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Part II: Species and species groups

Chapter 16

Vulnerability of marine mammals in the Great Barrier Reef to climate change

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16.1 Introduction

16.1.1 Scope of chapter

Throughout this volume the reality and general nature of climate change impacts have been reiterated and thus we do not do so here. Our focus in this chapter is to relate how those impacts, and the flow-on consequences of them, will manifest in changes to habitats and food resources that in turn may affect the marine mammals of the Great Barrier Reef (GBR).

The marine mammals of the GBR are an ecologically diverse group (Table 16.1). They possess some important similarities in terms of life history and basic physiology that make general interpretations of their vulnerability to some impacts appropriate. These similarities are:

- they are mammals, and thus air breathing and endothermic, consuming relatively large quantities of food relative to body size in comparison to fishes and invertebrates, and
- they are long-lived and slow breeding so are susceptible to low levels of mortality, particularly of breeding adults.

However, in other aspects of their ecology, such as diet and movements, they differ sufficiently that we have addressed them separately. For these purposes, we have made the general distinction between dugongs, dolphins, and whales (Table 16.1). Note that 'dolphins' refers to members of the family Delphinidae, including some of the toothed whales (such as killer whales). 'Whales' includes baleen whales, sperm whales and the little known beaked whales. Where substantial differences between species within these groups exist, and there are sufficient data on these differences, we address these separately.

Our conclusions about the impacts of climate change on most (if not all) marine mammals of the GBR are tentative and speculative due to: i) uncertainty about the magnitude and direction of the impacts of climate change on the GBR, and ii) our overall lack of knowledge about the ecology of most marine mammals in the GBR. However, the information presented identifies areas of concern for these species under climate change and highlights the importance of gathering baseline ecological data on marine mammals in the GBR.

16.1.2 Significance of marine mammals in the GBR ecosystem

Marine mammals are significant in the GBR in ecological, cultural and economic contexts. There are particular legal obligations to protect marine mammals under the federal *Environment Protection and Biodiversity Conservation Act*, the *Great Barrier Reef Marine Park Act 1975* and the *Queensland Nature Conservation Act 1992*.

Whales in particular support active tourist industries via whale watch boats for dwarf minke whales in the northern GBR and humpback whales in the Whitsundays. One commercial dugong watching operation also exists but this is a relatively small scale and infrequent operation. There is no commercial dolphin watching within the GBR. However significant dolphin-feeding tourism occurs for bottlenose dolphins in Moreton Bay and, to a lesser extent, for Indo-Pacific humpback dolphins in Tin Can Bay in the Great Sandy Straits. Dolphins from these populations may range within the GBR.

Table 16.1 *Marine mammal species known or suspected to occur in the GBR*[a]

Group	Family	Common Name	Scientific Name
Dugongs	Dugongidae	Dugong	*Dugong dugon*
Dolphins	Delphinidae	Australian snubfin dolphin	*Orcaella heinsohni*
		Bottlenose dolphin*	*Tursiops spp.*
		False killer whale	*Pseudorca crassidens*
		Fraser's dolphin	*Lagenodelphis hosei*
		Indo-Pacific humpback dolphin	*Sousa chinensis*
		Killer whale	*Orcinus orca*
		Long beaked common dolphins	*Delphinus capensis*
		Long-finned pilot whale	*Globicephala melas*
		Melon headed whale	*Peponocephala electra*
		Pantropical spotted dolphin	*Stenella attenuate*
		Pygmy killer whale	*Feresa attenuata*
		Risso's dolphin	*Grampus griseus*
		Rough-toothed dolphin	*Steno bredanensis*
		Short beaked common dolphins	*Delphinus delphis*
		Short finned pilot whale	*Globicephala macrorhyncus*
		Spinner dolphin	*Stenella longirostris*
		Striped dolphin	*Stenella coeruleoalba*
Whales	Physeteridae	Sperm whale	*Physeter macrocephalus*
	Kogidae	Dwarf sperm whale	*Kogia simus*
		Pygmy sperm whale	*Kogia breviceps*
	Ziphidae	Blainville's beaked (or dense beaked) whale	*Mesoplodon densirostris*
		Cuvier's beaked whale	*Ziphius cavirostris*
		Longman's beaked whale	*Mesoplodon pacificus*
		Strap-toothed (Layard's) beaked whale	*Mesoplodon layardii*
	Balaenopteridae	Dwarf minke whale	*Balaenoptera acutorostrata subsp.*
		Fin whale	*Balaenoptera physalus*
		Humpback whale	*Megaptera novaeangliae*
		Sei whale	*Balaenoptera borealis*
		Blue whale	*Balaenoptera musculus*
		Pygmy blue whale	*Balaenoptera musculus brevicauda*
		Bryde's whale*	*Balaenoptera edeni*
		Antarctic minke whale	*Balaenoptera bonaerensis*

* The distinctive forms and relationships of these species are still unresolved and more than one species/subspecies may occur within the GBR.

a Modified from: Great Barrier Reef Marine Park Authority[25]

Dugongs also have special cultural significance for Indigenous people with hunting being an activity closely associated with Indigenous culture[31]. Dugongs were also cited as one of the World Heritage values of the GBR[24].

The ecological roles of marine mammals are largely determined by their diet and the effects of their feeding on the food resources. As these are the areas of greatest difference we address them separately for the three groups.

16.1.2.1 Significance of dugongs

Dugongs are specialist seagrass feeders that feed predominantly on fast-growing, low-biomass pioneer species such as *Halodule* and *Halophila*[40]. Feeding by dugongs has been shown to affect the community composition of seagrass beds such that it favours pioneer species at the expense of slower growing climax species[4]. Feeding by dugongs also affects the chemical composition of seagrass species with re-growth of both *Halophila* and *Halodule* showing, for example, higher whole plant nitrogen concentrations up to a year after grazing[5]. Chapter 8 (Waycott et al.) on seagrasses describes the multitude of fauna and flora that are dependent on various seagrass species. Thus, the effect of dugong grazing may carry through to a wide range of taxa and communities, particularly where dugongs are abundant.

It is difficult to quantify just how important this role is, or should be, for dugongs. The population in the GBR has been substantially reduced since at least the 1960s. In some areas, reflected by the location of Dugong Protection Areas along the urban coast of the GBR, dugong densities are high and we might expect them still to have a significant structuring effect on seagrass communities. Marsh et al.[43] hind-cast the population for Queensland south of Cairns based on an index of the rate of population decline and the present day population estimate. They then used an estimate of the carrying capacity of the GBR south of Cairns, itself based on estimates of seagrass areas and productivity, to constrain the upper bounds of the dugong population estimate. Their estimates ranged between 31,000 and 165,000 (upper and lower 95% confidence limits), but they concluded that the lower estimate was more consistent with present day seagrass resources. This contrasts with a present day estimate for the same area of approximately 4500 dugongs.

16.1.2.2 Significance of dolphins

Delphinids (family Delphinidae) represent a unique component of marine biodiversity. They are the most diverse and widespread of marine mammals, and the only mammals (together with whales and dugongs) that live their entire lives at sea. In addition delphinids represent one of the most socially diverse and complex groups of mammals, and have evolved cognitive and communication abilities found only in few mammalian species.

Sixteen species of delphinids are estimated to occur within the waters of the GBR (Table 16.1), ranging from the coastal medium sized and potentially endemic Australian snubfin dolphin (*Orcaella heinsohni*) to the large, offshore and widespread killer whale (*Orcinus orca*).

Most dolphin species in the GBR feed on patchy resources of fishes and cephalopods found throughout the water column in estuarine and marine environments. As large, mobile marine vertebrates in high trophic levels, dolphins have the potential to profoundly affect their prey populations, which in turn may result in significant influence on food-web interactions (ie trophic cascades), and ecosystem function and structure. Similarly, decreases in the availability or abundance of dolphin prey may have strong influences on dolphin distribution and abundance. Examples of such interactions and their ecological consequences include: i) depletion of krill and silverfish by minke whales, killer whales and Adélie penguins[1]; and ii) increase of planktivorous fishes in the Black sea due to decreases in abundance of pelagic predators (dolphins, mackerel, bonito, bluefish) caused by overfishing[20].

For most species occurring in the GBR, information on some of the most basic ecological (distribution, abundance, movement patterns, feeding habits) and biological aspects is lacking. Thus, it is difficult to assess and quantify the importance of their ecological role and the consequences of anthropogenic impacts on their populations and the environment. However, given increasing evidence of the importance of large marine predators, it is reasonable to infer that substantial changes to the distribution and abundance of dolphins in the GBR could have strong consequences for the structure and functioning of coastal and open ocean ecosystems in the GBR. It is also important to note that some of the interactions or their follow-on consequences have only been shown because of substantial long-term research effort. Such effort has not yet been undertaken in the GBR, and perhaps may never be. The inability to demonstrate such effects should not be taken to imply that they have not, or will not occur. The precautionary principle should be applied here because of this lack of information.

Additionally, for many humans, dolphins have aesthetic value contributing to the beauty and diversity of the planet. This value has resulted in the proliferation of whale and dolphin ecotourism activities throughout the world. Tourism based on free-ranging dolphins, including boat-based tours, shore-based observation, swim interactions, and hand feeding, is one of the most popular icons for marine tourism along Australia's coastline and an increasing industry along the east coast of Queensland[11]. Although at present the level of wildlife tourism involving dolphins in the GBR waters is low, it is expected to increase. Thus, changes in dolphin communities occurring in the GBR could have substantial economic impacts on the tourism industry and local economies.

16.1.2.3 Significance of whales

Most cetaceans apart from dolphins are referred to as whales. There are two main groups of whales: toothed (odontocetes), which includes the dolphins, and baleen (mysticetes). In the GBR, many species of odontocetes and at least seven species of mysticete have been recorded. Of the non-dolphin odontocetes, all species that have been recorded are deep diving whales including sperm and beaked whales. It is unlikely that these whales occur commonly in the GBR itself but rather inhabit adjacent deep waters. While the sperm whale is reasonably well known, the other species are not. Pygmy and dwarf sperm whales are found sporadically and are little studied. Even more cryptic, the beaked whales, a family comprising approximately one quarter of all species of cetaceans and second only to dolphins in marine mammal species diversity[58], are the least known group of large mammals in the world. These odontocetes are thought to all rely heavily on cephalopods as prey.

While four species of mysticetes are recorded with some regularity in the GBR, only the humpback whale is found routinely in large numbers in the area. Humpback whales migrate annually from summer feeding grounds in Antarctic waters to winter breeding grounds within the GBR[21,63,15]. The vanguard probably enters GBR waters in May with numbers increasing to a peak in August and then subsiding again with most gone by late October. During this time the whales calve, mate and fast[17,21].

Competition among males for access to females can be seen as energetic 'competitive groups' where a single female is generally pursued by several males[67,7]. Male humpbacks can also be heard producing complex acoustic displays known as 'songs'[54]. While songs are likely to be associated with courtship and mating, the precise function is not clear, particularly whether it is aimed at attracting females or in dominance sorting or competition with other males[29,22,18,19].

East Australian humpback whales are currently thought to comprise a single discrete population with low levels of interchange with the west Australian and South Pacific populations[17,23]. This assumption has not been tested, however, and it is possible the whales may form more than one discrete population with core breeding areas in different parts of the GBR. The humpback population was hunted extensively by shore-based and Antarctic pelagic whalers in the 1950s and early 1960s and may have been reduced to less than one percent of its original level. Despite this, the population is recovering strongly with an estimated 7090 whales in 2004 and a rate of increase of between 10 and 11 percent per annum[52,53,46].

Humpback whales have the potential to form the basis of a thriving and important whale watching industry in the GBR in the future. As their population continues to grow strongly, opportunities for whale watching are increasing with steadily increasing densities of whales reported in many parts of the GBR.

The dwarf minke whale is probably one of two or three sub-species of the common or Northern minke whale[6,58]. While little is known about the habits of this sub-species, they form a well known winter aggregation in the Ribbon Reefs off Port Douglas and Lizard Island where they are the focus of a small but important whale watching and swim-with-the-whale tourist industry, the only one of its kind in Australia[12]. As with humpback whales, this aggregation probably represents the terminus of an annual migration with the whales likely moving to temperate waters for summer feeding.

Other mysticetes reported in the GBR include the fin, pygmy blue, sei and Bryde's whales. Along with humpback and minke whales, these are all species from one of four extant mysticete families, the Balaenopteridae. Little is known, however, about the visitation of these less frequently seen species to GBR waters and it is likely that they occur sporadically, at low abundance or as occasional migrants to the area.

16.2 Vulnerability

In this section we first address the potential impacts of climate change common to each marine mammal group and then address those specific to each group separately. Throughout this volume a range of impacts have been addressed for varying taxa or attributes of the GBR ecosystem. Not all apply to marine mammals and thus for conciseness we have omitted those that do not apply. The absence of an impact in this section should be taken to indicate that we feel it will have little or no direct observable impact on marine mammals. For example, static organisms, such as seagrasses or corals will likely be directly affected by sea level rise while marine mammals are unlikely to experience any direct effect. Where indirect effects may be experienced these are addressed in the linkages section 16.3 (eg impacts on seagrasses due to sea level rise may have flow-on effects for dugongs).

16.2.1 Impact – ocean acidification

All marine mammals will be exposed to ocean acidification. However, there is presently no information with which to assess the sensitivity of marine mammals to the expected pH decrease. There have been a number of studies showing that fish populations can do relatively well in lakes with water at considerably lower pH than expected in the GBR, but the extent to which these can be extended to mammals is unknown. There is extensive literature on the effect that metabolic acidosis has on bone reabsorption in mammals[14,60], but this focuses on dietary or disease-based causes. We can find no literature on the effect of long-term immersion in fluids of lower pH. However, data presented on long-term ocean pH levels (Pandolfi and Greenstein chapter 22) indicates that the expected changes will not be outside the range experienced in the past by marine mammals. Consequently, we conclude that the risk of ocean acidification to marine mammals is relatively minor.

While there is unlikely to be a direct effect of acidification, were this to adversely affect the distribution of prey species, there may be some effect on marine mammals. Some groups of squid in particular are extremely sensitive to pH[55] and changes in squid abundance may have large impacts on some odontocetes, particularly sperm whales and beaked whales. While fish are probably less sensitive to hypercapnia[55] changes in abundance may also occur.

As many of the mysticetes that are found in the GBR feed in temperate and polar waters, acidification impacts on the Antarctic ecosystem in particular may also impact on GBR whales. Discussion of these impacts is beyond the scope of this book but may be widespread and serious.

16.2.2 Impact – sea surface temperature

In chapter 2, Lough described sea surface temperature of the GBR as greater than 29°C in the summer in the north to less than 22°C in winter in the south. Increases in mean sea surface temperature are predicted to be 1 to 3°C by 2100, but are likely to be greater in winter and greater in the south.

Dugongs

It seems unlikely that the range of dugongs within the GBR will be limited by water temperature. The distribution of dugongs is known to be limited by colder temperatures[3,57], but there is little evidence of warm water limitation. Dugongs have a wide tropical distribution and are found in the Arabian Gulf where sea surface temperatures reach 36°C. This exceeds the projected increases described above.

The more likely scenario for dugongs is that their range will extend southward. The current limit of significant and consistent populations is Moreton Bay. In recent years dugongs have been sighted as far south as Sydney and archeological studies show them to be present in Aboriginal middens from the region[2]. Waycott et al. (chapter 8) suggest that seagrass distribution may also shift south. If this occurs, dugongs may actually become permanent residents in areas south of their current range, rather than such animals being considered unusual vagrants. However, Allen et al.[2] noted that the total seagrass meadows in New South Wales (NSW) are less than those of Moreton Bay alone (which currently supports some 500 dugongs[16]. Consequently, it is unlikely that the numbers of dugong occupying habitats in NSW under climate change scenarios will ever be substantial relative to the total GBR population of some 14,000[38,39].

Dolphins

There is some evidence that warming of ocean waters has led to distributional shifts and changes in social behaviour of dolphins. Increased water temperatures in northwest Scotland have resulted in a decline in occurrence of cold water species of dolphins, an increase in the occurrence of existing warm water species and the addition of new warm water species to the community[37]. The group size of bottlenose dolphins in the Moray Firth, Scotland, and killer whales (*Orcinus orca*) in Johnstone Strait, Canada, varied from year to year in relation to large-scale ocean climate variation and local indices of prey abundance[34].

Most of the dolphin species found in the GBR are cosmopolitan, occurring throughout tropical, subtropical and temperate waters of the world. The only exception is the Australian snubfin dolphin, which is endemic to the Australian and Papua New Guinean Region[9]. The predicted 1 to 3°C rise in mean sea surface temperature in the GBR by 2100 may cause range expansions of warm water species and contractions of those more typically found in cold temperate waters. However, it is difficult to predict species-specific responses without adequate knowledge of their distribution and seasonal patterns within the GBR.

Whales

The majority of baleen whales in the GBR are migratory species that routinely encounter large variability in water temperature. The exception is the Bryde's whale (or complex of whales)[61] which does not appear to be migratory, but which is found globally from tropical to temperate regions suggesting that it tolerates a range of water temperatures. It is unlikely that predicted changes in water temperature would have any effect on this group, as there is no evidence that this is a factor limiting or governing their current distribution.

Although probably more philopatric, the deep diving odontocetes are also routinely exposed to a large range in water temperatures with each dive. Sperm, pygmy and dwarf sperm whales are found in a wide range of latitudes[58] and their distribution is likely to be linked to primary productivity rather than water temperature. While some species of beaked whales are tropical and others temperate or polar[58], factors that control their distribution are not known but maybe related to diet and niche separation[36]. As they too experience a wide range of temperatures during deep dives, it is unlikely however, that water temperature alone is a major factor.

16.2.3 Impact – storms, floods and cyclones

Cyclones are expected to become more intense, but there is less certainty about whether their frequency or distribution will change (Lough chapter 2). Marine mammals may be vulnerable to storms, floods and cyclones via direct mortality caused by physical injury or via the effects of these impacts on food sources. The latter will be dealt with below in section 16.3. Their vulnerability to direct mortality will largely be a function of their distribution, particularly in relation to water depth and proximity to shore. Coastal dolphins and dugongs are likely to be most vulnerable, as they inhabit areas where it may be impossible to avoid physical disturbance via diving, and where stranding due to storm surge may occur. Offshore dolphins and whales are less likely to be injured due to the great water depths in which they are found.

Dugongs

The vulnerability of dugongs to stranding during cyclones is likely dependent on a range of factors. The most well know example of such an event was that during Cyclone Kathy in the Gulf of Carpentaria in 1984[41]. The cyclone crossed the coast at high tide with the resultant storm surge carrying dugongs, turtles and other marine life over the shoreline and onto the flats behind. Stranded dugongs were found up to 9 kilometres inland. In total, 27 dugongs were seen, of which 23 were rescued, but Marsh et al.[41] considered it unlikely that all dugongs had been found. It should be noted that recent estimates suggest that the area supports several thousand dugongs[47].

While such examples are compelling, they are not common. Other cyclones have crossed the coast with few or no stranded animals reported. The increasing severity of cyclones may exacerbate this effect, but direct mortality is only likely where the cyclone crosses a high-density dugong population coincident with high tide. This alone is unlikely to be a significant threat to the GBR dugong population. However, the impact that cyclones and flooding may have on the food resources available to dugongs can be massive, and cause great disruption to local dugong populations. We address that issue in section 16.3.

A caveat on the above discussion is that there may be mortality effects that have gone unnoticed because of the difficulty in studying demographic processes in dugong populations. There are no data available on injuries or mortalities that may occur offshore as a result of cyclones.

Florida manatees are ecological correlates of dugongs, occupying similar habitats and feeding on seagrasses. They are also amenable to study, as they are very easily approached and observed and because the high occurrence of boat strikes in Florida means that individuals can be identified via the resultant scars. This has enabled the survivorship of manatees to be assessed over a period of nearly two decades and the effect of severe storms on survivorship to be estimated[32]. Over the period from 1980 to 1998 survivorship was essentially constant at 0.972 but dropped to as low as 0.817 in years with severe storms. Thus an increase in severe storms (such as cyclones) may pose a threat to dugong populations. However, Langtimm and Beck[32] were unable to identify the specific causes behind the reduced survivorship estimates and thus could not discern whether increased mortality was due to storm related injury, starvation due to lack of food or rather to permanent migration from the area.

Dolphins

Increased frequency and intensity of cyclones in the GBR with climate change may have direct effects on coastal dolphins via stranding as a result of storm surge. This will particularly affect species restricted to coastal areas such as snubfin, Indo-Pacific humpback and bottlenose dolphins. As mentioned above for dugongs, direct mortality will only be likely in the event where a cyclone crosses high-density populations of these species coincident with high tide.

A more serious threat posed by an increased frequency in cyclones and associated rain and flooding is an increase in the transport of pathogens and agricultural and urban-sourced pollutants into coastal waters of the GBR. As top-level predators, dolphins concentrate contaminants through bioaccumulation. High concentrations of heavy metals and persistent organic compounds containing halogens have damaging effects on marine mammals[65,66]. Recent studies have shown that pathogen pollution may have considerable negative effects on populations of coastal marine mammals[30]. The carcasses of three humpback dolphins recovered in the Townsville region between 2000 and 2001 were infected with *Toxoplasma gondii*[13], a terrestrial parasite that can be fatal or have deleterious effects to the health of marine mammals (eg infection with *T. gondii* is one of the leading causes of mortality of southern sea otters along the California coast[30]). The introduction of this parasite to the coastal ecosystem appears to be linked to runoff of contaminated water with cat faeces or litter carrying oocysts of *T. gondii*[45]. Given the apparently small populations of snubfin and humpback dolphins in the GBR[50], an increase in the incidence of this pathogen is of serious concern.

Cyclones and flooding will also have an impact on prey availability to the dolphins. We address this issue in section 16.3.

Whales

Most baleen whales are present in the GBR outside the cyclone season and so are less likely to be impacted. Odontocete whales in the GBR are usually found in deep water and so cyclones are unlikely to have serious effects on them as strandings are less likely than for coastal dolphins and dugong.

16.3 Linkages with other ecosystem components

Marine mammals predominantly link to other ecosystem components via feeding. As large homeotherms, the energy requirements of marine mammals are disproportionately large and, where mammal densities are sufficiently high, they may exert significant structuring effects on prey species at both population and community levels. Consequently, this is the avenue by which climate change is most likely to exert an influence on marine mammals. Similarly, where marine mammals are affected by climate change or other factors, the broader consequences are likely to be seen most clearly in their food resources.

There are few commonalities between marine mammal groups in their food sources. Despite the distributional overlaps between dugongs and coastal dolphins their food sources are entirely different and thus we have assessed them as such.

Dugongs

The most likely way for the effects of climate change to manifest on dugong populations will be via effects on seagrasses, the dugong's primary food resource. Waycott et al (chapter 8) described in detail the potential responses of seagrasses to climate change. Briefly, increasing temperatures may cause seagrass distribution to contract seaward, but rising sea levels may counter that effect to some degree. Flooding and sedimentation may also reduce seagrass density or availability. However, throughout the chapter, Waycott et al. note that pioneer species such as *Halophila* and *Halodule* are likely to be less affected than those adapted to more stable conditions. In fact, some more stable meadows may change species composition towards pioneer species.

This last point is important for dugongs, as they feed preferentially on pioneer species. If pioneer species of seagrass fare well under climate change scenarios then so too might dugongs. However, Waycott et al. caution that some intertidal and shallow subtidal seagrass meadows (which are important to many dugong populations) may become more prone to 'boom-bust' cycles, potentially threatening seagrass dependent species because of unpredictable loss of local resources.

It is important also to consider whether dugongs are currently limited by food resources. That is, if seagrass resources are diminished, will it impact significantly on dugongs? Above we described the work of Marsh et al.[43] who estimated the carrying capacity of the Queensland coast south of Cairns for dugongs and compared it to present population size. The conclusion was that the urban coast region could support approximately 30,000 dugongs. At the whole of GBR scale, unless seagrasses are reduced dramatically under climate change, it seems unlikely that the dugong population will be reduced. We caution, however, that this conclusion is based on regional scale interpretation. It remains possible that at the local scale individual dugong habitats might be disproportionately affected. This would depend on a suite of factors as addressed by Waycott et al. (chapter 8). At present, there are insufficient data to evaluate the possibilities at such a scale.

Despite the low level of concern for overall seagrass resources, there is one mechanism by which local dugong populations might be severely affected by climate change. Cyclones, and their associated flooding, can have a devastating effect on seagrass resources at the scale of an individual bay. The cyclone and two floods that hit Hervey Bay in 1992 caused the dugong population to crash from 2206 (+/- 402 standard error) to 600 (+/- 126 standard error)[56]. Many dugongs starved while others probably moved out of the area. The seagrass apparently recovered in six years[35], but it appears that it has taken until 2005 (over a decade) for the dugong population to recover[44]. Similarly, Heinsohn and Spain[27] noted an increase in catches of dugongs in shark nets after Cyclone Althea hit Townsville, which they attributed to increased movements in search of food. Stomach contents of those animals also showed a dramatic shift in diet, from seagrass to algae which was thought to be due to local seagrass resources having been destroyed[27]. If the intensity of cyclones becomes such that even greater losses of seagrass occur and/or the return time of cyclones becomes more frequent than the recovery time, then this may pose a significant threat to the dugong population of the GBR. Such an effect may be compounded by the subsequent stranding and other associated mortalities if cyclones make landfall at high tide.

Dolphins

The distribution and abundance of dolphins is largely related to prey availability and predation risk[28]. Detailed information on the feeding habits of most species found in the GBR is lacking. Data from elsewhere indicates most dolphin species in the GBR are opportunistic-generalist feeders, eating a wide variety of coastal, estuarine and reef-associated fishes, cephalopods (mainly squid), and crustaceans both on the bottom and within the water column.

Munday et al. (chapter 12) indicate that changes in the physiology, distribution extent and abundance of fishes on the GBR due to rising temperatures is likely to be relatively small because: i) many of the fishes in the GBR have ranges that include predicted changes in sea temperature, and ii) phenotypic plasticity of resident populations, or gene flow from more northern populations will allow most GBR fishes to accommodate small increases in sea temperature. In the case of squid, and cephalopods in general, the situation appears to be the same: Squid and other cephalopods are ecological opportunists that can occupy broad trophic niches and respond quickly to environmental or ecosystem changes[59] Thus, in general, cephalopods have the intrinsic flexibility to adapt to climate change.

On the other hand, habitat degradation caused by increases in sea temperature, cyclone activity and sea level may have substantial consequences for the persistence of several species of fish. Munday et al (chapter 12) and Lovelock and Ellison (chapter 9) indicate that many species of fish in the GBR depend on corals and mangrove forests and are unable to persist once their habitat has been seriously degraded. Thus, significant declines in fish diversity and abundance may occur if there is large-scale loss of live coral and mangrove habitat resulting from climate change.

Declines in prey resources may result in shifts in the distribution and diet of dolphins[64,68], changes in their social structure[34], or local depletion/extinction[37]. The particular response of dolphins in the GBR will depend on their ability to adapt to changes in prey resources. Most species in the GBR are wide ranging and feed on a large variety of fishes and cephalopods. Thus most species are likely to be able to adapt to these changes. However, species such as the Australian snubfin and Indo-Pacific humpback dolphin, which are restricted to coastal estuarine waters and display high site fidelity, are potentially vulnerable to declines in prey resources[50].

Whales

Baleen whales are thought to feed primarily in temperate or polar waters[8], migrating to the GBR or adjacent waters for their winter breeding seasons when they usually fast, and so are unaffected by the local availability of food resources. Changes in Antarctic and temperate ecosystems, however, including changes salinity, pH and current systems, may have profound impacts on these species by fundamentally altering these ecosystems[33]. The factors that trigger migration in baleen whales are not known. Whether or not changes in sea surface temperature or prey availability, particularly in the Antarctic, and resultant body condition alters the migratory timing of baleen whales remains to be seen.

Beaked, sperm, pygmy sperm and dwarf sperm whales are all deep diving odontocetes that are likely to rely primarily on cephalopods and deep water fish. As mentioned above, changes to these prey groups may occur as a result of ocean acidification but the potential for this is not clear. It should be noted, however, that we are still far from having a complete picture of the distribution or ecology of any of these species in the GBR or adjacent waters, which makes definitive predictions even more difficult.

16.3.1 Constraints to adaptation

Marine mammal species have the advantages of mobility and the capacity to learn about their environment, both of which perhaps enhance their ability to adapt to changing circumstances. However, this suggestion should be qualified with observations of the current habitat choices of these species.

Dugongs utilise an inherently variable resource. Meadows of seagrass come and go over relatively short time frames and probably have done so over evolutionary time. Dugongs make frequent movements between seagrass habitats, sometimes covering distances of hundreds of kilometres[62]. At times they remain resident in these areas, but at others they return quickly to the point of origin, indicating that they are assessing alternatives. However, these movements are very individualistic and reflect different animals having differing knowledge of the distribution of alternative food sources.

The fact that some movements by dugongs bypass suitable alternative seagrass beds[62] and that many animals starved after the Hervey Bay floods described above, some having also passed by suitable habitats[56], indicate that if known resources are lost, individuals may not be effective at finding new sites. The persistence of dugongs in this environment shows that they do have the ability to adapt at a population level, but the question of the rate of change under climate change is again pertinent. At present there are insufficient data to assess whether this will be significant.

Coastal dolphins show quite specific habitat requirements. While there is some spatial separation between the two species, both Australian snub-fin dolphins and Indo-Pacific humpback dolphins show preferences for shallow water near river mouths[48,49,51]. These preferences are thought to be related to the productivity of the environments but it is not known whether, or how much, individuals would be able to alter with changes in overall productivity, or the distribution of productivity. Oceanic dolphins are wide ranging and feed on a large variety of fishes and cephalopods and thus are potentially more likely to adapt to changes in their environment. However, changes in their distribution and abundance within the GBR are likely to occur as a result of climate change. As for dugongs, preference for an inherently variable environment perhaps indicates a high level of adaptability, but whether the current or projected rates of environmental change will exceed adaptability is unable to be assessed with the current data.

16.3.2 Interactions between stressors

As noted above, there is limited prospect for any of the climate change impacts to directly affect marine mammals, given their mobility and general adaptability. Similarly, it is unlikely that such stressors will interact in any manner in which impacts on marine mammals can be reliably inferred. However, cumulative interactions can impact the food resources of marine mammals and these are addressed in the chapters on seagrass (chapter 8) and fish (chapter 12).

16.3.3 Threats to resilience

Climate change is only one of the many threats faced by marine mammals in the GBR. While assessment of the likely effects of climate change remains tentative, there are a number of other threats for which the evidence is more direct and more current. Some marine mammal species in the GBR are already under threat from incidental entanglement in gillnets and shark nets, pollution, overfishing of prey resources, and habitat degradation. Due to the lack of baseline data, or indeed current population estimates, for most species, the only species for which there are quantitative data to demonstrate a decline is the dugong. Marsh et al.[43] showed that catch rates of dugongs in the Queensland Shark Meshing Program declined by nearly 97 percent between 1962 and 1999. Given that: i) one of the identified causes of the decline was entanglement in gillnets[42], ii) gillnets are similar to shark nets, iii) shark nets are known to catch dolphins[26], and iv) coastal dolphins and dugongs show considerable overlap in distribution; there is a compelling argument that dolphin populations also are likely considerably reduced. Though whale and dolphin watching activities are in general low within the GBR, there is evidence that even low-level exposure to tour vessels can result in population declines over the long-term[10].

A large and stable population size is probably the most fundamental aspect of resilience to additional impacts. If several of the marine mammal species in the GBR have reduced population size, then there is the prospect that the cumulative effect of these threats and climate change may result in the loss of those species, particularly those restricted to certain types of habitats and those with small geographic ranges (eg Australian snubfin dolphin, Indo-Pacific humpback dolphins, dugongs).

16.4 Summary and recommendations

16.4.1 Major vulnerabilities

The major vulnerabilities of marine mammals under climate change are related to effects on their food resources. There is considerable uncertainty over what these will be, but they may include reduced quantity or quality and greater spatial and temporal variability, affecting the ability of marine mammals to adequately utilize the resource. These effects are exacerbated by the reduced population sizes of many marine species, particularly coastal species such as the Australian snubfin dolphin, Indo-Pacific humpback dolphin and the dugong.

16.4.2 Potential management responses

As described above, for dugongs and dolphins the principal effects of climate change are not likely to be from climate change itself, but rather the effect of climate change on food resources. The situation is similar for baleen whales, but the effects are likely to occur well outside the GBR. As the potential management responses to address impacts on these resources have been covered in detail in their respective chapters (seagrass: Waycott et al. chapter 8, fish: Munday et al. chapter 12) we do not do so here. We note specifically, and support, the suggestion in those chapters that terrestrial runoff needs to be controlled to maintain water quality. In addition to the benefits for seagrass and fish, this may confer direct benefits to dolphins and other marine mammals via the reduction in input of terrestrial toxins and pathogens.

More generally, we support the oft-repeated view in this volume that if climate change impacts are difficult to control, then the appropriate precautionary action is to control other factors known to impact marine mammals and which are sensitive to management response. In the case of marine mammals, such impacts include net entanglement, boat strike, marine debris, tourism and Indigenous hunting. Reduction in these impacts will confer on marine mammal populations greater resilience to withstand potential negative consequences of climate change.

16.4.3 Further research

Key information required for marine mammals, particularly cetaceans, will be distribution, abundance and habitat use. Perhaps because of the substantial logistical obstacles to studying these species, this information is lacking for many. More effective identification of key habitat requirements will allow more appropriate assessment of the risks posed by climate change and other impacts.

Even for the relatively well-studied dugong there is still uncertainty about important aspects of their ecology. In particular, the relationship between long distance movements and local seagrass resources is only beginning to be understood. Thus, for all marine mammal species, research into their interactions with food resources will be important.

As noted above, there are other more immediate impacts affecting marine mammal species in the GBR. However, while the fact that the threat exists is often well known, the relative importance of each is less well known. Similarly, the specific nature of the impacts and methods by which to control them are also unclear. Thus, we would see higher priority attached to research and management of these threats to be an appropriate response to climate change.

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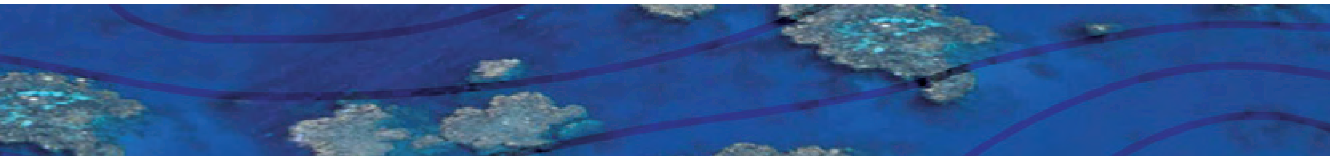

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