Monitoring whales within the Reef 2050 Integrated Monitoring and Reporting Program:

Final Report of the Whales Team in the Megafauna Expert Group

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The Great Barrier Reef Marine Park Authority acknowledges the continuing sea country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Islander Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

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1.0 Executive Summary

Two species of great whales are commonly encountered on a seasonal basis in the Great Barrier Reef (the Reef): the humpback, *Megaptera novaeangliae*, and the dwarf minke, *Balaenoptera acutorostrata* subsp. This report focuses on these two species, acknowledging that many other large and migratory whales utilise the Reef.

This desktop report provides a summary of:

- Current status of these whales relevant to the Reef, including an evaluation of primary drivers, pressures and responses using the Drivers, Pressures, State, Impacts, Responses (DPSIR) framework;
- Priority indicators for monitoring relevant components of the DPSIR framework and key values associated with these whales;
- Current and potential sources of monitoring data to address the abovementioned priority indicators;
- An appraisal of the adequacy of existing monitoring activities to achieve the objectives and requirements of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP);
- Recommendations for the design of an integrated monitoring program as a component of RIMReP, specifically considering:
    - The management information requirements for each species (relevant to the Reef) to ensure that appropriate data and information are being collected to meet the fundamental objectives of RIMReP;
    - The spatial and temporal sampling design (including logistics) to ensure effectiveness and efficiency of data collection;
    - Resources and effort required to implement the recommended monitoring design.

Previous studies relevant to both species in the Reef are presented within the report, and the status of both whales is discussed, noting data deficiencies for dwarf minkes. The DPSIR Framework and terminology were used to develop a schematic diagram of the relationships among drivers, pressures and the state of humpback and dwarf minke whales in the Reef. Pressures applicable to these whales are organised into four categories: environmental, extraction/alteration, pollution, and cumulative effects (i.e. the interaction of multiple pressures).

Priority indicators for monitoring key values of humpback whales in the Great Barrier Reef World Heritage Area (World Heritage Area) include:

1. Abundance and trend estimates (from Point Lookout land-based surveys)

2. Spatial distribution and density (including calving areas, migration corridors; via passive acoustic monitoring, aerial surveys, satellite tagging)
3. Vessel interactions (maritime vessel traffic, e.g. commercial and recreational vessels)
4. Anthropogenic noise levels, exposure and risk
5. Age composition and body condition of free-ranging and stranded whales; health of stranded whales

Priority indicators for monitoring key values of dwarf minke whales in the World Heritage Area include:

1. Abundance of the ‘interacting population’ (via passive acoustic monitoring and mark-recapture photo identification) in the northern Reef aggregation area
2. Relative abundance of the migrating population, via passive acoustic monitoring at appropriate location(s) along the migration path
3. Interacting population characteristics, demography (age composition, sex ratio, genetics) and body condition, via in-water photogrammetry, photo identification, sloughed skin collection and biopsy
4. Tourism interaction levels and ‘encounters per unit effort’ in the Ribbon Reefs aggregation area
5. Health, body condition, genetics and photo identification of stranded whales

A number of recommendations are presented in the relevant sections of this report to assist with monitoring design and implementation for both species. While other great whales have not been identified specifically as a target species for monitoring in RIMReP, methods used to monitor humpbacks and dwarf minke whales (e.g. Point Lookout surveys; Eye on the Reef reports) will likely detect, identify and provide data on additional species.

2.0 Introduction

The *Reef Long-Term Sustainability 2050 Plan* (Reef 2050 Plan; Commonwealth of Australia, 2015) is a joint initiative between the Australian and Queensland governments to provide strategic and adaptive management for the Great Barrier Reef (the Reef). The Reef 2050 Plan identifies a set of actions, targets, objectives and outcomes to protect the Reef's values, health and resilience, while allowing ecologically sustainable development and use, and protecting the Reef's outstanding universal value. Among the actions identified in the Reef 2050 Plan is the development of a Reef 2050 Integrated Monitoring and Reporting Program (RIMReP), to evaluate whether the Reef 2050 Plan is on track to meet its targets and objectives, and to serve as a knowledge system that drives adaptive management of the Reef and its adjacent catchments. Development of RIMReP includes a program design phase, in which a series of expert theme groups were convened to develop recommendations for monitoring and/or modelling of key values and components of the Reef system, including consideration of associated drivers, pressures, states, impacts and management responses. Megafauna represents one such expert theme group, encompassing coastal dolphins, dugongs, turtles, seabirds and great whales.

Relevant themes, objectives and targets from the Reef 2050 Plan for monitoring of great whales in the Reef include:

Biodiversity 2050 Outcome:

- The Reef maintains its diversity of species and ecological habitats in at least a good condition with a stable to improving trend.

Biodiversity 2035 Objectives:

- BO2: The survival and conservation status of listed species within the World Heritage Area is promoted and enhanced.
- BO3: Trends in populations of indicator species across their natural range are stable or increasing.

Biodiversity 2020 Target:

- BT5: Trends in populations of key indicator species and habitat condition are stable or improving at Reef-wide and regionally relevant scales.

Economic Benefits 2020 Target:

- EBT4: Shipping within the Reef is safe, risks are minimised, and incidents are reduced to as close to zero as possible.

2.1 Report scope

Two species of great whales are commonly encountered on a seasonal basis in the Reef, the humpback, *Megaptera novaeangliae*, and the dwarf minke, *Balaenoptera acutorostrata* subsp. This report focuses on these two species, acknowledging that many other large and migratory whales utilise the Reef.

Other limitations of this report include spatial and jurisdictional boundaries (i.e. a focus on specific information needs for agencies responsible for protection and management of values within the World Heritage Area). We acknowledge the need for more research to improve our overall understanding of these whale populations (e.g. stock structure and population connectivity through the south Pacific and Southern oceans), and the significance of risks to them through their extended habitat and range outside the World Heritage Area.

2.2 Objectives

Objectives of this desktop report included a synthesis and presentation of:

- Current status of these whales relevant to the Reef, including an evaluation of primary drivers, pressures and responses using the Drivers, Pressures, State, Impacts, Responses (DPSIR) framework;
- Priority indicators for monitoring relevant components of the DPSIR framework and key values associated with these whales;
- Current and potential sources of monitoring data to address the abovementioned priority indicators;
- An appraisal of the adequacy of existing monitoring activities to achieve the objectives and requirements of RIMReP;
- Recommendations for the design of an integrated monitoring program as a component of RIMReP, specifically considering:
    - The management information requirements for each species (relevant to the Reef) to ensure that appropriate data and information are being collected to meet the fundamental objectives of RIMReP;
    - The spatial and temporal sampling design (including logistics) to ensure effectiveness and efficiency of data collection; and
    - Resources and effort required to implement the recommended monitoring design.

3.0 The DPSIR Framework

The Driver, Pressure, State, Impact, Response (DPSIR) framework (overview in Figure 1) provides a multidisciplinary and integrative model for analysis to inform assessments of cumulative effects.

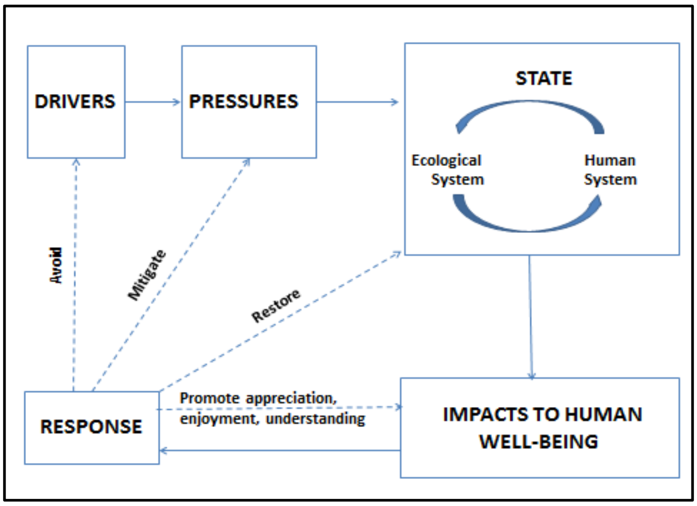

Figure 1: DPSIR Framework (from DPSIR terminology guide; Great Barrier Reef Marine Park Authority 2017).

3.1 DPSIR model for great whales in the Great Barrier Reef

Using the DPSIR framework and terminology, we present a schematic diagram of the relations among drivers, pressures and the state of humpback whale (Figure 2) and dwarf minke whale (Figure 3) populations in the Reef. Pressures applicable to both whale populations are organised into four categories: environmental, extraction/alteration, pollution, and cumulative effects (i.e. the interaction of multiple pressures). We note that accounting for cumulative effects is very challenging, and (rather than simply adding up the individual effects) requires an in-depth understanding of complex ecological interactions between risks and values, and system synergistic/antagonistic feedback loops. We also note that the figures below focus on pressures, states, impacts and responses primarily within the Reef, and we acknowledge that much of the critical life history for these long-distance migratory whales occurs outside the Reef, and indeed outside the Australian Exclusive Economic Zone.

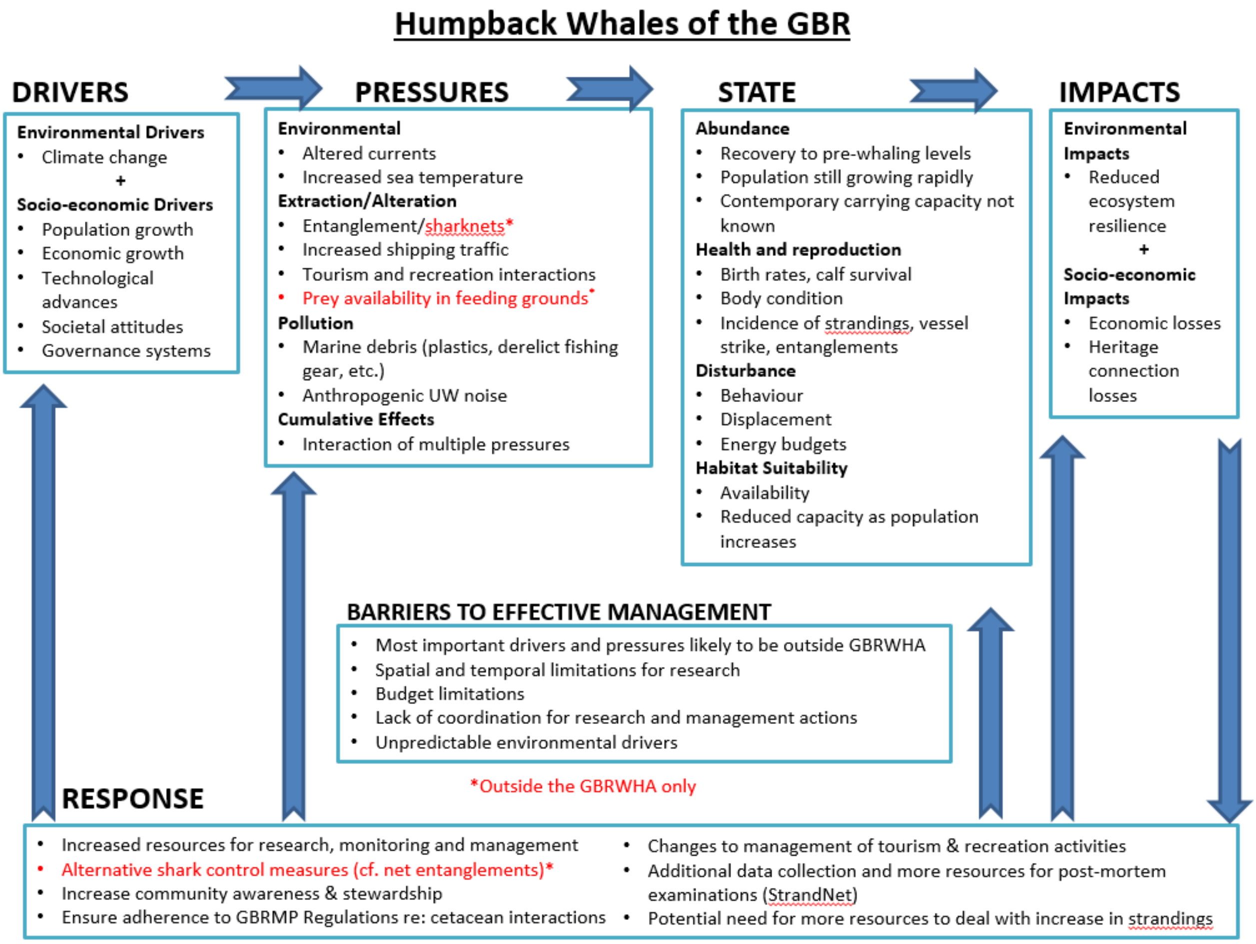

Figure 2: Schematic diagram of the relations among drivers, pressures and the state of humpback whale population(s) in the Great Barrier Reef.

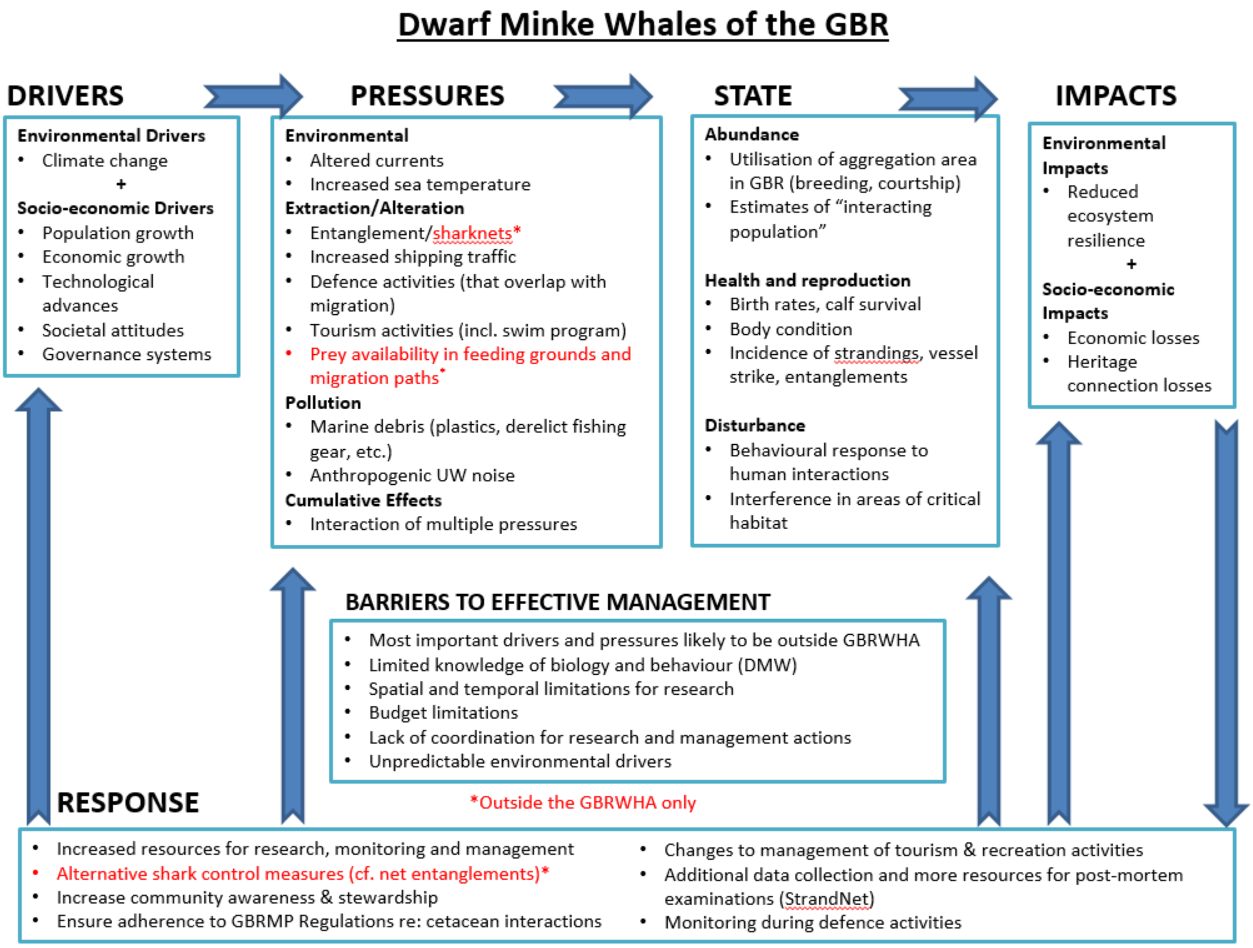

Figure 3: Schematic diagram of the relations among drivers, pressures and the state of dwarf minke whale population(s) in the Great Barrier Reef.

Drivers

Drivers are the overarching causes/trends that influence a range of pressures and drive changes in the environment (Commonwealth of Australia, 2011; Great Barrier Reef Marine Park Authority, 2014; Great Barrier Reef Marine Park Authority, 2017). Six drivers of change have been identified for the Reef system, which can operate across a range of spatial and temporal scales, and are interlinked (Great Barrier Reef Marine Park Authority, 2017):

1. Climate change
2. Whale population growth
3. Economic growth
4. Technological development
5. Societal attitudes
6. Governance systems

Pressures

Pressures (often referred to as threats) are the processes or activities that result from drivers, which affect changes to values (Great Barrier Reef Marine Park Authority, 2017). For humpback and dwarf minke whales, pressures have been arranged into four broad categories:

1. Environmental change
2. Extraction/Alteration
3. Pollution
4. Cumulative effects

Environmental change includes altered ocean currents and sea surface temperature anomalies. Environmental changes that affect sea surface temperatures may be of particular concern as water temperature could influence migration and distribution patterns (Rasmussen et al., 2007). For humpback and dwarf minke whales environmental changes may impact critically on the population in areas outside of the Reef, notably in driving their prey abundance in the Southern Ocean. Environmentally induced changes in prey availability and feeding success will be reflected by changes in whale demographics and health within the Reef but may not necessarily be caused by such changes in the Reef.

Extraction/alteration includes incidental catch in the shark control program and in commercial fisheries, potential disturbance from shipping and defence activities (e.g. along migration paths or in potential feeding grounds), potential take (hunting) in the Southern Ocean, vessel strike and disturbance (e.g. from commercial and recreational vessel interactions, including tourism), and reduced prey availability (e.g. due to extraction, reduced/altered productivity in feeding grounds). As above, it should be noted that feeding grounds for both species occur outside the World Heritage Area; however, reduced prey availability would significantly impact the populations utilising the Reef, and signs of this pressure would become apparent in the World Heritage Area.

Pollution includes marine debris (including derelict fishing gear, ropes and increasingly, plastics) and underwater noise pollution from anthropogenic sources (e.g. shipping, industry).

Cumulative effects are identified as a distinct category, representing the interaction of multiple pressures. A conceptual diagram is provided in the Appendix to show potential cause and effect relationships between identified drivers, pressures and the state for humpback and dwarf minke whale populations in the Reef.

State

In the DPSIR framework, ‘state’ represents the condition of a value (e.g. a characteristic of a whale population), that can change, qualitatively or quantitatively, over time (Great Barrier Reef Marine Park Authority, 2017). Humpback and dwarf minke whales are migratory species that use the Reef seasonally, for breeding purposes. Here, we describe the state of these whale populations in four broad categories, including abundance, health and reproduction, disturbance, and habitat suitability. The state of their populations is more fully described below after brief reviews of the management context and information needs in the Reef.

Impacts

Impact is the resultant effect to human well-being that flows from a change in the state of a value (regardless of whether that value is biophysical, socioeconomic or heritage) (Great Barrier Reef Marine Park Authority, 2017). Values are those aspects or attributes of an environmental and/or human system that are of significance (Great Barrier Reef Marine Park Authority, 2014).

For humpback and dwarf minke whales, impacts have been arranged according to:

1. Environmental impacts
2. Socio-economic impacts (includes heritage impacts)

Response

Responses are actions taken (by resource managers and/or communities) to influence drivers (e.g. societal attitudes), mitigate pressures, and/or restore the state of values within the ecological/human system. We also note a number of barriers to effective management responses that are associated with these migratory whale populations, in particular, that the most important drivers and pressures are likely to be outside the World Heritage Area. In future, monitoring of these whale populations in and adjacent to the World Heritage Area may, however, indicate a need for coordinated management responses involving other state (e.g. New South Wales, Victoria, Tasmania) and Commonwealth government agencies, and potentially other agencies outside Australia (e.g. International Whaling Commission, Convention on Migratory Species, Commission for the Conservation of Antarctic Marine Living Resources, New Zealand government).

4.0 Management context

All whales are protected in Australian waters under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act; Commonwealth of Australia 1999). Humpback and dwarf minke whales are migratory species, utilising the World Heritage Area seasonally during the austral winter for breeding purposes, with feeding grounds located outside Australia's Exclusive Economic Zone in the Southern Ocean and around the Antarctic continent. Australia is a party to multiple international conventions associated with their management and protection, including (but not limited to) the International Union for the Conservation of Nature (IUCN), Convention on Migratory Species, The International Whaling Commission, the Convention for the Conservation of Antarctic Marine Living Resources, and the Convention on Biological Diversity. Within Australian waters, the whales' migration paths cross several state government and Commonwealth jurisdictions, thus responsibility for their management is shared by multiple state and Commonwealth agencies. The Action Plan for Australian Mammals 2012 (Woinarski et al., 2014) outlines several actions required for the continued conservation of the humpback population, including improved national coordination of assessing, planning and management of anthropogenic underwater noise pollution, marine pollution, shipping and fisheries, to reduce the risk of whales using Australian waters. The Plan also identifies several conservation objectives for both species of whale that are still relevant today including managing human activities to reduce anthropogenic threats, allowing minimal disturbance and continued use of breeding grounds and migratory routes. Improving knowledge of species distribution, abundance and population trends has also been identified as a conservation objective (Woinarski et al., 2014).

To date, all monitoring of the Reef humpback whale population (East Australian E1 stock; explained below under Current Status) has occurred outside the Reef, with relative and absolute abundance estimates conducted via land-based surveys overlooking the narrow migration corridor adjacent to Point Lookout, North Stradbroke Island (e.g. Paterson and Paterson, 1984; Noad et al., 2008; Noad et al., 2016), with funding provided primarily by the Commonwealth government. All monitoring of dwarf minke whales (population and stock structure unknown) to date has occurred inside the Marine Park, based on interactions from platforms of opportunity (dive tourism vessels) within the Ribbon Reefs Sector of the Marine Park's Cairns Planning Area (Birtles et al., 2014). There is currently no other known predictable aggregation area for dwarf minke whales in Australia or elsewhere, nor any other monitoring programs focussed on this species.

5.0 Management information needs in the Great Barrier Reef

A consultancy report commissioned by the Great Barrier Reef Marine Park Authority (the Authority) identified and categorised the range of management requirements for RIMReP monitoring and modelling (Udy 2017). The report outlines requirements for a stratified or hierarchical design that enables understanding of (i) spatial extent, (ii) temporal trends, and (iii) system processes. Through a series of consultative meetings with different management agency sections, Udy identified five main categories of management uses for monitoring/modelling information: tactical, operational, strategic planning, quantifying effectiveness, and reporting. A matrix of these management uses mapped to the hierarchical monitoring program design is presented below, with examples of potential uses of monitoring data for management of great whales in the Reef (Table 1).

Table 1: Management information uses in a hierarchical monitoring program design (adapted from Udy, 2017).

	Category of management use				
	Tactical	**Operational**	**Strategic planning**	**Quantifying effectiveness**	**Reporting**
	Event/incident response: • Stranding	• Permit assessments • Prioritise compliance effort	• Revisions to Operational Policy • Plans of Management	Outcomes of resource investment, policy implementation	• Report cards • Outlook

	• Vessel collision • Oil spill		• Preparedness for events/ incidents		
Hierarchical monitoring:	**Example use/application of data by managers**				
Spatial extent: • Map values (e.g. areas of occupancy), pressures, activities (*Pressure*; *State*)	Estimate extent of potential impacts from an incident; identify areas that require management actions	Improve ability for environmental assessments and permitting to balance conflicting activities	Ensure future planning, policy and assessments consider important habitat, high density areas and overlap with human uses	Improve cost benefit assessment of actions by identifying high value areas/regions	Use reporting to communicate the values, uses, management effort in the Reef
Temporal trend: • Compare condition and values over time (*State*; *Impact*)	Understand severity of an incident/impact – is intervention required?	Provide guidance on choice of management tool(s) for achieving desired outcome(s)	Focus use of planning tools on problem areas/regions and issues	Compare effectiveness of management actions over different timescales	Track progress over long-term and report on attributes against desired state, changes over time
Process understanding: • Cause-effect relationships (*All of DPSIR*)	Identify probable outcome scenarios and the optimal management response	Understand likely impacts of a proposed activity; linkages between human pressures and value(s) state	Predict the likely pathway for recovery and use planning tools to enhance resilience	Understand the multiple impacts of interventions and monitor to ensure actions achieve intended outcomes	Report on actions completed and outcomes achieved, supporting cause and effect understanding

To assist the expert group with identifying and prioritising monitoring information needs relating specifically to great whales in the Reef, feedback was sought from relevant staff of different sections in the Authority to provide an indication of the most important information needs. Expert staff from seven different sections within the Authority were asked to identify monitoring data and information about humpbacks and dwarf minke whales that was considered relevant to the needs of their section in its decision making processes. Outcomes of this informal consultative process are summarised in Tables 2 and 3.

Table 2: Indicative* management agency information needs relevant to humpback whales in the Great Barrier Reef

Management Information Needs **- Humpback whales**	**Section**
Population trends (*acknowledging that monitoring occurs outside GBRMP and is funded elsewhere*)	EAP, FM, OR, RK, CARE, ESP
Interactions with vessels (shipping, tourism, recreation) esp. w.r.t. impacts, compliance, collisions, entanglements	EAP, FM, RK, PP
Areas of occupancy, e.g. breeding grounds/important habitat areas (density, seasonality)	EAP, ESP, FM
StrandNet statistics	FM, OR, RK
Social and economic benefits of whale watching tourism activities	PP
Underwater noise levels and thresholds w.r.t. risks and impacts	RK
General facts and statistics (e.g. as provided through Eye on the Reef)	CARE
Is the Whitsundays Whale Protection Area still appropriate? (i.e. impacts from vessel interactions, risks)	PP

Section key:
- EAP - Environmental Assessment & Permits
- FM - Field Management
- OR - Outlook Report
- PP - Policy & Planning
- RK - Reef Knowledge
- CARE - Communications and Regional Engagement
- ESP - Education Stewardship and Partnerships

**Information needs compiled through an informal consultative process.*

Table 3: Indicative* management agency information needs relevant to dwarf minke whales in the Great Barrier Reef

***Management Information Needs* - Dwarf minke whales**	**Section**
Population trends	EAP, FM, OR, RK, CRE, ESP
Areas of occupancy (density and seasonality) & important habitat areas (e.g. for breeding)	EAP, FM, ESP, PP
Swim-with-whales/tourism activity: impacts and appropriateness of scale of activity	EAP, PP, OR, RK
StrandNet statistics	OR, RK, FM
Compliance with permit conditions (swim-with-whales permittees)	EAP, ESP, PP
Interactions with vessels (shipping, tourism, recreation) esp. w.r.t. impacts, compliance, collisions, entanglements	FM
Social and economic benefits of whale watching tourism activities	PP
Underwater noise levels and thresholds w.r.t. risks and impacts	RK

Section key:
- EAP - Environmental Assessment & Permits
- FM - Field Management
- OR - Outlook Report
- PP - Policy & Planning
- RK - Reef Knowledge
- CSP - Communications and Regional Engagement
- ESP - Education Stewardship and Partnerships

**Information needs compiled through an informal consultative process.*

6.0 Current status of humpback whales in the Great Barrier Reef

The International Whaling Commission identifies several humpback whale breeding populations from the western South Pacific that potentially feed in Antarctic areas V and VI, and include the Australian east coast population (E1) (IWC, 2005). Although the E1 population is increasing at the theoretical maximum rate (Brandão et al., 2000; Noad et al., 2011) and may have already surpassed its estimated historical carrying capacity (*K;* Noad et al., 2016), the E1 breeding stock is classified within the Oceania population structure, thus the current conservation status for *Megaptera novaeangliae* (Oceania population) is 'Endangered' under the IUCN listing (Childerhouse et al., 2008). While this may seem misleading, complications lie within the longitudinal boundaries of the Antarctic Areas V and VI, where pooling of sub-populations E1, E2, E3 and F were necessary for catch allocation scenarios (Childerhouse et al., 2008). The IUCN determined it was not possible to assess the Oceania population independently of the East Australian population (Childerhouse et al., 2008).

The conservation status of humpback whales within Australia is covered by both Commonwealth and State legislation. Due to their increasing population, it has been proposed that their conservation status in Australian waters be revised (Bejder et al., 2016). Under current Commonwealth legislation, humpback whales are listed as Vulnerable (EPBC Act 1999; Commonwealth of Australia 1999). In addition, humpback whales are listed as a Migratory Species (Commonwealth of Australia, 2000) and are included among the Matters of National Environmental Significance (MNES) protected under the EPBC providing further conservation protection under the Act. Within Queensland waters, humpback whales are listed under the Queensland Government (1992) Nature Conservation Act as Vulnerable. Additionally, humpback whales are listed in the World Heritage nomination, and are part of the World Heritage Area, and Marine Park MNES.

Distribution, migration and habitat use

Humpback whales (*M. novaeangliae*) are distributed globally. Migration for most populations involves long-distance movements between summer feeding grounds in high latitudes (Antarctic waters east of 130°E for E1 stock), and winter breeding grounds in low latitudes (sub-tropics and tropics). Along the east coast of Australia, this migration occurs between April and November. Breeding and calving in the Reef occurs from June to September (Smith et al., 2012). Warm, comparatively shallow (less than 100 metres deep) waters are preferred by humpbacks for breeding and calving areas.

Spatial distribution models of humpback whales in the Reef have identified the likely breeding ground approximately 100 kilometres east of Proserpine south to Mackay (particularly the inner and outer Proserpine and the outer reefs off Mackay). Within this area, two main areas of higher whale density were identified, located approximately 120 kilometres to the north and 120 kilometres south of Mackay in the Whitsundays and southern lagoonal area (Smith et al., 2012; Smith and Hedley 2013; Peel et al., 2015). It is considered likely that the breeding ground encompasses the entire area given the mobile nature of the species. These proposed breeding areas are supported by a small number of satellite tracked whales (Smith et al., 2012). This identification of breeding grounds for humpbacks whales in the Reef is based on four years of incidental sightings data (Smith et al., 2012) and two years of dedicated systematic aerial surveys (Smith and Hedley 2013; Peel et al., 2015). Specifically, a dedicated humpback whale aerial survey was undertaken in 2012 to validate the spatial habitat model in three main areas of the Reef throughout the length of the Reef (latitude minus 15°S to minus 22°S).

Aerial whale sightings data were modelled against habitat parameters in the Reef, to identify a probable core preferred breeding area based on temperature and depth (see Figure 5 below). A second core area of likely high use was approximately 100 kilometres east of Gladstone around the Capricorn Bunker Group, which is considered to be more likely a migratory corridor rather than breeding terminus *per se* (Smith et al., 2012). It has been possible to identify areas of high densities of animals in the Reef, although whether there are fine scale spatial uses of areas in the Reef for various activities such as mating, calving or nursing is not known. Sightings data and the modelled distribution of humpback whales in the Reef suggest potential calving areas (occurrence of groups with a calf) throughout the Reef whereas hypothesised mating areas (predominance of groups without a calf) were restricted to the southern Reef area (Smith et al., 2012; Smith and Hedley 2013; Peel et al., 2015).

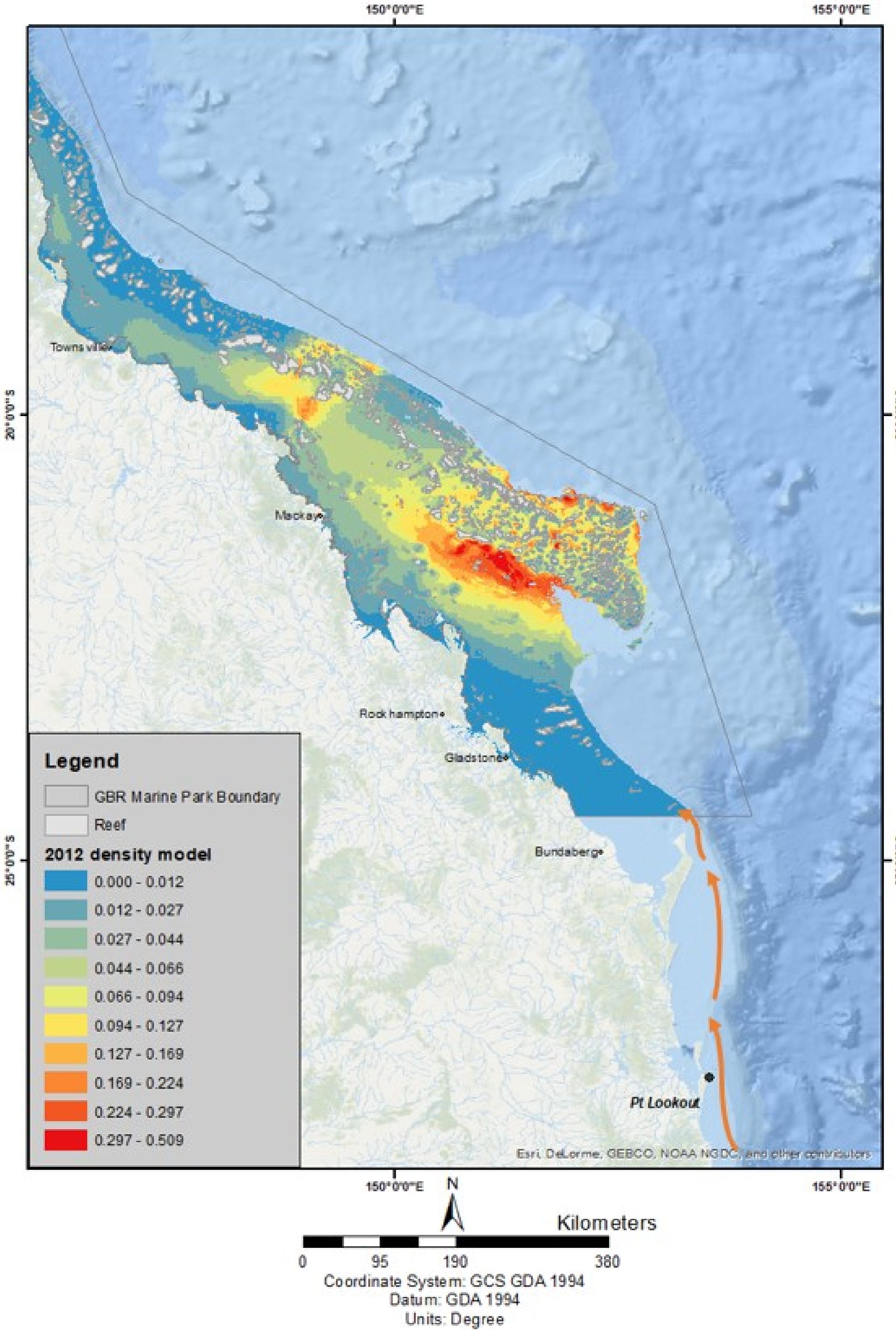

Figure 5: Indicative regions of (a) humpback northward migration path to the Great Barrier Reef (orange arrows) and (b) humpback density in the Great Barrier Reef during the winter breeding season, based on a smoothed density surface model selecting potentially influential physiographic and environmental covariates; adapted with data from Peel et al., 2015.

Relative abundance

After heavy exploitation in the 1950s and early 1960s, the E1 population was at a critically low level. Estimates of abundance at this time were difficult to discern due to vast illegal whaling efforts in the Southern Ocean by the Soviet Union (Clapham et al., 2009). Estimates of the remaining east Australian population stock range from fewer than 100 individuals (Paterson et al., 1994), to up to 500 (Chittleborough, 1965). Dedicated abundance surveys for the E1 population have been conducted since 1984 (Paterson et al., 2004; Noad, et al., 2016). In 2015, the abundance of the east Australian population was estimated to be 24,545 whales (95 per cent confidence interval; 21,637-27,851) with a long-term rate of increase (from 1984 to 2015) of 11.0 per cent per annum (95 per cent confidence interval; 10.6 to 11.3 per cent per annum). This is thought to be near the theoretical reproductive limit for humpback whales. The current rate of increase in the population suggests that the population had recovered to 58-98 per cent of pre-whaling numbers in 2015 (Noad et al., 2016). The population continues to grow exponentially.

Current surveys for humpback whale abundance are conducted south of the World Heritage Area with no abundance surveys conducted within the World Heritage Area. During the winter breeding season in the World Heritage Area, humpbacks are distributed throughout the Reef complex and adjacent coast, making abundance estimates extremely difficult. South of the World Heritage Area, Point Lookout on North Stradbroke Island (shown on Figure 5 above) provides an ideal platform to monitor the population as it is one of the few locations where the migratory corridor is very tight and close to land, allowing accurate land-based surveys of the migratory population. At this location, 89 per cent of whales passed the land-based study area within 5 kilometres for the coast. Only a small per cent of whales (1 per cent) passed further than 10 kilometres from the coast (Noad et al., 2008).

7.0 Current status of dwarf minke whales in the Great Barrier Reef

Dwarf minke whales are an undescribed sub-species of the northern hemisphere ordinary or common minke whale (*Balaenoptera acutorostrata*), a species listed by the IUCN globally as 'Least Concern'. This listing has been extended to the dwarf minke whale as the IUCN determines it is not possible at this time to establish abundance estimates due to a lack of data (Reilly et al., 2008). Both Commonwealth and state legislation do not provide specific conservation protection for dwarf minke whales in Australian waters. The EPBC Act (1999) provides protection for all cetaceans in Australian waters (and dwarf minke whales are regarded as a listed migratory species and MNES); however, this undescribed subspecies has not been individually assessed. However, like all whales, dwarf minkes are considered a protected species under the Marine Park Regulations, and hence are afforded additional protections through permit assessment criteria (e.g. for tourism, research).

Distribution, migration and habitat use

Dwarf minke whales are widely distributed throughout the southern hemisphere. Originally described by Best (1985) in South Africa, they have been recorded in the Pacific, Indian and Atlantic oceans. Satellite tagging studies in the Reef indicate a similar migration pattern to humpbacks, between feeding grounds in the Southern Ocean, and winter breeding grounds in the Reef (Birtles et al. 2015). Sighting records show dwarf minke whales are present in the Reef from April to September. The majority of sightings are reported by tourism vessels in the Cairns/Cooktown Management Area of the Marine Park as this is where the swim-with-whales tourism industry operates. The highest levels of sightings and interactions occur in the offshore Port Douglas and Ribbon Reefs region, reflecting a region of concentrated effort bias by tourism vessels. Within this region, 90 per cent of sightings consistently occur in June and July (Birtles et al. 2002; Curnock et al. 2013; Birtles et al., 2014). Distribution and abundance elsewhere in the Reef is not quantified.

A migration path along the east Australian coast was identified via a satellite tracking study from 2013 to 2015 (Birtles et al., 2015). The southward migration was consistent over the three-year study with tagged animals travelling from the Ribbon Reefs along the continental shelf edge until reaching the area around the Swain Reefs in the southern Reef (Birtles et al., 2015). Here the migration path becomes diffuse through the complex reef system before once again becoming consistent as the continental shelf narrows at the north-east point of Fraser Island south of the Reef (see Figure 6).

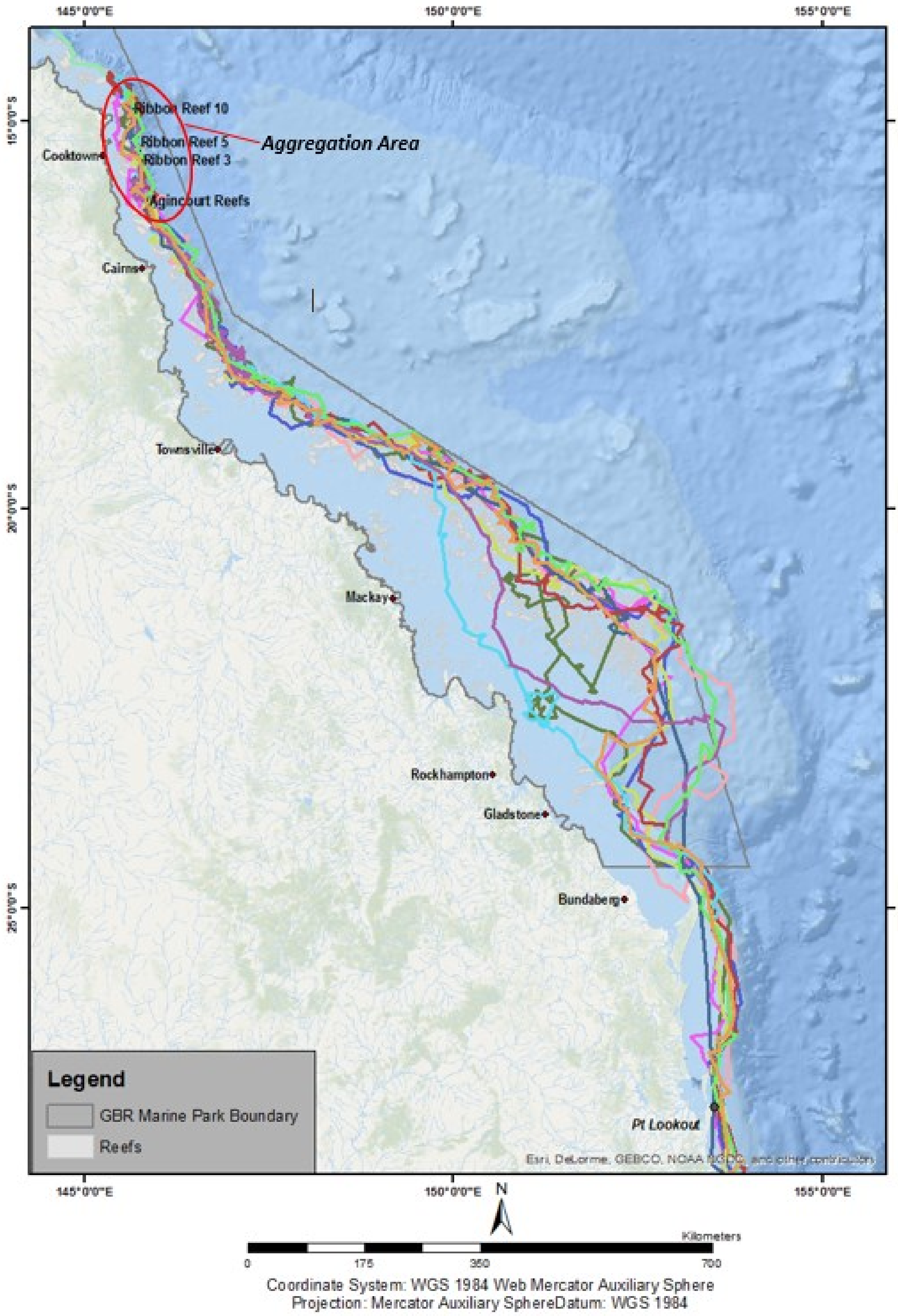

Figure 6: Indicative regions of (a) dwarf minke whale aggregation area in the northern Great Barrier Reef (red circled area), and (b) dwarf minke whale southward migration path (coloured lines); adapted with data from Birtles et al., 2015.

Dwarf minke whales are commonly reported also on the Western Australian coast by visual sightings and by their distinct acoustic signature, but little is known of the habits or migration patterns of these animals. On the Western Australian coast they have been reported as far north as 14°S (Scott Reef; McCauley *pers. comm*.) a similar latitude to the Ribbon Reefs in the Reef. There is currently no information to suggest the east and west Australian coast dwarf minke whales are from the same or different stocks.

Relative abundance

To date there have been no systematic surveys to determine dwarf minke whale abundance or areas of spatial occupancy in the Reef. Within the aggregation area in the northern Reef (shown in Figure 6 above), relative abundance estimates rely on sightings by 'platforms of opportunity' such as tourism vessels operating under permits to swim-with-whales. Underwater photo-identification of individual dwarf minke whales has provided estimates of the 'interacting population' (Birtles et al., 2002; Arnold et al., 2005; Sobtzick, 2010). At present, only baseline information of the interacting population has been estimated over a three-year study from 2006 to 2008 (Sobtzick, 2010). This study showed that the interacting dwarf minke whale population shows several characteristics of an open population (i.e. includes continual immigration and emigration). Using open population models, Sobtzick (2010) provided the first abundance estimate of the interacting minke whale population which consisted of several hundred animals each year. The total number (± standard error) in 2006 was 449 (± 68) whales; in 2007 was 342 (± 62) whales; and in 2008 was 789 (± 216) whales.

8.0 Priority indicators for monitoring

Priority indicators presented below were developed in an expert workshop held in Brisbane on 19 February 2018, and refined with subsequent feedback from the co-authors.

8.1 Humpback whales

Priority indicators for monitoring key values of humpback whales in the World Heritage Area include:

1. Abundance and trend estimates (from Point Lookout land-based surveys)
2. Spatial distribution and density (including calving areas, migration corridors; via passive acoustic monitoring, aerial surveys, satellite tagging)
3. Vessel interactions (maritime vessel traffic, e.g. commercial and recreational vessels)
4. Anthropogenic noise levels, exposure and risk
5. Age composition and body condition of free-ranging and stranded whales; health of stranded whales

8.1.1 Abundance and trend estimates

Although there are currently no dedicated monitoring programs for humpback whales in the Reef, the population is being monitored south of the Marine Park during their northward migration. Point Lookout on North Stradbroke Island, provides a unique platform to conduct land based surveys at a location where the migration path bottlenecks and is very close to shore. This location is the most viable site for monitoring the population, given its location and long standing data set of population trends, and has provided the only relative and absolute abundance estimates for the population (see Noad et al., 2008; Noad et al., 2011; Noad et al., 2016).

Relative abundance estimates are conducted approximately every three years. These surveys use the average number of whales passing per 10-hour day during the peak four weeks of migration as a consistent index of abundance that can be compared with previous years' surveys.

Absolute abundance estimates should be conducted approximately every nine to 12 years. These surveys are longer, occurring over 14 weeks to capture most of the northward migration. Daily counts determine the migratory rise and fall and are used to model the total passing population including whales passing during non-survey periods (e.g. night time) and in the tails of the migration, before and after the survey. The last absolute abundance survey was in 2004 and another is overdue. These surveys are conducted less frequently as they are more expensive, and while they are used to ground-truth abundance estimates, the shorter relative abundance estimates can be used to extrapolate absolute abundance from the last absolute abundance survey.

It is assumed that most or all of the whales passing Point Lookout are part of the breeding aggregation in the Reef, but it is possible that a small number of whales may split off and go to the Chesterfield Reefs or New Caledonia. Genetic analyses are underway comparing the migratory whales with samples collected from within the Reef and acoustic analyses are underway to estimate the degree of contact with the Chesterfield whales.

Existing monitoring – adequacy and gaps

The narrow, in-shore migration of humpback whales past Point Lookout has grown at a very consistent rate since the start of surveys in the 1980s. This indicates that it is likely that the entire population passes through this area. The consistency and relatively high survey effort (every few years) has allowed both the rate of increase and absolute abundance to be estimated with narrow confidence intervals. This means that a change in trend can be picked up very quickly here. The confidence intervals are much narrower, and the resultant ability to detect changes in trend much stronger, than would be possible with any mark-recapture study conducted in the Reef. Additionally, any mark recapture study in the Reef would require very high effort and cost to obtain enough samples (photo identification or biopsies) to generate meaningful estimates in such a large population.

The surveys at Point Lookout face their own challenges as the size of the population increases. There are so many whales in the study area at any time that it can be difficult to differentiate one group from another and new methods, such as ‘cue counting’ (counting blows rather than whales) might be useful. Another option may be an automated approach using a visual or infra-red camera system with automatic cue recognition. Regardless, it is critical that this monitoring program continues.

Resources required to implement/continue monitoring

Surveys at Point Lookout cost approximately $80,000 for relative abundance surveys and approximately double that for an absolute abundance survey. As noted above, surveys are every three years or so. Funding is for two salaried survey coordinators as well as food and accommodation for volunteer observers.

8.1.2 Spatial distribution and density

Satellite tagging

Satellite tagging of whales is capable of providing movement patterns and habitat use of individual whales in the Reef, which could be undertaken on the migratory corridor (e.g. Point Lookout) as the whales migrate northwards. In addition to tagging whales, other data can be collected about each tagged whale (e.g. sex, age, pregnancy status) from a biopsy sample as the whale is tagged.

This would allow spatial distribution for different cohorts to be defined. A series of such deployments over time would indicate changes in spatial distribution, although inter-annual variation in whale distribution will need to be assessed independently. Another option would be to use satellite tags to define potential areas cohort-specific areas of use initially and then use vessels to monitor whales in those areas over time.

Aerial surveys

Aerial surveys are the most common method used for providing information on spatial distribution and density of whales, and are capable of delineating sightings of calf versus non-calf groups close to the track line. Each survey provides a snapshot in time of the distribution of whales, although the frequency and timing between surveys dictates the spatial and temporal resolution of data on the distribution of humpback whales in the Reef. Fine scale aerial surveys within areas currently identified at the broader scale to contain high densities of whales would be particularly useful to further refining our knowledge of whale distribution. Several surveys within the breeding season would capture spatial changes in distribution and investigate intra-seasonal variation in whale movement and when done over consecutive years can explore inter-annual variation.

Previous aerial surveys in the Reef (Smith and Hedley, 2013; Peel et al., 2015) demonstrate they are feasible during the whale breeding season and that weather conditions do not prohibit undertaking them.

New approaches to aerial surveys include the use of unmanned aerial vehicles (UAVs), which offer many potential advantages (including eliminating human risk) and can incorporate computer-automated detection algorithms from digital imagery to replace manual counts of marine fauna by aerial observers (Hodgson et al., 2017). A separate RIMReP report is being compiled within the Marine Megafauna Expert Group by A. Hodgson. Such methods may become standard for aerial surveys of whales and other marine megafauna in the near future.

Acoustic monitoring

Acoustic monitoring can monitor humpback presence over long periods by detection of their song. A relative abundance (not absolute abundance) measure can be derived, although how this is achieved varies as the density of ‘singers’ (vocalising males) increases. There are different ways acoustic monitoring can be carried out, such as: 1) wide spatial scale surveys using sonobuoys or towed receivers which span a short time frame only; or 2) single point receivers which remain in-situ, fully submerged so offering no navigation hazard, for a full humpback whale season. Each technique is well proven although the former requires specialised hardware and while has been done in the Reef cannot be routinely done without some difficulty. Deploying remote instruments on the seabed to log sea noise suitable for monitoring humpback whales was routinely carried out by the Integrated Marine Observing System (IMOS, www.imos.org.au) Passive Acoustic Sub Facility, run by Curtin University. A site on the east Australian coast at near to 32^{o} 19’S, 152^{o} 56’E was sampled by IMOS between 2010 and 2017. A ball-park estimate of costs to deploy an instrument in the Reef in an area regularly visited by humpback whales for a one year duration would be in the vicinity of $35,000, a figure which could reduce considerably given in-kind support by The Australian Institute of Marine Science (AIMS) for vessel and field support.

A one year deployment would return a simple estimate of humpback whale presence based on energy levels (no whales present or some relative abundance estimate) with an estimate of listening area. The listening area needs to be calculated on a site by site basis and is subject to considerable variability produced by fluctuating ambient noise levels (which are logged by the system), but can be routinely expected to be at least 20 kilometres.

Habitat modelling

Species distribution models and specifically habitat modelling use environmental data (e.g. habitat features such as depth, seafloor rugosity, sea surface temperature, sea height anomaly) to model sightings of species occurrence across space. It is possible to identify specific niches in environmental parameters (e.g. water depth) that is particularly useful for management applications such as spatial risk assessments (e.g. vessel and fisheries). Any modelling of future species distribution data should incorporate environmental parameters in the analysis.

Existing monitoring — adequacy and gaps

Spatial distribution and density is not formally monitored at this time. The Authority's Eye on the Reef Program may provide some data on relative density in some areas, but effort is likely to be too clumped to provide reliable data on spatial distribution, or any quantitative data on density. Limited aerial surveys have been conducted providing the best information to date on distribution and density of humpback whales in the Reef.

Currently, broadscale patterns in humpback whale distribution in the Reef have been identified although this understanding of humpback whale spatial distribution can be refined. Aerial surveys of the Reef have provided sightings data and quantitative distribution models that suggests, along with a limited number of satellite tagged whales, that there are more whales in the southern than the north. Smith et al. (2012) produced a spatial habitat model to identify potential whale distribution based on incidental Coast Watch aerial sightings data. Aircraft effort was not available, nor were the flights dedicated cetacean surveys, making it difficult to evaluate biases in sampling effort, via a presence-only distribution model. The model, however, was supported by a small number of satellite tagged whales that mostly went to the same general area off Mackay. A dedicated humpback whale aerial survey was undertaken in 2012 to validate the spatial habitat model in three main areas of the Reef, throughout the length of the Reef (latitude -15°S to -22°S), which provided similar results in distribution patterns (Smith and Hedley 2013). More work is required to validate the existing spatial distribution models, and to explore cohort (sex, reproductive status) specific spatial use and evaluate intra- and inter-seasonal variation in whale distribution.

Resources required to implement/continue monitoring

Satellite tagging — the cost of a satellite tagging campaign could be significant. Satellite tags are in the order of $3000 each (not including satellite time) and several tens of whales would need to be tagged to provide a meaningful snapshot of spatial use. Additionally their biopsies would need to analysed (sex, age, hormones) at probably around $800 each. Tagging at Point Lookout only requires a small vessel with a paid coxswain; in the order of $12,000 for 15 days on the water. A complete season, deploying 50 tags, would cost in the order of $240,000 (plus significant in-kind).

Aerial surveys — these would be a way of monitoring density and spatial distribution in selected areas and in targeted areas of high whale density (for example, part of the Whitsundays). Aerial surveys require the availability of suitable aircraft (twin engine, high wing) as well as a number of professional, experienced spotters. Previous aerial surveys of humpback whales in the Reef (Smith and Hedley, 2013; Peel et al., 2015) demonstrate they are feasible during the whale breeding season and that weather conditions do not prohibit undertaking them. The largest cost associated with aerial surveys is the charter of the aircraft and pilot which is typically $1000 per hour. The total cost is entirely dependent on the size and location/s of the area to be surveyed.

8.1.3 Vessel interactions

The *National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna 2017* (Commonwealth of Australia, 2017) provides a framework for identifying species at risk, areas where vessel strikes are most likely to occur, and mitigation measures to reduce the risk of collisions. An analysis of the current and historical vessel strike records from Australian waters by Peel et al (2018) found the majority of records were reported in the last 20 years, which coincides with the formalisation of the vessel strike incident reporting undertaken by Australia to the International Whaling Commission's National Progress Reports in 1997. This highlights the importance of a formalised and mandatory reporting system to better understand the impacts of vessel strikes on the E1 humpback whale population. An additional 76 records of vessel strike in Australian waters previously not reported were discovered, resulting in a revised estimate of approximately 15 per cent of global vessel strikes occurring in Australian waters. This shows strong evidence that vessel strike occurs more often than historically perceived (Peel et al., 2018).

While vessel strike is presently not considered a major threat to the Reef humpback whale population (based on the current population growth trend), the increasing abundance of humpbacks seasonally in the Reef combined with an increase in shipping traffic in the World Heritage Area (associated with coastal and ports development) is likely to lead to higher incidence of vessel strikes (Commonwealth of Australia, 2017). A large proportion of fatally injured whales do not wash ashore and thus StrandNet reports alone will not adequately assess the incidence of mortality from vessel strike. There is a need to introduce more stringent requirements for reporting ship strikes, as well as vessel interactions generally in areas of high vessel traffic (e.g. via the Authority's Eye on the Reef Reporting in tourism and recreational areas).

Existing monitoring — adequacy and gaps

Currently, many vessel strike incidents are considered likely to go unreported or are not detected. There are also reporting biases in relation to the spatial coverage of reports and the type of vessel involved (Peel et al., 2018). The current reporting system is not sufficient and ship strike is grossly under reported. Linking reporting with vessels that undergo compulsory pilotage could be a viable option.

Resources required to implement/continue monitoring

Recommended engagement between Queensland Department of Environment and Science, the Authority, the Australian Maritime Safety Authority and Maritime Safety Queensland, to review, develop and implement an improved reporting system for vessel strikes.

Recommended improvements to the Eye on the Reef reporting systems are noted in a separate report under the Megafauna Expert Group.

8.1.4 Anthropogenic noise levels, exposure and risk

Passive acoustic monitoring to monitor trends in anthropogenic noise is best carried out by deploying long term sea noise loggers, as indicated above for humpback whales. Analysis of such data sets for anthropogenic noise is open-ended, they can be analysed indefinitely and to a fine resolution, although it is relatively straightforward to extract simple trends such as numbers and levels of large ships passing through time. A critical aspect to monitoring anthropogenic noise using passive acoustics in fixed locations (over a medium to long time scale) is the identification of the types of noise to be monitored and the appropriate locations of acoustic receivers to be deployed.

Existing monitoring – adequacy and gaps

There is currently no strategic passive acoustic monitoring in the Reef.

Resources required to implement/continue monitoring

Vessel time – one day per year to deploy, one day per year to recover, equals two days per year, plus relevant steaming to site/s.

Infrastructure – it is recommended that RIMReP contact the Integrated Marine Observation System to ask if the Passive Acoustic Facility can be extended into the Reef. This facility has suitable hardware available and the expertise.

Equipment – sea noise logger/s, mooring with dual acoustic release units, around $1200 consumables per mooring, freight ($2000 to $3000 per deployment depending on number moorings) plus several days of gear preparation and de-mobilisation plus calibrations each mooring.

Analysis – is open ended, and needs to be specified. This can be discussed with IMOS as a desired product.

8.1.5 Age composition, body condition of free-ranging and stranded whales; health of stranded whales

Age composition

The composition of a population can be used to infer the health and growth rate of that population. Age structure is likely to change as a population approaches carrying capacity and this would be most evidenced in the number (or ratio) of calves produced each year. Pregnancy rate would also be useful and could be monitored relatively easily using biopsies and measurement of blubber progesterone.

Body condition of free-ranging whales (photogrammetry and biopsy sampling)

One routine way to monitor the health of any group of wild animals is by assessing changes in body condition. For many migratory animals, this will change over the migratory cycles, but if assessed at a standard point (e.g. on the breeding grounds) then can serve as a measure of population health over time. Monitoring body condition of humpback whales could help to predict and prepare for years with elevated stranding rates. Body condition in a capital breeding mysticete (i.e. one that uses previously stored energy to support reproduction) is also likely to be closely related to reproductive rates (Christiansen et al., 2014), and hence could be an important predictor of population dynamics.

Recent studies have developed indices of body condition for free-ranging humpback whales based on surface area measurements from unmanned autonomous vehicles (Christiansen et al., 2016) and from a blubber adipocyte index based on remote biopsy samples (Castrillon et al., 2017; Bengtson Nash et al., 2018). These are low-cost compared to traditional aerial surveys, and much safer. Calibrated drone photos can yield length and width, and software is available to determine dorsal surface area from this as a proxy of body condition. If this is coupled with another more direct measure of body condition (adiposity from biopsies or blubber depth from stranded animals) then it may prove to be a reliable, calibrated indicator of body condition.

There is currently no UAV monitoring of humpback whale body condition in Queensland and monitoring of body condition through remote biopsy sampling is undertaken by Griffith University outside of the Reef.

From a monitoring perspective, biopsies can be a very useful tool. Biopsies can be used to monitor pregnancy rate and sex ratio of animals in either specific areas or as a population. Biopsies can also be used to monitor the age structure of the population which is an important additional indicator of population trajectory (Polanowski et al., 2014) and body condition which is also likely to change as the population nears its carrying capacity. For population parameters, biopsy collection is probably most efficient at Point Lookout during the northward migration. Site specific biopsy campaigns would be needed for site specific data within the Reef.

Assessing the health of stranded whales

It is also possible that the prevalence of infectious disease or the risk of an epizootic will increase in the Reef as the humpback whale population recovers. Information on exposure of a population to disease can be obtained from necropsies by qualified veterinarians and sample analysis by appropriate individuals or laboratories. Although stranded animals represent a biased sample of general health (i.e. animals in poor health may be the most likely to strand), comparatively unbiased information may be obtained for whales that have drowned in nets or that have been killed by vessel strikes.

Existing monitoring – adequacy and gaps

There is no current monitoring of the demographic ratio, health and body condition of humpback whales on the east coast of Australia. There have been several projects that have collected biopsies for various reasons on humpbacks both within the Reef and outside the Reef on migration. These samples are usually collected for specific research questions and are not likely to represent random samples of the population.

It is time for management agencies to review and reconsider their current restrictions on biopsy sampling of lactating females. A lot of important information on population structure, fecundity, calf survival, and female body condition could be collected which would better inform managers on the state of the population. This could also provide an early warning for a population crash (i.e. limited food in Antarctica would result in females that have poor body condition and would be less fit; Noad et al., in review). Biopsying of lactating females is common practice in many other jurisdictions and can be done with essentially no risk to the calf or risk of separation from the mother (Clapham and Mattila 1993; Smith et al., 1999; Smith et al., 2008).

The numbers of calves produced are not currently monitored. Current abundance surveys occur during the northward migration at Point Lookout prior to the main period of calving. There are some data on calf/adult ratios from other work undertaken in south-east Queensland (e.g. Noad and Cato, 2007; Dunlop et al., 2015) but these are not designed as surveys and data are not reliable in terms of demographics. Dedicated southward migration surveys at Point Lookout would need to be instigated to capture this information. Aerial surveys in the Reef itself could also be used to estimate the calf/adult ratio. While these would be useful for assessing this in specific targeted areas, the size of the Reef and potential extent of humpback whales through the Reef precludes complete coverage by traditional aerial surveys at a population level. However, in future, surveys of such scales may become feasible with UAVs.

StrandNet

All records of sick, injured, incapacitated or dead baleen whales reported to the Department of Environment and Science are entered into the StrandNet database. Body length and sex is routinely recorded, and used to estimate the age class as a 'calf', 'immature' or 'adult'. This information is then entered StrandNet along with other relevant information such as photos, time, location and outcome of the incident (e.g. Meager, 2016). Except when a necropsy or detailed post-mortem investigation is undertaken, body condition is evaluated from photos. A more quantitative and reliable measure of body condition is blubber depth at a standard location (Geraci and Loundsbury, 1993), which can be compared to reference intervals for healthy whales. At present, blubber depth is not routinely measured. A detailed evaluation of the health of a stranded animal is only undertaken when a live stranding is attended to by a veterinarian or when a fresh carcass is salvaged for necropsy. In practice, necropsies on baleen whales are rarely undertaken because of the logistics and expense of dealing with large carcasses. Genetic (skin) and blubber samples are routinely taken from humpback and dwarf minke whales to support research (currently Griffith University and the University of Queensland have permits for humpback whale blubber collection).

The possibility of mass strandings or unusual mortality events should the humpback whale population 'crash' in the near future (modelling predicts by 2021 to 2026; Noad et al., in review), has a number of implications for the Authority, the Queensland Government and local governments, such as having the resources to respond to live strandings and carcass disposal.

To address the indicators identified above, additional data should be collected from strandings, including:

- Blubber thickness at a standardised location for comparison with reference intervals for healthy whales.
- Information on the health of stranded whales, including blood tests of live stranded whales and necropsies of dead whales.
- Where a necropsy is undertaken, earplugs could be also sampled for ageing.

Efforts to take genetic (skin) and blubber samples should also continue. An increased understanding of the health of the population could be obtained with more resources allocated for undertaking post-mortem investigations and necropsies.

Resources required to implement/continue monitoring

A biopsy campaign at Point Lookout would require a small boat team as well as a land-based observer team improve random selection of groups (i.e. to spot quieter groups and send to the boat to the groups that the boat would have difficulty spotting at sea). Population monitoring is likely to involve the collection of more than 100 biopsies per year to ensure some representation of different cohorts and have some idea of age structure etc. Total cost, including boat time, personnel food and accommodation, a paid coxswain, and sample analysis may be in the order of $100,000. Economies would be possible if paired with a Point Lookout land-based survey. Biopsy campaigns in specific areas would depend on available vessels and personnel, and required sample size. They would have to be costed case-by-case.

For stranded whales, it is practical for necropsies and other sampling to be undertaken in regional areas by local vets in consultation with a marine mammal vet. Appropriate resourcing for such monitoring requires discussion and agreement by the Authority and Queensland Department of Environment and Science at a high level.

8.2 Dwarf minke whales

Priority indicators for monitoring key values of dwarf minke whales in the World Heritage Area include:

1. Abundance of the 'interacting population' (via passive acoustic monitoring and mark-recapture photo-identification) in the northern Reef aggregation area.
2. Relative abundance of the migrating population, via passive acoustic monitoring at appropriate location(s) along the migration path.
3. Interacting population characteristics, demography (age composition, sex ratio, genetics) and body condition, via in-water photogrammetry, photo identification, sloughed skin collection and biopsy.
4. Tourism interaction levels and 'encounters per unit effort' in the Ribbon Reefs aggregation area.
5. Health, body condition, genetics and photo identification of stranded whales.

8.2.2 Abundance of the interacting population

Photo-identification studies (mark-recapture estimations)

Monitoring the size of the dwarf minke whale population that is interacting with a swim-with industry in the World Heritage Area relies on standardised data collection from participating vessels. Protocols for photo identification data collection need to be established and adhered to, to minimise sampling bias and ensure comparability of data between seasons.

The Doctor of Philosophy study by Sobtzick (2010) utilised mark-recapture analysis of underwater images (still photos and videos) provided by researchers, tourism vessel crew and tourists to provide the first estimates of the 'interacting population' of dwarf minke whales in the Ribbon Reefs aggregation area, for the years 2006 to 2008. Such analyses require a process of:

- *Data collection* — requiring tourism industry engagement prior to and during each minke whale season (June and July).
- *Image sorting/quality control* — of the tens of thousands of images typically collected from the 'platforms of opportunity' each season, only a proportion are of sufficient quality and information content to enable identification of individual whales.
- *Secure storage* — photo-identification data collected each minke whale season are currently stored and backed up in the James Cook University (JCU) Tropical Data Hub.
- *Identification analysis* — the current method requires manual inspection and verification of image content to match new images with an identified whale in the catalogue. This process is time consuming, and has only been possible in the past through the contributions of trained volunteers.

Due to the large quantities of images collated each season from tourism vessels (c. tens of thousands), the manual photo-identification matching process is no longer considered cost-effective, and new computer pattern recognition tools are currently being developed to automate this process (Konovalov et al., in review). Konovalov et al. (in review) report the first ‘proof of concept’ for recognising individual dwarf minke whales using the Deep Learning Convolutional Neural Networks tool. Rapid advancements in the development and training of such tools may lead to a viable alternative to manual photo identification analysis in the very near future.

Passive acoustic monitoring:

Acoustic monitoring of the interacting population of dwarf minke whales is a viable option and should focus on the aggregation area (cf. acoustic monitoring of the migrating population as discussed below). This could be done through IMOS as indicated above for humpback whales and anthropogenic noise. A receiver site should be focussed at a ‘hotspot’ locations such as Lighthouse Bommie. These receivers are designed for long-term statistics and sample at 6 kilohertz, for 500 seconds of every 15 minutes. The instruments will run for one year thus requiring minimal servicing. AIMS has expressed an interest in deploying and recovering these instruments, thus keeping costs down. These recordings will tell us if whales are still utilising the area when there are no vessels there.

The passive acoustics will detect the distinct dwarf minke whale signal types. Detection algorithms can be prepared and run across data sets and the outputs returned, giving time stamps of each sample with the number of dwarf minke whale detections and when they occur, the time of occurrence of each. These detections are best manually checked, although this is a time consuming process and requires software to be carried out efficiently. The raw counts of dwarf minke whale calls once checked can be processed to give an estimate of the number of calling dwarf minke whales, although this will require some initial analysis to identify call repeat rates from individual whales. Curtin has an automated process to do this, but being a new ‘acoustic stock’ there will undoubtedly be idiosyncrasies to calling patterns which need to be defined in order to streamline analysis and turn numbers of calls into a more powerful relative abundance metric. This would make a good student project. Once the initial details are established analysis can become more of a routine. As an initial estimate the receiver listening range for dwarf minke whales could be expected to be 10 to 20 kilometres (based on detection off the New South Wales coast and their probable location based on satellite tracks).

Research efforts (beyond the scope of this RIMReP proposal) should be made to establish which whales vocalise (e.g. males only hypothesis) and the frequency of such vocalisations; however, assuming that the proportion of vocalising animals in the population doesn’t change drastically over time, and that their vocal output remains relatively steady, then cue counting minke whale calls in the aggregation area (as well as further south along the migratory route) does provide valuable information for assessing trends in relative abundance. It has been noted that acoustic monitoring without a detailed knowledge of which whales are vocalising and why is common in other species of large whales (e.g. blues, fins) and is considered valuable in the absence of other data.

Existing monitoring — adequacy and gaps

There is currently no strategic passive acoustic monitoring in the Reef.

Resources required to implement passive acoustic monitoring

Vessel time — one day per year to deploy, one day per year to recover, equals two days per year, plus relevant steaming to site/s.

Infrastructure — it is recommended that RIMReP contact IMOS to ask if the Passive Acoustic Facility can be extended into the Reef. This facility has suitable hardware available and the expertise.

Equipment — sea noise logger/s, mooring with dual acoustic release units, around $1200 consumables per mooring, freight ($2000 to $3000 per deployment depending on number moorings) plus several days of gear preparation and de-mobilisation plus calibrations each mooring.

Analysis is open ended, and needs to be specified. This can be discussed with IMOS as a desired product.

8.2.3 Relative abundance of the migrating population

Passive acoustic monitoring:

As noted above for estimating the abundance of the interacting population (and as per recommendations for humpback whales), the identification of a site for deployment of an IMOS acoustic data logger on the migration route can potentially provide relative abundance estimates of the migrating population. Site selection should consider potential narrow migration corridors (e.g. like Point Lookout for humpback whales), validated by satellite tracking data.

Existing monitoring – adequacy and gaps

As noted above - there is currently no strategic passive acoustic monitoring in the Reef. Existing recordings from IMOS station(s) further south along the east Australian coast (for example, near Forster, New South Wales) can provide an important basis for preliminary analyse to determine the rate of vocalisations. In the longer term, further research on individual vocal rates, as well which whales are vocalising (potentially males only), may enable this passive acoustic monitoring to contribute to more robust abundance estimates for the migrating population.

Resources required to implement/continue monitoring

As noted above.

8.2.4 Interacting population characteristics, demography and body condition

Underwater photogrammetry combined with photo identification:

Underwater body length measurements can be used as a proxy for the age and state of sexual maturity of identified whales. Previous studies by Dunstan et al. (2007) and Sobtzick (2010) used underwater videogrammetry to estimate the lengths of interacting dwarf minke whales. Sobtzick (2010) showed that the majority (around two-thirds) of dwarf minke whales that are interacting with swim-with vessels in 2006 and 2007 were sexually immature, although every age class was present. A current PhD study by S. Hillcoat builds on Sobtzick (2010)'s first length measurements, using a diver-operated stereo-video system to investigate body size and condition (among other morphometrics), growth, and differential behavioural responses (e.g. passing distances) to tourism activities across life-history stages. Long-term monitoring of population structure (i.e. as an index of recruitment/population health) and behaviour are expected to become valuable monitoring indices, once methods are refined and processing becomes automated.

Genetics

A JCU Honours study by Omar Ramirez-Flores (2017) has successfully used DNA from sloughed minke skin samples to show that the Reef population is genetically similar to the South West Pacific population sampled by Japanese scientific whaling in the Southern Ocean, providing additional support for the migration route indicated by recent satellite tagging. Analysis of further opportunistic collection of such sloughed skin samples from the tourism platforms of opportunity and more systematic collection of biopsied samples (following the techniques pioneered during the Minke Whale Project satellite tagging 2013-15; Birtles et al. 2015) opens up the potential for ongoing monitoring of several important biological parameters.

Existing monitoring – adequacy and gaps

A photo catalogue exists spanning more than 20 years of interactions with dwarf minke whales in the Reef aggregation area. However, there is currently no formal monitoring of interacting population demography and/or body condition for dwarf minke whales. Research and development of the new methods described above form a core part of the PhD study by S. Hillcoat (expected completion in 2019–20). Recommendations from this study should be taken into account to improve monitoring of key indicators identified for this poorly understood whale.

Resources required to implement/continue monitoring

Further development of Dwarf Minke Whale Photo-identification Catalogue: the ongoing analysis of new whales entering the open population and known whales returning to the aggregation area and monitoring of their growth, condition, fecundity requires the further development and maintenance of a comprehensive catalogue. Although a partial catalogue of more than 500 individuals exists, funding to support the curation of this research and monitoring tool has been limited and sporadic.

Additional recommendations are anticipated as an outcome of the PhD study by S. Hillcoat.

8.2.5 Tourism interaction levels

Completion of a *Whale Sighting Sheet* for every minke whale encounter is a permit requirement for operators that hold an endorsement to conduct swims with the whales. These data have been curated and analysed periodically by Minke Whale Project researchers; however, no specific funding has supported this activity since 2009. Tourism industry ‘effort’ in the Ribbon Reefs aggregation area varies from year to year. Thus sightings-only data provided by the Whale Sighting Sheets, without corresponding effort data, cannot provide any indication of a change in levels of interaction on the part of the whales. Effort data have been provided by tourism operators on a voluntary basis (reported in Curnock, 2010); however, such data have not been collected with consistency since 2009.

Indices of sightings per unit effort (referred to here as ‘encounter rates’) have been shown to vary between sites, and some sites are known to be hotspots with consistently high encounter rates between vessels and between years (for example, Lighthouse Bommie, in vicinity of Ribbon Reef #10). Any significant declines in these encounter rates can be used to trigger further investigation and an assessment of a potential management response.

Eye on the Reef reporting system

It is proposed that a smartphone/tablet application be developed to facilitate and partially automate collection of both sightings and effort data. The app can collect continuous GPS data to log vessel time spent at sites in the Ribbon Reefs aggregation area, and sightings data can be input by vessel crew in near-real time. Such an app can be custom-designed for this industry at a relatively low cost, and data can be uploaded automatically to the Authority’s Eye on the Reef reporting system. Design of such an app requires consultation and input from industry, researchers and managers; however, the user interface must focus on the respondents (i.e. vessel crew on dive tourism boats).

Additional recommendations have been made in the study by Lazar (2017) to improve the Eye on the Reef (Sightings Network) reporting system for recording sightings of a wider range of megafauna species. These recommendations are reported under a separate component of the RIMReP Megafauna Expert Group.

Resources required to implement/continue monitoring

Industry workshop(s) — involving swim-with-whales endorsed tourism operators, Reef managers and researchers, to review minimum reporting requirements and data collection tools (including app development and automated logging of vessel effort).

App development — costs currently unknown, but potentially inexpensive, depending on source of expertise (i.e. with or without institutional support).

Ongoing engagement with participating tourism operators — experience with this industry has shown a high level of data quality and quantity can be achieved when a modest investment is made towards ongoing engagement, feedback and review of data in collaboration with the tourism industry (Curnock, 2010).

8.2.6 Health, body condition and photo identification of stranded whales

Dwarf minke whales rarely strand in Queensland. Between 1971 and 2018, there were 33 dwarf minke whales reported to StrandNet and only two of these whales stranded in the Reef region. More information on stranded dwarf minke whales would be obtained if resources are available for salvaging carcasses and undertaking necropsies. However, most strandings of dwarf minke whales tend to occur in remote areas such as Fraser and Moreton Island where necropsies will be logistically challenging. It is recommended that identification photos and genetic samples be taken in remote areas, in addition to standard data, and that necropsies are undertaken where practical on fresh carcasses elsewhere.

Images for photo-identification should be high-resolution, showing body colouration patterns and any distinctive scars. Most of the information used to identify individual free-ranging whales in the northern Reef aggregation area (underwater photo identification) is in the vicinity of the flipper and shoulder region. Due their left-right asymmetry, images should be taken of both sides and the top of the body, wherever possible.

9.0 Summary and conclusion

Monitoring large whales in the Reef is not an easy undertaking. The potential habitat is very large and humpback whales at least are dispersed widely. The migrations of the whales, however, provides the opportunity to assess population characteristics along the migratory corridor, outside the Reef. Such a program has existed for humpback whales for almost 40 years, and provides accurate and reliable data on abundance and trends on the east Australian population. Despite this, monitoring can be improved substantially to address management information needs for both humpbacks and dwarf minke whales, for which many knowledge gaps remain.

Current spatial distribution models of humpback whales in the Reef suggests that the core of the breeding area is south of the Whitsundays to the southern lagoonal area offshore of Mackay. Our understanding of the whales' distribution requires more validation and refinement, and year to year variation needs to be understood. This is best addressed with targeted aerial surveys and with additional satellite tagging of migratory whales. Coupled with biopsies of tagged whales, this also has the potential to demonstrate any cohort specific spatial distribution related to reproductive state. Passive acoustics in specific areas of the Reef can be used to monitor local densities, at least of males. Demographic parameters can be obtained via a combination of visual observation (calf:adult), biopsies (adiposity, age structure, sex, pregnancy), photogrammetry (size, body condition), aerial surveys (local calf:adult), and examination of stranded whales (body condition, age, sex).

The development of a robust monitoring plan will inevitably involve some targeted research to develop the techniques requires (e.g. adiposity, photogrammetry, epigenetic aging) but these are not new techniques, and the research required is more about calibrating these techniques to the east Australian humpback whales than developing them *de novo*. There is also some capacity building required, however, in terms of developing labs that are able to process samples efficiently and correctly.

For dwarf minke whales there remains much greater uncertainty of their abundance and other population characteristics, with historic and current monitoring reliant on 'platforms of opportunity' (i.e. tourism vessels) rather than systematic or dedicated survey programs. The establishment of new monitoring methods, including passive acoustic monitoring in the Ribbon Reef aggregation area and along the migration path will provide new baseline data, and if/when combined with mark-recapture estimates from photo-identification, may eventually assist with more reliable estimates of abundance (i.e. not just of the 'interacting' population). Ongoing engagement with the tourism industry sector conducting swims with dwarf minke whales in the Ribbon Reefs will be an important consideration for cost-effective monitoring into the future, and the development of new technology and techniques over the next few years will provide important new monitoring tools that should be incorporated into RIMReP as they become available.

The long-term funding and ‘institutionalisation’ of monitoring great whales in the Reef is an issue/problem that remains unresolved. Currently such monitoring and research is almost entirely reliant on individual ‘champions’ who have developed programs with sporadic funding, and through their own long-term involvement have provided continuity of standardised data collection that would otherwise not have been possible. Institutionalisation of monitoring that continues beyond the involvement of these champions, that can operate cost-effectively, presents a challenge that requires further discussion between the relevant research and monitoring partners.

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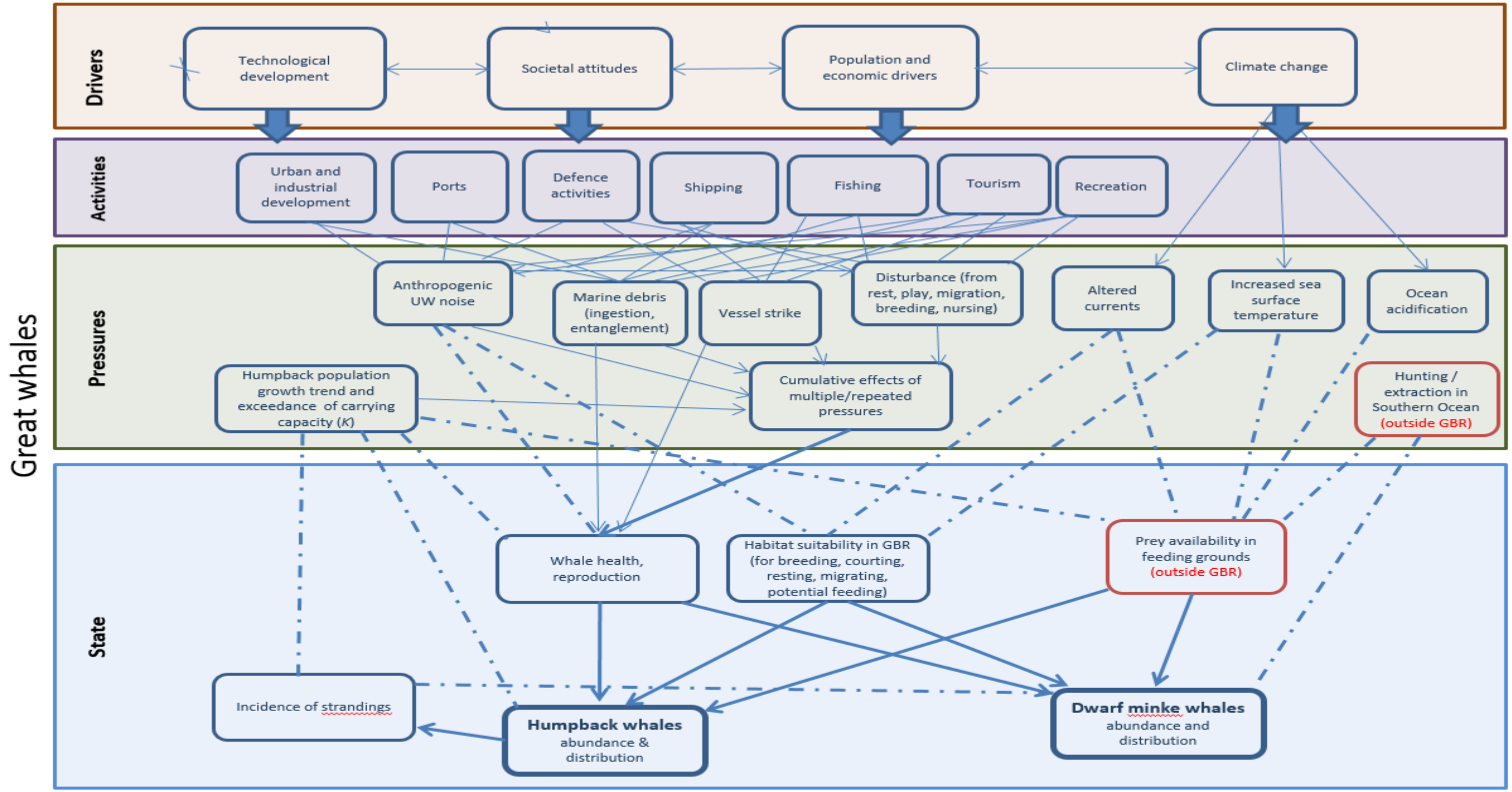
11.0 Appendix



Thickness of lines indicative of relative influence. Dashed lines indicate linkages are uncertain or contentious.

Figure 4: Conceptual diagram of potential cause and effect relationships between drivers, pressures and the state for humpback and dwarf minke whale populations in the Great Barrier Reef.