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

Final Report of the Fisheries Expert Group

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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Executive Summary

Fisheries on the Great Barrier Reef (the Reef) provide an important source of income, nutrition, recreation and cultural development for many regional communities in Queensland. However, fishing can impact the Reef and the communities it supports. Removal of key predators and herbivores, incidental catch of threatened species, post-release effects on discarded species, fishing of spawning aggregations and illegal fishing have all been identifed as risks to reef fish populations. Despite significant reforms in management of Queensland's fisheries resources, such as the mandatory use of bycatch reduction devices by trawlers and the setting of total allowable commercial catch limits for some species, the 2019 Great Barrier Reef Outlook Report concluded that fishing continues to be a threat to the future vitality of the Reef. Understanding the status of fish stocks and fishing activities is important in ensuring effective and sustainable management of the Reef and its assets.

This report provides a suite of recommendations for monitoring fishery systems as part of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). These recommendations were based on a desktop analysis of peer-reviewed literature, technical reports and other scientific publications, expert knowledge and advice from members of the various RIMReP Expert Groups and outcomes from a series of workshops and meetings. This report includes:

- an overview of the fisheries-related information required to inform Reef managers, the Great Barrier Reef Outlook Report and other relevant reporting products;
- actions within the *Reef 2050 Long-Term Sustainability Plan* relevant to the monitoring of fishery systems on the Reef;
- a summary of the current understanding, status and trends of fisheries on the Reef;
- a list of priority indicators for monitoring fisheries in the Great Barrier Reef Marine Park (the Marine Park);
- a synopsis of all programs that currently monitor and assess fishery systems on the Reef, including an evaluation of their adequacy and the identification of any gaps;
- a review of new technologies and approaches and their ability to improve the monitoring of fishery systems on the Reef.

Applying this information to the objectives of RIMReP, the Fisheries Expert Group provides a set of recommendations in three parts:

1. recommendations to utilise and build upon established monitoring and assessment programs that are managed and funded by Department of Agriculture and Fisheries (DAF);

2. recommended actions to ensure linkages between RIMReP Expert Groups are fully exploited, such as the establishment of pathways for efficient information exchange and taking advantage of opportunities to integrate and optimise monitoring efforts; and

3. additional monitoring activities recommended to address major, unresolved gaps including abundance surveys of sea cucumbers, fishery-independent surveys in under-represented habitats and an expanded monitoring program on spawning aggregations.

Contents

Background and design considerations

Objectives of the Reef 2050 Integrated Monitoring and Reporting Program

The *Reef 2050 Long-Term Sustainability Plan* (the Reef 2050 Plan) provides an overarching strategy for managing the Great Barrier Reef (the Reef). It contains actions, targets, objectives and outcomes to address threats and protect and improve the health and resilience of the Reef, while allowing ecologically sustainable use. The Reef 2050 Plan has been developed in consultation with partners, including Traditional Owners and the resource, ports, fishing, agriculture, local government, research and conservation sectors.

A key component of the Reef 2050 Plan is the establishment of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). RIMReP will provide a comprehensive and up-to-date understanding of the Reef — the values and processes that support it and the threats that affect it. This knowledge is fundamental to informing actions required to protect and improve the Reef's condition and to drive resilience-based management.

There are currently over 90 monitoring programs operating in the Great Barrier Reef World Heritage Area (World Heritage Area) and adjacent catchment. These programs have been designed for a variety of purposes and operate at a variety of spatial and temporal scales. The comprehensive strategic assessments of the World Heritage Area and adjacent coastal zone – – both of which formed the basis for the Reef 2050 Plan — identified the need to ensure existing monitoring programs align with each other and with management objectives.

RIMReP will provide information across the seven themes that make up the Reef 2050 Plan Outcomes Framework. The themes are ecosystem health; biodiversity; water quality; heritage; community benefits; economic benefits and governance.

The intent of RIMReP is not to duplicate existing arrangements but to coordinate and integrate existing monitoring, modelling and reporting programs across disciplines. For example, the Reef 2050 Water Quality Improvement Plan underpins the Reef 2050 Plan's water quality theme and its Paddock to Reef Integrated Monitoring, Modelling and Reporting Program will form a key part of RIMReP.

As the driver of resilience-based management under the Reef 2050 Plan, RIMReP's primary purpose is to enable timely and suitable responses by Reef managers and partners to emerging issues and risks and enable the evaluation of whether the Reef 2050 Plan is on track to meet its outcomes, objectives and targets.

RIMReP's vision is to develop a knowledge system that enables resilience-based management of the Reef and its catchment and provides managers with a comprehensive understanding of how the Reef 2050 Plan is progressing (see **Error! Reference source not found.** for a program logic).

Three goals for the knowledge system are that it is:

- ***Effective*** in enabling the early detection of trends and changes in the Reef's environment, informing the assessment of threats and risks, and driving resilience-based management.
- ***Efficient*** in enabling management priorities and decisions to be cost effective, transparent, and based on cost-benefit and risk analyses.
- ***Evolving*** based on the findings of Great Barrier Reef Outlook Reports, new technologies and priority management and stakeholder needs.

RIMReP will be central to ensuring decisions regarding the protection and management of the Reef are based on the best available science, consistent with the principles of transparency and accountability, and underpinned by a partnership approach.

FIGURE 1: RIMReP program logic. Each of the three goals has associated development and implementation objectives as well as foundational inputs.

Information needs for the Great Barrier Reef Outlook Report and other reporting requirements

The Great Barrier Reef Outlook Report contains ‘an assessment of the factors influencing the current and projected future heritage values…’ within the Region as required by the *Great Barrier Reef Marine Park Regulations 1983*. Of these influencing factors, direct use activities such as fishing are generally considered to be relatively low-impact on the ecological, heritage, economic and social values of the Region (Great Barrier Reef Marine Park Authority 2014). However, fishing can have impacts on the structure and functioning of aquatic ecosystems, particularly when coupled with stressors such as climate change, ocean acidification, cyclones, and coastal development (Dulvy et al. 2004; Guillemot et al. 2014). Several studies on coral reef systems, including the Reef, have demonstrated that fishing pressure can reduce the diversity, biomass, density, and size structure of fish assemblages (Boaden & Kingsford 2015; Campbell & Pardede 2006; Floeter et al. 2006; Friedlander & DeMartini 2002; Graham et al. 2017; Jennings and Polunin 1997; Mora et al. 2011; Nanola et al. 2011; Pet-Soede et al. 2001; Polunin & Roberts 1993). Fishing has also been demonstrated to reduce the size and recruitment of corals via the extraction of functionally important herbivores, leading to macroalgal growth and increased competition for space and light in the benthic habitat (Mumby et al. 2007; Hughes et al. 2007). On the Reef, Boaden & Kingsford (2015) found strong evidence that predator depletion was a strong driver of prey densities and community structure. In addition, it has been suggested that the removal of fish predators is a key factor in crown-of-thorns starfish (*Acanthaster planci*) outbreaks, which pose a major threat to corals on the Reef (Pace et al. 1999; Wooldridge & Brodie 2015). Other impacts of fishing on aquatic ecosystems include bycatch, ghost fishing, boat strikes, pollution, sedimentation, introduction of invasive species and mechanical damage to reefs and the sea floor (Bryant et al. 1998; Donohue et al. 2001; Gilman 2015).

The Outlook Report also contains ‘an assessment of the current biodiversity within…’ the Region as required by the *Great Barrier Reef Marine Park Act 1975*. A variety of species are assessed that are either directly targeted or otherwise impacted by fishing, including corals, other invertebrates, bony fishes, sharks and rays, sea snakes, marine turtles, estuarine crocodiles, seabirds, shorebirds, whales, dolphins and dugongs.

Data from current fisheries monitoring programs are also utilised in a number of existing reports that are relevant to Reef management such as the Mackay-Whitsunday Healthy Rivers to Reef report card, the Australia State of the Environment Report and the Gladstone Harbour Report Card. In addition, current fisheries monitoring programs support the information needs of local councils, community groups, industry bodies, environmental consultancies, research providers and other key stakeholders within the Region.

Relevant Reef 2050 Long-Term Sustainability Plan targets, objectives and outcomes

The Reef 2050 Plan identifies seven priority areas for action including ecosystem health, biodiversity, heritage, water quality, community benefits, economic benefits and governance (**Error! Reference source not found.**). To ensure progress is being made in each of these areas, the Reef 2050 Plan has developed a framework of targets, objectives and outcomes to be achieved by 2020, 2035 and 2050, respectively. The areas within this framework that are most relevant to the Fisheries Expert Group have been summarised in Table 1.

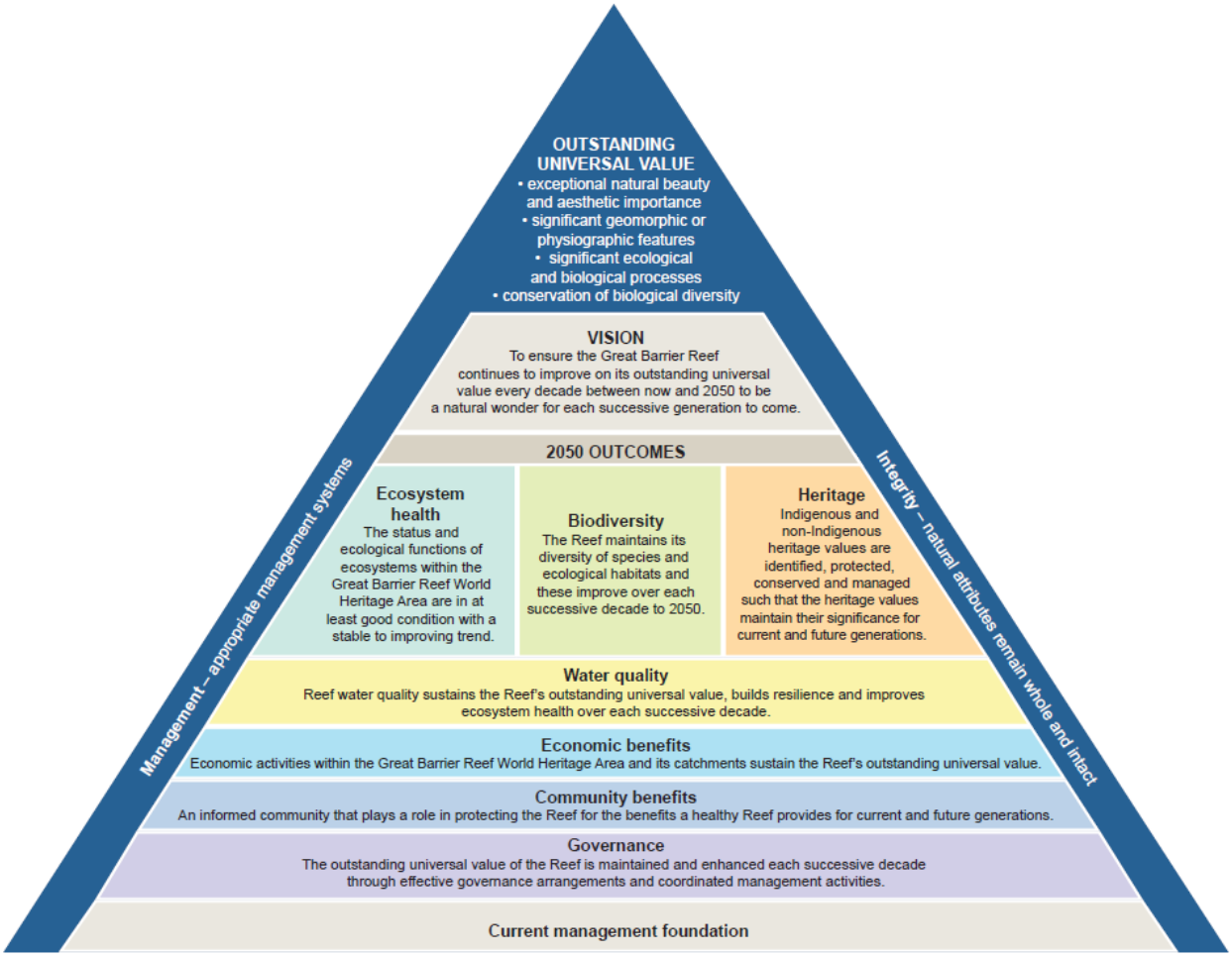


FIGURE 2: The Outcomes Framework central to protecting the Outstanding Universal Value of the Great Barrier Reef World Heritage Area through the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia 2015).

TABLE 1: Reef 2050 Plan targets, objectives and outcomes that are relevant to monitoring fishery systems on the Reef.

REEF 2050 OUTCOMES	REEF 2050 OBJECTIVES	REEF 2050 TARGETS
Ecosystem Health The status and ecological functions of ecosystems within the World Heritage Area are in at least good Condition with a stable to improving trend.	**EHO2** The World Heritage Area retains its integrity and system functions by maintaining and restoring the connectivity, resilience and condition of marine and coastal ecosystems.	**EHT4** Key direct human-related activities are managed to reduce cumulative impacts and achieve a net benefit for the Reef.
Biodiversity The Reef maintains its diversity of species and ecological habitats in at least a good condition with a stable to improving trend.	**BO1** Traditional Owners are engaged and participate in and manage the conservation and ecologically sustainable use of cultural keystone species and bio-cultural resources. **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.	**BT1** Customary use of biological resources, in accordance with traditional cultural practices that are compatible with conservation or cultural use requirements, are formally recognised and adopted in management arrangements. **BT3** Incidental catch of species of conservation concern is declining. **BT5** Trends in populations of key indicator species and habitat condition are stable or improving at Reef-wide and regionally relevant scales.
Community Benefits An informed community that plays a role in protecting the Reef for the benefits a healthy Reef provides for current and future generations.	**CBO2** A healthy Reef that supports sustainable lifestyles and livelihoods, and provides coastal communities with protection from extreme weather events. **CBO3** Community benefits provided by the Reef, including its superlative natural beauty and the sense of place, are maintained for current and future generations. **CBO4** Local, regional and Reef-wide community benefits are understood and the community is actively engaged in managing Reef activities.	**CBT2** Community benefit values have been identified and are considered in decision-making. **CBT4** Community benefit values for Reef coastal ecosystems are being monitored and show a positive trend.
Economic Benefits Economic activities within the World Heritage Area and its catchments Sustain the Reef's Outstanding Universal Value.	**EBO1** Traditional Owners derive economic benefits from conservation and sustainable use of biological resources. **EBO3** Reef-associated industries are planned and managed in such a way as to protect the Reef's Outstanding Universal Value and are sustainable, productive and profitable. **EBO4** Reef-dependent industries are productive and profitable based on a healthy Reef and are ecologically sustainable.	**EBT3** Cumulative impacts on the Reef from human activities are understood and measures to ensure a net environmental benefit approach for the Reef are in place. **EBT5** The relationship between Reef health and the viability of Reef-dependent industries (e.g. tourism and fishing) is understood and considered in planning and development decisions. **EBT6** Economic indicators are included in RIMReP.

Information needs for Great Barrier Reef management

As part of establishing an integrated monitoring framework for Reef management, a list of priority monitoring objectives was established based on workshop discussions and a review of existing government recovery plans, strategies, management programs and vulnerability assessments (Hedge *et al.* 2013). This list was revised to identify information needs for Reef management that are relevant to the RIMReP Fisheries Expert Group, including:

- **spatial and temporal trends in fishing effort, retained catch (including numbers and weights) and discarded catch for key species of sharks, rays and bony fishes** – especially for the reef line and inshore net and line fisheries;
- **trends in status and condition (abundance, biomass and size classes) of targeted sharks, rays, bony fishes and sea cucumbers** with reference to different types of marine park zoning;
- **changes to inshore fish populations and productivity,** particularly in association with the restoration of coastal ecosystems such as removal of barriers to flow;
- **trends in ontogenetic migratory patterns for bony fish**;
- **extent of disease outbreaks in bony fishes and trends in fish health** in association with significant coastal developments such as dredging activity;
- **trends in numbers of registered recreational vessels** by Local Government Area and vessel size;
- **trends in grounds subjected to trawling** through vessel tracking data;
- **trends and impacts of fishing activities that interact with migratory species and other species of conservation interest** (SOCI), ensuring that current monitoring is independently validated and provides statistically representative coverage of vessel effort in the trawl and inshore net fisheries;
- **trends in the extent of illegal fishing** and other activities that are non-compliant with fishing-related regulations;
- **trends in the number and density of key species on fish spawning aggregation sites**; and
- **effects of climate change and extreme weather events on bony fish, sharks and rays**, including their recovery from these impacts.

Aside from fisheries-specific information needs, several core information requirements were identified as common to all RIMReP Expert Groups (Udy 2017). Based on these requirements,

a comprehensive system of monitoring and reporting programs for the Reef would be expected to have the following attributes:

- ability to go from a simplistic summary to obtaining the underlying details in a relatively short period of time; spatial representation of information with the ability to scale from the area of the entire Reef to a specific reef or bay, while also providing easy access to information on processes relevant to management decisions;

- provide current information to managers appropriate to the timescale of management decisions (daily or weekly for tactical management, yearly for strategic management, etc.);

- clear and simple communication of the cause-and-effect relationships between human actions, condition of the Reef and the impact this has on how current and future generations are able to use the Reef and obtain benefits from it;

- provide information on the range and location of habitats and species existing within the Reef and show the interconnectedness of these habitats through key processes; and

- spatially represent risks to the Reef to facilitate prioritisation of management actions.

Five main categories of management use were also recognised that, if considered in the design of RIMReP, will assist in collecting information at spatial and temporal scales appropriate to the management question (**Error! Reference source not found.**) (Udy 2017). Within each of these categories, three scales of monitoring will be required:

- **spatial distribution (maps)** of *pressures* relating to fishing, the *state* of fisheries on the Reef as well as management *responses* taken to reduce *impacts* on human well-being;

- **temporal trends** in *pressures* relating to fishing and *state* of fisheries on the Reef; and

- **process understanding** of causal relationships between the *state* of fisheries on the Reef, *pressures* relating to fishing and *impacts* on human well-being.

TABLE 2: Main categories of management use for the Reef, including examples of how fisheries-related information could be applied.

MANAGEMENT CATEGORY	EXAMPLE OF APPLICABLE FISHERIES DATA
Tactical responses to an event or incident	Location and number of interactions with species of conservation interest, catch and catch rates of target species.
Operational management such as prioritisation of compliance effort, provision of infrastructure to protect high-usage habitats and permit assessment	Compliance with fishing restrictions such as Net-Free Zones
Strategic planning such as zoning and policy development	Trends in biomass estimates for key fish stocks
Quantifying effectiveness of management actions (e.g. assess trends in standardised catch rates following changes in management)	Trends in a species' recruitment following the implementation of a minimum legal size limit
Reporting to community and stakeholders	Maps showing annual trends in total commercial catch and effort

Current understanding of fishery systems and status on the Great Barrier Reef

Fishery Systems on the Great Barrier Reef

Common-pool natural resources such as fisheries are complex socio-ecological systems that may shift, sometimes rapidly and unexpectedly, between different stable states with potentially dire consequences for the communities that depend on them (Hughes et al. 1999, Laborde et al. 2016). These systems may be studied using tools to analyse the feedbacks and other cause-and-effect relationships between socio-ecological processes (Liu et al. 2007, Carpenter et al. 2009).

One such tool is the *Driver*, *Pressure*, *State*, *Impact*, and *Response* (DPSIR) framework, which the European Environmental Agency developed to assess and monitor the sustainability of socio-ecological systems from a holistic viewpoint (Malekmohammadi and Jahanishakib 2017). According to this framework, *Drivers* are overarching anthropogenic or natural factors that exert human-mediated *Pressures* on the environment, leading to changes in the *State* of the environment with potential biophysical and socio-economic *Impacts* on human well-being that may trigger a *Response* by policy or management (Hedge et al. 2013).

This report has adopted the DPSIR framework to describe the complex socio-ecological processes that influence fisheries on the Reef (Figure 3). *Drivers* most relevant to the Region were adopted from the Great Barrier Reef Region Strategic Assessment Report and the Great Barrier Reef Outlook Reports with additional input from Reef scientists and relevant peer-reviewed literature. *Pressures* relating to fishing were based on 'threats' identified in the Reef 2050 Plan and listed in the Great Barrier Reef Outlook Report (see Appendix 1 for a complete list of threats). Relevant *States* and *Impacts* were adapted from a list of indicators identified in a recent review of the application of the DPSIR framework to fisheries management (Martins et al. 2012).

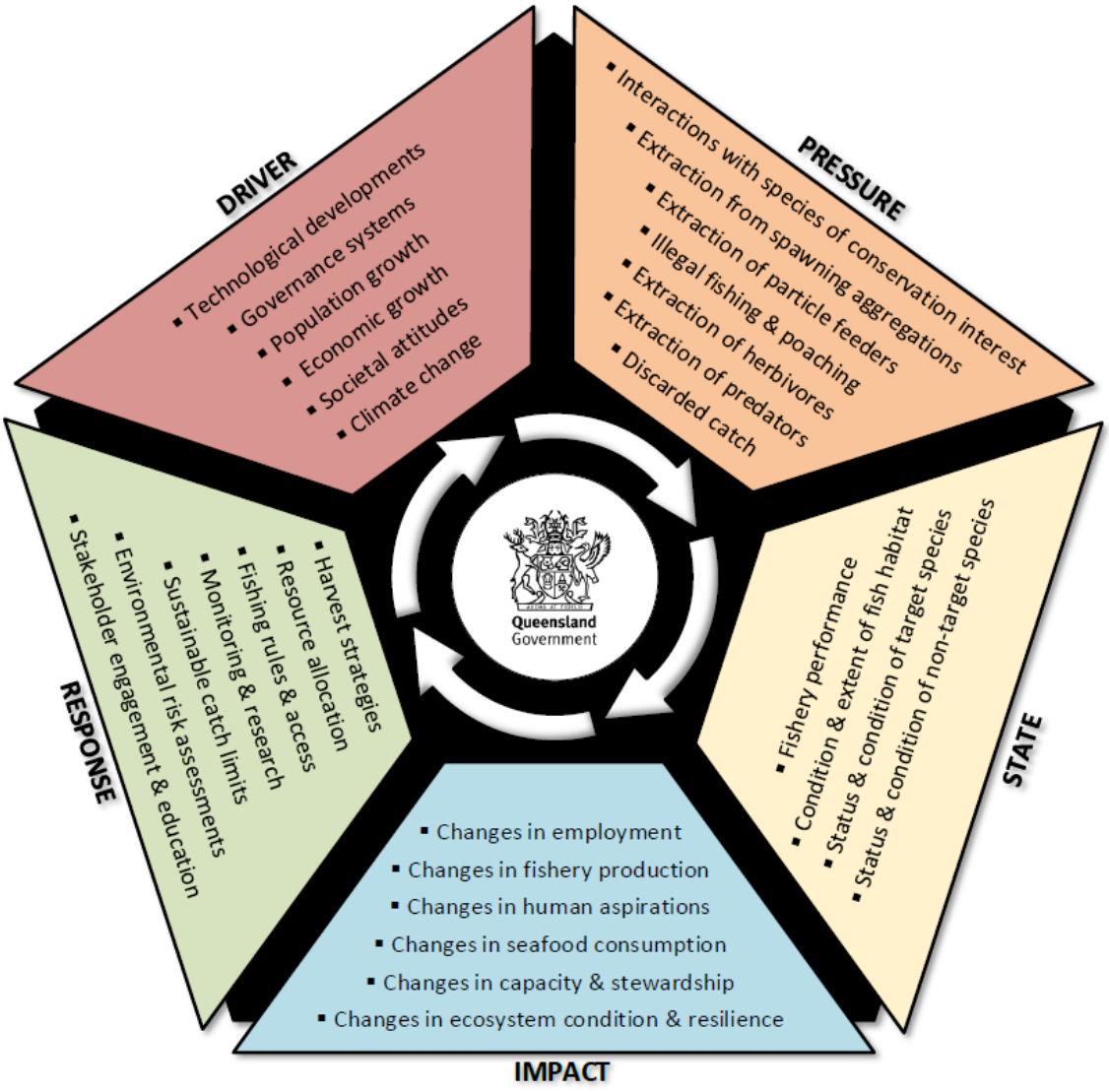


FIGURE 3: A simplified DPSIR framework that summarises the socio-ecological factors influencing fisheries on the Reef.

Current Status of Fishery Systems on the Great Barrier Reef

The Region represents an important resource for Queensland's fishers and supports a wide range of commercial, charter, recreational and Indigenous fishing activities.

Recreational fishing continues to be one of the most popular outdoor activities in Queensland, particularly in northern regions with access to the Reef. A 2013 survey of residents in coastal towns adjacent to the Reef found that more than two thirds had recently visited islands, reefs and shoals within the Region to take part in activities such as fishing, snorkelling and diving (Tobin et al. 2014b). Of the various recreational activities on the Reef, fishing appears to be the most popular with an estimated 3.8 million fishing trips taking place in 2015-2016 and $70 million generated in related expenditures (O'Mahony et al. 2017).

Participation in recreational fishing has been reported at 22 per cent and 27 per cent for local residents and visitors, respectively (Tobin et al. 2014b, Webley et al. 2015). In 2013-2014, an estimated 642,000 Queenslanders had recently partaken in recreational fishing across the state, taking home around 8,500 tonnes of seafood (Webley et al. 2015). In Queensland, approximately 80 per cent of fishing occurred in estuaries and coastal waters with the remainder in offshore waters and freshwater rivers, lakes and dams. Similar to previous surveys, line fishing was the dominant fishing method in Queensland, accounting for approximately 81 per cent of effort, followed by pot fishing and other less common methods such as cast netting, hand collection, pumps and spades. Fishers caught a diverse range of marine and freshwater species including bony fishes, elasmobranchs, crustaceans, cephalopods and other taxa. Bream and whiting were the most abundantly caught fish, but there were also significant catches of reef fish such as coral trout, tropical snapper, seaperch, emperor, morwong and sweetlip as well as invertebrates such as prawns, yabbies, mud crabs, and molluscs.

Queensland's series of state-wide surveys indicate that there is a downward trend in recreational fishing effort and participation across the state, possibly to due to changing demographics, declining fishing satisfaction or competition with an increasing range of alternative recreational activities (Webley et al. 2015). Compared to previous years, there has also been a significant increase in the use of paddleboats such as kayaks for fishing. Trends in recreational catch over time varies between species, most likely due to the influence of complex interacting factors such as recruitment success, predation, extreme weather events and changes to fishing regulations (Webley et al. 2015). However, there has been an overall reduction in Queensland's recreational catch since 2000-2001.

Indigenous fishing represents an important traditional and cultural activity for many Aboriginal and Torres Strait Islander people living in Queensland with key roles in nutrition, income and trade, cultural connection to the land and waters, ceremonial occasions, maintaining social cohesion, and the education of successive generations. Within the Region, more than 70 Traditional Owner groups maintain an active interest in the conservation and management of their land and sea country (Great Barrier Reef Marine Park Authority 2014).

Data on Indigenous fishing is limited, but a national survey conducted in 2000-2001 estimated that there were 10,600 Indigenous active fishers in northern Queensland based on a participation rate of over 90 per cent among the surveyed population (Henry and Lyle 2003). Indigenous fishers in these communities primarily fished in coastal and inshore waters with relatively little activity in rivers, lakes, dams and offshore waters. Similarly, more than three quarters of Indigenous fishing effort was shore-based with boat-based fishing comprising the remainder. Line fishing was the predominant fishing method in northern Queensland, although methods such as hand collection, spears and nets were also used. Indigenous fishers in northern Queensland harvested approximately 700,000 animals across the survey period, which was relatively low when compared to the estimated 37 million animals taken by Queensland's recreational fishers. In northern Queensland, the species most commonly harvested by Indigenous fishers were saltwater prawns, pipis, small baitfish, mullet and bream.

Commercial fishing is one of the Queensland's oldest and most geographically diverse primary industries and is a significant contributor to national and state economies, generating around $190 million in seafood production each year and 10 per cent of Australia's total seafood production.

There are five main types of fisheries in the Region including trawl, net, line, pot and harvest. An overview of these fisheries is provided in Table 3 and Appendix 2. Although commercial catch and effort has fluctuated over time, there has been an overall downward trend. These patterns are influenced by a multitude of interacting factors such as species abundance, extreme weather events (e.g. cyclones Hamish and Yasi), management arrangements (e.g. licence buyback schemes, introduction of quotas, fishing gear changes, capping fishery licences, marine park zoning), market demands and other external factors (e.g. foreign exchange rates and fuel prices) (Great Barrier Reef Marnie Park Authority 2014). Predators and filter feeders are the most common ecological groups targeted by these fisheries and represent the vast majority of the Region's total retained catch. A small amount of herbivorous fish are harvested to supply the aquarium industry, but overall the fishing pressure on herbivore populations is minimal.

Of the 79 stocks assessed for species caught in the Region, 39 stocks were classified as sustainable, two stocks as overfished, one stock as transitional-depleting and 37 stocks as undefined (see Appendix 3).

TABLE 3: Summary of commercial fisheries within the Great Barrier Reef Marine Park.

Fishery type	Fishery	Main target species in the Region	Active licences 2017 (2013)	Retained commercial catch in the Region 2017 (2013)	Proportion (%) of Queensland catch occurring within the Region 2017 (2013)
Trawl	East Coast Otter Trawl Fishery (ECOTF)	Prawns, scallops, bugs and squids	180 (172)	3,636 (4,027) tonnes	49 (52)
	River and Inshore Beam Trawl Fishery (RIBTF)	Prawns	18 (27)	33 (45) tonnes	9 (27)
Net	East Coast Inshore Fin Fish – Net Component (ECIFFF)	Barramundi, sharks, grey mackerel and threadfin	143 (218)	1,010 (1,590) tonnes	18 (25)
Line	Coral Reef Fin Fish Fishery (CRFFF), Spanish Mackerel Fishery (SMF), ECIFFF – Line Component	Coral trouts, cods, emperors, tropical snappers, Spanish mackerel and other mackerels, barramundi, sharks and cobia	262 (257)	1,842 (1,936) tonnes	81 (84)
Pot	Mud Crab Fishery (MCF), Blue Swimmer Crab Fishery (BSCF)	Mud crab and blue swimmer crab	188 (213)	670 (819) tonnes	47 (49)
	Spanner Crab Fishery (SCF)	Spanner crab	9 (18)	132 (290) tonnes	15 (31)
Harvest	Coral Fishery*	Live rock and corals	32 (33)	81 (90) tonnes	100 (100)
	Marine Aquarium Fish Fishery (MAFF)	Mostly damselfish, anemone fish, wrasses and angel fish	21 (25)	50,988 (55,558) fish	56 (47)
	Crayfish and Tropical Rock Lobster Fishery (TRLF)	Tropical rock lobster	8 (7)	185 (177) tonnes	100 (98)
	Sea Cucumber (East Coast) Fishery	White Teatfish and burrowing blackfish	3 (6)	262 (317) tonnes	100 (100)

**Figures for the coral fishery are reported by financial year (July 2012 - June 2013, July 2016 - June 2017)*

Aquaculture is an important component of Queensland's seafood industry with a production value of approximately $120 million in 2016-2017, equating to 38.4 per cent of Queensland's total fisheries production. Across the past seven years, this represents an overall increase in aquaculture production of approximately 5.2 per cent per annum.

In Queensland, the most valuable sectors continue to be prawn and barramundi at $77.8 million and $28.4 million, respectively. The remaining sectors were valued at $13.5 million, including redclaw crayfish, freshwater fish, hatchery and aquarium, edible oysters and other sectors that only operate in some years (marine fish, eels, crabs and pearls).

Although aquaculture farms are widely distributed across Queensland, the majority of the industry, in terms of ponded area, employment, value and production, is concentrated within three regions adjacent to the Reef, including the Cairns, Townsville and Mackay statistical divisions (see Appendix 4).

Priority indicators to monitor fishery systems on the Great Barrier Reef

Priority indicators for monitoring fisheries on the Reef were selected based on existing monitoring efforts, information needs for Reef management and other reporting requirements. Recommended priority indicators are summarised in Table 4.

TABLE 4: Priority indicators recommended for monitoring fisheries under RIMReP with reference to the DPSIR framework and targets under the Reef 2050 Plan.

Priority indicator	Justification for selection
Aboriginal & Torres Strait Islander (TSI) customary fishing	Provides an indication of *pressures* (extraction of predators, herbivores and particle feeders, extraction from spawning aggregations, death of discarded species and interactions with SOCI), s*tate* (fishery performance and target/non-target species characteristics) and *impacts* (changes in fisheries production, seafood consumption, employment, human aspirations, capacity and stewardship).
	Relevant Reef 2050 targets: BT1, BT3, EHT4, EBT3, EBT5
Biomass ratios	Provides an indication of *state* (target/non-target species characteristics and fishery performance) and *impacts* (changes in ecosystem condition and resilience and fishery production).
	Relevant Reef 2050 targets: BT5
Compliance statistics	Provides an indication of *drivers* (societal attitudes and governance systems), p*ressures* (illegal fishing, poaching and other illegal activities such as entering a protected area) and *impacts* (changes in human aspirations, capacity and stewardship).
	Relevant Reef 2050 targets: EHT4
Discarded catch (excluding species of conservation interest)	Provides an indication of *pressures* associated with the immediate or post-release effects (such as death, injury or reduced reproductive success) of interactions between fishing gear/vessels and discarded species (not including species of conservation interest).
	Relevant Reef 2050 targets: EHT4

Ecological risk categories	Provides an indication of potential *pressures* (interactions with species of conservation interest, discarded catch, extraction from spawning aggregations and extraction of predators, herbivores and filter feeders).
	Relevant Reef 2050 targets: EHT4
Fishing effort & retained catch – commercial, charter & recreational sectors	Provides an indication of *pressures* (extraction of predators, herbivores and particle feeders and extraction from spawning aggregations), *state* (fishery performance and target/non-target species characteristics) and *impacts* (changes in fisheries production).
	Relevant Reef 2050 targets: CBT2, CBT4, EHT4, EBT3, EBT5
Natural/fishing mortality	Provides an indication of *pressures* associated with the death of fish species after discarding or due to causes unrelated to fishing such as disease, competition and predation.
	Relevant Reef 2050 targets: EBT3
Recruitment indices	Provides an indication of *state* (target/non-target species characteristics and fishery performance) and *impacts* (changes in ecosystem condition and resilience and fishery production).
	Relevant Reef 2050 targets: BT5
Shark Control Program (SCP) impacts	Provides an indication of *pressures* (extraction of predators and herbivores, death of discarded species and incidental catch of species of conservation interest).
	Relevant Reef 2050 targets: BT3, EHT4
Socio-economic data	Provides an indication of *drivers* (population growth, economic growth, societal attitudes, technological developments and governance systems) and *impacts* (changes in employment, fishery production, seafood consumption, human aspirations, capacity and stewardship).
	Relevant Reef 2050 targets: CBT2, CBT4, EBT3, EBT5, EBT6
Spawning aggregation characteristics	Provides an indication of *state* (target/non-target species characteristics) and *impacts* (changes in ecosystem condition and resilience).
	Relevant Reef 2050 targets: BT5
Species biology (age, length and sex) and abundance	Provides an indication of *state* (target/non-target species characteristics) and *impacts* (changes in ecosystem condition and resilience).
	Relevant Reef 2050 targets: BT5
Species of conservation interest (SOCI) interactions	Provides an indication of *pressures* associated with the immediate or post-release effects (such as death, injury or reduced reproductive success) of interactions between fishing gear/vessels and species that are protected, endangered or of other conservation concern.
	Relevant Reef 2050 targets: BT3, EHT4
Standardised catch rates	Provides an indication of *state* (target/non-target species characteristics and fishery performance) and *impacts* (changes in ecosystem condition and resilience and fishery production).
	Relevant Reef 2050 targets: BT5
Status of fish stocks	Provides an indication of *state* (target/non-target species characteristics and fishery performance) and *impacts* (changes in ecosystem condition and resilience).
	Relevant Reef 2050 targets: BT5

Evaluation of the adequacy of current monitoring of fishery systems on the Great Barrier Reef

Synopsis of existing monitoring programs

Over a period of almost 30 years, Fisheries Queensland has accrued a significant body of information through a framework of routine monitoring and assessment programs as well as day-to-day operations. The elements of this framework are outlined in the conceptual model below (**Error! Reference source not found.**; see **Error! Reference source not found.**). Fisheries Queensland's monitoring programs collect a range of data such as catch and effort, fish biology, socio-economic data and compliance statistics. This information is used in assessment processes managed by Fisheries Queensland and other sections of DAF, ranging from qualitative Ecological Risk Assessments (ERAs) to quantitative stock assessment modelling. Outputs from these monitoring and assessment programs are then reported through a number of platforms and are used to inform management decisions, investment,

FIGURE 4: An outline of Fisheries Queensland's framework of monitoring, assessment and management.

enforcement and compliance.

Monitoring and assessment programs relevant to the RIMReP Fisheries Expert Group will be briefly described here, including those undertaken by DAF and others listed in previous reports (Addison et al. 2015) (**Error! Reference source not found.**).

TABLE 5: Summary of monitoring and assessment programs relevant to monitoring fisheries on the Reef.

Program	Organisation	Indicator(s) measured		Frequency	Location*
Logbook program	DAF	*Primary*	Fishing effort & retained catch; discarded catch; SOCI interactions	Daily	CY, WT, B, MW, F, BM
		Secondary	Socio-economic data; compliance statistics		
Quota Monitoring System	DAF	*Primary*	Retained catch	Daily	CY, WT, B, MW, F, BM
		Secondary	Socio-economic data; compliance statistics		
Vessel tracking	DAF	*Primary*	Fishing effort; compliance statistics	Near real-time	CY, WT, B, MW, F, BM
		Secondary	Socio-economic data		
Licensing	DAF	*Primary*	Fishing effort; compliance statistics; socio-economic data	Daily	CY, WT, B, MW, F, BM
		Secondary	Aboriginal & TSI customary fishing		
Aquaculture production surveys	DAF	*Primary*	Aquaculture production	Annual	CY, WT, B, MW, F, BM
Impact Assessment and Management	DAF	*Primary*	Developments in fish habitats	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Shark Control Program	DAF	*Primary*	Shark Control Program impacts; SOCI interactions	Every 1 to 3 days	WT, B, MW, F, BM
Freshwater fish stocking	DAF	*Primary*	Fish stocking data	Ad-hoc/ opportunistic	WT, B, MW, F, BM
Field compliance monitoring	Various	*Primary*	Compliance statistics	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
		Secondary	Socio-economic data		
Commercial catch sampling	DAF	*Primary*	Species biology & abundance	Daily	CY, WT, B, MW, F, BM
Recreational catch sampling	DAF	*Primary*	Species biology & abundance; retained catch; discarded catch	Variable	CY, WT, B, MW, F, BM
State-wide recreational fishing surveys	DAF	*Primary*	Retained catch; discarded catch	Every 1 to 5 years	CY, WT, B, MW, F, BM
		Secondary	Socio-economic data		
Economic and social surveys	Various	*Primary*	Socio-economic data	Variable	CY, WT, B, MW, F, BM
		Secondary	Aboriginal & TSI customary fishing		
Fishery-independent surveys	DAF	*Primary*	Species biology & abundance	Annual	F, BM
Ecological risk assessments	DAF	*Primary*	Ecological risk categories	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM

Stock assessments	DAF	*Primary*	Biomass ratios; natural/fishing mortality; recruitment indices; standardised catch rates	Every 5 to 10 years	CY, WT, B, MW, F, BM
Fisheries and aquaculture RD&E	Various	*Primary*	Biomass ratios; natural/fishing mortality; recruitment indices; standardised catch rates; fishing power estimates; other RD&E outputs	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Stock status assessments	DAF	*Primary*	Status of fish stocks	Annual or biennial	CY, WT, B, MW, F, BM
Long-term monitoring program	AIMS	*Primary*	Species biology & abundance	Biennial	CY, WT, B, MW, F, BM
StrandNet	DES	*Primary*	SOCI interactions	Ad-hoc/ opportunistic	WT, B, MW, F, BM
Benthic fauna assessments	Ports North	*Primary*	Species biology & abundance	Every 3 or more years	WT
Project Manta	UQ	*Primary*	Species biology & abundance	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Reef Check monitoring	Reef Check	*Primary*	Species biology & abundance	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Reef Life Survey	RLS	*Primary*	Species biology & abundance	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Infofish monitoring	Infofish	*Primary*	Species biology & abundance; fishing effort & retained catch; discarded catch; fish stocking data; recruitment indices; natural/fishing mortality	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
ANSA Qld tagging program	ANSA Qld	*Primary*	Species biology & abundance; recruitment indices; natural/fishing mortality	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM
Eye on the Reef program	The Authority	*Primary*	Species biology & abundance	Variable	CY, WT, B, MW, F, BM
Long-term shark tagging program	CSIRO	*Primary*	Species biology & abundance; natural/fishing mortality	Near real-time	WT, B, MW, F, BM
Fish spawning aggregation monitoring	The Authority	*Primary*	Spawning aggregation characteristics, species biology & abundance, fishing effort & retained catch	Annual	B
NERP Project 8.2 (effects of marine park zoning)	JCU/AIMS	*Primary*	Species biology & abundance	Annual	WT, B, MW, F, BM

**Natural Resource Management (NRM) regions: CY = Cape York, WT = Wet Tropics, B = Burdekin, F = Fitzroy and BM = Burnett Mary*

Since the introduction of Fisheries Queensland's **logbook program** in 1988, commercial and charter fishers operating in Queensland's state-managed fisheries have been required to submit daily catch records. Details of these catch records include species caught, estimated weights and/or numbers of individual species, time spent fishing, number of persons fishing, number of vessels operating, type of fishing gear/method, number of gear used, location, bycatch and interactions with species of conservation interest.

Through Fisheries Queensland's **Quota Monitoring System** (QMS), fishers are required to report accurate catch weights and numbers for quota-managed species via an automated interactive voice response (AIVR) system. Fishers must call in before landing and provide a description of the number of retained quota species as well as where and when the catch will be landed. After the catch has been landed, a secondary report detailing accurate unload weights is logged. For select quota fisheries, fishers are also required to fill out catch disposal records with information on how much product is sold or disposed, the disposal fate of the product and where it is disposed. QMS also records the details of temporary and permanent quota transfers between licence holders.

Vessel tracking was originally introduced by Fisheries Queensland in 1996 as a voluntary requirement to gain access to scallop replenishment areas and has since been mandated across a number of fisheries including east coast trawl, bêche-de-mer and some net fisheries. Fisheries Queensland is committed to having vessel tracking on all commercial fishing boats by the end of 2020. This system uses satellite tracking to monitor and assess the position and activity of commercial fishing vessels. This information is used to monitor effort quota in near real-time, monitor compliance with area and seasonal closures, provide intelligence and evidence for investigations, help validate logbook data on where and when fishing occurred, provide fishing effort data that is used in stock assessments and to identify fishery management changes that may be required.

Fisheries Queensland's **licensing** unit is responsible for managing any of the authorities or approvals that are required for various fishing activities in Queensland such as aquaculture, ceremonial fishing events and commercial, charter and stocked impoundment fishing. Various details on individual fishing authority holders are collected over time such as number of fishery symbols held, conditions on the authority (e.g. maximum number of crab pots allowed), vessel size, engine power and fuel capacity, number of tenders, previous owners, reasons for suspension or cancellation, transaction history and more.

Since the 1980s, mandatory **aquaculture production surveys** undertaken by Fisheries Queensland have collected information from all sectors of Queensland's aquaculture industry on production volume, value and efficiency in terms of land use and labour. These surveys provide a key measure of aquaculture industry development by benchmarking the annual performance of each sector against previous years.

Fisheries Queensland's **Impact Assessment and Management** unit is responsible for assessing the impacts of development on declared Fish Habitat Areas (FHAs), marine plants or fish passages. Development applications required for impacts to fisheries habitats are now managed by the State Assessment and Referral Agency (SARA) at the Department of Infrastructure, Local Government and Planning (DILGP).

The Impact Assessment and Management unit provides SARA with technical advice on applications that involve aquaculture, significant residual impacts on marine plants and the

construction or raising of waterway barrier works. Additionally, this unit assesses proposals in declared Fish Habitat Areas (FHAs) on behalf of the Department of National Parks, Sport and Racing (DNPSR).

The purpose of Fisheries Queensland's **Shark Control Program** (SCP) is to reduce the possibility of shark attacks in Queensland's coastal waters that are adjacent to beaches used for bathing. This is primarily achieved using baited drumlines and large mesh nets to remove large and potentially dangerous sharks from the immediate vicinity of 85 popular beaches along the Queensland coastline. These drumlines and nets are regularly checked and the details of any captured animals, including non-target species, are recorded, including catch numbers, species caught, body size, maturity, stomach contents, fate of interaction, catch location, current weather conditions and the tag or band details of any captured SOCI. Photos, voice recordings and videos of the catch may also be included.

Freshwater fish stocking is the process of releasing young fish into dams, weirs and rivers to support fisheries, control mosquito populations and assist in the recovery of threatened fish species. In Queensland's public waters, fish are stocked by around 70 community-based fish stocking groups. Through the Stocked Impoundment Permit Scheme (SIPS), Fisheries Queensland provides funding for stocking groups at 63 impounded waters in Queensland and collects information on the number of permits issued, maximum stocking number, species stocked and number of fish stocked. Fisheries Queensland is also partnered with the New South Wales Department of Primary Industries to collect some information on environmental flows in the Border Rivers valley to assist in monitoring fish responses to environmental watering actions.

Within Fisheries Queensland, **field compliance monitoring** is undertaken by the Queensland Boating and Fisheries Patrol (QBFP) to enforce fishing rules and regulations. QBFP employs a number of strategies to monitor compliance, including the intelligence gathering from all available sources, random and targeted patrols and inspections on land and at-sea, specialist investigations of complex breaches, the surveillance of emerging issues and reporting of illegal activities by the public through the Fishwatch hotline. Additional compliance monitoring is conducted under the Field Management Program (FMP), which is a joint undertaking by the Authority, Queensland Parks and Wildlife Service, QBFP, Queensland Water Police and Maritime Border Command. The FMP is specific to the World Heritage Area and includes education programs, aircraft, vessel and land-based surveillance, remote vessel tracking and audits of activities that require a permit.

Field compliance monitoring collects a wide range of information on illegal activities and non-compliance such as the unlawful use of nets, fishing in closed waters or seasons, taking of female crabs or undersized fish, using an excess number of crab pots/dillies, destruction of marine habitat, interference with fishing apparatus and failure to adhere to possession limits on fish.

Commercial catch sampling is largely driven by seafood wholesalers and retailers who voluntarily allow Fisheries Queensland scientists to measure fish and collect samples including frames after being filleted and otoliths (ear bones) from whole fish. Some commercial fishers also assist by providing samples and measurements. Commercial catch sampling is used to collect representative length, sex and age information on nineteen priority species – barramundi, blue threadfin, crimson snapper, dusky flathead, goldenline whiting, king threadfin, mangrove jack, pearl perch, red emperor, saddletail snapper, sand whiting, sea mullet, snapper, spangled emperor, Spanish mackerel, spotted mackerel, stripey snapper, tailor and yellowfin bream.

As part of the Sustainable Fisheries Strategy 2017 – 2027, Fisheries Queensland is committed to collecting additional biological information on sharks to address key information gaps. Shark monitoring activities will focus on east coast and Gulf of Carpentaria net fisheries with year-round representative sampling of catches in ports, at processors or on-water. The sampling will describe the species composition of the retained catch and will include the collection of photographic and genetic samples to assist with accurate species identification and data on the size, sex and maturity of the sampled catch. This program will also involve surveying commercial net fishers to document the behavioural and economic drivers that influence a fisher's decision to retain or discard sharks.

Recreational catch sampling undertaken by Fisheries Queensland involves the collection of biological data on key recreationally caught species from a number of sources including boat ramp and roving surveys, the Keen Angler Program, competition fishers and charter boat operators (Table 6). Recreational fishers are interviewed at more than forty-five boat ramps up to five times a month and at key shore-based fishing locations across the state. Through these surveys, recreational fishers provide information about where they live and the species, number and length of fish caught. Fishers can also choose to participate in the Keen Angler Program by donating fish frames to DAF scientists. The frames are measured, their sex determined by examining the gonads, and their otoliths are removed and used to estimate the age of the fish. Competition fishers and charter boat operators also assist in recreational catch sampling by voluntarily providing fish measurements.

Statewide recreational fishing surveys are conducted by Fisheries Queensland every one-to-five years using a telephone-diary method that was developed as a cost-effective way to collect recreational fishing data over a broad spatial scale. The surveys specifically targets Queensland residents who recreationally fish in Queensland and aim to provide reliable estimates on the number of recreational fishers, participation rate by region and demographic group, boat ownership and fishing/diving club membership, recreational fishing effort, recreational catch, motives for fishing and attitudes to and awareness of various fishing and environmental topics. The latest survey collected information from approximately 1800 randomly selected households and covered more than 200 species groups (Tailor *et al.* 2013). Over a period of almost 20 years, seven state-wide surveys have been conducted in Queensland with the most recent having taken place in 2019.

TABLE 6: Species current monitored through DAF recreational catch sampling.

Species	
Barramundi (*Lates calcarifer*)	**Mackerel – spotted** (*Scomberomorus munroi*)
Black Jewfish (*Protonibea diacanthus*)	**Mangrove Jack** (*Lutjanus argentimaculatus*)
Bream – pikey (*Acanthopagrus pacificus*)	**Mulloway** (*Argyrosomus japonicus*)
Bream – yellowfin (*Acanthopagrus australis*)	**Pearl perch** (*Glaucosoma scapulare)*
Cod – blackspot (*Epinephelus malabaricus*)	**Queenfish – giant** (*Scomberoides*)
Cod – goldspot (*Epinephelus coioides*)	**Shark** (Selachimorpha)
Coral trout – **barred-cheek** (*Plectropomus maculatus*)	**Snapper** (*Pagrus auratus*)
Coral trout – common (*Plectropomus leopardus*)	**Snapper – crimson** (*Lutjanus erythropterus*)
Crab – blue swimmer (*Portunus armatus*)	**Snapper – golden** (*Lutjanus johnii*)
Crab – mud (*Scylla* spp.)	**Snapper – saddletail** (*Lutjanus malabaricus*)
Emperor – grass (*Lethrinus laticaudis*)	**Snapper – stripey** (*Lutjanus carponotatus*)
Emperor – red (*Lutjanus sebae*)	**Tailor** (*Pomatomus saltatrix*)
Emperor – redthroat (*Lethrinus miniatus*)	**Threadfin – blue** (*Eleutheronema tetradactylum*)
Emperor – spangled (*Lethrinus nebulosus*)	**Threadfin – king** (*Polydactylus macrochir*)
Flathead – dusky (*Platycephalus fuscus*)	**Tropical rock lobster** (*Panulirus ornatus*)
Javelin – barred (*Pomadasys kaakan*)	**Tuskfish – blackspot** (*Choerodon schoenleinii*)
Javelin – silver (*Pomadasys argenteus*)	**Tuskfish – Venus** (*Choerodon venustus*)
Jewfish – silver (*Lutjanus erythropterus*)	**Whiting – goldenline** (*Sillago analis*)
Mackerel – grey (*Scomberomorus semifasciatus*)	**Whiting – sand** (*Sillago ciliata*)
Mackerel – school (*Scomberomorus queenslandicus*)	**Whiting – winter** (*Sillago maculata*)
Mackerel – Spanish (*Scomberomorus commerson*)	

Economic and social surveys undertaken by Fisheries Queensland largely involve the interviewing of recreational fishers at more than forty-five boat ramps up to five times a month and at key shore-based fishing locations across the state. In addition to providing important information on recreational catch and effort, these surveys also use a modified travel cost method to estimate the value of recreational fishing. Future state-wide recreational fishing surveys will collect information on fisher attitudes towards management arrangements (e.g. towards Queensland's recently established Net Free Zones) and responses to other various questions on employment, demographics and optimism for the future. As part of the SFS, Fisheries Queensland is also committed to developing new methods for collecting socio-economic information from the commercial, recreational and Indigenous fishing sectors.

Another important source of socio-economic information relating to fisheries on the Reef is the Social and Economic Long-Term Monitoring Program for the Great Barrier Reef (SELTMP) led by researchers from CSIRO and James Cook University (JCU). SELTMP surveys collect attitudinal data from various Reef user groups between Cairns and Bundaberg with a number of survey questions directed at commercial and recreational fishers.

Fisheries Queensland carries out **fishery-independent surveys** to collect information that would otherwise not be available through fisheries dependent methods. The abundance of juvenile and adult spanner crabs throughout southern Queensland is surveyed each May, using chartered commercial vessels and DAF's own research vessel. Fisheries Queensland has also commenced surveys on sea scallops and eastern king prawns, collecting information to track stock recovery and improve estimates of biomass and mortality rates. These surveys will also add value by collecting additional information on blue swimmer crabs, Moreton Bay bugs and the abundance of juvenile snapper.

Utilising statistical and mathematical methods, quantitative **stock assessments** are undertaken by DAF scientists to make quantitative statements about the status of fish populations and predict their responses under various management strategies. Specific assessments are also completed in collaboration with mathematicians at the University of Queensland's Centre for Applied Resource Mathematics (CARM). Each stock assessment is managed using a "Project Team" approach. This involves representatives from a range of groups within Queensland Government, as well as external scientists and stakeholders if required, to ensure that outputs are delivered on time, meet the needs of management and stakeholders, and deal with any operational matters or issues identified. Multiple stock assessments have been conducted since the early 2000s, covering 24 species across Queensland (Table 7**Error! Reference source not found.**).

TABLE 7: Species that have been assessed through the DAF stock assessment program.

Species	
Barramundi (*Lates calcarifer*)	**Prawn – endeavour** (*Metapenaeus endeavouri, M. ensis*)
Blacktip Shark (*Carcharhinus tilstoni, C. limbatus, C. sorrah*)	**Prawn – red spot king** *(Melicertus longistylus*)
Coral trout (*Plectropomus* and *Variola* spp.)	**Prawn – tiger** (*Penaeus esculentus* and *P. semisulcatus*)
Emperor – red (*Lutjanus sebae*)	**Scallop – saucer** (*Amusium balloti*)
Emperor – redthroat (*Lethrinus miniatus*)	**Sea mullet** (*Mugil cephalus*)
Mackerel – grey (*Scomberomorus semifasciatus*)	**Snapper** (*Pagrus auratus*)
Mackerel – Spanish (*Scomberomorus commerson*)	**Snapper – crimson** (*Lutjanus erythropterus*)
Mackerel – spotted (*Scomberomorus munroi*)	**Snapper – golden** (*Lutjanus johnii*)
Mangrove Jack (*Lutjanus argentimaculatus*)	**Snapper – saddletail** (*Lutjanus malabaricus*)
Pearl perch (*Glaucosoma scapulare)*	**Tailor** (*Pomatomus saltatrix*)
Prawn – banana (*Fenneropenaeus merguiensis*)	**Tropical rock lobster** (*Panulirus ornatus*)
Prawn – eastern king (*Melicertus plebejus*)	**Whiting – stout** (*Sillago robusta*)

Fisheries and aquaculture research, development and extension (RD&E) is managed by DAF scientists within Agri-Science Queensland, who provide high quality technical advice and recommendations to Fisheries Queensland, other government bodies and industry to optimise the environmental, social and economic benefits to the Queensland community.

Ongoing research programs investigate a wide variety of issues concerning the sustainability of target species, bycatch mitigation and environmental issues. Fisheries research focuses on stock assessments and management strategy evaluation of the major fisheries, assessing impacts of seasonal variability and adaptation needs for fisheries, determining optimal harvest rates and reference points to maximise economic yields and improve recreational fishing success, and providing management options for Fisheries Queensland. The major focal point of aquaculture research and development is to increase productivity through genetic improvement, nutrition and broodstock husbandry as well as minimising off-site impacts through effluent reduction.

Research priorities are reviewed annually and determined by a number of factors such as requirements for management reviews, the setting of fishing harvest-effort quotas, assessing the impact of recent management changes, concerns raised about the status or sector access of fished resources, the availability/quality of data, the need to improve efficiency and accuracy of monitoring designs, the need for automation and modernisation of statistics required for rapid stock status reporting, the need for decision support tools for management and the need to deliver new options or specifications for management.

In addition to the research conducted by DAF, scientific information on fisheries and aquaculture in the Region is provided by a wide range of research institutions, government agencies, universities, corporations, consultancies, community groups and other stakeholders. Major research providers in this area include the Fisheries Research and Development Corporation (FRDC), Australian universities and associated research centres, the Australian Institute of Marine Science (AIMS), CSIRO Oceans and Atmosphere, the NESP Marine Biodiversity Hub, the Reef and Rainforest Research Centre (RRRC), the Queensland Museum, the ARC Centre of Excellence for Integrated Coral Reef Studies and others.

Ecological risk assessments (ERAs) are accepted best practice in many Australian fishery jurisdictions, utilising qualitative or quantitative methods to understand the impacts of commercial fishing activities on target and non-target species and to prioritise management actions or future monitoring and research. The framework for the ERA process is based on a hierarchical approach and describes how a fishery will move from a qualitative assessment (level 1) through to a quantitative assessment (level 3) while utilising semi-quantitative (e.g. productivity-susceptibility analyses – PSA) or low-data quantitative (e.g. sustainability assessment for fishing effects – SAFE) risk assessment methodologies. This approach is designed to allow efficient use of data and screens out low risks at each level.

Multiple risk and vulnerability assessments have been conducted on Queensland's various fisheries, including:

- the East Coast Otter Trawl Fishery
- the Coral Fishery
- the Marine Aquarium Fish Fishery

- the East Coast Spanish Mackerel Fishery
- the Queensland Eel Fishery
- the Blue Swimmer Crab Fishery
- the Mud Crab Fishery
- the Marine Specimen Shell Collection Fishery
- the Coral Reef Fin Fish Fishery
- the Gulf of Carpentaria fisheries.

These assessments have previously been conducted as needed to fulfil reporting requirements, but future assessments will systematically cover all fisheries in Queensland.

Through a rolling 2-year program of **stock status assessments**, DAF assesses the stock status of 69 fish species important to Queensland and Australia as a whole (Table 8). These assessments follow a weight-of-evidence approach where an expert panel reviews all available information on species biology, biomass and fishing pressure to determine the status of each stock.

This approach was adopted from the Status of Key Australian Fish Stocks (SAFS) assessment framework, which assesses the biological sustainability of key wild-caught fish stock in Australia using a nationally agreed classification framework and reporting template. The national SAFS assessments are conducted every other year and are determined by a list of species agreed on by all participating jurisdictions. In non-SAFS years, DAF assesses the status of other important Queensland species that are of concern or are not covered by the SAFS assessments. Where fish stocks extend into the waters of other states, DAF only assesses the Queensland component.

The **AIMS Long-Term Monitoring Program** was initiated to detect changes in reef communities at a subregional scale and, for more than 20 years, has surveyed the health of 47 midshore and offshore reefs across the Region. A key component of this program are underwater visual census (UVC) surveys that are conducted along fixed transects and record counts of reef fish, juveniles corals and agents of coral mortality (crown-of-thorns starfish, coral-eating snails and coral disease/bleaching).

These surveys cover 191 commercial and non-commercial species and typically involve an experienced observer swimming along 50 metre transect lines and counting large mobile fishes and damselfishes in the immediate vicinity. Surveys are conducted on the program's core reefs every second year while, in the alternate years, a second set of reefs is surveyed to monitor the effects of the 2004 Marine Park re-zoning plan. The information collected during these surveys is increasingly valuable to DAF, providing an absolute measure of coral trout abundance that was directly used in the most recent stock assessment of Queensland's east coast coral trout fishery (Leigh et al. 2014).

StrandNet is a database of marine wildlife strandings and deaths maintained by the Department of Environment and Science (DES). The database stores information on the location of stranded or dead marine animals including cetaceans, pinnipeds, dugongs and turtles. The cause of injury or death and incidental information on sharks, rays, seabirds and other marine animals is also collected. Reports of strandings and deaths come from a range of sources including DES and Authority staff, Queensland's Shark Control Program, the Royal Society for the Prevention of Cruelty to Animals (RSPCA) hotline, Sea World, Underwater World and the wider public.

Within the Region, **Ports North benthic infauna assessments** are periodically conducted at the ports of Cairns and Mourilyan to monitor benthic infauna associated with soft sediment habitats and manage the impacts of port operations.

Project Manta is a multidisciplinary research project based at the University of Queensland (UQ) that investigates the population biology and ecology of manta rays in eastern Australia. Professional and recreational divers submit photographs and sighting information of manta rays, which can be used to identify individual manta rays due to their unique ventral markings that are comparable to human fingerprints.

TABLE 8: Current species list for Queensland stock status assessments including SAFS and non-SAFS species.

SAFS species	
Albacore (*Thunnus alalunga*)	**Royal Red Prawn** (*Haliporoides sibogae*)
Barramundi (*Lates calcarifer*)	**Sandbar Shark** (*Carcharhinus plumbeus*)
Black Jewfish (*Protonibea diacanthus*)	**Scallop – saucer** (*Amusium balloti*)
Blacktip Shark (*Carcharhinus tilstoni, C. limbatus, C. sorrah*)	**Sea cucumber White Teatfish** (*Holothuria fuscogilva*)
Blue-eye trevalla (*Hyperoglyphe antarctica*)	**Sea mullet** (*Mugil cephalus*)
Bream – yellowfin (*Acanthopagrus australis*)	**Silver Trevally** (*Pseudocaranx dentex*)
Bugs – Balmain (*Ibacus chacei* and *I. brucei*)	**Snapper** (*Pagrus auratus*)
Bugs – Moreton Bay (*Thenus australiensis* and *T. parindicus*)	**Snapper – crimson** (*Lutjanus erythropterus*)
Coral trout (*Plectropomus* and *Variola* spp.)	**Snapper – golden** (*Lutjanus johnii*)
Crab – blue swimmer (*Portunus armatus*)	**Snapper – saddletail** (*Lutjanus malabaricus*)
Crab – mud (*Scylla* spp.)	**Tailor** (*Pomatomus saltatrix*)
Crab – spanner (*Ranina ranina*)	**Threadfin – blue** (*Eleutheronema tetradactylum*)
Emperor – red (*Lutjanus sebae*)	**Threadfin – king** (*Polydactylus macrochir*)
Emperor – redthroat (*Lethrinus miniatus*)	**Tropical rock lobster** (*Panulirus ornatus*)
Emperor – spangled (*Lethrinus nebulosus*)	**Whiting – sand** (*Sillago ciliata*)
Flathead – dusky (*Platycephalus fuscus*)	**Whiting – stout** (*Sillago robusta*)
Goldband Snapper (*Pristipomoides multidens*)	**Yellowtail Kingfish** (*Seriola lalandi*)
Grey Morwong (*Nemadactylus douglasii*)	**Yellowtail scad** (*Trachurus novaezelandiae* and *T. declivis)*
Hapuku (*Polyprion oxygeneios*)	**Non-SAFS species**

John Dory (*Zeus faber*)	**Burrowing Blackfish** (*Actinopyga spinea*)
Luderick (*Girella tricuspidata*)	**Cobia** (*Rachycentron canadum*)
Mackerel – grey (*Scomberomorus semifasciatus*)	**Dart** (*Trachinotus* spp.)
Mackerel – school (*Scomberomorus queenslandicus*)	**Emperor – grass** (*Lethrinus laticaudis*)
Mackerel – Spanish (*Scomberomorus commerson*)	**Freshwater eel** (*Anguilla australis* and *A. reinhardtii*)
Mackerel – spotted (*Scomberomorus munroi*)	**Garfish** (*Hemiramphidae*)
Mangrove Jack (*Lutjanus argentimaculatus*)	**Javelin** (*Pomadasys* spp.)
Mulloway (*Argyrosomus japonicus*)	**Mahi-mahi** (*Coryphaena hippurus*)
Murray Cod (*Maccullochella peelii*)	**Prawn – red spot king** *(Melicertus longistylus*)
Pearl perch (*Glaucosoma scapulare)*	**Queenfish** (*Scomberoides* spp.)
Prawn – western king (*Melicertus latisulatus*)	**Shark – Hammerhead** (*Sphyrnidae*)
Prawn – banana (*Fenneropenaeus merguiensis*)	**Snapper – hussar** (*Lutjanus adetii* and *L. vitta*)
Prawn – eastern king (*Melicertus plebejus*)	**Snapper – stripey** (*Lutjanus carponotatus*)
Prawn – endeavour (*Metapenaeus endeavouri, M. ensis*)	**Trevally** (*Carangidae*)
Prawn – school (*Metapenaeus macleayi*)	**Trochus** (*Trochus niloticus*)
Prawn – tiger (*Penaeus esculentus* and *P. semisulcatus*)	**Tuskfish** (*Choerodon* spp.)

Reef Check monitoring is a community-based program that trains volunteer SCUBA divers to survey popular dive sites in Australia to determine broad-scale trends in reef health. Standard surveys collect information on reef composition, signs of reef stress, abundance of key invertebrates (e.g. crown-of-thorns starfish, sea cucumbers, anemones and sea urchins), abundance of indicator fish (e.g. coral trout, butterflyfish, snapper and sweetlips), site use and disturbances. Currently, Reef Check Australia monitor more than 40 sites in locations around Cairns, Port Douglas, Townsville, the Whitsunday Islands and Heron Island.

Reef Life Survey is a citizen science program that utilises trained volunteer SCUBA divers to surveys of rocky and coral reef ecosystems around the world, including 38 sites within the Reef. Surveys are conducted along 50 metre transect lines with a separate component for each major taxonomic grouping, including:

- a visual census of fishes and other large mobile animals in 5 metre x 5 metre bands along the transect line
- a visual census of mobile macro-invertebrates and cryptic fish species in 1 metre x 2 metre bands along the transect line
- digital photo-quadrats taken for sessile invertebrates and seaweeds at 2.5 metre intervals along the transect line.

This program also allows divers to record the presence of species outside the transect lines, providing useful information on rare species or species outside their usual range.

Infofish monitoring programs collect a significant body of information on Australian fisheries, primarily through citizen science approaches. The catch monitoring component, currently

focused on the Fitzroy River and the nearby Net Free Zone (NFZ), collects catch and effort data and uses statistical models to estimate catch rates of T20 recreational fishers – the 20 per cent of fishers that catch 80 per cent of the fish. Catch monitoring also involves the tagging and collection of catch data during fishing competitions. Recruitment monitoring, currently focused on Barramundi in the Fitzroy River and Bream in the Gladstone area, involves the use of castnet and tagging methods to measure the catch rates of recruits in the context of climate indices such as river flow and rainfall. Fish in the Gladstone area are also monitored for fish deaths and serious health issues such as lesions, parasites, injuries, deformities and disease. Impoundment monitoring is facilitated by stocking groups that tag stocked fish to monitor growth, movement, survival, escapement and mixing with wild populations. Other programs include the monitoring of tagged fish across Queensland (Suntag) as well as pest fish species in the Fitzroy River region.

The **ANSA Queensland tagging program** is managed by recreational fishing clubs affiliated with the Queensland branch of the Australian National Sportfishing Association (ANSA). Individual clubs are encouraged to develop and implement recreational fishery monitoring plans, which guides the club members to collect tagging data for the purposes of monitoring:

- the success of restocking programs
- survival rates, growth patterns or movement characteristics of fish species
- the general health or potential recovery in a particular area (e.g. Net Free Zones)
- other indicators as governed by the monitoring objectives set by each club.

Eye on the Reef is a reef monitoring and assessment program run by the Authority to collect information on Reef health, marine animals and incidents. The program has four distinct reporting tools with varying levels of expertise required.

The Sightings Network is a community-based tool that allows anyone from the public to use the Eye on the Reef smartphone app and submit photos of any sightings on the Reef such as wildlife, marine animal strandings and incidents, pests (e.g. crown-of-thorns starfish), marine pollution and bleaching.

Rapid Monitoring Surveys are available to members of the public with more knowledge of the Reef and after completion of an online training course. Participants are provided an underwater monitoring slate to record counts and sizes of keystone fish species, habitat types, environmental conditions and indicators of reef health.

Tourism Weekly Monitoring allows tour operators to commit to surveying a particular reef site on a weekly basis, requiring hours of training and attendance at quarterly workshops. Participants use survey forms to record indicators of reef health, environmental measures, the presence of protected and iconic species and the sizes and numbers of grazing herbivores.

The Reef Health and Impact Survey (RHIS) is primarily used by staff from the Authority and the Queensland Parks and Wildlife Service as well as experienced Eye on the Reef participants. These surveys are designed for assessing corals and do not collect information on fish species.

Operating for almost 20 years, the **long-term shark tagging program** led by CSIRO has tracked approximately 210 white sharks (*Carcharodon carcharias*) from central Queensland to Western Australia through a combination of satellite and acoustic tagging. This research provides insight into shark movement patterns and behaviour, patterns of habitat use including juvenile nursery areas, adult population estimates, shifts in abundance and shark survival rates (McAuley et al. 2017, Bruce et al. 2018, Hillary et al. 2018).

A workshop convened by the Authority highlighted the need for **fish spawning aggregation monitoring** (Russell and Pears 2007). Monitoring will involve support from DAF as well as Science and Conservation of Fish Aggregations (SCRFA), a non-government organisation that utilises a range of methodologies to identify and document fish spawning aggregations around the world. Information collected will vary depending on the resources available and management needs for each species, but may include maps of aggregation sites, number of fish in aggregations, seasonality and time of spawning, trends in fishing effort and catch rates on spawning aggregations, size-frequency distributions, sex ratios, DNA samples, gut contents, courtship and spawning behaviour and migratory patterns (Colin et al. 2003). Within the Reef, several coral trout spawning aggregation sites have been characterised (Samoilys and Squire 1994, Zeller 1998).

Similar research is being conducted on the east coast Spanish mackerel fishery to quantify spatial patterns in historical exploitation, construct a historical timeline of fishery performance, understand the aggregating behaviours of spawning Spanish mackerel and evaluate the protection offered by marine park zoning (Tobin et al. 2014a, Buckley et al. 2017).

NERP Project 8.2 ‘Do no-take marine reserves contribute to biodiversity and fishery sustainability? Assessing the effects of management zoning on inshore reefs of the Marine Park’ was established in 1999 to assess the ecological effects of marine park zoning (Commonwealth of Australia 2015). The joint project between JCU and AIMS involves UVC and BRUVS surveys of reef fish, benthic communities and coral health within no-take (Green) and fished (Blue and Yellow) zones on near-shore, mid-shelf and offshore reefs and inter-reefal shoal country. Additional information is collected during the selection of shoal monitoring sites including high-resolution 3D topography maps and imagery of habitat features.

Gaps in current monitoring effort and adequacy of existing monitoring programs

Many of the existing fisheries monitoring and assessment programs in Queensland were designed explicitly for fisheries management purposes and often rely on fishery-dependent methods. Subsequently, there is a wealth of information available on targeted species with commercial or recreational value, but limited information on non-target species and other

features of the environment that are not directly applicable to fisheries management. Furthermore, such programs were designed to collect information at scales that are relevant to fisheries managers, which may not align with the regional and Reef-wide scales required for reporting on progress towards some Reef 2050 targets, objectives or outcomes.

The adequacy of current monitoring and assessment programs was assessed based on their ability to report on the priority indicators proposed for monitoring fisheries on the Reef (**Error! Reference source not found.**). Previous evaluations of DAF-managed programs were also considered (see **Error! Reference source not found.**).

TABLE 9: Adequacy of current programs for monitoring fishery systems on the Reef.

Priority indicator	Adequacy of current monitoring/assessment	Strategies to address gaps in current monitoring/assessment
Aboriginal & TSI customary fishing	**Inadequate** Available information on Indigenous fishing activity is limited, largely due to a current lack of reporting requirements for customary fishing in Queensland.	• Review of relevant policies to better understand the fishing rights of Traditional Owners and the regulatory powers of DAF • Development of a monitoring project that will determine what socio-economic information should be collected and how best to engage with Indigenous communities • Engagement with Indigenous communities (e.g. cross-decking between QBFP and the Indigenous Land and Sea Ranger Program)
Biomass ratios	**Partially adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there is a lack of recent data for some key species with stock assessments tending to focus on data-rich species.	• Improved data-sharing with other organisations (particularly in regards to acquiring environmental data – e.g. AIMS weather buoys, river flow inputs, meteorological data) • Continued development of a rapid assessment program
Compliance statistics	**Adequate** Compliance is extensively monitored across the Marine Park, but this information can be difficult for Reef managers to access due to its often confidential nature.	• Explore options for addressing confidentiality and data privacy issues and increasing availability of compliance data for research and management purposes
Discarded catch (excluding species of conservation interest)	**Inadequate** Data on recreationally discarded catch is collected across Queensland, but data on commercially discarded catch is limited to a select few fisheries (e.g. spanner crab, stout whiting, charter). Additionally, data on commercially discarded catch is not always reliable due to range of reasons.	• Continued development of an affordable automated electronic monitoring system • Continued education programs • Surveys to document socio-economic drivers that influence fishers' decisions to retain or discard catch

Priority indicator	Adequacy of current monitoring/assessment	Strategies to address gaps in current monitoring/assessment
Ecological risk categories	**Partially adequate** Information is not available for some fisheries, but all fisheries in Queensland will be assessed as future ecological risk assessments adopt a more systematic process. A significant limitation of these assessments is a lack of available data on the distribution, biology (life history traits) and abundance of non-target species and on Indigenous fishing (e.g. fishing mortality, gear usage, SOCI interactions).	• Improved data-sharing with other organisations, particularly for information on species biology, abundance and distributions (shapefiles preferred where possible) • Building a network of connections to access expert knowledge and advice • Engagement with Indigenous communities (e.g. cross-decking between QBFP and the Indigenous Land and Sea Ranger Program)
Fishing effort & retained catch – commercial, charter & recreational sectors	**Partially adequate** Catch and effort from the commercial, charter and recreational sectors is comprehensively monitored across the state; only the Indigenous sector remains largely unmonitored. However, there are a number of limitations such as a lack of accurate daily catch weights, self-reported fishing locations at a relatively low resolution (6 nautical mile grids), poor species identification and separation of species complexes (particularly for sharks), poor spatial resolution for recreational fishers, a lack of coverage of some species by boat ramp and roving surveys, no monitoring of transient fishing activity through the state-wide recreational fishing surveys and a lack of detail collected by the roving surveys in comparison to the boat ramp surveys. Improvements are expected following plans to validate fisheries data, implement fleet-wide vessel tracking and establish a dedicated shark monitoring program.	• Continued development of a recreational fishing app • Encourage more nationally coordinated recreational fishing surveys • Improved data-sharing with other organisations • Continued implementation of vessel tracking on all commercial vessels • Continued developments under Fisheries Queensland's Data Validation Plan • Investigation of novel technologies for tracking recreational vessels (e.g. mobile phones)
Natural/fishing mortality	**Partially adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there is a lack of recent data for some species with stock assessments tending to focus on data-rich species. There is also a gap in the unmeasured mortality of fish due to shark predation during fishing operations.	• Improved data-sharing with other organisations • Investigation of novel technologies for tracking shark-related mortality during fishing operations (e.g. towed camera systems)

Recruitment indices	**Partially adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there is a lack of recent data for some species with stock assessments tending to focus on data-rich species.	• Improved data-sharing with other organisations
SCP impacts	**Partially adequate** Every interaction between the Shark Control Program and captured species is recorded, but there are issues arising from poor species identification and separation of species complexes. There is also a lack of biological data (i.e. skin samples and necropsies) collected from captured animals that would be valuable for research and management purposes.	• Consider the expansion of the SCP to collect skin samples and perform necropsies • Consider enhancing the training of SCP contractors to more accurately identify captured animals
Socio-economic data	**Inadequate** Socio-economic information relating to fisheries is currently limited with gaps such as no up-to-date beach price data for commercial catch, little information on the economic value of fishing beyond the beach price (e.g. fish shop revenue) and lack of information on Indigenous communities. There are also issues with the availability of voluntary data (e.g. gaps in geographic coverage, sensitivity of personal information, lack of voluntary participation).	• Consider recommencing the collection of beach price data • Continued development of community engagement strategies and socio-economic monitoring programs • Improved data-sharing of socio-economic data and potential collaboration on monitoring programs (e.g. SELTMP) • Improved understanding of stakeholders (e.g. engagement programs)
Spawning aggregation characteristics	**Inadequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, regular monitoring is limited and there is a lack of data on many key species with most previous studies having focused on common coral trout.	• Improved communication with research providers (e.g. AIMS, CSIRO, FRDC, the Authority) to identify opportunities for data-sharing and collaborative research • Consider enhancement of existing spawning aggregation monitoring program

Species biology (age, length and sex) and abundance	**Partially adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there are a number of gaps such as incomplete coverage of all key species, limited sample sizes for some species, limited resources for fishery-independent sampling, non-standardised methodology, a poor understanding of spawning aggregations for some species, little information on food sources (e.g. bait fish populations) and limited abundance data (particularly for sea cucumbers, cryptic and pelagic species and inter-reefal, inshore and deep water habitats).	• Encourage in-kind contributions from industry (e.g. industry-funded surveys) • Improved communication with research providers (e.g. AIMS, CSIRO, FRDC) to identify opportunities for data-sharing and collaborative research • Consider introducing conditions for commercial fishers that require a minimum number of fish samples to be provided • Development and assessment of novel technologies for data collection (e.g. underwater drones, automated image processing, BRUVS)
SOCI interactions	**Inadequate** Available information on SOCI interactions is limited and thought to be unreliable due to the inherent difficulty in validating records. However, improvements are expected following plans to validate fisheries data and develop tools for the automated, electronic monitoring of commercial fishing operations.	• Continued development of an automated, electronic monitoring system • Continued education programs
Standardised catch rates	**Partially adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there is a lack of recent data for some key species with stock assessments tending to focus on data-rich species. There are also concerns of hyperstability, potentially necessitating the collection of alternative abundance indices.	• Improved data-sharing with other organisations • Continued development of a rapid assessment program • Collaborative research with other organisations, particularly in regards to developing alternative indices of abundance for key species (e.g. snapper, pearl perch, Spanish mackerel)
Status of fish stocks	**Adequate** Information is available on a number of species that are of concern or are valuable to the commercial and/or recreational fishing sectors. However, there is a lack of recent data for some key species with assessments tending to focus on data-rich species. Another potential limitation is uncertainty around stock determination, which carries risks of mismanagement and/or inability to detect change.	• Improved data-sharing with other organisations (particularly information on data-poor species) • Continued development of a rapid assessment program

New technologies for monitoring fishery systems on the Great Barrier Reef

Following widespread advances in technology, the range of sampling tools and techniques available for measuring socio-economic and ecological indicators has rapidly increased in recent years. Many of these technological developments are potential game-changers for fisheries management such as increased computational power of mobile devices, more accessible and accurate satellite imagery, improved sensors, on-board digital cameras and remote monitoring platforms (drones), expanded use of vessel tracking systems and increased capacity for 'big data' storage and analysis (Girard and Du Payrat 2017).

Modern **vessel tracking systems** typically use a combination of satellite and Global Packet Radio System (GPRS) networks to provide near real-time data on the location, course and speed of fishing vessels. Vessel tracking in Queensland was originally introduced in 1996 as a voluntary requirement to gain access to scallop replenishment areas and has since been mandated across several fisheries, including East Coast trawl, Bêche-de-mer and some net fisheries. Fisheries Queensland is committed to implementing vessel tracking on all commercial fishing boats by the end of 2020. This information is critical to effective fisheries management and is currently used to track quota usage, map dynamic patterns of human activity, monitor compliance with area and seasonal closures, provide intelligence on illegal fishing, assist in maritime safety and rescue operations, validate logbook data on where and when fishing occurred, calculate fishing effort for stock assessments and to identify fishery management changes that may be required.

A key challenge for vessel tracking will be the analysis and interpretation of the data, which can be difficult as patterns in fishing activity vary considerably for different fishing methods such as trawl, net, line and pot. In combination with the implementation of vessel tracking, the development of sophisticated algorithms to automatically identify and classify fishing activity from vessel tracking data will have considerable benefits for fisheries management (de Souza et al. 2016).

Another type of vessel tracking system is the **Automatic Identification System (AIS)**, which broadcasts a vessel's identity, course, speed and position via a very-high frequency (VHF) transmitter to nearby vessels, coastal stations and satellites. The primary function of AIS is to prevent vessel collisions and allow safe navigation in low visibility conditions, however there are applications in determining whether a vessel is fishing and detection of noncompliant activities such as illegal trans-shipments.

Fisheries Queensland are currently developing **electronic reporting tools** for both the commercial and recreational fishing sectors, primarily as mobile-enabled apps. The commercial fishing app is intended to eventually replace the current paper logbooks and will allow fishers to provide all relevant logbook catch and effort data as well as information on quota, non-commercial fishing activities and, should the primary vessel tracking device malfunction, vessel position. The commercial fishing app is expected to improve the efficiency

of data collection as the system moves away bulky paper logbooks and manual data entry and increase the accuracy of logbook data following due a reduction in input errors and an improvement in data validation capabilities. The recreational fishing app is currently available as an easy-to-access guide on rules, species identification and other information on fishing. Fisheries Queensland is committed to continually improving this technology, providing opportunities for the voluntary collection of recreational fishing information through surveys and uploading catch details such as photographs. Expected benefits of the recreational fishing app are improved data quality, more comprehensive recreational fishing data, community engagement and an improved understanding on the effectiveness and relevance of existing fishery regulations (e.g. size and possession limits). Development of mobile apps also confers an economic benefit since a significant proportion of Australia's population already own smartphone devices.

Smart weighing systems can be employed on fishing vessels to measure and store raw catch weight at sea while compensating for boat movement. Although these systems are more expensive than land-based weighing systems, this technology would benefit fisheries management through the validation of catch data from other sources such as logbooks or quota reporting (Girard and Du Payrat 2017).

On-board electronic monitoring typically involves an integrated system of on-board video cameras and hydraulic gear and drum sensors, where the cameras are triggered to record by fishing activity. The Australian Fishing Management Authority (AFMA) currently employs such systems to monitor and record fishing activities on commercial vessels across several fisheries. Electronic monitoring is typically more cost-effective than traditional observer-based methods, allowing more extensive monitoring and likely avoiding biases that may arise from observer effects and low fleet coverage (McCluskey and Lewison 2008, Benoit and Allard 2009, Faunce and Barbeaux 2011). This technology is particularly useful for collecting information on discarded catch and interactions with species of conservation interest, which has proven difficult to validate using other methods such as logbooks. As part of the Sustainable Fisheries Strategy 2017 – 2027 and through the Advance Queensland Small Business Innovation Research (SBIR) initiative, Fisheries Queensland is seeking an affordable automated electronic monitoring system that will record all information required for commercial trawl, net and crab fishing operations (taking into account different sized vessels) and submit this to Fisheries Queensland in real or near real time.

Environmental DNA (eDNA) is a technique that obtains a DNA snapshot of the taxa present in any given aquatic system, sampling genetic material from the environment rather than organisms directly. The eDNA approach is already successfully used in a variety of important areas across the globe; for example, to detect incursions of cryptic pest fish, trace impact of faecal contamination on recreational waters, measure biodiversity, assess habitat connectivity, identify new species, detect illegally-harvested species in food products and understand the complex life cycles of marine animals (Trivedi et al. 2016, Yamanaka and Minamoto 2016, Bastos Gomes et al. 2017, Wang et al. 2017, Evans and Lamberti 2018, Tillotson et al. 2018).

Within Queensland, the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) currently applies eDNA techniques to monitor aquatic environments for the presence and distribution of aquatic invasive species (tilapia and climbing perch) or rare and endangered species (freshwater sawfish, frogs and turtles) and to determine the effects of barriers to fish passage on barramundi. DAF scientists are also exploring the use of eDNA on prawn aquaculture farms to test the fitness of seawater delivered by upstream land-users. This research may establish a key role for marine aquaculturalists in the early detection of water contaminants bound for the ocean and the Reef. Key advantages of eDNA include time- and cost-efficiency, very low disturbance to wildlife, ability to overcome logistical and regulatory barriers typically associated with monitoring rare or endangered species, improved species detection probabilities and improved morphological identification for closely related or cryptic species.

Towed video systems typically involve towing a camera behind a survey vessel at fixed speeds to view benthic habitats in real-time and record video for the detailed analysis of habitat types, species distributions and seabed biodiversity. This approach has been successfully used to estimate fish abundance and determine habitat preference and is currently utilised by AIMS to monitor offshore shoals in the north-west of Australia (Grasty 2014). Advantages over traditional diver-based monitoring include reduced observer bias, lowered health and safety risks and associated insurance costs, access to normally inaccessible areas and the ability to efficiently survey large areas of habitat.

Scientific echosounders and **active sonar** devices can detect objectives under the surface of the water by emitting sound pulses and characterising the returning echoes based on the known acoustic properties of the target (MacLennan and Simmonds 2005). This technology is well established in fisheries monitoring and assessment with the ability to collect information on seabed types, artificial reef structures, aquatic vegetation, fish passage and the size, abundance, density, biomass and behaviour of fishes (Patterson and Melvin 1996, Bollinger 2017). Compared to traditional diver-based methods, acoustic surveys offer a rapid, cost-effective, low risk and non-invasive approach to monitor large and sparsely populated areas of habitat with little sensitivity to water column visibility (Zenone et al. 2017).

Unmanned vehicles or **drones** are a particularly promising development for fisheries monitoring and can be categorised into three main types:

- unmanned underwater vehicles (UUV) with a distinction between autonomous underwater vehicles (AUV) and remotely operated underwater vehicles (ROV);
- unmanned surface vehicles (USV); and
- unmanned aerial vehicles (UAV).

AUV are programmed to navigate aquatic environments and collect data using video cameras and other various sensors. In contrast**,** ROV are manually operated and must be tethered to a

survey vessel by a fibre optic cable. These underwater drones have been used for a range of monitoring activities in aquatic environments including the collection of data on invasive pest species, deep-sea benthic community structure, reef fishes, coral mound morphology and sensitive coral-dominated habitats (Smale et al. 2012, Fernandes et al. 2014). COTSbot and RangerBot are two AUV that have been developed by the Queensland University of Technology (QUT) to automatically identify and control crown-of-thorns starfish on the Reef, potentially providing a platform to collect image data on reef fish.

USV are remote-controlled or autonomous watercraft that use wind, solar or wave power to operate independently for periods of up to 12 months, collecting a range of biophysical data from surface and sub-surface water. CSIRO has recently acquired a small fleet of USV that will use ocean chemistry, meteorological and marine acoustic sensors to gather information for climate and environmental monitoring as well as fisheries research and stock assessments.

UAV are remote-controlled or autonomous aircraft that are typically outfitted with radar, AIS receivers, GPS, optical/infrared imaging sensors and optical cameras. Although this technology was historically developed for military purposes, there are a growing number of applications for fisheries management (Selbe 2014). The National Oceanic and Atmospheric Administration (NOAA) based in the United States is currently testing UAV as a tool for vessel tracking, marine monitoring and enforcement of marine protected areas.

The main advantage of drone-based survey methods is their increased capabilities compared to stationary platforms and cost-effectiveness compared to surveys conducted from oceanographic vessels or piloted aircraft (Girard and Du Payrat 2017).

Baited remote underwater video stations (BRUVS) is a survey tool originally developed by AIMS that uses bait to attract nearby fish into the field of view of a stationary, remote-controlled camera positioned on the seafloor. Analysis of the video footage provides information on fish diversity, abundance and behaviour as well as length and biomass estimates and habitat types. Within the Marine Park, AIMS currently uses BRUVS to monitor the effects of marine park zoning on fish populations and to map the diversity of fishes, sharks and sea snakes. CSIRO is also using a modified BRUVS system, which can operate at depths of up to one kilometre, to monitor deep-water fish communities and track the recovery of depleted fish stocks. In addition to the benefits of other video-based methods, BRUVS enables the study of more elusive fauna that reside in deep-water environments or tend to avoid divers and research vessels.

Development of **automated image processing** software will be an essential step in applying image-based methods – such as towed video, BRUVS and on-board electronic monitoring – to routine fisheries monitoring. Without automation, image processing is intensively time-consuming and can often make image-based monitoring impractical if human resources are limited. This software will also allow the reanalysis of a significant body of existing data that has been collected for studies on aquatic habitats and the effects of commercial fishing

(Williams et al. 2012). There are significant challenges associated with automatically processing underwater imagery, but new methodology is continually being developed for the purposes of identifying, counting, sizing, and tracking the movements of aquatic organisms (Liu et al. 2007, Gerami et al. 2015, Hao et al. 2016).

Acoustic telemetry involves sound-emitting devices that are attached to or surgically implanted into an animal for the purposes of monitoring of their movements using a network of hydrophone receivers. Many of these receivers, although deployed by individual research groups, are part of a larger, integrated network such as the Ocean Tracking Network that allows the tracking of animals at the national or global scale. Such technology has important applications as a non-invasive tool to study the animal movements, distributions and habitat use, particularly for migratory or pelagic species. On the Reef, the Integrated Marine Observing System (IMOS) Animal Tracking Facility has three permanent receiver arrays deployed at locations near the Heron Island, One Tree Island and Orpheus Island research stations.

Recommendations for integrated monitoring of fishery systems on the Great Barrier Reef

Utilisation of DAF monitoring and assessment programs

Building on previous work under RIMReP, the Fisheries Expert Group identified a set of existing programs that are critical for the monitoring and assessment of fisheries on the Reef and for meeting targets, objectives and outcomes listed in the Reef 2050 Plan. Of these monitoring and assessment programs, several are directly managed by DAF with a significant amount of committed funding. To ensure that pre-existing investments are fully exploited and RIMReP monitoring efforts are optimised, it is recommended that Reef managers utilise existing DAF programs to monitor fisheries on the Reef, track progress against relevant Reef 2050 milestones and directly inform the design of RIMReP (Table 10). Although the core function of these programs will continue to be informing fisheries management, there may be co-investment opportunities with external organisations to enhance existing DAF programs, allowing the collection of additional data (e.g. more species, greater spatial coverage, previously unmeasured attributes) and increasing the comprehensiveness and regularity of assessment outputs.

Publicly reporting on the status of Queensland's fisheries is an important aspect of managing fisheries on behalf of the Queensland community and much of this information is publicly available through the DAF website (https://www.daf.qld.gov.au/), including:

- results of recreational fishing surveys and biological monitoring of fish species
- information on the stock status assessment framework and processes

- information about the importance of stock assessments and links to stock assessment reports
- links to progress reports against the Department of the Environment conditions and recommendations by fishery
- links to ecological risk assessment reports
- the Queensland Fisheries Summary Report, which provides catch and effort information for each of Queensland's fisheries
- QFish (http://qfish.fisheries.qld.gov.au/), an interactive data portal which provides data on Queensland's Shark Control Program and commercial, charter and recreational fisheries
- FishNet (https://fishnet.fisheries.qld.gov.au/), a web-based service that provides information on Queensland fishing authorities (details on licences, quotas and permits).

Fisheries Queensland is also in the process of developing a publicly accessible digital dashboard, which will summarise and visualise over 25 years of fisheries information from various monitoring and assessment programs through an interactive and integrated electronic interface.

Requests for information not available through the above avenues or any enquiries regarding the data can be directed to fishdatacoordinator@daf.qld.gov.au. The release of any information must be in accordance with the principles of the *Information Privacy Act 2009*. As such, fisheries information originating from less than five licences will not be released to third parties, unless it is a summary of the fishery at an annual scale and with no spatial information (i.e. whole of Queensland).

TABLE 10: Recommended utilisation of DAF monitoring and assessment programs to monitor fishery systems on the Reef.

Priority indicator	Relevant Reef 2050 targets	DAF monitoring/ assessment program	Location[1]	Frequency
Aboriginal & TSI customary fishing	BT1, BT3, EHT4, EBT3, EBT5	Licensing	CY, WT, B, MW, F, BM	Daily
		Economic and social surveys	CY, WT, B, MW, F, BM	Variable
Biomass ratios	BT5	Stock assessments	CY, WT, B, MW, F, BM	Every 5 to 10 years[2]
Compliance statistics	EHT4	Logbook program	CY, WT, B, MW, F, BM	Daily
		Quota monitoring system	CY, WT, B, MW, F, BM	Daily
		Vessel tracking	CY, WT, B, MW, F, BM	Near real-time

		Licensing	CY, WT, B, MW, F, BM	Daily
		Field compliance monitoring	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic
Discarded catch (excluding species of conservation interest)	EHT4	Logbook program	CY, WT, B, MW, F, BM	Daily
		Recreational catch sampling	CY, WT, B, MW, F, BM	Variable
		State-wide recreational fishing surveys	CY, WT, B, MW, F, BM	Every 1 to 5 years
Ecological risk categories	EHT4	Ecological risk assessments	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic[3]
Fishing effort & retained catch – commercial, charter & recreational sectors	CBT2, CBT4, EHT4, EBT3, EBT5	Logbook program	CY, WT, B, MW, F, BM	Daily
		Quota monitoring system	CY, WT, B, MW, F, BM	Daily
		Vessel tracking	CY, WT, B, MW, F, BM	Near real-time
		Licensing	CY, WT, B, MW, F, BM	Daily
Natural/fishing mortality	EBT3	Stock assessments	CY, WT, B, MW, F, BM	Every 5 to 10 years[2]
		Fisheries and aquaculture RD&E	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic
Recruitment indices	BT5	Stock assessments	CY, WT, B, MW, F, BM	Every 5 to 10 years[2]
		Fisheries and aquaculture RD&E	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic
SCP impacts	BT3, EHT4	Shark Control Program	CY, WT, B, MW, F, BM	Every 1 to 3 days
Socio-economic data	CBT2, CBT4, EBT3, EBT5, EBT6	Logbook program	CY, WT, B, MW, F, BM	Daily
		Quota monitoring system	CY, WT, B, MW, F, BM	Daily
		Vessel tracking	CY, WT, B, MW, F, BM	Near real-time
		Licensing	CY, WT, B, MW, F, BM	Daily
		Field compliance monitoring	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic
		State-wide recreational fishing surveys	CY, WT, B, MW, F, BM	Every 5 to 10 years[2]
		Economic and social surveys	CY, WT, B, MW, F, BM	Variable
Species biology (age, length and sex) and abundance	BT5	Commercial catch sampling	CY, WT, B, MW, F, BM	Daily
		Recreational catch sampling	CY, WT, B, MW, F, BM	Daily
		Fishery-independent surveys	F, BM	Annual

SOCI interactions	BT3, EHT4	Logbook program	CY, WT, B, MW, F, BM	Daily
		Shark Control Program	WT, B, MW, F, BM	Every 1 to 3 days
Standardised catch rates	BT5	Stock assessments	CY, WT, B, MW, F, BM	Every 5 to 10 years[2]
		Fisheries and aquaculture RD&E	CY, WT, B, MW, F, BM	Ad-hoc/ opportunistic
Status of fish stocks	BT5	Stock status assessments	CY, WT, B, MW, F, BM	Annual or biennial

[1]NRM regions: CY = Cape York, WT = Wet Tropics, B = Burdekin, F = Fitzroy and BM = Burnett Mary
[2]Increasing to annual outputs with the development of a rapid assessment program
[3]More regular outputs as a systematic process is implemented

Linkages, information exchange and integrated monitoring with other RIMReP Expert Groups

Following the two RIMReP integration workshops led by AIMS, the Fisheries Expert Group hosted a two-day workshop and several meetings with other RIMReP Expert Groups to find gaps in current monitoring, recognise and exploit linkages between groups, confirm information exchange and identify opportunities to integrate and optimise monitoring efforts. Key outcomes from these discussions are summarised in **Error! Reference source not found.**.

TABLE 11: Key outcomes from the RIMReP Fisheries Theme Workshop and pre-workshop meetings.

RIMReP Expert Group(s)	Key outcomes
Megafauna	**Linkages identified between RIMReP Expert Groups** • A number of DAF programs were identified as relevant to megafauna monitoring, including ERAs, logbooks, vessel tracking, quota monitoring, field compliance monitoring, fishery-independent surveys, recreational catch sampling, state-wide recreational fishing surveys, the Shark Control Program and the proposed shark monitoring program. – In particular, ERAs will benefit from receiving data from the other megafauna monitoring programs under RIMReP and, feeding back into such programs, the ERA outputs will provide valuable information on the risks of fishing for megafauna populations. – In addition to the monitoring design recommended by the Megafauna Expert Group, monitoring of megafauna (e.g. large, endangered sharks, cetaceans, dugongs, turtles, etc.) abundance and distribution (e.g. acoustic/satellite tags, citizen science; aerial/drone surveys) will need to occur across all NRM regions on the Reef and in near real-time to align with fisheries management needs. • Indigenous fishing was recognised as an important component of megafauna monitoring but also a significant gap in current monitoring efforts.

	• Key linkages were identified between fisheries and seabirds with evidence that fishery dynamics influence seabird foraging patterns and vice versa. In particular, seabird data may address gaps in current DAF monitoring (e.g. limited bird component in current ERAs, limited data on baitfish).
	Recommendations for the Fisheries Expert Group • Provide logbook data on SOCI interactions to support megafauna monitoring with independent validation of the data using automated on-board camera systems, gear sensors and/or vessel tracking. • Investigate QBFP body cameras and Authority compliance monitoring as a potential data source for megafauna monitoring, addressing issues of data-sharing due to confidentiality. • Coordinate with Reef managers to creative a positive narrative surrounding the collection and use of megafauna data, focussing on stories such as the recovery of turtles following the introduction of turtle exclusion devices (TEDs). • Consider the expansion of the state-wide recreational fishing surveys to collect data on megafauna, particularly winghead sharks, dolphins and narrow sawfish. • Consider the expansion of the Shark Control Program to include necropsies and collect skin samples. • Consider approaches to validate Shark Control Program data such as mandatory photographs of captured animals, use of an electronic reporting app and training staff in species identification. • Establish a two-way information exchange with seabird researchers to exploit linkages between fisheries and seabird foraging patterns and support stock assessments, ecological risk assessments and seabird research. • Establish an exchange of information on other megafauna such as turtles, cetaceans and dugongs to support ecological risk assessments and satisfy other information needs.
Coral Reefs	**Linkages identified between RIMReP Expert Groups** • AIMS visual census fish data was recognised as a valuable resource for fisheries management, providing an absolute measure of reef fish abundance that has been utilised in DAF stock assessments and may have further applications in validating logbook-derived catch rates and as an input in stock status assessments and ERAs. High-level outputs from these assessments could then feed back into other RIMReP monitoring and assessment programs. – Habitat data (i.e. coral cover) collected through the AIMS surveys may have similar applications in DAF modelling. • DAF commercial catch data was recognised to have the potential to inform ecosystem models, the assessment of blue/green zones in the Marine Park and give context to other coral reef monitoring data. • Reef Check monitoring data was identified as a potentially useful source of data for fisheries management, particularly regarding sea cucumber abundance on reefs.
	Recommendations for the Fisheries Expert Group

	• Establish a two-way information exchange with the Coral Reefs Expert Group to validate commercial catch, support existing assessment programs and satisfy other information needs (e.g. ecological risk assessments, stock status assessments, stock assessments, comparison of blue/green zones) – in particular, compiling a list of target species to information patenting data-sharing between DAF and AIMS. • Coordinate with the Coral Reefs Expert Group to ensure that the monitoring of fish species across both Expert Groups is comparable, complementary and optimised with little or no redundancy. • Establish an exchange of marine physico-chemical data to support existing assessment programs (e.g. ecological risk assessments, stock status assessments and stock assessments).
Marine Physico-Chemical	**Linkages identified between RIMReP Expert Groups** • Environmental data from the Marine Physico-Chemical Expert Group was recognised as a valuable input for a number of DAF programs, including stock assessments, stock status assessments and ERAs. High-level outputs from these assessments could then feed back into other RIMReP monitoring and assessment programs.
	Recommendations for the Fisheries Expert Group • Establish an exchange of marine physico-chemical data to support existing assessment programs (e.g. ecological risk assessments, stock status assessments and stock assessments).
Indigenous Heritage, Human Dimensions	**Linkages identified between RIMReP Expert Groups** • Links were identified between fisheries data and the Human Dimensions Expert Group: – Effectiveness of stewardship activities/regulations/governance arrangements that reduce discarded catch or are associated with spawning aggregations, incidental catch of SOCI, illegal fishing and poaching or the extraction of herbivores/predators. – Compliance with regulations regarding discarded catch, incidental catch of SOCI, illegal fishing and poaching, spawning aggregations or the extraction of predators. • Links were identified between proposed human dimensions indicators and the Fisheries Expert Group, including indicators for aspirations, capacity and stewardship, community vitality, culture and heritage, economic viability and governance. • Many areas of alignment were identified between the sampling effort and survey questions of the DAF state-wide recreational fishing surveys and SELTMP. • Links were identified between the Fisheries and Indigenous Heritage Expert Groups, particularly regarding the streamlining of Traditional Owner engagement.
	Recommendations for the Fisheries Expert Group

	• Review legislative and regulatory frameworks to better define Indigenous fishing rights and align with Indigenous custodian and stewardship values. • Address ethics and data privacy concerns and continue to support the appropriate sharing and handling of cultural information, following Australian Privacy Principles and Indigenous Heritage Intellectual Property Rights. • Develop an integrated consultation plan that will consider Indigenous Heritage values, minimise consultation fatigue and ensure data agreements are symmetrical and feed back into Indigenous communities. • Establish an Indigenous Working Group as part of the Sustainable Fisheries Strategy 2017-2017. • Review and build on engagement strategies of other key organisations (e.g. the Authority, AIMS, TropWATER and DES), recognising that such strategies will vary depending on the individual needs of targeted communities. • Establish a two-way exchange of socio-economic data with the Human Dimensions Expert Group. • Coordinate with the Human Dimensions Expert Group to ensure that the socio-economic monitoring across both Expert Groups is complementary and optimised with little or no redundancy and to collaborate on surveys where appropriate.
*Seagrass**	**Linkages identified between RIMReP Expert Groups** • Seagrass habitat data (extent and condition) was recognised as a key information need for monitoring fisheries and as a valuable input for several DAF programs, including stock assessments, stock status assessments, ERA and Impact Assessment and Management. High-level outputs from these assessments could then feed back into other RIMReP monitoring and assessment programs. – In addition to the monitoring design recommended by the Seagrass Estuaries Expert Group, monitoring of seagrass condition and extent (e.g. field surveys, aerial mapping) will need to occur across all NRM regions on the Reef and at a minimum of every two years to align with fisheries management needs. • BRUVS was recognised as a potential tool for monitoring fish on seagrass habitats and better understanding the relationship between seagrass condition and fish assemblages. • Data on the extraction of herbivores was recognised as relevant to the Seagrass Expert Group.
*Catchments and Estuaries**	**Linkages identified between RIMReP Expert Groups** • Data collected through the Paddock to Reef Program was identified as valuable to fisheries management, including trends in water quality (e.g. sedimentation, nutrients, pesticides, turbidity) and the condition and extent of mangrove habitats. – In addition to the monitoring design recommended by the Catchments and Estuaries Expert Group, monitoring of mangrove condition and extent (e.g. field surveys, aerial mapping) will need to occur across all NRM regions on the Reef and at a minimum of every two years to align with fisheries management needs.

**No recommendations for the Fisheries Expert Group provided*

Additional monitoring to address remaining gaps

Gaps in current fisheries monitoring on the Reef will largely be addressed through reforms under the Sustainable Fisheries Strategy 2017 – 2027, monitoring efforts proposed by other RIMReP Expert Groups and actions recommended by the RIMReP Fisheries Theme Workshop. However, some major gaps remain unaddressed and will require the implementation of additional monitoring activities (see recommendations in Table 12 and the associated resource requirements in **Error! Reference source not found.**).

TABLE 12: Recommendations for additional monitoring to address major, unresolved gaps.

Priority indicator	Sub-indicators	Method	Location	Frequency
Spawning aggregation characteristics	Location of spawning site	*Discovery* • Fisher interview surveys[1] • Analysis of spatial trends in fishing effort & catch (e.g. DAF logbook data) *Verification* • Acoustic surveys (echosounders) • UVC surveys	Interviews and exploratory data analysis covering all NRM regions; acoustic and UVC surveys at suspected spawning sites	Ad-hoc/ opportunistic
	Counts & size of fish, seasonality & time of spawning	• UVC surveys	Determined by location of spawning sites	Annual
	Sex ratio, age-length frequency, population structure, migratory patterns, diet composition	• Commercial/charter/recreational catch (fishery-dependent) sampling • Fishery-independent sampling • Analysis of biological samples (e.g. gonads, otoliths, gut contents, DNA)	Determined by location of spawning sites	Annual
Species biology & abundance – sea cucumbers	Counts of sea cucumbers, habitat preference	• UVC surveys (belt transect) • Underwater camera surveys[2]	Representative subset of sea cucumber habitats within each NRM region	Annual
Species biology & abundance – deep water habitats (>30m)	Counts & size of fish, counts of macro-invertebrates, habitat preference	• BRUVS surveys	Representative subset of deep water habitats within each NRM region	Annual
Species biology & abundance – inter-reefal habitats	Counts & size of fish, counts of mobile & sessile macro-invertebrates, habitat preference	• BRUVS surveys	Representative subset of inter-reefal habitats within each NRM region	Annual
Species biology & abundance – inshore habitats (non-reef)	Counts & size of fish, counts of macro-invertebrates, habitat preference	• BRUVS surveys	Representative subset of inshore habitats within each NRM region	Annual

[1]Including interviews of dive operators, dive guides, tropical fish collectors and others who spend a lot of time on/in the water
[2]Cameras mounted on commercial fishing vessels

Overview of recommended monitoring design

TABLE 13: Overview of the recommended monitoring design including the maintenance or expansion of existing programs and the implementation of novel programs.

Type[1]	Program (and organisation)	Priority indicators	Method	Frequency	Location[2]	Other monitoring details
U	Aquaculture production surveys (DAF)	Aquaculture production	Compulsory mail surveys	Annual	CY, WT, B, MW, F, BM	
E	Commercial catch sampling (DAF)[3]	Species biology & abundance	Voluntary donations of biological samples	Daily	CY, WT, B, MW, F, BM	Biological data collected on additional species and locations and at a higher frequency
E	Ecological risk assessments (DAF)[3]	Ecological risk categories	Quantitative/qualitative analysis	Every 1 to 3 years	CY, WT, B, MW, F, BM	Additional data made available for input into assessments
E	Economic and social surveys (DAF)[3]	Socio-economic; Aboriginal & TSI customary fishing	Boat ramp and roving surveys; telephone-diary surveys; additional methods yet to be determined	Variable	CY, WT, B, MW, F, BM	Additional socio-economic data collected (specifics yet to be determined)
U	Eye on the Reef program (the Authority)	Species biology & abundance	Volunteer submission of sightings; volunteer underwater surveys (amateur & professional)	Variable	CY, WT, B, MW, F, BM	
U	Field compliance monitoring (various)	Compliance; socio-economic data	Intelligence and information gathering; investigation and surveillance operations; patrols and inspections	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM	
E	Fish spawning aggregation monitoring (the Authority)	Species biology & abundance; fishing effort & retained catch	Fisher interview surveys; analysis of spatial trends in fishing effort and catch; acoustic surveys; UVC surveys; catch sampling; fishery-independent sampling; analysis of biological samples	Annual	CY, WT, B, MW, F, BM	Biological, abundance and fishing (catch & effort) data collected on additional species
U	Fisheries and aquaculture RD&E (various)	Biomass ratios; natural/fishing mortality; recruitment indices; standardised catch rates; fishing power estimates; other RD&E outputs	Various	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM	
E	Fishery-independent surveys (DAF)[3]	Species biology & abundance	Fishery-independent sampling	Annual	CY, WT, B, MW, F, BM	Biological and abundance data collected on additional species
I	Fishery-independent surveys of deep water habitats (?)	Species biology & abundance	BRUVS surveys	Annual	CY, WT, B, MW, F, BM	

I	Fishery-independent surveys of inter-reefal habitats (?)	Species biology & abundance	BRUVS surveys	Annual	CY, WT, B, MW, F, BM	
I	Fishery-independent surveys of non-reef, inshore habitats (?)	Species biology & abundance	BRUVS surveys	Annual	CY, WT, B, MW, F, BM	
U	Freshwater fish stocking (DAF)	Fish stocking data	General record keeping of stocking through the Stocking Impoundment Permit Scheme (SIPS)	Ad-hoc/ opportunistic	WT, B, MW, F, BM	
U	Impact Assessment and Management (DAF)	Developments in fish habitats	Case-by-case assessments	Ad-hoc/ opportunistic	CY, WT, B, MW, F, BM	
U	Licensing (DAF)	Fishing effort; compliance statistics; socio-economic data; Aboriginal & TSI customary fishing	General record keeping of details and transactions of fishing authorities, permits and symbols	Daily	CY, WT, B, MW, F, BM	
U	Logbook program (DAF)	Fishing effort & retained catch; discarded catch; SOCI interactions; socio-economic data; compliance statistics	Compulsory logbooks	Daily	CY, WT, B, MW, F, BM	
U	Long-term monitoring program (AIMS)	Species biology & abundance	Underwater visual census (UVC) surveys	Biennial	CY, WT, B, MW, F, BM	
U	NERP Project 8.2 – effects of marine park zoning (JCU/AIMS)	Species biology & abundance	BRUVS surveys; UVC surveys	Annual	WT, B, MW, F, BM	
U	Quota Monitoring System (DAF)	Retained catch; socio-economic data; compliance statistics	Automated interactive voice response (AIVR) system	Daily	CY, WT, B, MW, F, BM	
E	Recreational catch sampling (DAF)[3]	Species biology & abundance; retained catch; discarded catch	Voluntary donations of biological samples; boat ramp and roving surveys	Variable	CY, WT, B, MW, F, BM	Biological and fishing (catch & effort) data collected on additional species; boat ramp and roving surveys expanded to cover additional locations
I	Sea cucumber abundance surveys (?)	Species biology & abundance	Underwater visual census (UVC) surveys; vessel-mounted, underwater camera surveys	Annual	CY, WT, B, MW, F, BM	

E	Shark Control Program (DAF)	Shark Control Program impacts; SOCI interactions	General record keeping of animals captured by baited drumlines and large mesh nets	Every 1 to 3 days	WT, B, MW, F, BM	Additional biological data collected from skin samples and necropsies; mandatory photographs of captured animals; additional training in species identification
E	State-wide recreational fishing surveys (DAF)	Fishing effort & retained catch; discarded catch; socio-economic data	Telephone-diary surveys	Annual	CY, WT, B, MW, F, BM	Additional socio-economic data collected (specifics yet to be determined)
E	Stock assessments (DAF)[3]	Biomass ratios; natural/fishing mortality; recruitment indices; standardised catch rates	Quantitative analysis	Every 1 to 3 years	CY, WT, B, MW, F, BM	Additional data made available for input into assessments
U	Stock status assessments (DAF)	Status of fish stocks	Weight-of-evidence approach	Annual or biennial	CY, WT, B, MW, F, BM	
U	StrandNet (DES)	SOCI interactions	Reports of marine wildlife strandings and deaths	Ad-hoc/ opportunistic	WT, B, MW, F, BM	
U	Vessel tracking (DAF)	Fishing effort; compliance statistics; socio-economic data	Satellite tracking	Near real-time	CY, WT, B, MW, F, BM	

[1]U = utilisation of existing programs with no changes or additional funding required; E = expansion or maintenance of existing programs requiring additional funding from RIMReP; I = implementation of novel programs requiring additional funding from RIMReP
[2]Natural Resource Management (NRM) regions: CY = Cape York, WT = Wet Tropics, B = Burdekin, F = Fitzroy and BM = Burnett Mary
[3]Note that currently some elements of these DAF programs are only funded until July 2020 through the Sustainable Fisheries Strategy 2017 – 2027; RIMReP will need to provide funding to preserve monitoring at current state

Assessment of the resources required to implement the recommended design

The resources required to implement the recommended monitoring design (excluding existing programs with no requirement for additional funding/resources) have not been estimated as these are contingent on integration with other monitoring themes.

References

Addison, P., Walshe, T., Sweatman, H., Jonker, M., Anthony, K., MacNeil, A., Thompson, A., Logan, M. 2015, Towards an integrated monitoring program: Identifying indicators and existing monitoring programs to effectively evaluate the Long-Term Sustainability Plan, Reef and Rainforest Research Centre Limited, Cairns.

Bastos Gomes, G., Hutson, K. S., Domingos, J. A., Chung, C., Hayward, S., Miller, T. L., Jerry D.R. 2017, Use of environmental DNA (eDNA) and water quality data to predict protozoan parasites outbreaks in fish farms, Aquaculture, 479:467–473.

Benoit, H., Allard, J. 2009, Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards?, Canadian Journal of Fisheries and Aquacultural Science, 66:2025–2039.

Boaden A. E., Kingsford, M. J. 2015, Predators drive community structure in coral reef fish assemblages, Ecosphere, 6:46.

Bollinger, M.A. 2017, Validating Sidescan Sonar as a Fish Survey Tool over Artificial Reefs, Journal of Coastal Research, 33:1397–1407.

Bruce, B., Bradford, R., Bravington, M., Feutry, P., Grewe, P., Gunasekera, R., Harasti, D., Hillary, R., Patterson, T. 2018, A national assessment of the status of white sharks. National Environmental Science Programme, Marine Biodiversity Hub, CSIRO.

Bryant, D., Burke, L., McManus, J., Spalding, M. 1998, Reefs at risk: a map-based indicator of threats to the world's coral reefs, World Resources Institute, Washington D.C.

Buckley, S. M., Thurstan, R. H., Tobin, A., Pandolfi, J.M. 2017, Historical spatial reconstruction of a spawning-aggregation fishery, Conservation Biology, 31:1322–1332.

Campbell, S. J., Pardede, S. T. 2006, Reef fish structure and cascading effects in response to artisanal fishing pressure, Fisheries Research, 79:75-83.

Carpenter, S., Mooney, H., Agard, J. 2009, Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment, Proceedings of the National Academy of Sciences of the United States of America, 106.

Colin, P., Sadovy, Y., Domeier, M. 2003, Manual for the Study and Conservation of Reef Fish Spawning Aggregations, Society for the Conservation of Reef Fish Aggregations.

Commonwealth of Australia. 2015, Reef 2050 Long-Term Sustainability Plan, Australian Government, Canberra.

Donohue, M. J., Boland, R. C., Sramek, C. M., Antonelis, G. A. 2001, Derelict fishing gear in the northwestern Haiwaiian Islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. *Marine Pollution Bulletin*, 42:1301-1312.

Dulvy, N. K., Freckleton, R. P., Polunin, V. C. 2004, Coral reef cascades and the indirect effects of predator removal by exploitation, Ecology Letters, 7:410-416.

Evans, N. T., Lamberti, G. A. 2018, Freshwater fisheries assessment using environmental DNA: A primer on the method, its potential, and shortcomings as a conservation tool, Fisheries Research, 197:60–66.

Faunce, C. Barbeaux, S. 2011, The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer, ICES Journal of Marine Science, 68.

Fernandes, P. G., Stevenson, P., Andrew, S. 2014, AUVs as research vessels: the pros and

cons, ICES CM2002/J:02:11.

Floeter, S. R., Ferreira, C. E. L., Dominici-Arosemena, A., Zalmon, I. 2004, Latitudinal gradients in Atlantic reef fish communities: trophic structure and spatial use patterns, J. Fish Biol., 64:1680-1699.

Friedlander, A. M., DeMartini, E. E. 2002, Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators, Marine Ecology Progress Series, 230:253-264.

Graham, N. A. J., McClanahan, T. R., MacNeil, M. A., Wilson, S. K., Cinner, J. E., Huchery, C., Holmes, T. H. 2017, Human Disruption of Coral Reef Trophic Structure, Current Biology, 27: 231-236.

Great Barrier Reef Marine Park Authority. 2014, Great Barrier Reef Outlook Report 2014, Commonwealth of Australia, Townsville.

Gerami, M. H., Safiyari, H., Jafari, A., Mousavi Nasab, M. 2015, Application of Machine-vision to assess weight of fish (Case study: Oncorhynchus mykiss), Iranian Journal of Fisheries Science, 15:575-584.

Gilman, E. 2015, Status of international monitoring and management of abandoned, lost and discarded fishing gear and ghost fishing, Marine Policy, 60:225-239.

Girard, P., Du Payrat, T. 2017, An inventory of new technologies in fisheries, Green Growth and Sustainable Development Forum, OECD, Paris.

Grasty, S. E. 2014, Use of a Towed Camera System for Estimating Reef Fish Populations Densities on the West Florida Shelf, MS thesis, University of South Florida, Tampa.

Guillemot, N., Chabanet, P., Kulbicki, M., Vigliola, L., Leopold, M., Jollit, I., Le Pape, O. 2014, Effects of fishing on fish assemblages in a coral reef ecosystem: Fromfunctional response to potential indicators, Ecological Indicators, 43:227-235.

Hao, M., Yu, H., Li, D. 2016, The Measurement of Fish Size by Machine Vision - A Review, Computer and Computing Technologies in Agriculture IX: 9th IFIP WG 5.14 International Conference, CCTA 2015, Beijing, China.

Hedge, P., Molloy, F., Sweatman, H., Hayes, K., Dambacher, J., Lawrence, E., Kroon, F. 2013, An integrated monitoring framework for the Great Barrier Reef World Heritage Area, Department of the Environment, Canberra.

Henry, G. W., Lyle, J. M. 2003, The National Recreational and Indigenous Fishing Survey, NSW Fisheries, Cronulla.

Hillary, R. M., Bravington, M. V., Patterson, T. A., Grewe, P., Bradford, R., Feutry, P., Gunasekera, R., Peddemors, V., Werry, J., Francis, M. P., Duffy, C. A. J., Bruce, B. D. 2018, Genetic relatedness reveals total population size of white sharks in eastern Australia and New Zealand, Scientific Reports, 8.

Hughes, T. P., Connell, J. H., The, P., Stressors, M. 1999, Multiple stressors on coral reefs : A long-term perspective, Limnology and Oceanography, 44:932–940.

Hughes, T. P., Rodrigues, M. J., Bellow, D. R., Caccarelli, D., Hoegh-Guldberg, O., McCook, L., Moltschaniwskyj, N., Pratchett, M. S., Steneck, R. S., Willis, B. 2007, Phase shifts, herbivory, and the resilience of coral reefs toclimate change, Current Biology, 17:1-6.

Jennings, S., Polunin, N. V. C. 1997, Impacts of predator depletion by fishing on the biomass and diversity of non-target reef fish communities, Coral Reefs, 16:71-82.

Laborde, S., Fernández, A., Phang, S. C., Hamilton, I. M., Henry, N., Jung, H. C., Mahamat, A., Ahmadou, M., Labara, B. K., Kari, S., Durand, M., Mark, B., Scholte, P., Xiao, N., Ziebe, R., Moritz, M. 2016, Social-ecological feedbacks lead to unsustainable lock-in in an inland fishery, Global Environmental Change, 41:13–25.

Langlois, T. J., Harvey, E. S., Fitzpatrick, B., Meeuwig, J. J., Shedrawi, G., Watson, D. L. 2010, Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects, Aquatic Biology, 9:155-168.

Leigh, G. M., Campbell, A. B., Lunow, C. P., O'Neill, M. F. 2014, Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery, Technical Report, Queensland Department of Agriculture, Fisheries and Forestry, Brisbane.

Liu, J., Dietz, T., Carpenter, S., Alberti, M., Folke, C., Moran, E., Pell, A., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C., Schneider, S., Taylor, W. 2007, Complexity of coupled human and natural systems, Science 317:1513–1516.

Mackie, M. C. 2009, Management and Monitoring of Fish Spawning Aggregations within the West Coast Bioregion of Western Australia, Final FRDC Report – Project Number 2004/051, Department of Fisheries, Western Australia.

MacLennan, D., Simmonds, J. 2005, Fisheries Acoustics: Theory and Practice, 2nd edition, Blackwell Science, Oxford.

Malekmohammadi, B., Jahanishakib, F. 2017, Vulnerability assessment of wetland landscape ecosystem services using driver-pressure-state-impact-response (DPSIR) model, Ecological Indicators, 82:293–303.

Martins, J. H., Camanho, A. S., Gaspar, M. B. 2012, A review of the application of driving forces - Pressure - State - Impact - Response framework to fisheries management, Ocean and Coastal Management, 69:273–281.

McAuley, R. B., Bruce, B. D., Keay, I. S., Mountford, S., Pinnell, T., Whoriskey, F. G. 2017, Broad-scale coastal movements of white sharks off Western Australia described by passive acoustic telemetry data, Marine and Freshwater Research, 68:1518–1531.

McCluskey, S. M., Lewison, R. L. 2008, Quantifying fishing effort: A synthesis of current methods and their applications, Fish and Fisheries, 9:188–200.

Mora, C., Aburto-Oropeza, O., Ayala Bocos, A., Ayotte, P. M., Banks, S., Bauman, A. G., Beger, M., Bessudo, S., Booth, D. J., Brokovich, E., Brooks, A., Chabanet, P., Cinner, J. E., Cortés, J., Cruz-Motta, J. J., Magaña, A. C., DeMartini, E. E., Edgar, G. J. Feary, D. A., Ferse, S. A. C., Friedlander, A. M., Gaston, K. J., Gough, C., Graham, N. A. J., Green, A., Guzman, H., Hardt, M., Kulbicki, M., Letourneur, Y., Pérez, A. L., Loreau, M., Loya, Y., Martinez, C., Mascareñas-Osorio, I. Morove, T., Nadon, M., Nakamura, Y., Paredes, G., Polunin, N. V. C., Pratchett, M. S., Bonilla, H. R., Rivera, F., Sala, E., Sandin, S. A., Soler, G., Stuart-Smith, R., Tessier, E., Tittensor, D. P., Tupper, M., Usseglio, P., Vigliola, L., Wantiez, L., Williams, I., Wilson, S. K, Zapata, F. A. 2011, Global Human Footprint on the Linkage between Biodiversity and Ecosystem Functioning in Reef Fishes, PLoS Biol., 9: e1000606.

Mumby, P. J., Hastings, A., Edwards, H. J. 2007, Thresholds and the resilience of Caribbean coral reefs, Nature, 450:98–101.

Nanola, C. L., Alino, P. M., Carpenter, K. E. 2011, Exploitation-related reef fish species richness depletion in the epicenter of marine biodiversity, Environmental Biology of Fishes, 90:405-

420.

O'Mahony, J., Simes, R., Redhill, D., Heaton, K., Atkinson, C., Hayward, E., Nguyen, M. 2017. The economic, social and icon value of the Great Barrier Reef, Deloitte Access Economics, Brisbane.

Pace, M. L., Cole, J. J., Carpenter, S. R., Kitchell, J.F. 1999, Trophic cascades revealed in diverse ecosystems, Trends Ecol. Evol., 14:483-488.

Patterson, K., Melvin, V. 1996, Integrated catch-at-age analysis, Version 1., Scottish Fisheries Research Report, 58.

Pet-Soede, C., Van Densen, W. L. T., Hiddink, J. G., Kuyl, S., Machiels, M. A. M. 2001, Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia, Fisheries Management and Ecology, 8:15-36.

Polunin, N. V. C., Roberts, C. M. 1993, Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves, Marine Ecology Progress Series, 100:167-176.

Russell, M., Pears, R. 2007, Workshop Summary: Management and Science of Fish Spawning Aggregations in the Great Barrier Reef Marine Park, 12-13 July 2007, Great Barrier Reef Marine Park Authority, Townsville.

Samoilys, M. A., Squire, L. C. 1994, Preliminary Observations on the Spawning Behavior of Coral Trout, Plectropomus Leopardus (Pisces: Serranidae), on the Great Barrier Reef, Bulletin of Marine Science, 54:332–342.

Selbe, S. 2014, Monitoring and Surveillance Technologies for Fisheries, Waitt Institute, Washington DC.

Smale, D., Kendrick, G., Harvey, E., Langlois, T., Hovey, R., Van Niel, K., Waddington, K., Bellchambers, L., Pember, M., Babcock, R., Vanderklift, M., Thomson, D., Jakuba, M., Pizarro, O., Williams, S. 2012, Regional-scale benthic monitoring for ecosystem-based fisheries management (EBFM) using an autonomous underwater vehicle (AUV), 69:1108–1118.

de Souza, E., Boerder, K., Matwin, S., Worm, B. 2016, Improving fishing pattern detection from satellite AIS using data mining and machine learning, PLoS ONE, 11.

Tillotson, M. D., Kelly, R. P., Duda, J. J., Hoy, M., Kralj, J., Quinn, T. P. 2018, Concentrations of environmental DNA (eDNA) reflect spawning salmon abundance at fine spatial and temporal scales, Biological Conservation, 220:1–11.

Tobin, A., Heupel, M., Simpfendorfer, C., Pandolfi, J., Thurstan, R., Buckley, S. 2014a, Utilising innovative technology to better understand Spanish mackerel spawning aggregations and the protection offered by marine protected areas, Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville.

Tobin, R., Bohensky, E., Curnock, M., Goldberg, J., Gooch, M., Marshall, N., Nicotra, B., Pert, P., Scherl, L., Stone-Jovicich, S. 2014b, The Social and Economic Long-Term Monitoring Program (SELTMP) 2014, Commercial Fishing in the Great Barrier Reef, Cairns.

Trivedi, S., Aloufi, A. A., Ansari, A. A., Ghosh, S. K. 2016, Role of DNA barcoding in marine biodiversity assessment and conservation: An update, Saudi Journal of Biological Sciences, 23:161–171.

Wang, H. Y., Dong, C. A., Lin, H. C. 2017, DNA barcoding of fisheries catch to reveal composition and distribution of cutlassfishes along the Taiwan coast, Fisheries Research, 187:103–109.

Webley, J., McInnes, K., Teixeira, D., Lawson, A., Quinn, R. 2015, Statewide Recreational Fishing Survey 2013-14, Department of Agriculture and Fisheries, Brisbane.

Williams, K., Rooper, C., Harms, J. 2012, Report of the National Marine Fisheries Service Automated Image Processing Workshop, U.S. Department of Commerce, Seattle.

Wooldridge, S. A., Brodie, J. E. 2015, Environmental triggers for primary outbreaks of crown-of-thorns starfish on the Great Barrier Reef, Australia, Marine Pollution Bulletin, 101:805-815.

Yamanaka, H., Minamoto, T. 2016, The use of environmental DNA of fishes as an efficient method of determining habitat connectivity, Ecological Indicators, 62:147–153.

Zeller, D. C. 1998, Spawning aggregations: Patterns of movement of the coral trout Plectropomus leopardus (Serranidae) as determined by ultrasonic telemetry, Marine Ecology Progress Series, 162:253–263.

Zenone, A. M., Burkepile, D. E., Boswell, K. M. 2017, A comparison of diver vs. acoustic methodologies for surveying fishes in a shallow water coral reef ecosystem, Fisheries Research 189:62–66.

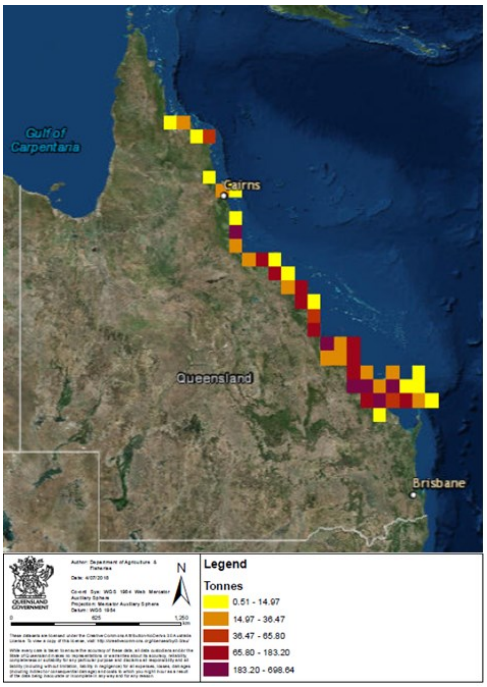
Appendices

APPENDIX 1: Threats to the Great Barrier Reef Region's values as listed in the Great Barrier Reef Outlook Report 2014 (Great Barrier Reef Marine Park Authority)

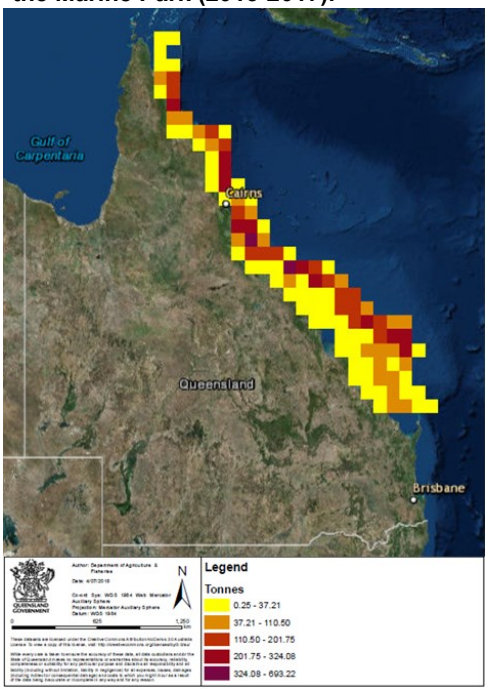
Outlook Report 2014 (41 threats)
Acid sulphate soils: Exposure of acid sulphate soils
Altered ocean currents: Climate change induced altered ocean currents
Altered weather patterns: Climate change effects on weather patterns (e.g. cyclones, wind, rainfall, air temperature)
Artificial light: Artificial lighting including from resorts, industrial infrastructure, mainland beaches and coastlines, vessels and ships
Atmospheric pollution: Pollution of the atmosphere related to domestic, industrial and business activities in both the Region and adjacent areas. The contribution of gases such as carbon dioxide to climate change is not included as this is encompassed under threats such as sea temperature increase and ocean acidification.
Barriers to flow: Artificial barriers to riverine and estuarine flow (e.g. dams, weirs, breakwalls and gates)
Damage to reef structure: Physical damage to reef benthos (reef structure) through actions such as snorkelling, diving, anchoring and fishing, but not vessel grounding
Damage to seafloor: Physical damage to non-reef benthos (seafloor) through actions such as trawling and anchoring
Discarded catch: Immediate or post-release effects (such as death, injury, reduced reproductive success) on discarded species as a result of interactions with fishing gear. Does not include species of conservation concern.
Disposal of dredge material: Disposal and resuspension of dredge material
Dredging: Dredging of the seafloor
Exotic species: Introduced exotic species from aquaculture operations, hull fouling, ballast release, and release of aquarium specimens to the Region, plus the introduction of weeds, pests and feral animals to islands
Extraction from spawning aggregations: Retained take (extraction) of fish from unidentified or unprotected spawning aggregations
Extraction of herbivores: Retained take (extraction) of herbivores (e.g. some fish, molluscs, dugongs, green turtles) through commercial and non-commercial uses
Extraction of particle feeders: Retained take (extraction) of particle feeders (filter feeders, detritivores) through commercial and non-commercial uses
Extraction of predators: Retained take (extraction) of predators (e.g. sharks, fish) through commercial and non-commercial uses

Outlook Report 2014 (41 threats)
Grounding large vessel: Grounding of large vessels (>50m) including physical damage and the dislodging of antifoulants
Grounding small vessel: Grounding of small vessels (<50m) including physical damage and the dislodging of antifoulants
Illegal activities — other: Illegal activities such as entering a protected or restricted area, illegal release of industrial discharge, shipping outside of designated shipping areas
Illegal fishing and poaching: Illegal fishing, collecting and poaching
Incidental catch of species of conservation concern: Immediate or post-release effects (such as death, injury, reduced reproductive success) of interactions of species of conservation concern with fishing gear
Incompatible uses: Activities undertaken within the Region that disturb or exclude other users, such as recreational use in areas important for cultural activities
Marine debris: Manufactured material discarded, disposed of or abandoned in the marine and coastal environment (including discarded fishing gear and plastics)
Modifying coastal habitats: Clearing or modifying wetlands, mangroves and other coastal habitats
Noise pollution: Noise from human activities, both below and above water
Nutrient run-off: Nutrients from diffuse land-based run-off
Ocean acidification: Decreasing pH of the Region's waters
Outbreak of crown-of-thorns starfish: Outbreak of crown-of-thorns starfish
Outbreak of disease: Outbreak of disease, both naturally occurring and introduced
Outbreak of other species: Outbreak or bloom of naturally occurring species other than crown-of-thorns starfish
Pesticide run-off: Pesticides (including herbicides, insecticides, fungicides) from diffuse land-based run-off
Sea level rise: Rising sea level
Sea temperature increase: Increasing sea temperature
Sediment run-off: Sediments from diffuse land-based run-off
Spill — large chemical: Chemical spill that triggers a national or regional response or is more than 10 tonnes
Spill — large oil: Oil spill that triggers a national or regional response or is more than 10 tonnes
Spill — small: Chemical or oil spill that does not trigger a national or regional response and is less than 10 tonnes
Terrestrial discharge: Terrestrial point-source discharge including polluted water, sewage, wastewater and stormwater
Vessel strike: Death or injury to wildlife as a result of being struck by a vessel of any type or size
Vessel waste discharge: Waste discharge from a vessel (including sewage)
Wildlife disturbance: Disturbance to wildlife including from snorkelling, diving, fish feeding, walking on islands and beaches, and the presence of boats; not including noise pollution

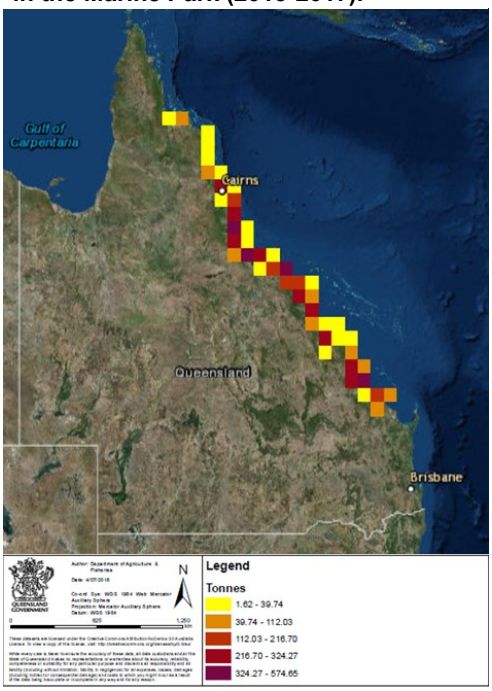
APPENDIX 2A: Commercial pot catch in the Marine Park (2013-2017).



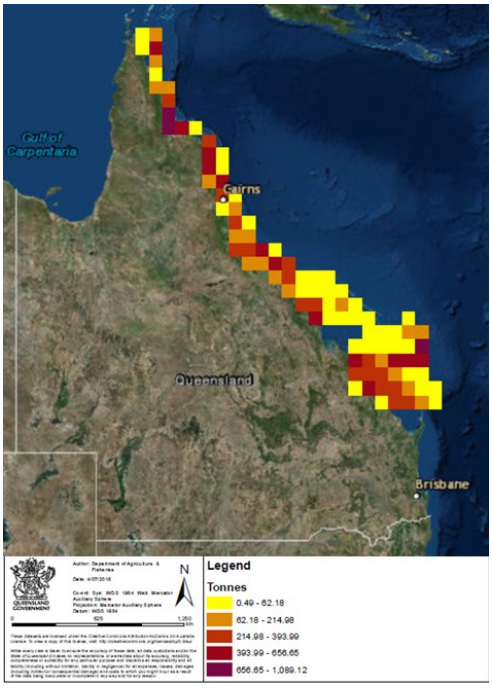
APPENDIX 2B: Commercial line catch in the Marine Park (2013-2017).



APPENDIX 2C: Commercial line catch in the Marine Park (2013-2017).



APPENDIX 2D: Commercial trawl catch in the Marine Park (2013-2017).

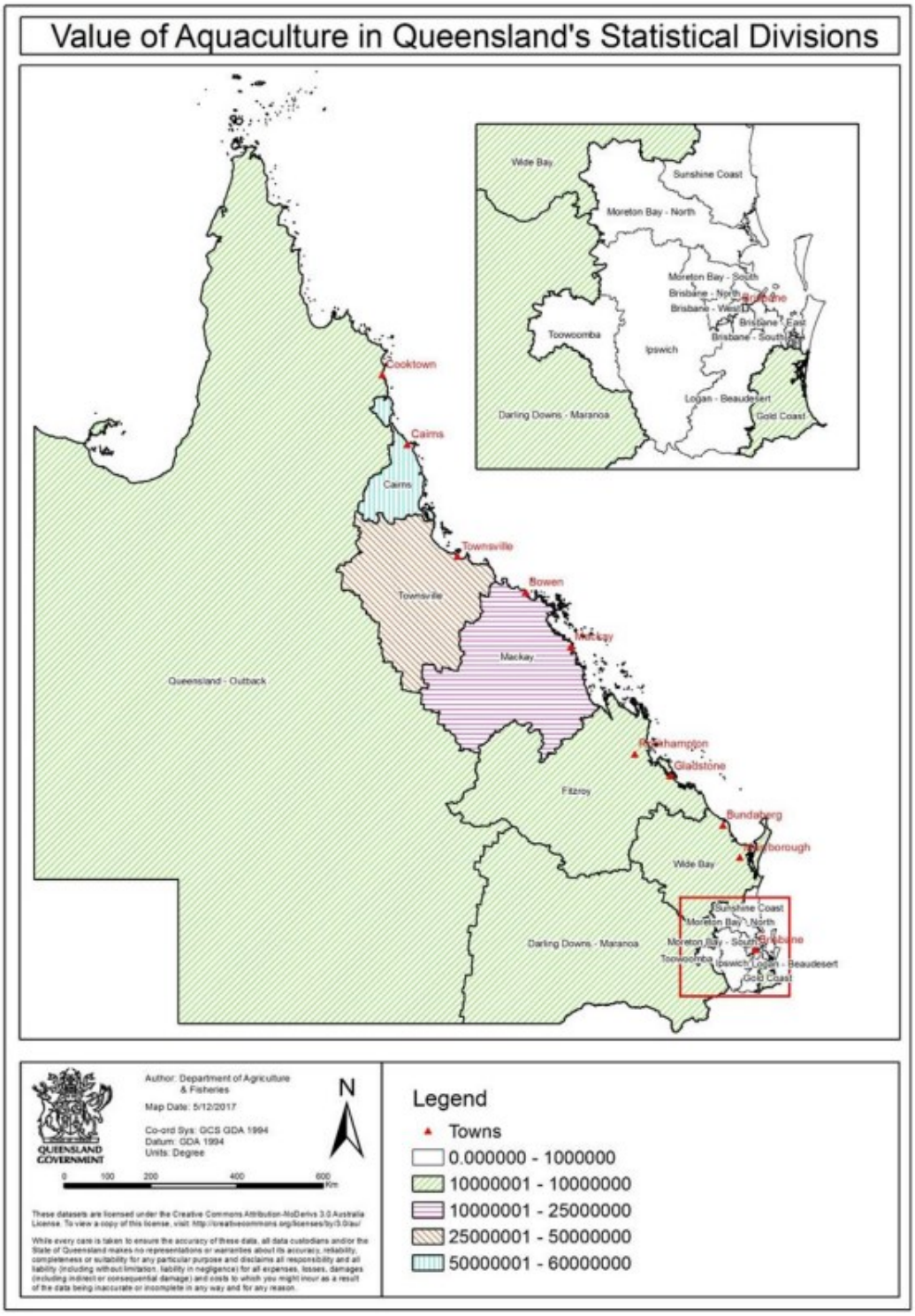


APPENDIX 3: Overview of Queensland's stock status assessments including SAFS and non-SAFS species.

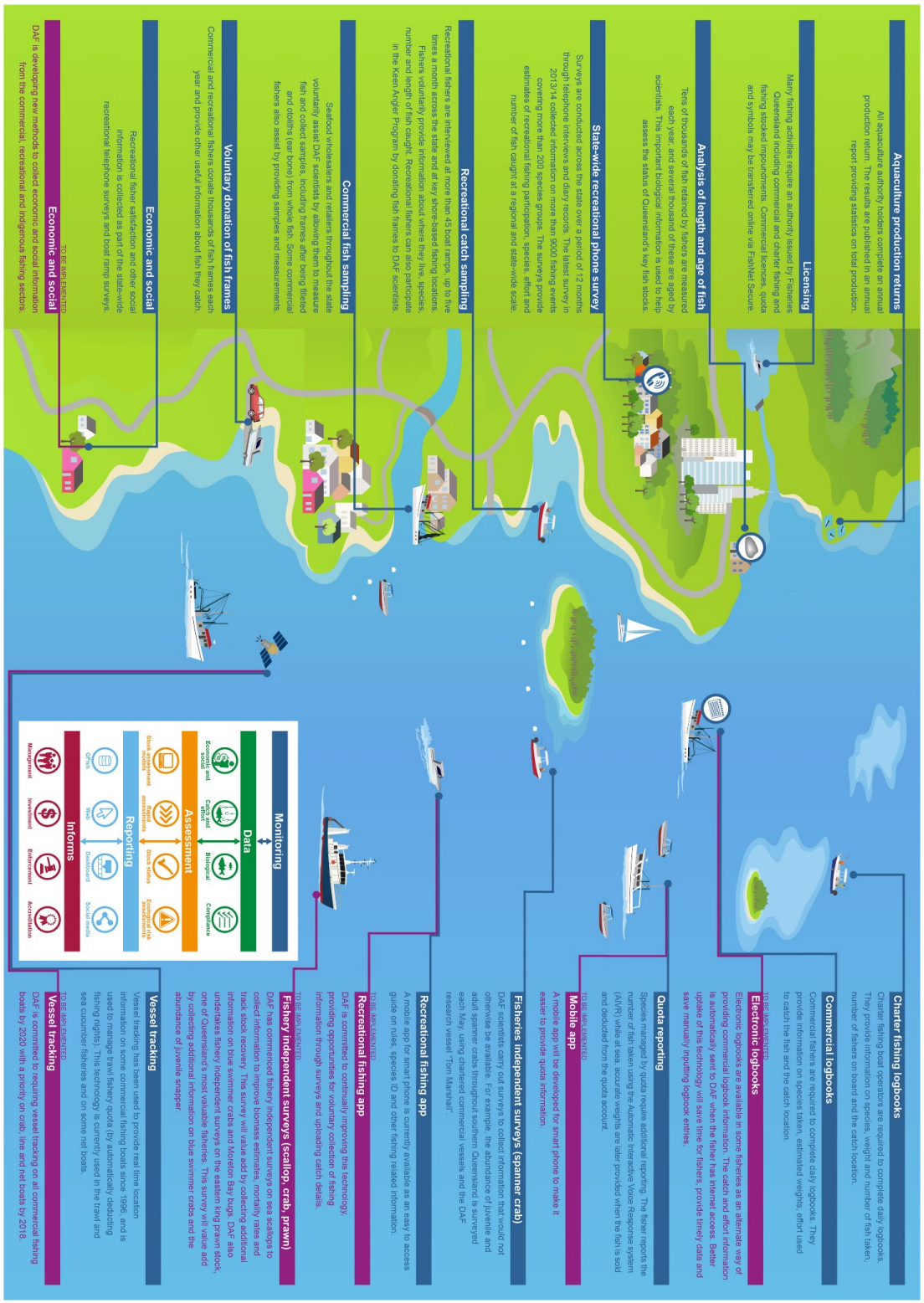
Common Name	Species	Stock	Most Recent Status
Amberjack	*Seriola dumerilli*	East Coast	Undefined (2013)
Albacore	*Thunnus alalunga*	South Pacific Ocean	Sustainable (2016)
Bar Rockcod	*Epinephelus sp.*	East Coast	Undefined (2013)
Barramundi	*Lates calcarifer*	Central East Coast Qld	Sustainable (2016)
Barramundi	*Lates calcarifer*	Mackay	Sustainable (2016)
Barramundi	*Lates calcarifer*	North East Coast Qld	Sustainable (2016)
Barramundi	*Lates calcarifer*	Princess Charlotte Bay	Sustainable (2016)
Bass Grouper	*Polyprion sp.*	East Coast	Undefined (2013)
Black Jewfish	*Protonibea diacanthus*	East Coast	Undefined (2016)
Blacktip Shark	*Carcharhinus tilstoni, C. limbatus, C. sorrah*	East Coast	Undefined (2016)
Blue Threadfin	*Eleutheronema tetradactylum*	East Coast	Undefined (2017)
Bonito	*Sarda spp.*	East Coast	Undefined (2013)
Cobia	*Rachycentron canadum*	East Coast	Undefined (2017)
Coral Trout	*Plectropomus spp., Variola spp.*	Coral Reef Fin Fish Fishery	Sustainable (2016)
Crimson Snapper	*Lutjanus erythropterus*	East Coast	Undefined (2016)
Cuttlefish	*Sepia spp.*	East Coast	Undefined (2013)
Dart – other	*Trachinotus* spp.	East Coast	Undefined (2017)
Dusky Flathead	*Platycephalus fuscus*	Queensland	Sustainable (2016)
Freshwater Eel	*Anguilla australis* and *A. reinhardtii*	East Coast	Sustainable (2017)
Garfish	*Hemiramphidae*	East Coast	Undefined (2015)
Goldband Snapper	*Pristipomoides multidens*	East Coast	Undefined (2016)
Golden Snapper	*Lutjanus johnii*	East Coast	Undefined (2016)
Grass emperor	*Lethrinus laticaudis*	East Coast	Undefined (2017)
Grey Mackerel	*Scomberomorus semifasciatus*	North East Coast Qld	Sustainable (2016)
Grey Mackerel	*Scomberomorus semifasciatus*	South East Coast Qld	Sustainable (2016)
Hammerhead Shark	*Sphyrna lewini, S. mokarran, S. zygaena & Eusphyra blochii*	East Coast	Sustainable (2017)
Hussar Snapper	*Lutjanus adetii* and *L. vitta*	East Coast	Sustainable (2017)
Javelin	*Pomadasys* spp.	East Coast	Undefined (2017)
King Threadfin	*Polydactylus macrochir*	East Coast	Sustainable (2016)
Mahi Mahi	*Coryphaena hippurus*	East Coast	Sustainable (2015)
Mangrove Jack	*Lutjanus argentimaculatus*	East Coast	Undefined (2017)
Octopus	*Octopus spp.*	East Coast	Undefined (2012)
Pearl Perch	*Glaucosoma scapulare*	East Coast	Transitional-depleting (2017)
Pencil Squid	*Uroteuthis spp.*	East Coast	Undefined (2013)
Queenfish	Scomberoides spp.	East Coast	Undefined (2017)
Red Emperor	*Lutjanus sebae*	East Coast	Undefined (2016)
Redthroat Emperor	*Lethrinus miniatus*	East Coast	Sustainable (2016)
Rosy Snapper	*Pristipomoides filamentosus*	East Coast	Undefined (2012)
Saddletail Snapper	*Lutjanus malabaricus*	East Coast	Undefined (2016)
Sand Whiting	*Sillago ciliata*	Queensland	Sustainable (2016)
School Mackerel	*Scomberomorus queenslandicus*	North East Coast	Sustainable (2017)
School Mackerel	*Scomberomorus queenslandicus*	South East Coast	Sustainable (2017)
Sea Mullet	*Mugil cephalus*	Eastern Australian	Sustainable (2016)
Shark Mackerel	*Grammatorcynus bicarinatus*	East Coast	Undefined (2013)
Silver Trevally	*Pseudocaranx dentex*	Queensland	Undefined (2016)
Snapper	*Pagrus auratus*	East Coast	Overfished (2017)
Spangled Emperor	*Lethrinus nebulosus*	East Coast	Undefined (2017)
Spanish Mackerel	*Scomberomorus commerson*	East Coast	Sustainable (2016)

Spotted Mackerel	*Scomberomorus munroi*	East Coast	Sustainable (2016)
Stripey Snapper	*Lutjanus carponotatus*	East Coast	Undefined (2017)
Swallowtail Dart	*Trachinotus copperingi*	East Coast	Undefined (2017)
Teraglin	*Atractoscion aequidens*	East Coast	Undefined (2013)
Trevally	Carangidae	East Coast	Undefined (2017)
Tuskfish	*Choerodon* spp.	East Coast	Undefined (2017)
Yellowfin Bream	*Acanthopagrus australis*	Eastern Australian	Sustainable (2016)
Yellowtail Kingfish	*Seriola lalandi*	Eastern Australian	Undefined (2016)
Ballot's Saucer Scallop	*Amusium balloti*	East Coast Otter Trawl Fishery	Overfished (2017)
Mud Scallop	*Amusium sp.*	East Coast	Undefined (2013)
Silverlip Pearl Oyster	*Pinctata maxima*	Eastern Australian	Sustainable (2016)
Trochus	*Trochus niloticus*	East Coast	Sustainable (2017)
Burrowing Blackfish	*Actinopyga spinea*	East Coast	Sustainable (2017)
White Teatfish	*Holothuria fuscogilva*	East Coast	Sustainable (2017)
Balmain Bug	*Ibacus alticrenatus, I. brucei, I. chacei, I. peronii*	East Coast	Sustainable (2016)
Banana Prawn	*Fenneropenaeus merguiensis*	East Coast	Sustainable (2016)
Blue & Red Endeavour Prawns	*Metapenaeus endeavouri, M. ensis*	East Coast Otter Trawl Fishery	Sustainable (2016)
Blue Swimmer Crab	*Portunus armatus*	North Eastern Australian	Sustainable (2016)
Eastern King Prawn	*Melicertus plebejus*	Eastern Australian	Sustainable (2016)
Coral Prawn	*Metapenaeopsis spp.*	East Coast	Undefined (2012)
Greasyback Prawn	*Metapenaeus bennettae*	East Coast	Undefined (2013)
Moreton Bay Bug	*Thenus australiensis, T. parindicus*	East Coast Otter Trawl Fishery	Sustainable (2016)
Mud Crab	*Scylla serrata, S. olivacea*	East Coast	Sustainable (2017)
Red Champagne Lobster	*Linuparus trigonus*		Undefined (2013)
Redspot King Prawn	*Melicertus longistylus*	East Coast	Sustainable (2017)
School Prawn	*Metapenaeus spp*	Queensland	Sustainable (2016)
Spanner Crab	*Ranina ranina*	East Coast	Sustainable (2016)
Tiger Prawns	*Penaeus esculentus, P. semisulcatus*	East Coast Otter Trawl Fishery	Sustainable (2016)
Three Spotted Crab	*Portunus sp.*	East Coast	Undefined (2013)
Tropical Rock Lobster	*Panulirus ornatus*	North Eastern Australian	Sustainable (2016)
Western King Prawn	*Melicertus latisulcatus*	East Coast Otter Trawl Fishery	Sustainable (2016)

APPENDIX 4: The total production value ($ million) of aquaculture for each of Queensland's statistical divisions.



APPENDIX 5: Fisheries Queensland monitoring program overview.



APPENDIX 6: Overview of previous evaluations of DAF fisheries monitoring and assessment programs.

Current monitoring/assessment program	Previous evaluations of adequacy/statistical power
Commercial catch sampling	The adequacy of commercial catch sampling was tested in 2016 by bootstrapping different sampling intensity. Pearl perch was the only species that was not demonstrably oversampled; all other species appeared to be robust to reduced sampling scenarios.
Ecological risk assessments	Many of Queensland's species/fisheries are considered data-poor, but ERAs offset this lack of data by taking a precautionary (worst-case scenario) approach; accuracy/adequacy will improve over time as more data is collected and data systems are enhanced.
Fisheries and Aquaculture RD&E	Each research project is peer-reviewed and the accuracy of quantitative results are indicated by confidence intervals or some other statistical measure.
Fishery-independent surveys	Most fishery-independent surveys have been tested for adequacy of survey design and the robustness of the indices produced, particularly the spanner crab and beam trawl surveys.
Logbook program	A number of issues relating to logbook data accuracy are recognised and will be addressed under a comprehensive Data Validation Plan as part of the Sustainable Fisheries Strategy 2017-2027. Approaches to improve accuracy will involve auditing, crosschecking of data sources, education programs, development of electronic logbooks, range checks and enhanced data systems.
State-wide recreational fishing survey	The current approach is thought to be efficient and accurate with a high response and retention rates, but sample sizes are low. Sample representativeness is tested for each survey using statistical methods and was recently assessed by comparing with a survey of fishers at tackle stores. The adequacy of the survey design is currently under review.
Stock assessments	There is often considerable uncertainty in the population parameter estimates used in the assessment models, particularly for parameters such as growth rates, natural mortality rates, fishing mortality rates and spawning stock-recruitment relationships. Assumptions often have to be made in order to model fished populations. For example, assumptions may be made about: • the size or age at which a species becomes vulnerable to capture • survival rates of discarded fish • fishermen's responses to alternative management measures. Stock assessments also rely on a series of data gathered over time. These series are usually incomplete, which complicates the reconstruction of the history of the fishery.
Stock status assessments	The SAFS framework, adopted by all Australian jurisdictions, is recognised to be independent, scientifically based and peer-reviewed. As of 2016, the national SAFS framework covered 83 species, which accounts for 90% of the gross value and total production of wild caught fisheries in Australia. In contrast, undefined stocks accounted for less than 5% of total catch. The adequacy and efficacy of the SAFS framework was independently audited by the FRDC in March 2017.
Vessel tracking	Vessel tracking is currently limited to a few Queensland fisheries, but Fisheries Queensland is committed to having vessel tracking on all commercial fishing boats by the end of 2020. The new devices will provide much higher temporal resolution with regular polling at 5-minute intervals.