals for management when there is ambiguity and lack of consensus among the players.

To deal with both challenges it helps to adopt an 'adaptive management' approach. Adaptive management is a systematic process to improve decision-making in the face of uncertainty. The process involves a cycle of planning, taking action, evaluating the results of the action, and then taking further action based on the results of that evaluation. In the following section we discuss a few key issues in marine biodiversity where progress is being made using this approach.

Fishing and ecosystem-based management

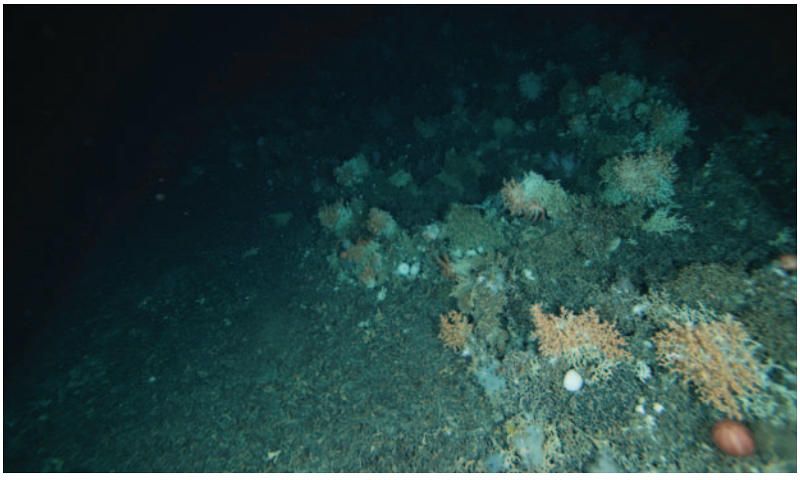
Of the many human impacts on marine biodiversity, the biggest single direct effect stems from fishing. However, it is also an encouraging story. The magnitude of the effect of fishing has encouraged research, invention of creative ideas and, in Australia at least, significant management interventions. Successes in the arena of fisheries management are now informing advice for managing biodiversity more generally.

Traditional management of fishing naturally concentrated on the target stock, including more recently potential loss of genetic variation within it. But fishing has effects on non-target biodiversity too, by inadvertently catching them, by physically altering habitats and damaging animals attached to the seafloor, or indirectly through removal of top predators so that some species lower in the food chain become more abundant. In the low productivity deep sea, recovery may take decades or centuries, well beyond the traditional management cycle. However, such effects are not to be assumed, and the results of each investigation are not necessarily as expected.

The cooperative system of management used by the Australian Fisheries Management Authority makes extensive use of harvest strategies and includes all key interest-groups in assessment of stocks and decision-making.[12] Several conditions need to be met if this kind of 'co-management' is to work; the Authority's system meets them well.[13] Naturally tensions arise, but there are clear goals and decisions are adhered to.

Numerous species in addition to prawns, Penaeus, *the target of the catch, are shown in this image. These are known as 'bycatch'; their numbers have been progressively reduced by improved gear and fishing techniques supported by research. The northern prawn fishery has recently been certified as sustainable by the Marine Stewardship Council, a certification which demanded the reduction of bycatch. Photo: CSIRO.*

Catches from two simultaneous tows of prawn nets without (left) and with (right) turtle-excluder devices. The latter have a chute on the top of the net near its mouth, allowing large, strongly-swimming animals to escape while still channelling most of the prawns to the end of the net. Bycatch of large animals like sharks and sea turtles is greatly reduced by the devices. Photo: Garry Day, AMC.



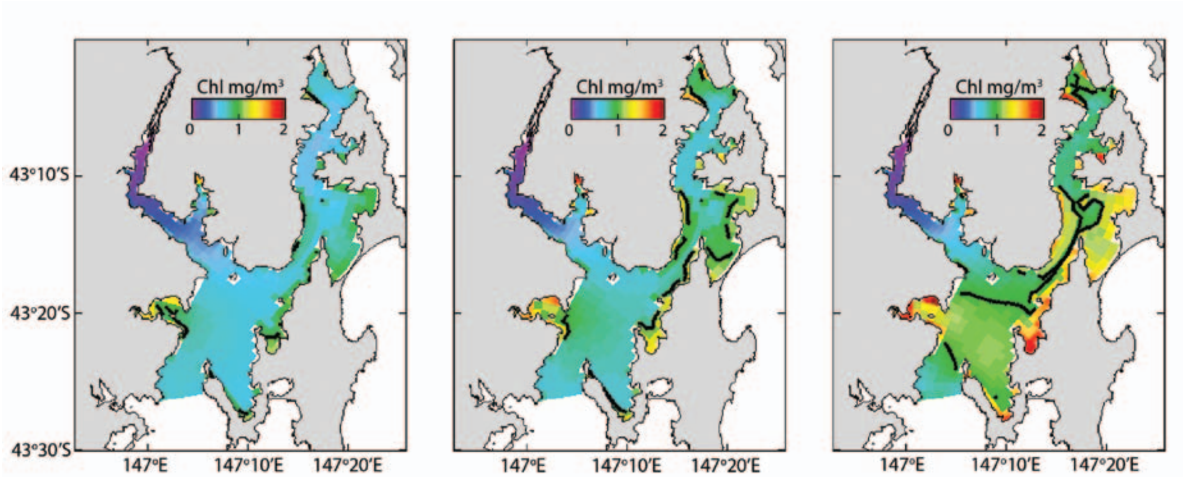
Seamount at 1338 m depth showing a sharp contrast between typical deepwater coral assemblage on the right and apparent removal of the assemblage from a single trawl passage on the left. Recovery in the cleared area is expected to be very slow. Photo: CSIRO.

Both understanding and approaches to management have progressed, and fishers and managers have now embraced the idea of ecosystem-based fisheries management, which aims to maintain ecosystem, species and genetic diversity. The move to ecosystem-based management puts us into complex decision-making territory where there may be no 'win-win' solutions and compromises have uncertain outcomes, so practice lags behind the theory (see also the discussion of 'wicked' problems in Chapter 4). Nevertheless, significant progress has been made and Australia is regarded internationally as leading in the application of ecosystem-based management.[14] One example may be the Commonwealth Marine Reserve Network, which is intended to be managed adaptively. Achieving the primary objective of providing for the protection and conservation of biodiversity and other natural or cultural values, while also providing for the sustainable use of natural resources (where there is no conflict), will require considering activities outside the reserves. The joint consideration of conservation and sustainable exploitation will help break down barriers between sectors and help create the opportunity for scientists to provide integrated advice to all managers.

Aquaculture

Aquaculture is required to fill the gap between wild-caught sources and the growing demand for healthy seafood. But the task is not simple! Aquaculture has to expand in the face of many

Atlantic salmon farm, Huon Estuary, Tasmania. Photo: CSIRO.



▲ ***Figure 9.6***: *Biogeochemical model of the Huon Estuary and D'Entrecasteaux Channel, Tasmania, developed to allow proactive management of potential nutrient pollution. The figures show annual mean chlorophyll concentration in the top 13 m of the water column from the model scenario without farm inputs (left); with 2002 farm inputs (middle); and with projected future farm inputs (right).*[16]

uncertainties and most of them encompass some aspect of biodiversity. They include unwanted environmental effects such as increased nutrients, and the sustainable provision of food. Tuna are still largely fed on small fish – such as anchovies – that are caught in the wild, with potential knock-on effects for other species, such as whales and penguins, that depend on them. Scientists are at present working on two ways around this. First, if the genes for the production of omega-3 oils can be inserted from marine microalgae into crops, this would reduce dependence on marine sources. Salmon and barramundi are already largely fed on terrestrially sourced food, but this reduces the omega-3 content and also competes with other possible uses for farmland. Second, it is now possible to grow food for prawns based on marine micro-organisms feeding on waste organic matter.[15] This new way of using marine biodiversity does not use valuable farmland.

Salmon farming (Figure 9.6) is adding nutrients to the Huon Estuary and D'Entrecasteaux Channel in Tasmania, increasing phytoplankton, which has knock-on effects up the food chain. The planktonic microalga *Noctiluca scintillans* has extended its range from the north into this ecosystem, probably in response to climate change, altering both zooplankton abundance and sedimentation and making the ecosystem work differently. The authorities have limited the number of future fish farms and set up a monitoring program.

Complementary management

Australia has been grappling with the challenge of integrated management of multiple uses of marine resources for over a decade. When Australia's Oceans Policy was introduced in 1998 it was hailed internationally as the first comprehensive, ecosystem-based, multiple-use management scheme. It is now a Marine Bioregional Planning Program, within which has been established the Commonwealth Marine Reserve Network, part of the National Representative System of Marine Protected Areas. There is as yet no policy for fully integrated marine planning and management, but as a step towards it, we can envisage complementary management where scientists collaborate to ensure that individual jurisdictions understand the implications of their actions on each other.

Despite the patchy progress, where instructive solutions to biodiversity issues in the sea are adopted well we can learn from them: first, how long it takes to institute effective change; and second, some of the mechanisms that are needed to make them work properly. As with many natural resource issues, the fisheries experience teaches us that successful management requires several features:

- Strong governance and clear responsibilities
- Transparency and trust
- Avoidance of perverse incentives (i.e. unintended consequences from laws and regulations leading to undesirable results contrary to the interests of society)
- Agreed controls
- Independent monitoring
- Ongoing collaboration between science, management and all those with an interest in the system.

ISSUES OUTSIDE NATIONAL BOUNDARIES

Australia contributes strongly in the international arena to support improved management of regional marine resources beyond our borders (Box 9.4). Connectivity in the seas requires this, to achieve sustainable harvesting and to respond to regional environmental issues. The experience is valuable, because solutions to other emerging problems, such as climate change and food security, require similar international cooperation.

Box 9.4: Ups and downs in the management of the southern bluefin tuna fishery

The southern bluefin tuna, *Thunnus maccoyii*, has long been known as a traveller. It spawns near Indonesia, swims into the Indian and South Atlantic oceans and around southern Australia and New Zealand, and is fished by six or more nations.

Such highly migratory species are managed under international conventions by regional fisheries management organisations. The Commission for the Conservation of Southern Bluefin Tuna is such an organisation, established in 1993, with a scientific committee to which Australian scientists contribute.[17] But scientists depend on reliable data, which in turn rest upon transparency and trust, and there have been problems with unreported catches of tuna.

Working on sensitive issues in international bodies requires a level of diplomacy in scientists that is rarely acknowledged or taught. Only through working at the front on these contentious issues can science have impact, through understanding of both the potential and the limits of science in decision-making. It takes a long time but eventually bears fruit; in 2011, the Commission adopted a scientifically tested, adaptive rebuilding strategy for the tuna stock.[18]

The quality of the data on tuna, and its independence from the fishery, are also improving: Australian scientists are using ‘smart’ tags and techniques based on close-kin genetic matching to estimate population size. Finally, innovation in aquaculture may also help reduce pressure on the fishery.

FUTURE DEVELOPMENTS

The biggest obstacle to understanding biodiversity in the sea, and providing clear advice on managing it, is still the difficulty of describing and measuring it. Rapid technological advances are telling us more about biodiversity than we dared hope a few years ago, and we can see further developments just around the corner. We can also anticipate exciting progress in making the data available to users (see 'Smarter techniques' above). An important step would be an international version of our Integrated Marine Observing System, with sufficient capacity-building to make it truly international and focused to support decision-making. This would allow development of ecosystem-based management of oceans in the future and address the first general challenge – the need for appropriate information.

The second general challenge – the need to clarify goals for management – will not be satisfied merely via reliable data and good models, but may require arrival at societal decisions in ways that are not yet familiar. Management styles will need to be adaptive (see Chapter 4). Scientists will need to expedite technical collaboration between the different disciplines. Most importantly, our society will have to achieve effective involvement of people from many walks of life in working towards decisions. Social science and economics continue to increase in importance as a component of biodiversity science.

These matters are so complex, with so many stakeholders and inevitable controversies, that discussions become political, stressful, and confused. Science can help. It can play a 'trusted adviser' role – providing information on the range of available options and their potential consequences, for all interested parties to consider.[19] For science to play this role, open minds and a willingness to consider all options are required both in scientific institutions and in wider society.

FURTHER READING

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