<Photograph of a coral reef scene with fish moving about. Copyright Chris Jones.

Resilience

Chapter 8

*‘an assessment of the current resilience of the ecosystem…’* within the Great Barrier Reef Region, Section 54(3)(e) of the *Great Barrier Reef Marine Park Act 1975*

*‘an assessment of the current resilience of the heritage values…’* of the Great Barrier Reef Region, Section 116A(2)(c) of the *Great Barrier Reef Marine Park Regulations 1983*

2014 Summary of assessment

|  |  |  |
| --- | --- | --- |
| **Recovery in the ecosystem** | Some disturbed populations and habitats have demonstrated recovery after disturbance (for example lagoon floor, loggerhead turtles, humpback whales). For some species, recovery is not evident (black teatfish, dugongs) and is dependent on the removal of all threats. Increasing frequency and extent of some threats are likely to continue to reduce the resilience of species and habitats in the Region. | **Poor,**Deteriorated |
| **Improving heritage resilience** | The resilience of built heritage values has improved where the values are well recorded and well recognised and there is strong regulatory protection and regular maintenance (for example heritage-listed lighthouses). The resilience of intangible values, such as many Indigenous heritage values, depends on the active involvement of the custodians of those values so that connections and knowledge are kept alive. Such involvement has continued to grow.  | **Good**, Trend not assessed |

Full assessment summary: see Section 8.6

# Resilience

## Background

Resilience refers to the capacity of a system to resist disturbance and undergo change while still retaining essentially the same function, structure, integrity and feedbacks.1 It is not about a single, static state, but rather the capacity of an ever-changing, dynamic system to return to a healthy state after a disturbance or impact.2,3,4 It is a concept that is applied to both natural and social systems — from habitats and species, to communities, businesses and social assets. Resilience and vulnerability are related concepts.5,6,7 Resilience (sensitivity and adaptive capacity) is a way of describing the properties of a system and how it responds to exposure to disturbance. Together with exposure, resilience helps determine a system’s overall vulnerability. In the Outlook Report 2009, the resilience of the Great Barrier Reef ecosystem was assessed, including through a series of case studies examining recovery after disturbance. In this report, the assessment is expanded to include the resilience of heritage values, also including some case studies. Each case study contains an introduction, a description of current management arrangements and evidence for recovery.

## Ecosystem resilience

**Outlook Report 2009: Overall summary of (ecosystem) resilience**

*…The vulnerabilities of the ecosystem to climate change, coastal development, catchment run-off and some aspects of fishing mean that recovery of already depleted species and habitats requires the management of many factors. In some instances, the ecosystem's ability to recover from disturbances is already being compromised with either reduced population growth or no evidence of recovery.*

 *…many of the management measures employed in the Great Barrier Reef Region and beyond are making positive contributions to resilience (as evidenced by recovery of some species and habitats). The Zoning Plans for both the Great Barrier Reef Marine Park and the adjacent Great Barrier Reef Coast Marine Park that were introduced in 2004 are the most significant action taken to enhance biodiversity protection. They provide a robust framework for management and are already demonstrating positive results. Compliance with and public support for these and other measures is a critical factor in building the resilience of the ecosystem.*

*Taken together, available information indicates that the overall resilience of the Great Barrier Reef ecosystem is being reduced. Given the effectiveness of existing protection and management in addressing the most significant pressures on the ecosystem (principally arising from outside the Region), this trend is expected to continue.*

Key message: A resilient system can resist pressures and return to a healthy state.

Tropical marine ecosystems such as the Great Barrier Reef, and the coastal ecosystems that support them, are subject to a wide range of natural and human-related threats that may damage their components. These ecosystems are resilient if, given sufficient time, they are able to resist or recover from those threats, and maintain key functions without changing to a different state.

Understanding the capacity of the Great Barrier Reef ecosystem to resist and recover from the broad range of threats and disturbances it is facing is crucial to improving its long-term protection.7,8,9,10,11 There is no comprehensive information on the ecosystem resilience of the Great Barrier Reef Region (the Region), largely due to the vast extent and complexity of the ecosystem, and because resilience is a complex, dynamic property that is difficult to measure. Therefore, this Reef-wide assessment is necessarily broad. It is based on an overall understanding of resilience; evidence presented in previous chapters on the biodiversity and health of the ecosystem, the impacts facing the Region and the effectiveness of management; and some case studies of recovery.

### Understanding ecosystem resilience

Key message: Ecosystem resilience relies on diversity, healthy processes, strong connectivity and time for recovery.

Key message: Resilience must be supported at both local and broad scales.

The resilience of an ecosystem is determined by a range of variables. A loss of ecosystem resilience cannot be attributed to any single cause, but is almost certainly the consequence of impacts from all the different activities and influencing factors, and their accumulation through time.

Systems are likely to have greater resilience if they have high levels of diversity, key functional species to maintain ecological processes and a level of functional redundancy (where species can perform different ecological roles).12,13 For example, a coral reef with high coral diversity that is affected by a cyclone may lose the more fragile and faster growing branching corals; however, the slower growing, more resistant coral species may be able to maintain the function of the coral reef system until coral diversity returns. Timescales are also important. At a species level, fast growing species may be more resilient in the long term because of their ability to rapidly recolonise.

Networks of components (for example interconnected habitats) may have greater resilience because their connectivity enhances recovery after disturbances.14,15 In addition, the resilience of an ecosystem is enhanced when connections with supporting ecosystems are functioning effectively and those supporting systems are in good condition.16 For the Great Barrier Reef, the health of supporting terrestrial and other coastal habitats and functional connections to those habitats (see Section 3.4.10) play an important role in maintaining resilience.17 Relevant ecological functions and processes provided by terrestrial habitats include physical processes (such as sediment and water distribution), biogeochemical processes (such as nutrient cycling) and biological processes (such as connectivity and recruitment).

The resilience of an ecosystem is also influenced by the extent and frequency of disturbances (exposure) — noting some ecosystems are naturally adapted to frequent (natural) disturbance events.18 If disturbances are too frequent and the system has insufficient time to recover between disturbances, the impacts can become compounded and resilience reduced. For example, before the 1980s, coral cover on Jamaican reefs ranged from 40 to 70 per cent and macroalgal cover was typically 10 per cent.19 The resilience of these reefs was subsequently compromised by several disturbances including two major hurricanes20,21, outbreaks of coral predators and coral disease22, the regional loss of a keystone herbivore23, and a series of coral bleaching events24. As a result of compounding pressures, the ecosystem has had little time to recover; coral cover has plummeted to 10 per cent and macroalgae has become dominant.19,25,26

Although the resilience of the ecosystem is distinct from its overall condition, they are related — a degraded system may have less capacity to recover if species populations are too depleted to supply enough new recruits (for example, larvae or seeds) or if ecosystem processes are no longer functioning effectively. For example, the replenishment of fish and coral larvae to an area after disturbance requires the processes of recruitment, ocean circulation and connectivity to be in good condition.

Thresholds or tipping points are a critical aspect of resilience. An ecosystem subject to ongoing threats and their chronic and acute effects may reach a tipping point and suddenly change in response to a relatively small increase in impacts. For example, a reef subject to excess nutrients and sediments may retain high coral cover, but have low recruitment of new corals. If a storm reduces the coral cover, the lack of recruitment may mean the reef is not able to recover, and suddenly changes state. These changes in state are often referred to as phase-shifts.9,27,28,29,30

Addressing local-scale impacts on tropical marine ecosystems is considered critical to building resilience and maintaining healthy ecosystems.9 If threats and their effects are manifesting at local or regional scales, they may be masked when ecosystem resilience is considered only at broad scales.17,31

[Photograph of a coral reef showing coral colonies with a variety of physical forms. Caption: Ecosystems with high diversity generally have greater resilience]

Managing for resilience is most important in situations where there is uncertainty about risks and appropriate management responses.32 Mitigating and minimising the multiple impacts that affect an ecosystem will improve its overall resilience. Managing agencies, industries and communities can all play a role. For example, where fishing and tourism operators on the Great Barrier Reef and landholders in the catchment practise strong stewardship, pressures are reduced and Reef health and resilience is supported.33

## Case studies of recovery in the ecosystem

Although recovery after disturbance is only one aspect of resilience, it is a critical attribute of a resilient system, is practical to measure and monitor, and gives an indication of overall resilience. The series of case studies below illustrate the extent to which some key components of the ecosystem have recovered after disturbance. They provide evidence of the overall resilience of the Great Barrier Reef ecosystem.

The case studies showcase a range of aspects relevant to resilience:

* the extent to which some key functional habitats have responded after human and natural disturbances — coral reef and lagoon floor habitats
* the extent to which some key ecological processes have responded after human and natural disturbances — black teatfish (particle feeding), urban coast dugong (herbivory) and coral trout (predation)
* the effectiveness of specific management actions implemented to address declines in specific species — loggerhead turtles and humpback whales.

The case studies are the same as those in the Outlook Report 2009 so that trends over time can be analysed and reported.

### Coral reef habitats

Key message: A wide range of measures address coral reef protection.

Key message: Average hard coral cover has declined; there is some evidence of recovery at a local scale.

Key message: There is an overall, long-term decline in coral reef condition and resilience.

Key message: Frequent disturbances and chronic stresses reduce the potential for reef recovery.

Coral reefs, and corals specifically, have a natural ability to recover from periodic disturbances such as cyclones, crown-of-thorns starfish outbreaks or coral bleaching. Corals on a resilient and relatively undisturbed reef will gradually re-establish their dominance as well as diversity within a couple of decades of a catastrophic coral mortality event.34,35 However corals exposed to chronic pressures, such as poor water quality, are likely to have less resilience and hence less ability to recover from these acute disturbances.36,37

The potential of a coral reef community to recover from disturbance depends on its condition, resilience and the frequency and intensity of disturbances. 15,28,38,39,40 Key indicators of coral condition (health) include coral cover, rates of coral growth during periods free from disturbance, juvenile abundance and macroalgae cover.36 With sufficient time between disturbances, recovery of coral cover can be substantial, which is evident from long-term data from reefs that have been free from disturbance following impacts such as bleaching35 and crown-of-thorns starfish outbreaks.41

Over the last decade, parts of the Great Barrier Reef have been exposed to repeated disturbance events, especially in the southern two-thirds of the Region (see Section 3.2.2, Section 3.2.3 and Figure 6.7). Figure 8.1 shows spatial extent of exposure of reef area, between 2001 and 2011, to key disturbances at levels that are likely to result in damage. Along with the disturbances mapped — cyclone-induced waves, crown-of-thorns starfish outbreaks, elevated sea surface temperatures and freshwater inflow — there may be more localised disturbances such as vessel groundings and anchor damage.



Figure 8. Cumulative exposure of coral reefs to key disturbances, 2001–2011

The map presents the modelled cumulative exposure of coral reefs to the following disturbances: cyclone-induced waves, crown-of-thorns starfish outbreaks, elevated sea surface temperatures and freshwater inflow.42 The magnitude of the impacts has been normalised between zero and one. The higher the exposure number, the greater the exposure to the disturbances modelled. Exposure to disturbance and coral health are not necessarily directly correlated; the effect of disturbance depends on a reef’s capacity to resist and recover. Source: Johnson *et al.* 201342

**Management** The range of management measures described in the Outlook Report 2009 that are in place to either eliminate or substantially reduce the magnitude and likelihood of threats affecting coral reef habitats43 remain, and additional measures have been introduced. The *Great Barrier Reef Biodiversity Conservation Strategy 2013*44 provides a framework for improving biodiversity conservation in the Region, including for coral reefs.

Environmental regulation measures include:

* establishment of zones or special areas prohibiting certain activities
* permit conditions for specific activities
* reef protection markers and moorings
* general protection of coral species in the Great Barrier Reef Marine Park
* fisheries legislation and associated (conditional) accreditation of the export component of the commercial coral harvest fishery under national sustainability guidelines.

Engagement-related measures include:

* Guidelines and codes of conduct, for example best practices for snorkelling, diving and anchoring
* implementation of activities to improve water quality by reducing the run-off of nutrients, sediments and pesticides (including under the *Reef Water Quality Protection Plan 2013* (Reef Plan)45andthe *Australian Government Reef Programme*)
* implementation of a crown-of-thorns starfish control program
* development of industry-led guidelines for aquarium supply collection practices 46.

Knowledge, innovation and integration measures include:

* research and monitoring to assess impacts and monitor ecosystem condition33,47,48,49
* social and economic long-term monitoring program50
* development of new incident response plans for coral disease, bleaching and tropical cyclones51,52,53
* significant expansion and integration of the Eye on the Reef program components and data management platform
* assessment and improved understanding of terrestrial ecosystem function and processes important to the long-term health of the Great Barrier Reef38.

The biodiversity conservation strategy, the starfish control program, the stewardship guidelines, social and economic monitoring, incident response plans, expansion and integration of the Eye on the Reef program and improved understanding of coastal ecosystems have all been introduced since the Outlook Report 2009.

**Evidence for recovery** Recent analysis has shown significant declines in hard coral cover on the Great Barrier Reef (see Figure 2.5 and Figure 8.2).39 However, there is evidence that healthy reefs can recover after disturbances at local scales.54

Reefs that are dominated by fast-growing coral species, such as the *Acropora*-dominated reef flats around the Keppel Islands, showed remarkably rapid initial recovery following substantial mortality induced by coral bleaching in 2006.54 However, continued recovery has since been suppressed by a combination of exposure to flooding, minor storms and ongoing incidents of coral disease.55,56 In 2012, the reefs in Keppel Bay were in poor condition, with little evidence of recovery, including little or no signs of recruitment (settlement of coral larvae and abundance of juvenile corals).55

This recent trend of declining recovery potential is evident along the inshore area from reefs in the Keppel Bay area to those adjacent to the Wet Tropics (Figure 8.2).36 Despite evidence that inshore reefs had remained healthy over many hundreds of years prior to European settlement57, these reefs are now being gradually but seriously damaged by disturbances occurring at a frequency that allows little or no time for recovery.55 The decline in coral cover and lack of recovery coincides with degraded water quality as a result of land clearing, land use changes and agricultural use of the catchment.57

The overall condition of inshore reefs in the Wet Tropics region has continued to decline from 2010 to 2013 (Figure 8.2).36 The causes of this decline vary spatially. Some Wet Tropics sub-regions experienced high levels of coral disease in 2010 and 2011 which resulted in slow rates of coral cover increase that, in combination with crown-of-thorns starfish outbreaks, has reduced overall coral cover.36 The density of juvenile corals has also declined to low levels.

[Photograph of a crown-of-thorns starfish. Caption: Outbreaks of crown-of-thorns starfish are a major cause of reduced coral cover]

There are some examples of recovery from disturbance. For example, while coral cover is still very low in the Herbert Tully sub-region following the severe reductions caused by cyclone Yasi in 2011, increases in the density of juvenile corals indicates reefs are now showing some level of recovery.36 Similarly, two and a half years after cyclone Yasi caused high to severe destruction on a number of reefs between Townsville and Cairns, reef health surveys found some mid-shelf and offshore reefs showing the promise of recovery, with moderate to high levels of small coral colonies evident.58



Figure 8. Changes in coral health of inshore reefs, 2008–2013

The coral health index aggregates cover of corals, cover of macroalgae, density of juvenile corals and the rate of coral cover increase. For corals to be considered in good or very condition, they would have a score of 0.6 or more. The figure presents information for inshore reefs only for the Reef as a whole and for the four areas indicated. Source: Reef Water Quality Protection Plan Secretariat 201459

Despite some positive examples of recovery from disturbance, the overall trend for coral reef habitats within the Region is one of long-term decline in health and diversity36,39,60,61 and therefore resilience. The causes include chronic disturbances such as poor water quality and outbreaks of coral disease, as well as a recent series of acute disturbances such as crown-of-thorns starfish outbreaks, coral bleaching events and cyclones36,39,62,63,64, which have left insufficient time for many coral communities to recover between events (Figure 8.2). In addition to the disturbances mentioned above, at a local or individual reef level many lower risk threats, such as anchor damage and vessel groundings, can also impede recovery (see Section 9.3.7).

Despite recent reductions in the loads of nutrients and sediments entering the Region (see Sections 3.3.1 and 7.3.11), there is a lag before improvements in catchment management translate into improved marine condition, particularly given the strong influence of extreme weather events in recent years. The projected vulnerability of coral reef habitats to changing climate variables (see Section 6.3.2), combined with other cumulative impacts, means coral reef habitats will face chronic effects plus more frequent and more severe disturbance events.9,42,65,66,67 This will reduce their resilience.15,68

### Lagoon floor habitats

Key message: Trawling, port activities and anchoring affect the lagoon floor.

Key message: Some previously at-risk lagoon floor habitats are likely recovering.

Key message: There is little monitoring of lagoon floor condition or recovery.

There is limited information on the condition of the lagoon floor (see Section 2.3.6), although it is reasonable to assume that it varies considerably across the Region.

A range of activities can affect lagoon floor habitats including trawling, dredging, disposal and resuspension of dredge material, vessel anchoring and turbulence from both natural sources (for example storm and cyclone-driven wave actions)69 and man-made sources (for example passage of vessel hulls and propellers close to the substrate).70

Trawling (see Section 5.4) has affected the lagoon floor over the past 40 years or more. The annual trawl fishing effort has remained stable over the past five years at levels that are about 40 per cent below the peak in 2005 (see Section 5.4).71 However, in the past, trawling within the Region was more intense, and unsustainable practices led to concerns about impacts on seabed habitats.72 The impacts of trawling and the recovery of the habitat following closures have been quantified for some areas of the Region and modelled for habitats down to 90 metres.72,73,74 In general, on a Region-wide scale, current risk levels from trawling are generally low, but some risks (and concerns) remain.71

Dredging involves the extraction of parts of the lagoon floor to deepen an area and allow increased access for navigation and docking. It is usually associated with ports, shipping channels, marinas and boat ramps. Both capital (to permanently create, lengthen, widen or deepen areas) and maintenance (to ensure that previously dredged depths are maintained) dredging are undertaken at the majority of trading ports and a number of marinas within and adjacent to the Region (see Section 5.5). Projected economic and population growth in coming decades (see Chapter 6) demonstrates there will be a need for increased capital and maintenance dredging.

Once material is extracted from the lagoon floor during dredging, it requires disposal. This has generally been in reclamation projects or at sea75, and some to land-based disposal sites. Between 2000 and 2013, the total volume of dredge material (from both capital and maintenance dredging) disposed in the Great Barrier Reef World Heritage Area was approximately 28 million cubic metres (see Figure 5.17).

The localised effects of dredging and disposal activities relevant to lagoon floor habitats are well documented and include: seabed disturbance76; removal or modification of habitats77,78; loss of species, including benthic organisms75,79; degradation of water quality77,80 including increased turbidity levels78; and changes to hydrodynamics and coastal hydrology78. Less well understood are the broader regional and cumulative effects of sea disposal on inshore biodiversity.

There is little information about the threats posed by vessel anchoring or turbulence from the passage of vessel hulls and propellers close to the lagoon floor.

**Management** Potential threats to the lagoon floor are managed through a range of environmental regulations, policy and research. Spatially based protection measures include:

* Marine Parks zoning that continues to protect representative examples of all habitats within the Great Barrier Reef ecosystem, with a minimum of 20 per cent of each relevant bioregion protected and more than 30 per cent in highly protected areas. Zoning arrangements also restrict trawling to about one-third of the Great Barrier Reef Marine Park.
* One hundred and fifty-four ship anchorages designated adjacent to some of the ports along the Region’s coast (see Figure 5.23). All but 12 are within the Great Barrier Reef Marine Park. Including swing room, the anchorages cover about 1200 square kilometres. They confine the impacts arising from anchoring for these ports.
* An increased number of Fish Habitat Areas have been declared in or adjacent to the Region to protect areas against physical disturbance from coastal development. Seventy areas now cover 880,000 hectares.81 Some of these areas significantly restrict development activities while others allow for more flexible management.82

A range of environmental impact assessment processes and guidelines of the Australian and Queensland governments aim to minimise the impact of coastal development activities (for example dredging associated with port developments) on the seabed. However there have been increasing concerns about their effectiveness at identifying and managing for biodiversity impact.83

The 2014 *Queensland Ports Strategy*84 will influence capital and maintenance dredging and dredge material disposal within, and adjacent to, the Region (see Section 5.5.1).

A 2012 ecological risk assessment examined the risks posed by the East Coast Otter Trawl Fishery to achieving fishery-related and broader ecological objectives of both the Australian and Queensland governments, including risks to the values and integrity of the Great Barrier Reef World Heritage Area.85

**Evidence for recovery** The Outlook Report 2009 concluded that some lagoon floor habitats previously at risk are recovering from disturbances. Full recovery will take decades.

There is evidence that lagoon floor habitats have the potential to recover from the impacts of trawling.72,86 Rates of recovery vary and are correlated to the intensity of past trawling as well as the biology of the affected species.72 Fan gorgonians recover slowly, while populations of hard coral such as *Turbinaria frondens* have been seen to recover within a couple of years.72

The resilience of trawled habitats in the Region varies.85 A deepwater habitat was estimated to be at high risk from consistently high levels of trawl fishing effort. This deepwater habitat is known to support species such as champagne lobster, Balmain bugs, skates and rays as well as the target eastern king prawns. For other habitats, the assessment indicated they were mostly at a relatively low risk from trawling.

Dredging permanently removes that portion of the seabed within the access channel and ongoing maintenance dredging means there is no opportunity for recovery of the area.

Dredged material is dispersed during the initial dredging and disposal activities, and may later be resuspended. A recent modelling study suggests dredge material placed at sea may have the potential to migrate over greater spatial and temporal scales than previously understood.87 Although the results are preliminary they highlight the need for improved information to better understand the impacts on and potential recovery of seabed communities from disposal of dredge material at sea.

There is limited quantitative information regarding the recovery of lagoon floor habitats after disturbances. There is little or no monitoring of seabed condition except as required through permit approval conditions associated with development activities (for example ports and marinas).

### Black teatfish

Key message: Recovery is likely to be slow for black teatfish.

The black teatfish, a sea cucumber, fishery was closed to fishing in the Region following concerns for the long-term viability of the harvested stock.88 At the time of closure in 1999, populations of the species were reduced by at least 75 per cent, with residual populations of approximately five individuals per hectare in harvested areas.89 Since that report, there is little new information on black teatfish populations in the Region.

**Management** Management arrangements for the black teatfish are limited to environmental regulation activities. There is a fishery closure for the species and Marine Parks zoning protects a minimum of 20 per cent of each reef bioregion from extractive activities, including those containing suitable habitat for the species.

**Evidence for recovery** As reported in the Outlook Report 2009, there was no evidence of recovery for the two years after the closure of the black teatfish fishery in 1999.89,90 The lack of recovery was attributed to their life history characteristics, such as slow growth, limited migration and low recruitment.89 It is also likely to be due to the fact that they need to be close to each other to achieve fertilisation after broadcast spawning, hence needing a critical population density for reproductive success.90,91 The populations have not been resurveyed since 2002 and there is no estimate of current population densities. Recent modelling predicts a slow recovery for this species, and estimates the spawning biomass could potentially double by 2030.88

Recent fisheries management and monitoring of the black teatfish fishery in the Torres Strait may provide some indication of trends in the Region as the shallow-water black teatfish found in the Region behave similarly and may respond in a similar way. In the Torres Strait, the black teatfish fishery was closed in 2003, with no signs of recovery in surveys two years later.92 However, when these surveys were followed up in 2010, the densities of black teatfish had increased significantly and were greater than those observed in 1995, well before the fishery closure.93 Also the average size of the adults was larger than any previous survey carried out in the Torres Strait and the data indicates that these populations have recovered to near natural (unfished) densities over the seven years of the fishery closure, indicating a recovery period of between five and seven years for this fishery.93

### Coral trout

Key message: There are concerns for the condition of coral trout populations.

Key message: Coral trout can recover quickly when disturbance is reduced.

Key message: Coral trout larvae from no-take areas disperse into other areas.

Coral trout is the collective name for several species of predatory fish in the genus *Plectropomus*. They occur in coral reef and shoal habitats and feed on other fishes and invertebrates. The life history characteristics of each coral trout species differ, for example the timing and location of spawning, and this may influence their individual resilience.

[Photograph of a large coral trout lurking under an overhang. Copyright Chris Jones. Caption: Coral trout are a target for both commercial and recreational fishing]

Coral trout are very important species for both commercial and recreational fishers (see Section 5.4.1) and nearly all coral trout caught in Queensland are caught on the Great Barrier Reef. They have high commercial value and make up 54 per cent of the total catch within the Coral Reef Fin Fish Fishery, which took a total of 221 tonnes in 2011–12.94 The retained recreational catch has been estimated to be between 200 and 550 tonnes over the last decade.94,95 Currently more than 65 per cent of the Great Barrier Reef is open to hook and line fishing (including trolling), the technique most commonly employed to catch coral trout.

Extraction by legal fishing reduces the abundance of coral trout96 and rapid local depletions of adults may occur under heavy fishing pressure. Between 1989 and 2003, 290 to 620 tonnes of coral trout were estimated to be discarded annually by the commercial Coral Reef Fin Fish Fishery on the Great Barrier Reef97 with the ecological effect of such discards unknown. They are also subject to illegal fishing. The full extent and impact of illegal take on coral trout is unknown. However, reported incidents of illegal fishing in general are of concern, and in 2012–13 the proportion of these involving recreational fishers was more than one and a half times that in 2008–09 — partly due to an increased compliance focus on recreational fishing activity (see Section 5.4.3).

Issues regarding decreased abundance and adverse impacts of fishing on the Region’s coral trout population, particularly at reefs near major population centres, have been reported since the 1970s.98,99,100 Concerns have been raised recently about the status of coral trout populations in several areas.101 Survey evidence suggests that coral trout stocks on some reefs had already been markedly depleted by 1984, well before the rezoning of the Great Barrier Reef Marine Park and the Great Barrier Reef Coast Marine Park in the early 2000s.102

The various threats from fishing are likely to be exacerbated by declines in coral reefs. Degradation of reefs will likely affect the abundance and diversity of prey species for coral trout.103 Additionally, when the physical structure of reefs is changed — for example by severe weather events63,104 — there are likely to be varying flow-on effects for different coral trout species including the availability of hiding places105, settlement habitat for juveniles105, and microhabitats for prey species103. Densities of coral trout in areas around the Keppel Bay islands declined more than 20 per cent following the 2006 coral bleaching event.106

[Photograph of a diver swimming over a section of reef where coral colonies have been reduced to rubble. Caption: Coral trout habitat can be almost completely destroyed when reefs are exposed to the full force of severe cyclones]

Under climate change projections, sea temperatures will continue to rise and the frequency of coral bleaching events and the intensity of storms are expected to increase (see Section 6.3.1). In addition to effects through changes in their habitats, increasing sea temperature may reduce coral trout fertilisation success and affect larval development and survival.107 Ocean acidification is likely to have serious implications for predator avoidance behaviour of coral trout larvae.107

**Management** A range of management arrangements (see Section 5.4.1) support the ability of coral trout populations to recover from disturbance.

The fishery focused on coral trout is primarily managed using the Fisheries (Coral Reef Fin Fish Fishery) Management Plan 2003 and *Fisheries Regulation 2008*. Size limits for coral trout apply to all fishers and there are in-possession limits for recreational fishers. At least one species, the common coral trout, forms spawning aggregations around the new moons in spring, as water temperature warms.108 In 2004, a total allowable commercial catch and three nine-day spawning closures during the spring new moons were introduced for coral trout. Significant reductions in the annual catch and the catch per unit effort since 2009 — indicative of a reduced coral trout population — have not triggered a reduction in the total allowable catch for the fishery, although this is under review. In addition, the spawning closures have been reduced to two five-day closures. The Queensland Government’s stock status of coral trout moved from ‘sustainably fished’ to ‘uncertain’ in 2012 due to low catches and catch rates.109

Marine Park zoning complements fisheries management arrangements by excluding fishing from a representative portion of all reef habitats where coral trout live. Compliance patrols enforce the management arrangements.

Preliminary results of the inaugural stock assessment of coral trout being conducted by the Queensland Government and due for release in 2014 are indicating that, at the scale of the Region, the common coral trout population has a reasonable portion of its stock protected by zoning and is being fished at biologically sustainable levels in the areas open to fishing.

**Evidence for recovery** The ability of coral trout populations to recover from disturbances is influenced by key life history traits, such as growing rapidly in the first few years of life, maturing relatively early, variable timing of the change from female to male, having high annual fecundity, and spreading reproductive effort over space and time. In addition, some fisheries management measures are well matched to coral trout, for example conservative size limits for most coral trout species allow individuals to spawn for at least one season before they reach legal harvestable size.

When disturbance from fishing is reduced, coral trout numbers have recovered reasonably quickly, as demonstrated by the two-fold increase in their biomass in zones closed to fishing within two years of implementation of revised zoning arrangements in 2004.106 Further work has confirmed this recovery has been maintained with coral trout generally found in greater abundance in no-take zones than fished zones (see Figure 2.10).96

The zoning arrangements provide critical support to the potential for coral trout recovery and their overall resilience throughout the Region. For example, coral trout are generally larger in protected zones.103 Size is especially important because larger fish produce disproportionately more larvae, improving overall reproduction within the population.102,110,111 Increased reproduction within no-take zones appears to also benefit zones open to fishing. While many coral trout larvae in the Keppel Islands remain on their original reef, many others are dispersed, both to other no-take reefs and to reefs open to fishing.112 An estimated 60 per cent of larvae on reefs open to fishing in the Keppel Islands area originated from reefs in protected zones.112 Importantly, spatial analyses have shown that the design of the Great Barrier Reef zoning means that most reefs, open to fishing and no-take, are within range of dispersal from a no-take reef.102,113,114 Thus, by maintaining connectivity between reefs, zoning has ensured they operate as a network, rather than in isolation — networks are recognised as more resilient than isolated components2.

In 2009 cyclone Hamish damaged a large number of coral reefs within the Region, including many used by commercial fishers.115 In 2011 cyclone Yasi also damaged reefs. In both instances one of the early hypotheses for the decline in commercial catch rates was that the cyclone increased mortality of coral trout. However, later work showed that adult fish were still present; it was their catchability that had been negatively affected.104,115

### Loggerhead turtles

Key message: Loggerhead turtles are recovering; some threats remain.

Key message: Mandatory excluder devices have reversed a long-term decline in loggerhead turtles.

The breeding sites in the southern Great Barrier Reef (islands and cays of the Swain Reefs and Capricorn–Bunker Group) and the Bundaberg coast support the only significant stock of nesting loggerhead turtles in the South Pacific Ocean.116,117 In the 1970s this area had an estimated population of 3500. By 2007, less than 300 breeding females were recorded, indicating a decline of 70 to 90 per cent. Various life history traits, including being long lived with slow growth rates, having delayed sexual maturity and high levels of egg and hatchling mortality, and inhabiting a range of habitats during their life stages, means it can take many decades for population decline or recovery to become evident.118

**Management** Loggerhead turtles continue to be protected under Commonwealth and Queensland legislation. Activities that threaten loggerhead turtles within the Region are managed through a combination of legislative requirements, operational policy and research addressing all known human-related pressures. Management actions specifically in place to protect loggerhead turtles include:

* Protection of the species under Commonwealth and Queensland environmental legislation, for example, ‘listed migratory species’ and ‘listed threatened species’ under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth); ‘protected species’ under the *Great Barrier Reef Marine Park Regulations 1983* (Cth); ‘endangered’ under the *Nature Conservation Act 1992* (Qld).
* Identification of the incidental catch of sea turtles during coastal otter trawling and the ingestion of or entanglement in marine debris as key threatening processes under Commonwealth legislation. This is supported by: mandatory use of turtle excluder devices since 2001; mandatory vessel monitoring systems; mandatory reporting of interactions with species of conservation interest; and, from July 2014, actions to reduce marine debris impacts on marine turtles with funding from Reef Trust119.
* Australian and Queensland government plans and strategies that integrate relevant information and help guide management activities, including the *Recovery Plan for Marine Turtles in Australia*, the *Great Barrier Reef Biodiversity Conservation Strategy 2013*, and *Back on Track Actions for Biodiversity.*120,121,122,123,124,125
* Spatial protection through zoning plans126,127, a summer trawl closure in the Woongarra Marine Park (south of the Region) since 1991 and 'go slow' zones in Moreton Bay Marine Park — an important foraging area to the south of the Region.
* Baiting for foxes adjacent to nesting beaches in south-east Queensland.
* Research and monitoring of loggerhead turtles and their recovery including: the Sightings Network component of Eye on the Reef where marine turtle observations by community members and others are collected; Marine Wildlife Strandings program, which reports on marine turtle strandings and causes of mortality; and annual monitoring of nesting loggerhead populations along the Woongarra coast and in the Capricorn–Bunker Group in the south of the Region and of foraging populations in Moreton Bay to the south of the Region.

[Photograph of a loggerhead turtle laying eggs – rear end, showing eggs in the nest. Photograph of a loggerhead turtle laying eggs – front end, showing head. Caption: The number of nesting loggerhead turtles is increasing]

[Photograph of a loggerhead turtle swimming in the ocean. Caption: Threats to loggerhead turtles have been reduced in the Region]

**Evidence for recovery** As reported in theOutlook Report 2009, after the effective implementation of the mandatory use of turtle excluder devices on trawlers in 2001, the previous long-term decline in nesting loggerhead turtle numbers reversed to an increasing trend at all eastern Australian loggerhead turtle index beaches.128 Mon Repos on the Woongarra Coast near Bundaberg is outside the Region; however, it is where the largest nesting aggregation for this stock occurs. During the 2011–12 nesting season, 377 nesting females were recorded nesting at Mon Repos (see Figure 2.12). This provides further evidence of a continued increasing trend in nesting females.128

Despite the positive trend observed in nesting adults, significant pressures from death during incidental capture in pelagic long-line fisheries in the South Pacific outside Australian waters and ingestion of synthetic marine debris are thought to continue to affect this stock, especially the post-hatchling, juvenile and sub-adult life stages.128 If the declines in juvenile and sub-adult life stages continue, then there may be a reduction in the number of nesting loggerhead turtles in another 20 or so years when they would have joined the breeding population.

### Urban coast dugongs

Key message: Loss of seagrass from recent cyclones and floods has affected urban coast dugongs.

Key message: Urban coast dugong populations are the lowest since surveys began.

The dugong population along the urban coast (south of Cooktown) is believed to be only a small fraction of pre-European levels.129,130 Commercial harvest of the population ceased in 1969131, but the legacy of this impact continues to affect the recovery and resilience of the population. Life history traits such as longevity, slow maturation, low reproductive potential, and dependence on inshore habitats make dugongs susceptible to a range of threats that affect their recovery.132,133

Dugongs are reliant on seagrass meadows that are susceptible to unfavourable environmental conditions.134 At the Reef-wide scale, the extent of seagrass meadows was considered to be relatively stable at the time of the Outlook Report 2009. Since then some warning signs have emerged. Declines in some areas have been reported over recent years, as have significant losses of seagrass in the areas directly affected by the path of cyclone Yasi and large flood events.134 Threats that affect seagrass, such as increased sediments and nutrients from land-based run-off, dredging and disposal and resuspension of dredge material, and physical damage to the seafloor, may have flow-on effects on dugongs.

Direct threats to dugongs along the urban coast include incidental capture in commercial fishing and shark control program nets (see Section 5.4.3), illegal fishing nets and poaching (see Section 5.4.3), vessel strike, legal take (see Section 5.9) and ingestion of marine debris. Some Traditional Owner groups have voluntarily ceased hunting dugongs along the developed coast in recognition of the pressure this species is under from a range of other threats (see Section 5.9). It is unknown how projected increases in recreational use of the Region will affect dugongs.

**Management** A number of management measures to reduce the direct and indirect impacts on dugongs are in place in the Region, including:

* Protection of the species under Commonwealth and Queensland environmental legislation for example, ‘listed migratory species’ under the Environment Protection and Biodiversity Conservation Act*;* ‘protected species’ under theGreat Barrier Reef Marine Park Regulations; ‘vulnerable’ under the Queensland Nature Conservation Act.
* Spatial protection of coastal and some estuarine areas through zoning plans, trawling closures, Dugong Protection Areas and Queensland Fish Habitat Areas.
* Traditional Use of Marine Resources Agreements and Indigenous Land Use Agreements.
* Improvement of water quality that enters the Region through the implementation of Reef Plan.
* Implementation of a dugong and turtle protection plan from July 2014, under the Australian Government’s Reef Trust.
* Voluntary vessel 'go-slow' transit lanes in important dugong habitat in the Hinchinbrook area.

Since the Outlook Report 2009, based on evidence provided by the Marine Wildlife Stranding program, specific regulations were enacted to address deaths to dugongs from commercial nets in Bowling Green Bay.

Knowledge about the Region’s dugong population continues to provide evidence for its condition. Specific programs include: the Sightings Network component of Eye on the Reef where dugong observations by community members and others are collected135; the Marine Wildlife Strandings program reports on dugong strandings and causes of mortality136; and regular aerial surveys to estimate dugong populations along the urban and remote coasts137,138,139,140.

**Evidence for recovery** Population modelling suggests that even with the most optimistic combinations of life history parameters (for example, low natural mortality and no human-induced mortality), the dugong population is unable to increase by more than four to five per cent per year.141

The Outlook Report 2009 reported that the urban coast dugong population may take more than a century to recover and is subject to many continuing pressures. Dugong mortalities recorded by the Marine Wildlife Strandings program in 2011 were the highest since the commencement of the publication of the program's annual reports in 1998. The 2011 aerial survey results for the urban coast of Queensland showed the lowest recorded presence of dugongs since the surveys began in 1986 (see Figure 2.15).137 This is in contrast to the previous survey in 2005, when the population was considered to have stopped declining.137

The recovery of dugong populations is strongly dependent on the condition of seagrass meadows, their primary food source, and reducing direct mortality, such as from incidental catch, marine debris and boat strike. Reducing fecundity is one response by dugongs to reduced habitat quality (available seagrass).133,142 Significant losses of seagrass habitats were recorded following higher than average rainfall (and associated flooding) during the summer of 2010–11 and the category five cyclone Yasi in 2011.143 The effects of these events were compounded by a number of previous years of extreme weather including cyclones and freshwater flooding.144,145,146,147,148

### Humpback whales

Key message: Humpback whales continue to show good recovery.

Humpback whales were hunted extensively during the nineteenth and twentieth centuries, causing the global population to collapse to five per cent of its original size.149 It is estimated that when the Australian east coast whaling industry ended in the 1960s, the east coast population of humpback whales had been reduced to a little over 500 individuals.

**Management**Banning whaling in Australian and international waters is the single largest contributing factor to the recovery of the humpback whale population in the Region. Management of other activities that threaten humpback whales within the Region is through a combination of legislative requirements, operational policy and research and monitoring.

The *Great Barrier Reef Marine Park Regulations 1983* specify minimum approach distances for vessels, aircraft and swimmers. Tourism operators are required to have a permit to operate within the Great Barrier Reef Marine Park, including to undertake whale watching. The Species Conservation (Whale or Dolphin Protection) Special Management Areas are in effect for important areas, such as the Whitsundays. The Environment Protection and Biodiversity Conservation Act and *Nature Conservation (Wildlife Management) Regulation 2006* (Qld) continue to provide for complementary protection. A national recovery plan for humpback whales remains in effect across the nation.

In addition to legislation, a range of policies provide additional guidance and strategic direction to management operations. These include: *Action Plan for Australian Cetaceans*; *Australian National Guidelines for Whale and Dolphin Watching 2005*; *Operational Policy on Whale and Dolphin Conservation in the Great Barrier Reef Marine Park 2007*; and *Great Barrier Reef Biodiversity Conservation Strategy 2013*.

Knowledge and understanding about humpback whales continues to increase through a variety of actions including:

* Marine Wildlife Strandings program
* Australian Marine Mammal Centre, which coordinates Australia’s marine mammal research expertise to provide scientific research and advice to underpin Australia’s marine mammal conservation and policy initiatives
* the Sightings Network component of Eye on the Reef where humpback whale observations by community members and others are collected
* annual population surveys of the east Australian humpback whale population.

**Evidence for recovery** Annual recovery rates of the east Australian humpback whale stock have been estimated at between 10.5 and 12.3 per cent per year.150 A survey in 2010 provides no evidence that the rate of population growth is slowing significantly and the re-estimation from these surveys sets growth between 10.5 and 11.3 per cent per year.151 Assuming an average population growth trend of 11 per cent, it is calculated the population in 2013 was approximately 17,000 (Figure 8.3).

[Photograph of the front half of a humpback whale underwater. Caption: Humpback whale rolling near the surface]



Figure 8.. Recovery of the east Australian humpback whale population, 1981–2013

The east Australian humpback whale population (E1 stock) continues to strongly recover since whaling ceased in the 1960s. The 2013 data point is an estimate calculated using published population growth rate information151. Source: Adapted from Noad *et al.* 2008150,Noad *et al.* 2011151, Great Barrier Reef Marine Park Authority 2009152

## Heritage resilience

Resilience is a concept yet to be widely applied in Australian heritage management.153 The *Australia State of Environment Report* *2011*153 provides a broad-ranging assessment of the resilience of Australia’s heritage. The following discussion is principally derived from that report.

### Understanding heritage resilience

Key message: Factors affecting heritage resilience vary for different types of values.

Broadly, heritage resilience is the ability of a heritage place, structure or value to experience impacts or disturbances while retaining the inherent heritage values for which it has been recognised.

The Region’s heritage is susceptible to changes brought about by impacts from a range of sources. Its resilience can be considered in relation to both individual heritage values and the total heritage resource. The ability of individual places or the wider resource to withstand impacts depends on the nature of specific heritage values and their tolerance to change. For example, the resilience of a large geomorphological feature will be vastly different from the resilience of a small cultural site such as a fish trap or midden. In addition, while physical impacts may be important for the resilience of heritage places, impacts on intangible qualities such as the loss of knowledge or appreciation may be more important for cultural heritage values.

The resilience of the Region’s heritage, while influenced by drivers such as climate change, population growth and economic development, is also strongly affected by knowledge, governance arrangements, resources and community attitudes.153

Resilience of heritage values will depend upon the nature and condition of the heritage value, the way it is valued, the use that is made of it, the impacts on it and the effectiveness of its management. In addition, the resilience of heritage values derived from the natural environment (such as Indigenous heritage values and world heritage values) is a direct function of the resilience of the underpinning natural values.

Factors that affect heritage resilience may be considered at different levels. For example, individual heritage places may be highly susceptible to impacts such as floods and cyclones; however, the total natural or cultural resource base may be sufficiently robust to withstand the loss of individual places without substantive overall loss of heritage value.153 For other heritage values, there may be only a few examples, making the overall value vulnerable to impacts.

The resilience of Indigenous cultural values is strengthened by the continuation of cultural practices and the retaining and creating of traditional ecological knowledge. Broader understanding and identification of the tangible and intangible aspects of Indigenous heritage values is also a critical component to improving its resilience. Some Great Barrier Reef Traditional Owners separated from land and sea country areas by European settlers are re-establishing connections to the ancestral lands by:

* undertaking on-country cultural camps
* promoting cross-generational knowledge sharing between knowledge holders (elders) and their youth
* cultural mapping of sacred sites, hunting and no hunting areas as well as turtle and dugong breeding and feeding grounds within their sea country areas
* surveys of burial sites, middens, birthing places, initiation sites, story places
* recording place names in traditional language.

Built heritage, such as lightstations, shipwrecks and buildings, are finite and irreplaceable — unlike a natural system, there is no capacity to regenerate. Such tangible heritage values, along with any associated intangible values of historic places, are generally more resilient where there is ongoing, relevant and viable use, and proactive management, including data collection, good conservation standards, regular maintenance and basic disaster planning.153

## Case studies of improving heritage resilience

The three case studies below illustrate the likely resilience of some heritage values in the Region. They provide a more detailed analysis of the factors that contribute to resilience as described above. As knowledge improves additional case studies may be added in future reports.

The case studies presented are:

* cultural practices, observances, customs and lore
* lightstations
* underwater wrecks.

### Cultural practices, observances, customs and lore

Key message: Displacement of Traditional Owners from country affects the resilience of cultural heritage.

Key message: Traditional Owners spending time on country is strengthening connections and transferring knowledge.

Indigenous heritage values are a major contributor to the heritage values of the Region (see Section 4.2). Traditional Owners are the custodians of these values and their resilience depends directly on the Traditional Owners and their connections to culture and sea country.

The Woppaburra people in the south of the Region are an example of a Traditional Owner group that has worked to improve the resilience of their cultural values by reasserting their cultural connections. They are the Traditional Owners of the Keppel islands and surrounding sea country. The name Woppaburra means ‘Island People’ or ‘People of the Islands’. The area is their ancestral homeland and they continue to keep alive their customary obligations and connections to country, making the Indigenous heritage values associated with the island group strong and resilient.

Between 1865 and 1903, severe illness and inhumane treatment such as forced labour and murder resulted in the population of Woppaburra on the islands being reduced by about 75 to 80 per cent, from an estimated 60 to 80 individuals to just 17.154 Predominantly only women and children remained, many suffering from ill health and poor treatment.154 They were forcibly removed from their country and held in Aboriginal missions and reserves around Queensland.155 Today, Woppaburra descendants number over 600, spread across five family groups living on the mainland.

**Management** Woppaburra have been engaged in formal management arrangements for their sea country since June 2007, managing 561 square kilometres of the Great Barrier Reef Marine Park to achieve better environmental outcomes for themselves, their country, their Traditional Owner neighbours and the wider community.

**Evidence for improvement** Woppaburra are traditional knowledge holders with lifelong spiritual and physical connections to their land and sea country. They maintain strong connections with their country, despite the dispersal of their people from their ancestral homeland, the geographical location of their country and the complexity of contemporary management issues.156 Woppaburra people often return to their ancestral homeland for knowledge sharing, and to undertake cooperative research, monitoring and hands-on management. They work cohesively as a group, communicating and negotiating with various stakeholders including neighbouring Traditional Owner groups, government agencies, educational institutions, museums and scientists to manage their estates for the protection of their living maritime culture. As a result, caring for the Keppel islands is now a shared responsibility amongst Traditional Owners and many other groups such as the island residents, tourism operators, recreational users, scientists and government management agencies.

[Photograph of people walking on the shore of North Keppel Island. Caption: Woppaburra Traditional Owners are working to improve the resilience of their cultural values, North Great Keppel Island]

### Lightstations

Key message: Formal recognition of lightstation heritage values has improved their resilience.

Historic lightstations within the Region are a highly visible part of the maritime heritage of Queensland. The four lightstations recognised on the Commonwealth Heritage List have values which have been well surveyed and recorded. In contrast, the Pine Islet lightstation has fallen into major disrepair. Little is recorded of the heritage values of the remaining historic lightstations and aids to navigation in the Region.

**Management** Two of the four Commonwealth heritage-listed lightstations have heritage management plans completed for them. In addition, there is strong ongoing management for these sites, with annual inspections by qualified people, annual general maintenance plans, asbestos management plans and, in some cases, a permanent onsite presence. Other lightstations and aids to navigation are being well maintained as navigational facilities.

**Evidence for improvement** The four Commonwealth heritage-listed lightstations are appreciated by the community and there has been a recent emphasis on their restoration and maintenance. There is less public appreciation of the concrete ‘tower’ lightstations built in the Region in the 1920s and 1930s — any heritage values of which are not formally recognised. These structures are unlikely to be preserved for their heritage values beyond their working life without additional justification for preservation.

### Underwater wrecks

Key message: Most underwater wrecks have poor resilience, particularly as they are poorly recorded.

Underwater wrecks, including historic shipwrecks and World War II wrecks, are a strong component of the heritage values of the Region. They are important both as individual wrecks, telling a particular story of endeavour and misfortune, and as a collection that improve understanding of the nation’s history. The knowledge base for underwater wrecks is improving all the time.

Of the more than 1300 historic shipwrecks known to be in Queensland waters, the majority are likely to be located in the Region and new shipwrecks are discovered regularly (see Section 4.3.1). The wreck of the HMS *Pandora* has been well described and recorded. The same assessment cannot be made for many of the other shipwrecks in the Region. For example, while the HMCS *Mermaid* is recorded and within a protected zone, it is unsurveyed and deteriorating because it is located in a high-energy zone. There has been no baseline survey or any recovery and analysis of artefacts from the *Foam* and the SS *Gothenburg*. For hundreds of other shipwrecks, understanding, and hence protection, is lacking because they are yet to be located.

An estimated 140 submerged plane wrecks from World War II have not been located or recorded. Two wrecks, Catalina A 24 25 and Catalina A 24 24 which hold the remains of 25 personnel, were recently located 70 years after their presumed loss.

The community profile is strong for some wrecks. For the HMS *Pandora*, this is particularly so because its story is the centrepiece of the Museum of Tropical Queensland in Townsville. For the SS *Yongala*, some of the recovered artefacts are conserved and available for research and interpretation. There is also strong community recognition of the wreck as a world-famous dive site. As wrecks are discovered they become valued by the community, especially those people with personal connections to the wreck.

**Management** Ships, like the HMS *Pandora* and SS *Yongala*, greater than 75 years old, are protected under the *Historic Shipwrecks Act 1976* (Cth). In addition protected zones declared under the Act around some wrecks, for example a 500 metre protected zone declared around the HMS *Pandora*, further improves protection by strictly controlling access. There is little existing protection for other wrecks in the Region, including shipwrecks less than 75 years old.

**Evidence for improving resilience** In some cases, the resilience of a wreck’s contribution to maritime heritage can be improved by recovering and preserving key artefacts and making them available. The HMS *Pandora* has been partially excavated, revealing a plethora of artefacts which have been conserved and are available for research, public display and interpretation, thus helping to improve understanding of the wreck and its heritage value.

The HMS *Pandora* has remained physically stable due to its depth and the local sedimentary regime, and a layer of sediment makes the significant remaining material within the wreck relatively secure. On the other hand, the fabric of the wreck of the SS *Yongala* is above the seabed and therefore extremely vulnerable to cyclone damage, most recently during cyclone Yasi in 2011157.

Underwater wrecks and their inherent heritage values are extremely vulnerable to unintended impacts such as anchor damage and marine debris from fishing activities. Most wrecks are not recorded, inspected, maintained or subject to dedicated regulatory protection. Some wrecks show signs of having been damaged by anchoring, trawling and recreational fishing.

[START COLOURED BOX]

**The wreck of the SS *Yongala***

The SS *Yongala* — now a protected historic shipwreck with a 797 metre protected zone — sank in 1911 off Cape Bowling Green in the central Great Barrier Reef, with the loss of 122 lives. It was a coastal trader in the early twentieth century. The wreck is about 110 metres long lying in 30 metres of water on a relatively flat sandy seabed. It has historic, technical, social, archaeological, scientific and interpretive values. Added to its heritage significance, the wreck’s structure provides a complex habitat for a wide variety of species and is a significant tourism destination157.

Cyclone Yasi significantly affected the wreck in 2011. The storm surge and associated churning sand abraded large sections of coral and other concretions off its steel hull. This calcareous layer was serving to reinforce and protect the wreck. The physical force of the storm and the movement of the sandy seafloor forced the ship to twist and move, causing the bow to drop onto the seafloor and the main deck section to partially collapse. 157 The damage inflicted is irreversible and will exacerbate deterioration of the wreck. Marine life is likely to re-establish and slow deterioration, however the wreck's ability to withstand future cyclonic events has been irreversibly compromised. 157

[Underwater photograph of the hull of the SS *Yongala*. Copyright Matt Curnock. Caption: The protective layer of marine life was abraded from the hull during cyclone Yasi.]

[END COLOURED BOX]

## Assessment summary — Resilience

Section 54(3)(e) of the *Great Barrier Reef Marine Park Act 1975* requires ‘… *an assessment of the current resilience of the ecosystem*…’ within the Great Barrier Reef Region, and Section 116A(2)(c) of the *Great Barrier Reef Marine Park Regulations 1983* requires‘… *an assessment of the current resilience of the* *heritage values…’* of the Region.

These assessments of ecosystem and heritage resilience are based on the information provided in earlier chapters, namely the current state and trends of the Great Barrier Reef’s biodiversity, ecosystem health and heritage values, as well as the trends in direct use, the factors influencing future values and the effectiveness of protection and management arrangements. A series of illustrative case studies provide additional information on:

* recovery in the ecosystem
* improving heritage resilience.

Over time, the case studies may be expanded or additional case studies developed.

### Recovery in the ecosystem

**Outlook Report 2009: Assessment summary**

*Some disturbed populations and habitats have demonstrated recovery after disturbance (for example coral reefs, lagoon floor, coral trout, humpback whales). For some species recovery has been very slow (for example loggerhead turtles) or not evident (black teatfish, dugongs) and is dependent on the removal of all major threats. Increasing frequency and extent of threats are likely to reduce the resilience of species and habitats.*

| **Assessment component** | **Summary** | **Grade 2009** | **Grade 2014 and trend since 2009** | **Confidence** |
| --- | --- | --- | --- | --- |
| **Grade** | **Trend** |
| Coral reef habitats | Increases in frequency and severity of disturbances, such as cyclones, flooding, crown-of-thorns starfish outbreaks have reduced the capacity for coral reefs to recover since 2009. There is some evidence of recovery at a local scale. | Good | Poor,Deteriorated | Adequate | Limited |
| Lagoon floor habitats | Ongoing management arrangements mean that some lagoon floor habitats previously at risk are continuing to recover from disturbances. There is little monitoring of lagoon floor condition or recovery. | Good | Good,Stable | Limited | Limited |
| Black teatfish  | Based on recent modelling, populations of black teatfish in the Region are likely to be slowly recovering. Populations have recovered in Torres Strait. | Very poor | Very poor,Improved | Limited | Limited |
| Coral trout | Coral trout populations demonstrate a strong ability to recover and increased reproduction in zones closed to fishing disperses beyond those zones. There are emerging concerns about the overall condition of coral trout populations.  | Good | Good,No consistent trend | Limited | Limited |
| Loggerhead turtles | Loggerhead turtle populations are recovering. There are comprehensive management arrangements in the Region, but some threats remain. Pressures from outside Australian waters are likely to influence their full recovery. | Poor | Poor, Improved | Adequate | Adequate |
| Urban coast dugongs | The urban coast dugong population has declined further since 2009, affected by the loss of seagrass from cyclones and flooding. Continued effective implementation of all management arrangements is required to reduce direct threats. | Very poor | Very poor, Deteriorated | Adequate | Limited |
| Humpback whales | Humpback whales continue to recover at their maximum population growth rate 50 years after whaling stopped. | Very good | Very good, Improved | Adequate | Adequate |
| **Recovery in the ecosystem** | Some disturbed populations and habitats have demonstrated recovery after disturbance (for example lagoon floor, loggerhead turtles, humpback whales). For some species, recovery is not evident (black teatfish, dugongs) and is dependent on the removal of all threats. Increasing frequency and extent of some threats are likely to continue to reduce the resilience of species and habitats in the Region. | **Good** | **Poor,****Deteriorated** |  |  |

|  |
| --- |
| **Condition** |
| **Very good** | Under current management, throughout the ecosystem, populations of affected species are recovering well, at rates close to their maximum reproductive capacity. Affected habitats are recovering within expected natural timeframes, following natural cycles of regeneration. |
| **Good** | Populations of affected species are recovering at rates below their maximum reproductive capacity. Recovery of affected habitats is slower than naturally expected but structure and function are ultimately restored within a reasonable timeframe. |
| **Poor** | Populations of affected species are recovering poorly, at rates well below their maximum reproductive capacity. Recovery of affected habitats is much slower than expected natural timeframes and the resultant habitat is substantially different. |
| **Very poor** | Affected species are failing to recover and affected habitats are failing to recover to their natural structure and function. |
| **Trend since 2009** |
| Improved, Stable, Deteriorated, No consistent trend |
| **Confidence in condition and trend** |
| Adequate | Adequate high-quality evidence and high level of consensus |
| Limited | Limited evidence or limited consensus |
| Inferred | Inferred, very limited evidence |

### Improving heritage resilience

**Outlook Report 2009:** *Not assessed*

| **Assessment component** | **Summary** | **Grade 2009** | **Grade 2014**  | **Confidence** |
| --- | --- | --- | --- | --- |
| **Grade** |  |
| Cultural practices, observances, customs and lore | Resilience of Indigenous heritage values depends on opportunities for Traditional Owners to access country and continue their cultural practices. Groups such as the Woppaburra in the south of the Region are working to strengthen cultural connections. Their aspirations are reflected in management arrangements such as the Traditional Use of Marine Resources Agreement. | Not assessed | Good | Limited |  |
| Lightstations | Formal recognition of the heritage values of the four major lightstations means there is comprehensive recording, restoration and regular maintenance. The heritage values of unlisted sites are less well known and more susceptible to being lost. | Not assessed | Good | Limited |  |
| Underwater wrecks | Most underwater wrecks are poorly recorded or their locations are unknown. Those that are comprehensively recorded and are within a protected zone have the highest resilience. In some cases heritage values can be protected by recovery and conservation of artefacts. Resilience varies depending on a wreck’s physical situation. | Not assessed | Poor | Limited |  |
| **Improving heritage resilience** | The resilience of built heritage values has improved where the values are well recorded and well recognised and there is strong regulatory protection and regular maintenance (for example heritage-listed lighthouses). The resilience of intangible values, such as many Indigenous heritage values, depends on the active involvement of the custodians of those values so that connections and knowledge are kept alive. Such involvement has continued to grow.  | **Not assessed** | **Good** |  |  |

|  |  |
| --- | --- |
| **Grade** | **Grading Statements** |
| **Very good** | Under current management, heritage values are well understood, well recorded and well protected. Actions are being taken to address major threats and restore values. Cultural connections and community awareness are strong. |
| **Good** | Heritage values are described and recorded for many components. Many of the values are protected under current management arrangements. Some actions are being taken to address major threats and there is restoration work in some areas. Cultural connections are generally strong and there is some community awareness of values. |
| **Poor** | Some of the heritage values are described and recorded, but most remain unrecorded and poorly understood. Some are protected under current management arrangements. The number of values where actions are being taken to address major threats and restore values is relatively small. Cultural connections have deteriorated. There is limited community awareness of values. |
| **Very Poor** | Heritage values are not well understood, recorded or protected. Few, if any, actions are being taken to address major threats and restore values. Cultural connections have deteriorated significantly and there is little community awareness. |

|  |
| --- |
| **Trend since 2009** |
| New assessment for this report; no trend provided. |
| **Confidence in condition and trend** |
| Adequate | Adequate high-quality evidence and high level of consensus |
| Limited | Limited evidence or limited consensus |
| Inferred | Inferred, very limited evidence |

### Overall summary of resilience

While the Great Barrier Reef Region may be one of the healthiest tropical marine ecosystems in the world, there is concern that its resilience is being seriously, and increasingly rapidly, eroded. There is no comprehensive information on the resilience of the Region’s ecosystem — due largely to its size and complexity and the difficulties of measuring resilience. However, there is increasing evidence of loss of resistance and recovery capacity, although the extent of that loss varies considerably between ecosystem components and between localities. The natural resilience of the Region’s values may be being overwhelmed by increases in levels of disturbance, and consequent impacts.

The emerging loss of ecosystem resilience is particularly critical in the context of the projected major increase in the effects of climate change impacts and the lag time between improved land management practices and observable ecosystem improvements. Current evidence suggests climate change trajectories remain on course for increasingly serious impacts in the Region. As these effects worsen, it is very likely that interactions between climate-related threats and other threats will have increasingly serious consequences. Managing for resilience is most important in situations where there is uncertainty about risks and appropriate management responses — the combined consequences of climate change and local and regional impacts on the Great Barrier Reef present such a situation. Maintaining the resilience of the Great Barrier Reef ecosystem will require major increases in effort to reduce local and global threats.

Resilience is a relatively new concept in heritage management, describing the ability of heritage values, both tangible and intangible, to experience impacts or disturbances while retaining the inherent values for which they are recognised. It depends upon the nature and condition of the values, the way they are appreciated and understood, the use that is made of them the impacts affecting them, and the effectiveness of management arrangements.

Built heritage values are finite and irreplaceable. Resilience is strongest for those places, structures and wrecks where: the structure and site are inherently stable; the values are well recorded, monitored and recognised; regulatory protection is in place and enforced; and planning, restoration and regular maintenance are undertaken. For such values in the Region, the four heritage-listed lightstations and the wreck of the HMS *Pandora* are likely to be the most resilient. Much of the remaining built heritage in the Region is likely to be less resilient because it is poorly recorded, rarely monitored or maintained, is not specifically protected or its significance is not well understood or appreciated.

The resilience of intangible values, such as many of the Region’s Indigenous heritage values, depends strongly on the active involvement of the custodians of those values so that connections and knowledge are kept alive. Broader understanding of these values and having regulatory systems that recognise and take them into account are also important contributors to their resilience.

The resilience of heritage values derived from the natural environment (such as Indigenous heritage values and world and national heritage values) is a direct function of the resilience of the underpinning ecosystem.

## References

1. Walker, B.H. and C. 2004, Resilience, adaptability and transformability in social-ecological systems, *Ecology and Society* 9(2): Article 5.

2. McCook, L.J., Folke, C., Hughes, T., Nyström, M., Obura, D. and Salm, R. 2007, Ecological resilience, climate change and the Great Barrier Reef, in *Climate Change and the Great Barrier Reef: A vulnerability assessment*, ed. J.E. Johnson and P.A. Marshall, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville, pp. 75-96.

3. Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D. and Pritchard, R. 2002, Resilience management in social-ecological systems: a working hypothesis for a participatory approach, *Conservation Ecology* 6(1): 14.

4. Holling, C.C. 1973, Resilience and stability of ecological systems, *Annual Review of Ecological Systems* 4: 1-23.

5. Marshall, N.A., Marshall, P.A., Tamelander, J., Obura, D., Malleret-King, D. and Cinner, J.E. 2010, *A framework for social adaptation to climate change. Sustaining tropical coastal communities and industries*, IUCN, Gland, Switzerland.

6. Marshall, N.A., Tobin, R.C., Marshall, P.A., Gooch, M. and Hobday, A.J. 2013, Social vulnerability of marine resource users to extreme weather events, *Ecosystems* 16(5): 797-809.

7. Mumby, P., Chollett, L., Bozec, Y. and Wolff, N. 2014, Ecological resilience, robustness and vulnerability: how do these concepts benefit ecosystem management? *Current Opinion in Environmental Sustainability* 7: 22-27.

8. Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Gosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J.A., Lough, J.M., Marshall, P.A., Nyström, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B. and Roughgarden, J. 2003, Climate change, human impacts, and the resilience of coral reefs, *Science* 301: 929-933.

9. Brodie, J., Waterhouse, J., Schaffelke, B., Kroon, F., Thorburn, P., Rolfe, J., Johnson, J., Fabricius, K., Lewis, S., Devlin, M., Warne, M. and McKenzie, L.J. 2013, *2013 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem conditions*, Reef Water Quality Protection Plan Secretariat, Brisbane.

10. Johnson, J.E. and Marshall, P.A. (eds) 2007, *Climate change and the Great Barrier Reef: a vulnerability assessment,* Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville.

11. Mumby, P.J., Wolff, N.H., Bozec, Y., Chollett, L. and Halloran, P. 2013, Operationalizing the resilience of coral reefs in an era of climate change, *Conservation Letters* DOI: 10.1111/conl.12047.

12. Hoey, A.S. and Bellwood, D.R. 2009, Limited functional redundancy in a high diversity system: single species dominates key ecological process on coral reefs, *Ecosystems* 12(8): 1316-1328.

13. Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L.J., Moltschaniwskyj, N.A., Pratchett, M.S., Steneck, R.S. and Willis, B. 2007, Phase shifts, herbivory, and the resilience of coral reefs to climate change, *Current Biology* 17(4): 360-365.

14. Nyström, M. and Folke, C. 2001, Spatial resilience of coral reefs, *Ecosystems* 4(5): 406-417.

15. Nyström, M., Graham, N.A.J., Lokrantz, J. and Norstrom, A.V. 2008, Capturing the cornerstones of coral reef resilience: Linking theory to practice, *Coral Reefs* 27: 795-809.

16. Olds, A.D., Pitt, K.A., Maxwell, P.S. and Connolly, R.M. 2012, Synergistic effects of reserves and connectivity on ecological resilience, *Journal of Applied Ecology* 49: 1195-1203.

17. Great Barrier Reef Marine Park Authority 2012, *Great Barrier Reef Coastal Ecosystems Assessment Framework*, GBRMPA, Townsville.

18. Pearson, R.G. 1981, Recovery and recolonization of coral reefs, *Marine Ecology Progress Series* 4: 105-122.

19. Hughes, T.P. 1994, Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef, *Science* 265(5178): 1547-1551.

20. Woodley, J., Chornesky, E., Clifford, P., Jackson, J., Kaufman, L., Knowlton, N., Lang, J., Pearson, M., Porter, J., Rooney, M., Rylaarsdam, K., Tunnicliffe, V., Wahle, C., Wulff, J., Curtis, A., Dallmeyer, M., Jupp, B., Koehl, A., Neigel, J. and Sides, E. 1981, Hurricane Allen's impact on Jamaican coral reefs, *Science* 214.

21. Woodley, J.D. 1992, The incidence of hurricanes on the north coast of Jamaica since 1870: are the classic reef descriptions atypical? *Hydrobiologia* 247: 133-138.

22. Knowlton, N., Lang, J.C. and Keller, B.D. 1990, Case study of natural population collapse: post-hurricane predation on Jamaican staghorn corals, *Smithsonian Contributions to the Marine Sciences*.

23. Hughes, T., Keller, B., Jackson, J. and Boyle, M. 1985, Mass mortality of the echinoid *Diadema antillarum* Philippi in Jamaica, *Bulletin of Marine Science* 36(2): 377-384.

24. Goreau, T.J. 1992, Bleaching and reef community change in Jamaica: 1951-1991, *American Zoologist* 32: 683-695.

25. Bruno, J.F., Sweatman, H., Precht, W.F., Selig, E.R. and Schutte, V.G.W. 2009, Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs, *Ecology* 90(6): 1478-1484.

26. Liddell, W.D. and  Ohlhorst, S.L. 1993, Ten years of disturbance and change on a Jamaican fringing reef, in *Proceedings of the Seventh International Coral Reef Symposium, Guam, 22-27 June 1992,* eds. R. H. Richmond, University of Guam Press, Mangilao, Guam, pp. 149-155.

27. Hughes, T.P., Graham, N.A.J., Jackson, J.B.C., Mumby, P.J. and Steneck, R.S. 2010, Rising to the challenge of sustaining coral reef resilience, *Trends in Ecology and Evolution* 25(11): 633-642.

28. Kubicek, A., Muhando, C. and Reuter, H. 2012, Simulations of long-term community dynamics in coral reefs: how perturbations shape trajectories, *PLoS Computational Biology* 8(11): e1002791.

29. Littler, M.M., Littler, D.S. and Brooks, B.L. 2009, Herbivory, nutrients, stochastic events, and relative dominances of benthic indicator groups on coral reefs: a review and recommendations, *Smithsonian Contributions to the Marine Sciences* 38: 401-414.

30. Van Woesik, R. 2013, Quantifying uncertainty and resilience on coral reefs using a Bayesian approach, *Environmental Research Letters* 8: 044051.

31. Bythell, J., Hillis-Starr, Z.M. and Rogers, C.S. 2000, Local variability but landscape stability in coral reef communities following repeated hurricane impacts, *Marine Ecology Progress Series* 204: 93-100.

32. Howell, L. 2013, *Global Risk 2013: An initiative of the Risk Response Network*, World Economic Forum, Geneva, Switzerland.

33. Great Barrier Reef Marine Park Authority 2012, *Climate change adaptation: Outcomes from the Great Barrier Reef Climate Change Action Plan 2007-2012*, GBRMPA, Townsville.

34. Graham, N.A.J., Nash, K.L. and Kool, J.T. 2011, Coral reef recovery dynamics in a changing world, *Coral Reefs* 30: 283-294.

35. Gilmour, J.P., Smith, L.D., Heyward, A.J., Baird, A.H. and Pratchett, M.S. 2013, Recovery of an isolated coral reef system following severe disturbance, *Science* 340(6128): 69-71.

36. Thompson, A., Schaffelke, B., Logan, M., Costello, P., Davidson, J., Doyle, J., Furnas, M., Gunn, K., Liddy, M., Skuza, M., Uthicke, S., Wright, M. and Zagorskis, I. 2014, *Reef Rescue Monitoring Program. Draft final report of AIMS activities 2012 to 2013 - Inshore water quality and coral reef monitoring. Report for Great Barrier Reef Marine Park Authority*, Australian Institute of Marine Science, Townsville.

37. Connell, J.H. 1997, Disturbance and recovery of coral assemblages, *Coral Reefs* 16(Suppl.): S101-S113.

38. Great Barrier Reef Marine Park Authority 2012, *Informing the outlook for Great Barrier Reef coastal ecosystems*, GBRMPA, Townsville.

39. De'ath, G., Fabricius, K.E., Sweatman, H. and Puotinen, M. 2012, The 27–year decline of coral cover on the Great Barrier Reef and its causes, *Proceedings of the National Academy of Sciences* 109(44): 17995-17999.

40. Graham, N.A.J., Nash, K.L. and Kool, J.T. 2011, Coral reef recovery dynamics in a changing world, *Coral Reefs* 30: 283-294.

41. Sweatman, H., Cheal, A.J., Coleman, G.J., Emslie, M.J., Johns, K., Jonker, M., Miller, I.R. and Osborne, K. 2008, *Long-term monitoring of the Great Barrier Reef: Status Report 8*, Australian Institute of Marine Science, Townsville.

42. Johnson, J.E., Maynard, J.A., Devlin, M.J., Wilkinson, S., Anthony, K.R.N., Yorkston, H., Heron, S.F., Puotinen, M.L. and  van Hooidonk, R. 2013, Resilience of Great Barrier Reef marine ecosystems and drivers of change, in *Synthesis of evidence to support the Reef Water Quality Scientific Consensus Statement 2013,* Department of the Premier and Cabinet, Brisbane.

43. Day, J.C. and Dobbs, K. 2013, Effective governance of a large and complex cross-jurisdictional marine protected area: Australia's Great Barrier Reef, *Marine Policy* 41: 14-24.

44. Great Barrier Reef Marine Park Authority 2013, *Great Barrier Reef Biodiversity Conservation Strategy 2013*, GBRMPA, Townsville.

45. Department of the Premier and Cabinet 2013, *Reef Water Quality Protection Plan 2013*, Reef Water Quality Protection Plan Secretariat, Brisbane.

46. Donnelly, R. 2009, *Pro-vision reef: Stewardship action plan, a statement of operational standards and climate change contingency planning*, Great Barrier Reef Marine Park Authority, Townsville.

47. Sweatman, H. 2013, *Australian Institute of Marine Science long term monitioring program, Latest surveys,* Australian Institute of Marine Science, <<http://www.aims.gov.au/docs/research/monitoring/reef/latest-surveys.html>>.

48. Thompson, A., Schaffelke, B., Logan, M., Costello, P., Davidson, J., Doyle, J., Furnas, M., Gunn, K., Liddy, M., Skuza, M., Uthicke, S., Wright, M. and Zagorskis, I. 2013 draft for review, *Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities 2012 to 2013– Inshore water quality and coral reef monitoring. Report for the Great Barrier Reef Marine Park Authority*, Australian Institute of Marine Science, Townsville.

49. Smith, R., Middlebrook, R., Turner, R., Huggins, R., Vardy, S. and Warne, M. 2012, Large-scale pesticide monitoring across Great Barrier Reef catchments: Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, *Marine Pollution Bulletin* 65(4-9): 117-127.

50. Marshall, N.A., Bohensky, E., Curnock, M., Goldberg, J., Gooch, M., Pert, P., Scherl, L., Stone-Jovicich, S. and Tobin, R.C. 2013, *A Social and Economic Long Term Monitoring Program for the Great Barrier Reef: key findings, 2013. Report to the National Environmental Research Program*, Reef and Rainforest Research Centre Limited, Cairns.

51. Great Barrier Reef Marine Park Authority 2011, *Tropical cyclone risk and impact assessment plan*, GBRMPA, Townsville.

52. Great Barrier Reef Marine Park Authority 2010, *Coral Bleaching Response Plan 2010-2011*, GBRMPA, Townsville.

53. Great Barrier Reef Marine Park Authority 2011, *Coral Disease Response Plan: predicting, assessing and responding to coral disease outbreaks on the Great Barrier Reef*, Great Barrier Reef Marine Park Authority, Townsville.

54. Diaz-Pulido, G., McCook, L.J., Dove, S., Berkelmans, R., Roff, G., Kline, D.I., Weeks, S., Evans, R.D., Williamson, D.H. and Hoegh-Guldberg, O. 2009, Doom and boom on a resilient reef: Climate change, algal overgrowth and coral recovery, *PLoS ONE* 4(4): e5239.

55. Thompson, A., Costello, P., Davidson, J., Schaffelke, B., Uthicke, S. and Liddy, M. 2013, *Reef Rescue Marine Monitoring Program. Report of AIMS activities: Inshore coral reef monitoring 2012. Report for Great Barrier Reef Marine Park Authority*, Australian Institute of Marine Science, Townsville.

56. Jones, A.M. and Berkelmans, R. 2014, Flood impacts in Keppel Bay, Southern Great Barrier Reef in the aftermath of cyclonic rainfall, *PLoS ONE* 9(1): e84739.

57. Roff, G., Clark, T.R., Reymond, C.E., Zhao, J., Feng, Y., McCook, L.J., Done, T.J. and Pandolfi, J.M. 2013, Palaeoecological evidence of a historical collapse of corals at Pelorus Island, inshore Great Barrier Reef, following European settlement, *Proceedings of the Royal Society B: Biological Sciences* 280(1750): 2012-2100.

58. Great Barrier Reef Marine Park Authority (Unpublished), *Eye on the Reef*, [database].

59. Reef Water Quality Protection Plan Secretariat 2014, *Great Barrier Reef report card 2012 and 2013, Reef Water Quality Protection Plan. Report card key findings*, Reef Water Quality Protection Plan Secretariat, Brisbane.

60. Bellwood, D.R., Hughes, T.P., Folke, C. and Nyström, M. 2004, Confronting the coral reef crisis, *Nature* 429: 827-833.

61. Roff, G. and Mumby, P.J. 2012, Global disparity in the resilience of coral reefs, *Trends in Ecology and Evolution* 27(7): 404-411.

62. Fabricius, K.E., Okaji, K. and De'ath, G. 2010, Three lines of evidence to link outbreaks of the crown-of-thorns seastar  *Acanthaster planci* to the release of larval food limitation, *Coral Reefs* 29: 593-605.

63. Great Barrier Reef Marine Park Authority 2011, *Impacts of tropical cyclone Yasi on the Great Barrier Reef: A report on the findings of a rapid ecological impact assessment*, GBRMPA, Townsville.

64. van Hooidonk, R., Maynard, J.A. and Planes, S. 2013, Temporary refugia for coral reefs in a warming world, *Nature Climate Change* 3(4): 508-511.

65. Anthony, K.R.N., Maynard, J.A., Diaz-Pulido, G., Mumby, P.J., Marshall, P.A., Cao, L. and Hoegh-Guldberg, O. 2011, Ocean acidification and  warming will lower coral reef resilience, *Global Change Biology* 17: 1798-1808.

66. Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A. and Hatziolos, M.E. 2007, Coral reefs under rapid climate change and ocean acidification, *Science* 318: 1737-1742.

67. van Hooidonk, R.J. and Huber, M. 2009, Quantifying the quality of coral bleaching predictions, *Coral Reefs* 28: 579.

68. Walker, B. and Salt, D. 2006, *Resilience thinking: sustaining ecosystems and people in a changing world,* Island Press, Washington DC.

69. Harris, P.T. and Hughes, M.G. 2012, Predicted benthic disturbance regimes on the Australian continental shelf: a modelling approach, *Marine Ecology Progress Series* 449: 13-25.

70. North-East Shipping Management Group 2013, *North-East Shipping Management Plan (Draft for consultation)*, Australian Maritime Safety Authority, Canberra.

71. Pears, R.J., Morison, A.K., Jebreen, E.J., Dunning, M.C., Pitcher, C.R., Courtney, A.J., Houlden, B. and Jacobsen, I.P. 2012, *Ecological risk assessment of the East Coast Otter Trawl Fishery in the Great Barrier Reef Marine Park: Technical report*, Great Barrier Reef Marine Park Authority, Townsville.

72. Pitcher, C.R., Austin, M., Burridge, C.Y., Bustamante, R.H., Cheers, S.J., Ellis, N., Jones, P.N., Koutsoukos, A.G., Moeseneder, C.H., Smith, G.P., Venables, W. and Wassenberg, T.J. 2008, *Recovery of seabed habitat from the impact of trawling in the far northern section of the Great Barrier Reef Marine Park: CSIRO final report to GBRMPA*, CSIRO Marine and Atmospheric Research, Cleveland, Queensland.

73. Grech, A. and Coles, R. 2011, Interactions between a trawl fishery and spatial closures for biodiversity conservation in the Great Barrier Reef World Heritage Area, Australia, *PLoS ONE* 6(6): e21094.

74. Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N.A., Bartlett, C., Browne, M., Campbell, N., Cannard, T., Cappo, M., Carini, G., Chalmeres, S., Cheers, S., Chetwynd, D., Colegax, A., Coles, R., Cook, S., Davie, P., De'ath, G., Devereux, D., Done, B., Donovan, T., Ehrke, B., Ellis, N., Ericson, G., Fellegara, I., Forcey, K., Furey, M., Gledhill, D., Good, N., Gordon, S., Haywood, M., Hendricks, M., Jacobsen, I., Johnson, J., Jones, M., Kininmonth, S., Kistle, S., Last, P., Leite, A., Marks, S., McLeod, I., Oczkowicz, S., Robinson, M., Rose, C., Seabright, D., Sheils, J., Sherlock, M., Skelton, P., Smith, D., Smith, G., Speare, P., Stowar, M., Strickland, C., Van der Geest, C., Venables, W., Walsh, C., Wassenberg, T.J., Welna, A. and Yearsley, G. 2007, *Seabed biodiversity on the continental shelf of the Great Barrier Reef World Heritage Area. AIMS/CSIRO/QM/QDPI CRC Reef Research Task final report*, CSIRO Marine and Atmospheric Research, Hobart.

75. Brunner, R.W.J. 2011, *Sustainability in the Design of Bulk Coal Ports: an Australian Case Study, General Manager Planning, Hay Point*, North Queensland Bulk Ports Corporation, Mackay, Queensland.

76. Foster, T., Corcoran, E., Erftemeijer, P.L., Fletcher, C., Peirs, K., Dolmans, C., Smith, A. and Yamamoto, H. 2010, *Dredging and port construction around coral reefs, Envicom Report 108*, PIANC Secretariat, Belgium.

77. Smith, R., Boyd, S.E., Rees, H.L., Dearnaley, M.P. and Stevenson, J. 2006, Effects of dredging activity on epifaunal communities - surveys following cessation of dredging, *Estuarine, Coastal and Shelf Science* 70(1-2): 207-223.

78. Erftemeijer, P.L. and Lewis, R.R. 2006, Environmental impacts of dredging on seagrasses: A review, *Marine Pollution Bulletin* 52(12): 1553-1572.

79. Erftemeijer, P.L., Riegl, B., Hoeksema, B.W. and Todd, P.A. 2012, Environmental impacts of dredging and other sediment disturbances on corals: a review, *Marine Pollution Bulletin* 64(9): 1737-1765.

80. Rasheed, K. and Balchand, A.N. 2001, Environmental studies on impacts of dredging, *International Journal of Environmental Studies* 58(6): 703-725.

81. Fisheries Queensland 2010, *Declared Fish Habitat Area network strategy 2009-14. Planning for the future of Queensland's declared Fish Habitat Area network*, The State of Queensland, Department of Employment, Economic Development and Innovation, Brisbane.

82. Department of Agriculture, Fisheries and Forestry 2012, *Declared Fish Habitat Area Network Assessment Report*, State of Queensland, Brisbane.

83. Grech, A., Bos, M., Brodie, J., Coles, R., Dale, A., Gilbert, R., Hamann, M., Marsh, H., Neil, K., Pressey, R.L., Rasheed, M.A., Sheaves, M. and Smith, A. 2013, Guiding principles for the improved governance of port and shipping impacts in the Great Barrier Reef, *Marine Pollution Bulletin* 75(1-2): 8-20.

84. Department of State Development, Infrastructure and Planning 2014, *Queensland Ports Strategy*, State of Queensland, Brisbane.

85. Pears, R.J., Morison, A.K., Jebreen, E.J., Dunning, M.C., Pitcher, C.R., Courtney, A.J., Houlden, B. and Jacobsen, I.P. 2012, *Ecological risk assessment of the East Coast Otter Trawl Fishery in the Great Barrier Reef Marine Park: summary report*, Great Barrier Reef Marine Park Authority, Townsville.

86. Pitcher, C.R., Burridge, C.Y., Wassenberg, T.J., Hill, B.J. and Poiner, I.R. 2009, A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia, *Fisheries Research* 99(3): 168-183.

87. Sinclair Knight Merz Pty Ltd and Asia-Pacific Applied Science Associates 2013, *Improved dredge material management for the Great Barrier Reef Region: Synthesis report*, Great Barrier Reef Marine Park Authority, Townsville.

88. Skewes, T., Plaganyi, E., Murphy, N., Pascual, R. and Fischer, M. 2014, *Evaluating rotational harvest strategies for sea cucumber fisheries: an MSE of the Qld east coast sea cucumber fishery. FRDC Project No. 2012/200*, CSIRO, Brisbane.

89. Benzie, J.A. and Uthicke, S. 2003, *Stock size of bêche-de-mer, recruitment patterns and gene flow in black teatfish, and recovery of over-fished black teatfish stocks on the Great Barrier Reef*, Australian Institute of Marine Sciences, Townsville.

90. Uthicke, S., Welch, D. and Benzie, J.A.H. 2004, Slow growth and lack of recovery in overfished holothurians on the Great Barrier Reef: evidence from DNA fingerprints and repeated large-scale surveys, *Conservation Biology* 18(5): 1395-1404.

91. Uthicke, S. 2004, Overfishing of holothurians: Lessons from the Great Barrier Reef, in *Advances in sea cucumber aquaculture and management*, ed. A. Lovatelli*, et al.*, Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 163-171.

92. Skewes, T.D., Taylor, S., Dennis, D.M., Haywood, M.E.D. and Donovan, A. 2006, *Sustainability Assessment of the Torres Strait Sea Cucumber Fishery*, CSIRO, Cleveland, Queensland.

93. Skewes, T.D., Murphy, N.E., McLeod, I., Dovers, E., Burridge, C. and Rochester, W. 2010, *Torres Strait Hand Collectables, 2009 survey: Sea cucumber*, CSIRO, Cleveland.

94. Department of Agriculture, Fisheries and Forestry 2013, *Coral Reef Fin Fish Fishery, 2011-12 Fishing Year Report*, DAFF, Brisbane.

95. Henry, G.W. and Lyle, J.M. 2003, *The National Recreational and Indigenous Fishing Survey*, Department of Agriculture, Fisheries and Forestry, Canberra.

96. Miller, I., Cheal, A.J., Emslie, M., Logan, M. and Sweatman, H. 2012, Ongoing effects of no-take marine reserves on commercially exploited coral trout populations on the Great Barrier Reef, *Marine Environmental Research* 79: 167-170.

97. Welch, D.J., Mapstone, B.D. and Begg, G.A. 2008, Spatial and temporal variation and effects of changes in management in discard rates from the commercial reef line fishery of the Great Barrier Reef, Australia, *Fisheries Research* 90: 247-260.

98. Goeden, G.B. 1982, Intensive fishing and a 'keystone' predator species: ingredients for community instability, *Biological Conservation* 22(4): 273-281.

99. Goeden, G.B. 1979, Is the Great Barrier Reef being overfished? *Australian Fisheries* 9: 18-20.

100. Craik, W. 1979, *Amateur Fishing on the Great Barrier Reef. Technical Memorandum No. 4,* Great Barrier Reef Marine Park Authority, Townsville.

101. Andersen, J. 2012, *Reef fishery in crisis as stocks drop,* 16 January 2012, Townsville Bulletin, Townsville.

102. McCook, L.J., Ayling, T., Cappo, M., Choat, J.H., Evans, R.D., DeFreitas, D.M., Heupel, M., Hughes, T.P., Jones, G.P., Mapstone, B., Marsh, H., Mills, M., Molloy, F.J., Pitcher, C.R., Pressey, R.L., Russ, G.R., Sutton, S., Sweatman, H., Tobin, R., Wachenfeld, D. and Williamson, D. 2010, Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves, *Proceedings of the National Academy of Sciences* 107(43): 18278-18285.

103. Williamson, D.H., Ceccarelli, D.M., Evans, R.D., Jones, G.P. and Russ, G.R. 2014, Habitat dynamics, marine reserve status, and the decline and recovery of coral reef fish communities, *Ecology and Evolution* 4: 337-354.

104. Great Barrier Reef Marine Park Authority 2011, *Extreme weather and the Great Barrier Reef*, GBRMPA, Townsville.

105. Wen, C., Pratchett, M., Almany, G. and Jones, G. 2013, Patterns of recruitment and microhabitat associations for three predatory coral reef fishes on the southern Great Barrier Reef, Australia, *Coral Reefs* 32: 389-398.

106. Russ, G.R., Cheal, A.J., Dolman, A.M., Emslie, M.J., Evans, R.D., Miller, I.R., Sweatman, H. and Williamson, D.H. 2008, Rapid increase in fish numbers follows creation of world's largest marine reserve network, *Current Biology* 18(12): R514-R515.

107. Pratchett, M., Messmer, V., Reynolds, A., Clark, T., Munday, P., Tobin, A.J. and Hoey, A. 2013, *Effects of climate change on reproduction, larval development, and adult health of coral trout (Plectopomus spp). FRDC project No:2010/554*, Fisheries Research and Development Corporation, Canberra.

108. Samoilys, M.A. 1997, Periodicity of spawning aggregations of coral trout *Plectropomus leopardus* (Pisces: Serranidae) on the northern Great Barrier Reef, *Marine Ecology Progress Series* 160: 149-159.

109. Department of Agriculture, Fisheries and Forestry 2013, *Stock status of Queensland's fisheries resources 2012 summary*, DAFF, Brisbane.

110. Evans, R.D., Russ, G.R. and Kritzer, J.P. 2008, Batch fecundity of *Lutjanus carponotatus* (Lutjanidae) and implications of no-take marine reserves on the Great Barrier Reef, Australia, *Coral Reefs* 27(1): 179-189.

111. Adams, S.M., Mapstone, B.D., Russ, G.R. and Davies, C.R. 2000, Geographic variation in the sex ratio, sex specific size, and age structure of *Plectropomus leopardus* (Serranidae) between reefs open and closed to fishing on the Great Barrier Reef, *Canadian Journal of Fisheries and Aquatic Sciences* 57: 1448-1458.

112. Harrison, H.B., Williamson, D.H., Evans, R.D., Almany, G.R., Thorrold, S.R., Russ, G.R., Feldheim, K.A., van Herwerden, L., Planes, S., Srinivasan, M., Berumen, M.L. and Jones, G.P. 2012, Larval export from marine reserves and the recruitment benefit for fish and fisheries, *Current Biology* 22(11): 1023-1028.

113. Almany, G.R., Connolly, S.R., Heath, D.D., Hogan, J.D., Jones, G.P., McCook, L.J., Mills, M., Pressey, R.L. and Williamson, D.H. 2009, Connectivity, biodiversity conservation, and the design of marine reserve networks for coral reefs, *Coral Reefs* 28: 339-351.

114. McCook, L.J., Almany, G.R., Berumen, M.L., Day, J.C., Green, A.L., Jones, G.P., Leis, J.M., Planes, P., Russ, G.R., Sale, P.F. and Thorrold, S.R. 2009, Management under uncertainty: guidelines for incorporating connectivity into the protection of coral reefs, *Coral Reefs* 28: 353-366.

115. Tobin, A.J., Schlaff, R., Tobin, R., Penny, A., Ayling, T., Ayling, A., Krause, B., Welch, D., Sutton, S., Sawynok, B., Marshall, N.A., Marshall, P.A. and Maynard, J.A. 2010, *Adapting to change: minimising uncertainty about the effects of rapidly-changing environmental conditions on the Queensland Coral Reef Fin Fish Fishery, Final Report to the Fisheries Research and Development Corporation, Project 2008/103*, James Cook University, Townsville.

116. Limpus, C.J. and  Reimer, D. 1994, The loggerhead turtle, *Caretta caretta,* in Queensland: a population in decline, in *Proceedings of the Australian marine turtle conservation workshop,* ed. R. James, Department of Environment and Heritage and Australian Nature Conservation Agency, Canberra, pp. 39-59.

117. Limpus, C.J. and Limpus, D.J. 2003, Loggerhead turtles in the Equatorial and Southern Pacific Ocean: a species in decline, in *Loggerhead sea turtles*, ed. A.B. Bolten and B.E. Witherington, Smithsonian Institution, Washington DC, pp. 199-209.

118. Heppell, S.S., Limpus, C.J., Crouse, D.T., Frazer, N.B. and Crowder, L.B. 1996, Population model analysis for the loggerhead sea turtle *(Caretta caretta)* in Queensland, *Wildlife Research* 23: 143-159.

119. Australian Government 2014, *Reef Trust - Investment strategy initiative design and phase 1 investment 2014-15*, Commonwealth of Australia, Canberra.

120. Department of Environment and Resource Management 2010, *Mackay Whitsunday Natural Resource Management Region back on track actions for biodiversity,* DERM, Brisbane.

121. Department of Environment and Resource Management 2010, *Cape York Peninsula Natural Resource Management Region back on track actions for biodiversity,* DERM, Brisbane.

122. Department of Environment and Resource Management 2010, *Wet Tropics Natural Resource Management Region back on track actions for biodiversity,* DERM, Brisbane.

123. Department of Environment and Resource Management 2010, *Fitzroy Natural Resource Management Region back on track actions for biodiversity*, DERM, Brisbane.

124. Department of Environment and Resource Management 2010, *Burnett Mary Natural Resource Management Region back on track actions for biodiversity,* Department of Environment and Resource Management, Brisbane.

125. Department of Environment and Resource Management 2010, *Burdekin Natural Resource Management Region back on track actions for biodiversity,* Department of Environment and Resource Management, Brisbane.

126. Great Barrier Reef Marine Park Authority 2004, *Great Barrier Reef Marine Park Zoning Plan 2003*, GBRMPA, Townsville.

127. Queensland Government 2004, *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004*, Queensland Government, Brisbane.

128. Limpus, C.J. 2008, *A biological review of Australian marine turtle species, 1 Loggerhead turtle, Caretta caretta (Linnaeus)*, Environmental Protection Agency, Brisbane.

129. Marsh, H., De'ath, G., Gribble, N.A. and Lane, B. 2005, Historical marine population estimates: triggers or targets for conservation? The dugong case study, *Ecological Applications* 15(2): 481-492.

130. Marsh, H., De'ath, G., Gribble, N.A. and Lane, B. 2001, *Shark control records hindcast serious decline in dugong numbers off the urban coast of Queensland*, Great Barrier Reef Marine Park Authority, Townsville.

131. Daley, B., Griggs, P. and Marsh, H. 2008, Exploiting marine wildlife in Queensland: the commercial dugong and marine turtle fisheries 1847-1969, *Australian Economic History Review* 48(3): 227-265.

132. Great Barrier Reef Marine Park Authority, 2013, Unpublished report, 'A vulnerability assessment for the Great Barrier Reef: Dugongs'.

133. Marsh, H., Eros, C., Corkeron, P. and Breen, B. 1999, A conservation strategy for dugongs: implications of Australian research, *Marine and Freshwater Research* 50(8): 979-990.

134. Great Barrier Reef Marine Park Authority 2012, *A vulnerability assessment for the Great Barrier Reef: Seagrass*, GBRMPA, Townsville.

135. Great Barrier Reef Marine Park Authority 2014, *Sightings network,* GGBRMPA, Townsville, <<http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/eye-on-the-reef/sightings-network>>.

136. Meager, J.J. and Limpus, C.J. 2012, Marine wildlife stranding and mortality database annual report 2011, I Dugong, *Conservation and Technical Data Report* 2011(1): 1-30.

137. Sobtzick, S., Hagihara, R., Grech, A. and Marsh, H. 2012, *Aerial survey of the urban coast of Queensland to evaluate the response of the dugong population to the widespread effects of the extreme weather events of the summer of 2010-11, Final report to the Australian Marine Mammal Centre and the National Environmental Research Program*, James Cook University, Townsville.

138. Grech, A., Sheppard, J.K. and Marsh, H. 2011, Informing species conservation at multiple scales using data collected for marine mammal stock assessments, *PLoS ONE* 6(3): e17993.

139. Marsh, H., Hodgson, A., Lawler, I.R., Grech, A. and Delean, S. 2007, *Condition, status and trends and projected futures of the dugong in the northern Great Barrier Reef and Torres Strait: Including identification and evaluation of the key threats and evaluation of available management options to improve its status, Report to the Marine and Tropical Sciences Research Facility*, Reef and Rainforest Research Centre, Cairns.

140. Marsh, H. and Lawler, I.R. 2001, *Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: Results of an aerial survey in October-December 1999*, Great Barrier Reef Marine Park Authority, Townsville.

141. Marsh, H., Corkeron, P., Lawler, I.R., Lanyon, J.M. and Preen, A.R. 1995, *The status of the dugong in the southern Great Barrier Reef Marine Park*, Department of Tropical and Environmental Studies and Geography, James Cook University, Townsville.

142. Kwan, D. 2002, *Towards a sustainable indigenous fishery for dugongs in Torres Strait : A contribution of empirical data analysis and process.* PhD thesis, James Cook University, Townsville.

143. McKenzie, L.J., Collier, C. and Waycott, M. 2012, *Reef Rescue Marine Monitoring Program: Inshore seagrass, annual report for the sampling period 1st July 2010 – 31st May 2011*, Fisheries Queensland, Cairns.

144. McKenna, S.A. and Rasheed, M.A. 2012, *Port of Townsville long-term seagrass monitoring: October 2011*, Fisheries Queensland, Cairns.

145. McCormack, C., Rasheed, M., Davies, J., Carter, A., Sankey, T. and Tol, S. 2013, *Long term seagrass monitoring in the Port Curtis Western Basin: Quarterly seagrass assessments and permanent transect monitoring progress report November 2009 to November 2012*, James Cook University, Cairns.

146. Amies, R.A., McCormack, C.V. and Rasheed, M.A. 2013, *Gladstone permanent transect seagrass monitoring - March 2013 Update report*, Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University, Cairns.

147. Fairweather, C.L., McKenna, S.A. and Rasheed, M.A. 2011, *Long term seagrass monitoring in Cairns Harbour and Trinity Inlet: December 2009 and 2010*, Fisheries Queensland, Cairns.

148. Fairweather, C., McKenna, S. and Rasheed, M. 2011, *Long-term seagrass monitoring in the Port of Mourilyan: November 2010*, Fisheries Queensland, Cairns.

149. Department of the Environment and Heritage 2005, *Humpback whale recovery plan 2005 - 2010*, DEH, Canberra.

150. Noad, M.J., Dunlop, R.A., Cato, D. and Paton, D. 2008, *Abundance estimates of the east Australian humpback whale population: Final report for the Australian Department of the Environment, Water, Heritage and the Arts*, University of Queensland, Brisbane.

151. Noad, M.J., Dunlop, R.A., Paton, D. and Kniest, H. 2011, *Abundance estimates of the east Australian humpback whale population: 2010 survey and update*, University of Queensland, Brisbane.

152. Great Barrier Reef Marine Park Authority 2009, *Great Barrier Reef Outlook Report 2009*, GBRMPA, Townsville.

153. State of the Environment 2011 Committee *Australia state of the environment 2011: Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities*, Department of Sustainability, Environment, Water, Population and Communities, Canberra.

154. Rowland, M. 2004, Myths and non‐myths. Frontier ‘massacres’ in Australian history: the Woppaburra of the Keppel Islands, *Journal of Australian Studies* 28(81): 1-16.

155. Muir, B. and Doherty, C. 2006, *The Woppaburra People Historical Fact Sheet*.

156. Great Barrier Reef Marine Park Authority 2013, *Woppaburra TUMRA Project 2013 Sea Country Partnerships Project Bulletin,* 1-2, Great Barrier Reef Marine Park Authority, Townsville.

157. Environmental Policy and Planning Division 2013, *The impact of severe tropical cyclone Yasi on the wreck of the SS Yongala*, Department of Environment and Heritage Protection, Brisbane.