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Rezoning of the Great Barrier Reef World Heritage Area: does it afford greater protection for marine turtles?

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Abstract. In 2004 the Australian Government implemented a revised zone-based management plan for the Great Barrier Reef World Heritage Area to increase protection of representative areas while minimising the impacts to the economic viability of important industries. In this study we evaluated the current zoning plan for its capacity to protect marine turtles from commercial trawling and netting activities at nesting sites and at inshore and offshore foraging areas to assess whether the Great Barrier Reef Marine Park Authority met their obligations under the Representative Areas Program (RAP). We found that protection from commercial fisheries increased within 5- and 10-km buffer zones of all very-high, high- and medium-priority nesting sites that were previously less than 100% protected. However, three very-high-priority sites and six high-priority sites remain less than 100% protected out to 5 km, falling short of the objectives of the RAP. There were variable increases in protection at foraging areas; however, each of them increased in the proportion of area protected from commercial fishing, fulfilling the objectives of the RAP. By using a broader-scale fisheries by-catch dataset as a proxy for turtle abundance we found that improvements in protection are not species-specific and can be attributed to the step-wise increases in protection since the mid 1990s.

Introduction

There is currently a high level of scientific, political and public concern for the state of several marine wildlife populations worldwide. Marine wildlife are subject to numerous anthropogenic impacts that threaten the health and stability of their populations, and life-history traits such as longevity, delayed maturity and low annual recruitment often result in a slow rate of population recovery. One tool often applied to protect marine species or ecosystems of conservation concern is the establishment of marine protected areas and zoning regulations that govern the inclusion or exclusion of particular activities.

Marine protected areas (MPA) that utilise zoning regulations to balance use and protection need to reach a compromise between existing and intended human use with design factors such as location and size of the protected zone, habitat quality and level of activity restriction. As these factors characterise the success of an MPA (Ballantine 1997; Hockings *et al*. 2000; Roberts *et al*. 2001; Jameson *et al*. 2002), the effectiveness of an MPA to reach its protection goals must be tested through means such as a postdevelopment assessment that delivers evidence of results (Day *et al*. 2002).

While MPAs are usually designated to protect ecosystems and biodiversity (Roberts 2005), they will not fulfil their desired role if they do not also serve to protect species of conservation concern (Nowlis and Friedlander 2005). For example, the presence of internationally significant foraging and nesting populations of marine turtles in the Great Barrier Reef World Heritage Area (GBRWHA) (Fig. 1) was an explicit reason for its World Heritage listing (Great Barrier Reef Marine Park Authority 1981) and all species of marine turtle residing in the GBRWHA are listed as threatened under the Australian *Environmental Protection and Biodiversity Conservation Act 1999*.

In 2004 the GBRWHA was rezoned to maximise the protection of marine biodiversity through a comprehensive and representative multiple-use zoning regime (Fernandes *et al*. 2005). The rezoning established an ecosystem-scale network of no-take areas covering ~33% of the Great Barrier Reef Marine Park and the contiguous Great Barrier Reef Coast Marine Park (an increase of ~28.5% from the former zoning regime). The 2004 changes to the zoning arrangements aimed to upgrade marine turtle protection in accordance with the program's biophysical operating principles (Fernandes *et al*. 2005) by increasing areas closed to commercial trawling and netting. No-take or area closures are a management tool designed to reduce the risk to the by-catch population by eliminating the likelihood of by-catch by commercial fishing to the proportion of the population that uses the closed area (Grech and Marsh, in press). Thus the rationale behind the closed, or no-take, area approach for conserving marine turtles was to both eliminate fishing from areas that support high densities of the marine turtle by-catch and to improve protection of species and key habitats, in turn influencing abundance, distribution and life-history traits.

There are several well documented threats to marine turtles and their habitats in the GBRWHA such as coastal development, disease, predation, habitat loss, boat strike, indigenous hunting and fisheries interactions (Limpus and Couper 1994; Limpus and Miller 1994; Robins 1995, 2002; Limpus *et al*. 2003; Hazel and Gyuris 2006). Among them, the pressure from commercial fisheries such as netting and trawling on both the turtles and their important habitats was regarded by the Great Barrier Reef

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Marine Park Authority (GBRMPA) as the two biggest concerns for marine turtles (Dobbs 2007). Various legislative Acts and zoning plans within the GBRWHA manage both of these commercial fisheries. However, while there have been changes to management boundaries it is unknown whether changes in overall GBRWHA protection will benefit specific species.

In this study, our overall objective was to assess and compare the previous and current zoning arrangements in the GBRWHA for their capacity to meet the GBRMPA's planning objectives for marine turtles and conduct an independent assessment, using more ecologically relevant data, to assess whether protection has improved for turtles and their habitats at three levels. First, we assessed whether areas in which turtles reside during their nesting season are afforded greater protection. Second, we assessed the capacity of the current zoning plan to protect marine turtles in selected inshore and offshore foraging areas. Third, we used marine turtle by-catch data collected within fisheries grids between 1991 and 1996 by the Queensland Department of Primary Industries and Fisheries (Robins 2002) to assess whether areas of high abundance of marine turtles had increased in protection on the introduction of new zoning relative to grids with lower abundance. From these three analyses we then assessed whether the current zoning plan fulfilled the GBRMPA's objective during the design phase to protect 20% of foraging habitats in the GBRWHA, and provide a 5-km no-take buffer zone around all high- and very-high-priority nesting beaches (Dobbs 2007).

Methods

Distribution of commercial netting and trawling in the GBRWHA

In 1975 the Australian Government enacted the *Great Barrier Reef Marine Park Act* that established the GBRMPA and set the geographical boundaries of the park. Following designation of the Great Barrier Reef (GBR) as a World Heritage Area in 1981 the first zoning plans were implemented in the mid 1980s to set aside ~4.5% of the GBR as no-take areas and thus regulated activities such as fisheries, tourism and research. In 1998,

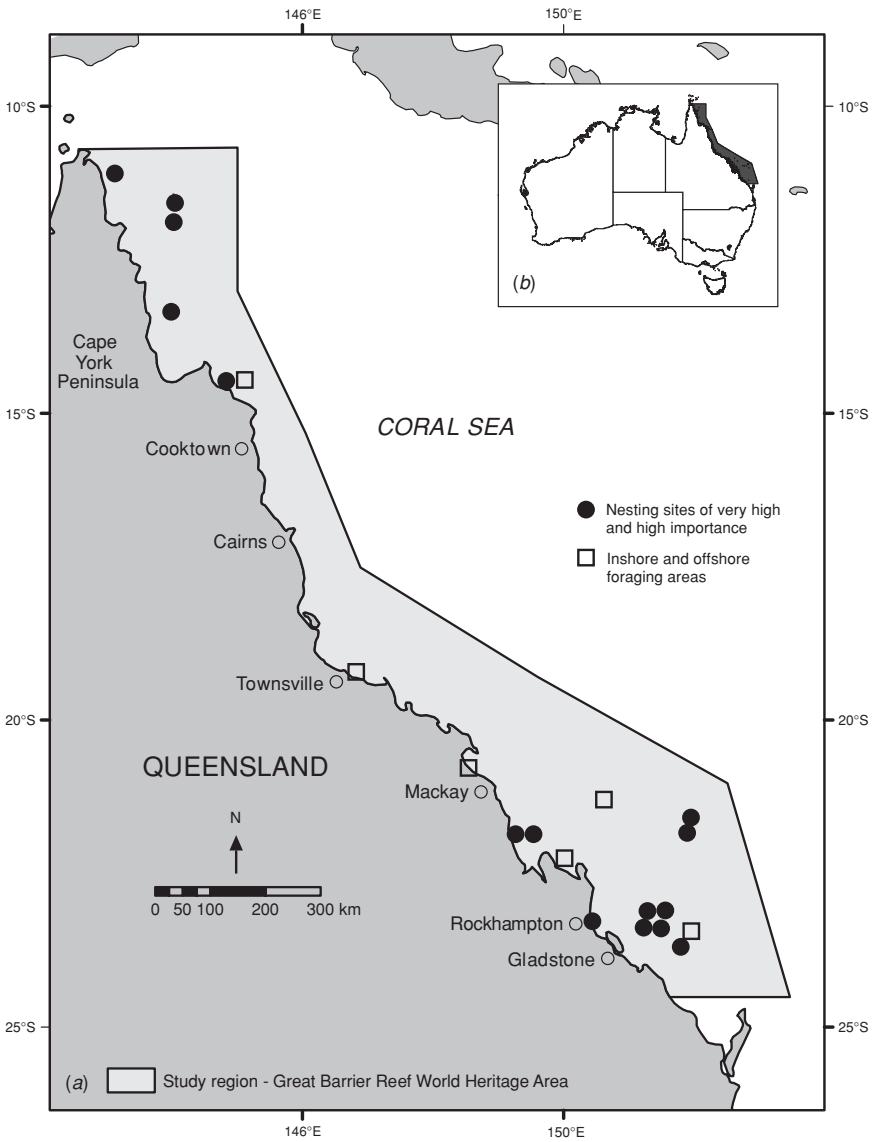

Fig. 1. (*a*) Extent of the Great Barrier Reef World Heritage Area off the coast of Queensland. (*b*) The extent of the Great Barrier Reef World Heritage Area relative to Australia.

following concerns about the impacts of commercial netting on dugong populations, Dugong Protection Areas (DPA) were established under the Queensland *Fisheries Act 1994* to regulate netting activities in areas of high dugong density. Similarly, in the late 1990s there was increasing concern about the ecological impacts of commercial trawling within the GBRWHA. This resulted in the development of the Fisheries (East Coast Trawl) Management Plan (1999) under the Queensland *Fisheries Act 1994*. These two developments under the Queensland *Fisheries Act 1994* along with former Australian and Queensland zoning plans regulated the geographic boundaries and management of commercial netting and trawling respectively. Together with the pre-2004 State Marine Parks legislation (Qld EPA), Queensland port authorities and developmental areas, these regulations governed the previous spatial distribution of commercial fisheries in the GBRWHA before 2004.

In 1998 the GBRMPA began the Representative Areas Program (RAP) that aimed to determine major habitat types in the GBRWHA and develop a new zoning plan to protect representative areas of each habitat type. The RAP program resulted in the enactment of the *Great Barrier Reef Marine Park Zoning Plan 2003* that was implemented in July 2004. This revised zoning plan combined with the Queensland *Great Barrier Reef Coast Marine Park Zoning Plan 2004* (Queensland Environmental Protection Agency), Dugong Protection Areas and boundaries of the Queensland port authorities define the current spatial distribution of commercial fisheries in the GBRWHA. Under the RAP process the biophysical operating principle pertaining to nesting turtles was: (1) very-high-priority nesting sites for each genetic stock should include a 5-km radius in no-take zones, and (2) high-priority nesting sites for each genetic stock should include a 5-km radius and be included in no-take areas whenever possible (Fernandes *et al*. 2005; Dobbs 2007). For foraging turtles the RAP aimed to include 20% of major habitat for each species.

In both the previous and current zoning plans there are several zones in which commercial netting and/or trawling are allowed. Commercial netting was/is allowed in the zones classed General Use A, General Use B (previous), and General Use and Habitat Protection (current). Trawling was/is allowed in zones classed General Use A (previous), and General Use (current). In our study we considered no-take zones to include 'Preservation', 'Marine National Park', 'Conservation Park' and 'Buffer' zones as no trawling or commercial netting can occur in these zones. To create a composite layer of all netting and trawling restrictions in the GBRWHA we used ArcGIS 9.0 (Environmental Systems Research Institute, 2004) to create layers representing the various zone boundaries controlling the distribution of activities. In order to provide a basis from which to compare protection between the pre-2004 (previous) and post-2004 (current) zoning regime, separate data layers were created by intersecting the various management boundaries that controlled netting and trawling under both zoning plans.

Nesting sites

The nesting sites of marine turtles in Queensland are well described and long-term monitoring data exist for each of the four species that have current nesting populations in the GBRWHA (Fig. 1) (Dobbs *et al*. 1999; Limpus *et al*. 2000, 2003; Limpus and Limpus 2003). Marine turtles lay multiple clutches of eggs during each breeding season, and the period between a turtle's successive clutches is known as the internesting period. In between clutches individual turtles generally remain within 10 km of the rookeries (Limpus and Reed 1985; Tucker *et al*. 1996; Hays *et al*. 1999; Hamann *et al*. 2005). We used the same nesting sites and priority rankings as those used by GBRMPA in the RAP (Fig. 1) (Dobbs 2007). These sites covered each of the eastern Australian genetic populations for green (*Chelonia mydas*), hawksbill (*Eretmochelys ibricata*), loggerhead (*Caretta caretta*) and flatback (*Natator depressus*) turtles (Dutton *et al*. 2002; Dethmers *et al*. 2006). In all, we assessed seven very-high-priority nesting sites (Heron Island, Milman Island, North West Island, Peak Island, Raine Island, Wild Duck Island and Wreck Island), 10 high-priority sites (Avoid Island, Boydong Island, Frigate Cay, Hoskyn Island, Masthead Island, Moulter Cay, Price Cay, Sandbank 7, Sinclair Island and Crocodile Cay) and 20 medium-priority sites. In addition, we assessed the change in protection at Wreck Rock Beach, an important mainland rookery for loggerhead turtles that was previously unprotected. To assess the change in protection within the internesting areas we created 5-km and 10-km buffer zones around nesting locations using the buffer function of ArcGIS® 9.0 (Environmental Systems Research Institute, 2004). For most islands the buffer zones were calculated from the shoreline and for Curtis Island, Facing Island and Wreck Rock beach the buffers were calculated from the area of beach that receives ~90% of nesting activity (based on best available local and expert knowledge).

Inshore and offshore foraging areas

Locations of inshore and offshore foraging sites for marine turtles were collated from literature (Limpus *et al*. 1983, 2005; Limpus 1992; Chaloupka and Limpus 2001) and expert opinion from people with knowledge of the region's turtle species distributions (see Dobbs 2007). These sites were identified as the inshore areas of Shoalwater Bay, Cleveland Bay and Repulse Bay, and the offshore areas of the Capricorn–Bunker Group, the Swain Reefs and the Howick Group. We created unique layers for each inshore bay and offshore foraging area in a Geographic Information System (GIS).

We intersected layers of the inshore bay and offshore foraging areas with the composite layer of netting and trawling restrictions in the GBRWHA. Next, we calculated the proportion of foraging area protected from trawling and netting, represented as a percentage, before and after the introduction of the current zoning. We then referred to the difference in the percentage protected under the previous zoning and the current zoning as the percentage change.

Turtle distribution predicted from trawl by-catch data

The Queensland Department of Primary Industries and Fisheries (QDPI&F) monitors the catch of commercial fishers through compulsory daily logbooks, and the information collected includes: day's catch (weight and species), location fished, time spent fishing, and the number of marine turtles (and other by-catch species) caught in their nets. The QDPI&F manages this information by consolidating catch and effort data into 30′ fisheries grids (30′ grid = 30 square nautical miles or ~1700 km^2). Robins (2002) used the logbook data to score

Table 1. Categories of turtle by-catch and the level of relative turtle abundance
Categories of by-catch are taken from Robins (2002)

Level of by-catch	Abundance level
>0.1429 sea turtles caught per <7 days fished	1 (high)
0.0333–0.1429 sea turtles caught per 7–30 days fished	2
0.0111–0.0333 sea turtles caught per 30–90 days fished	3
0.0055–0.0111 sea turtles caught per 90–180 days fished	4
0.000001–0.0055 sea turtles caught per >180 days fished	5
No turtles caught	6 (low)

marine turtle by-catch from each of the GBRWHA fisheries grids into one of six levels in terms of the rate of turtle by-catch per unit effort (CPUE) (low to high), the result being that for each grid there was a CPUE level for each marine turtle species. We then used CPUE grid levels (Robins 2002) to assess the broad-scale impact of the sequential changes to management, including the current zoning plan. The underlying premise behind this aspect of our study is that higher levels of by-catch per unit of effort of a particular species in a particular grid accorded higher abundance of that species for that grid.

Specifically, we used the six levels of by-catch within each of the fisheries grids created by Robins (2002) as a proxy for marine turtle abundance (Table 1). We created six unique GIS layers for each species: one of grids with low by-catch (low abundance), one of grids with high by-catch (high abundance), and the remaining four of grids with intermediate levels of turtle by-catch and thus abundance. Each unique layer was intersected with the composite layer of trawling restrictions in the GBRWHA. For each by-catch layer, we calculated the proportion of area that was protected from trawling at three levels under (1) the previous zoning regime, (2) the previous zoning regime including the *East Coast Trawl Management Plan* implemented in 2000 (ECTMP), and (3) the current zoning regime. We conducted these calculations for five species of marine turtle for which by-catch data were available (loggerhead, green, flatback, olive ridley and hawksbill turtles).

Analyses

All analyses were carried out using ArcMap 9.0 (Environmental Systems Research Institute, 2004) and the data were analysed in a vector environment. In order to increase the accuracy of distance and area measurements all coverages were projected in Universal Transverse Mercator Zone 55s. Statistical analyses were conducted using SPSS and proportion values were arcsine transformed before analysis using ANOVA with Type III sum of squares (Sokal and Rolfe 1995).

Results

Internesting turtle habitat

Four sites, Raine Island (very-high-priority green turtles), Moulter Cay (high-priority green turtles), Boydong Island (high-priority hawksbill turtles) and Bylund Cay (medium-priority green and loggerhead turtles) were completely protected from commercial netting and trawling activities within a 5-km and 10-km buffer under the previous zoning plan and thus remained unchanged in the current plan. Overall, the current zoning plan resulted in an increase in the area protected from netting and trawling within both the 5-km and 10-km buffer zones of the remainder of very-high-priority and high-priority sites and most of the medium-priority sites. There was no statistically significant difference in the proportional increase in protection between very-high-, high- and medium-priority sites (ANOVA: $F = 0.95$, d.f. = 2,33, $P = 0.90$).

Very-high-priority areas

Raine Island was already protected from netting and trawling out to 10 km and thus protection did not change and each of the other very-high-priority nesting sites received various levels of increased protection (Table 2). Overall, there are three very-high-priority sites where internesting turtles are afforded 100% protection from netting and trawling out to a 5-km radius (Wild Duck Island, Wreck Island, Milman Island) and one site where protection is >95% (Heron Island). Raine Island is the only very-high-priority site at which marine turtles are 100% protected out to a 10-km radius.

High-priority areas

Boydong Island and Moulter Cay were already protected from netting and trawling out to 10 km and thus protection for these islands did not change. Each of the other 10 high-priority sites received variable levels of increased protection (Table 3). Overall, of the 10 high-priority nesting sites, two are afforded complete protection out to 10 km (Boydong Island and Moulter Cay), four are afforded 100% protection within a 5-km radius, but not out to 10 km, and two sites have >95% protection out to 5 km but not out to 10 km (Price and Frigate Cays). Despite a substantial increase in protection, the water around Avoid Island remains the least protected of any of the high-priority sites.

Medium-priority areas

One medium-priority site (Bylund Cay) was formerly 100% protected out to 10 km and thus protection did not change. Protection increased at the other 19 medium-priority sites. In particular, two sites (MacLennan Cay and Lady Elliot Island) were afforded 100% protection from trawling and netting within their 5-km buffers and Bell Cay and Sandbank 8 were afforded 100% protection from trawling within a 10-km buffer zone. The remainder of the medium-priority sites (Gannet Cay Erskine Island, Lady Musgrave Island, Tyron Island, Russell Island, Curtis Island, Facing Island, Farmer Island, Bird Island and Douglas Island, Newry Island, Outer Newry Island, Rabbit Island, Thomas and Bacchi Cays) had variable increases in the protected area of their 5-km and 10-km buffer zones.

Inshore and offshore foraging areas

Prior to current zoning in the GBRWHA, several inshore and offshore foraging areas important for marine turtles had very low levels of protection from commercial netting and trawling. Our data show that upon implementation of current zoning, protection from commercial trawling and netting increased for each of the foraging areas used in this study. In particular, the proportion of the area protected from both trawling and netting within the inshore foraging areas ranges from 29% (Repulse Bay) to 100% (Shoalwater Bay). For the offshore foraging areas

Table 2. The proportion of 5-km and 10-km buffer around very-high-priority marine turtle nesting sites protected from trawling and netting under the former and current zoning of the Great Barrier Reef (GBR) World Heritage Area
The former area is shown in parentheses

Nesting site	Area protected from trawling within buffer (%)		Area protected from netting within buffer (%)	
	5 km	10 km	5 km	10 km
Green turtles (nGBR)				
Raine Island	100 (100)	100 (100)	100 (100)	100 (100)
Green turtles (sGBR)				
North West Island	68.9 (42.9)	39.1 (23.1)	68.9 (3.7)	39.1 (1.2)
Heron Island	96.1 (95.4)	88.2 (87.2)	96.1 (54.7)	88.2 (26.4)
Flatback turtle				
Wild Duck Island	100 (100)	100 (100)	100 (0.0)	80.8 (0.0)
Peak Island	76.0 (5.2)	52.0 (11.3)	69.7 (5.9)	45.5 (11.3)
Loggerhead turtle				
Wreck Is.	100 (100)	85.6 (85.0)	100 (14.0)	85.6 (3.6)
Hawksbill turtle				
Milman Island	100 (14.4)	84.2 (9.3)	100 (14.1)	84.2 (5.4)

included in the study the proportion of area protected from commercial trawling and netting has increased by 57% (Howick Group) to 96% (Capricorn Bunker) and 20% (Howick Group) to 80% (Capricorn Bunker) respectively.

Distribution of trawling and turtle by-catch

To investigate broader-scale protection to marine turtle habitats we used Robins' (2002) by-catch dataset as a proxy for turtle distribution and abundance (i.e. grids with higher by-catch per unit effort equal grids with higher abundance of turtles). Overall, we examined by-catch data and changes to zoning regulations in 143 30-min grids located within the GBRWHA. While there was no statistically significant difference in the protection gained among species (i.e. no species benefited more than the others from increased protection), there was a statistically significant difference in increase in protected area between proxy abundance categories (ANOVA: $F = 7.31$, d.f. = 4,74, $P < 0.001$) with Level 2 (0.03–0.14 turtles caught per unit of effort) and Level 6 (no turtles caught per unit of effort) showing the largest increases. Thus, areas with higher turtle abundance received less protection than sites with low turtle abundance or no turtles at all. Overall, there was a statistically significant stepwise increase in the area protected (with all six layers combined) from trawling following both the introduction of the ECTMP to the previous zoning plan in 2000 and the current zoning plan (Table 4) (two-way ANOVA: $F = 19.25$, d.f. = 2,72, $P < 0.001$).

Table 3. The proportion of 5-km and 10-km buffer around high-priority marine turtle nesting sites protected from trawling and netting under the former and current zoning of the Great Barrier Reef (GBR) World Heritage Area
The former area is shown in parentheses

Nesting site	Area protected from trawling within buffer (%)		Area protected from netting within buffer (%)	
	5 km	10 km	5 km	10 km
Green turtles (nGBR)				
Moulter Cay	100 (100)	100 (100)	100 (100)	100 (100)
Sandbank No.7	100 (82.3)	100 (73.4)	100 (59.7)	98.1 (38.7)
Green turtles (sGBR)				
Mast Head Island	85.3 (63.3)	52.2 (35.0)	85.3 (2.6)	52.2 (0.7)
Hoskyn Island	98.9 (76.7)	79.1 (50.7)	85.7 (0.0)	44.6 (0.0)
Frigate Cay	100 (100)	100 (100)	93.1 (89.6)	80.9 (76.2)
Flatback turtle				
Avoid Island	83.4 (11.1)	67.1 (15.3)	29.9 (0.0)	44.4 (0.0)
Loggerhead turtle				
Price Cay	100 (100)	100 (100)	98.6 (98.3)	74.9 (72.1)
Wreck Rock	59.9 (0.0)	36.8 (0.0)	59.7 (0.0)	36.7 (0.0)
Hawksbill turtle				
Boydong Island	100 (100)	100 (100)	100 (100)	100 (100)
Sinclair Island	93.4 (6.9)	62.6 (10.5)	92.4 (6.7)	57.4 (5.5)
Crocodile Cay	100 (17.7)	85.8 (12.7)	100 (3.0)	82.0 (5.6)

Discussion

The implementation of an MPA is usually justified on a combination of ecological, social, economic and cultural factors. However, a fundamental assumption of marine protected areas is that they serve to improve the conservation of species and ecosystems while maintaining or boosting economic benefits to industry such as commercial fishing or tourism. While they are generally not established for the preservation of single species, some charismatic species such as marine turtles are often used as 'flagships' for the MPA (see Eckert and Hemphill 2005; Frazier 2005 for examples), and, in the case of the GBR, they were an explicit reason behind its successful nomination for World Heritage status in 1981. Since 1981, protection of habitats within the GBRWHA has increased, culminating in the current zoning plan being enacted in 2004. Hence, the current zoning plan offers substantially improved conservation benefit for both species and habitats within the GBRWHA. In this study we used the environmental principles of the RAP to assess whether the current zoning plan has improved the protection for marine turtles during both foraging and breeding stages of their life cycle.

Protection of nesting habitats

During the RAP process, the GBRMPA assessed nesting sites for priority and incorporated a 5-km buffer zone around each site to represent the internesting habitat. Our data, using a more ecologically relevant 10-km radius, indicate that the current zoning plan did not provide 100% protection from trawling and netting within a 5-km radius of three of the seven very-high-priority sites (although Heron Island is within 3%) and six high-priority sites (although two additional sites are within 5%). Hence the current zoning plan failed to completely satisfy the RAPs biophysical operating principle for internesting habitat protection. In addition, while all very-high- and high-priority nesting sites had increases in protection, there was no statistical difference in the proportional increase among sites listed as very high, high or medium priority. However, if the sites that received no additional protection because they were 100% protected under the former plan are excluded from calculations, then the overall increases in protection from trawling and netting do become statistically significant. The overall increases in protection from trawling were 46% (very-high-priority sites), 43% (high-priority sites) and 30% (medium-priority sites) while the overall increases in protection from netting were 63% (very-high-priority sites), 43% (high-priority sites) and 32% (medium-priority sites). Of particular note are the large (>70%) increases in protection offered to the hawksbill turtle at Milman, Sinclair and Crocodile Islands, the flatback turtle at Wild Duck, Avoid and Peak Islands, and loggerhead turtles nesting on the mainland beach at Wreck Rock.

Table 4. Proportion (%) and total area of fisheries grids lying within six levels of turtle abundance for all species (as per catch per unit effort (CPUE) layers in Robins 2002) at three levels: (1) within the Great Barrier Reef (GBR) World Heritage Area (WHA) before the implementation of the *East Coast Trawl Management Plan (ECTMP) 1999*, (2) within the GBRWHA under previous zoning (inclusive of the ECTMP), and (3) after the implementation of the current zoning plan (*Great Barrier Reef Marine Park Zoning Plan 2003* and *Great Barrier Reef Coast Marine Park Zoning Plan 2004*)

	Area protected under sequential zoning for different levels of turtle abundance (as per Table 1)					
	1	2	3	4	5	6
Flatback turtles						
Pre-ECTMP	43	37	19	17	2	16
Pre-current zoning	43	37	26	24	2	55
Current zoning	51	50	43	42	19	72
Total area (km^2)	2364	15481	4579	2516	674	144849
Green turtles						
Pre-ECTMP	0	32	32	16	10	17
Pre-current zoning	0	33	50	17	10	56
Current zoning	0	49	58	37	32	73
Total area (km^2)	0	13798	14606	23273	26453	269573
Hawksbill turtles						
Pre-ECTMP	0	50	0	22	20	17
Pre-current zoning	0	50	0	25	23	51
Current zoning	0	58	0	48	45	67
Total area (km^2)	0	1165	0	4053	17375	325109
Loggerhead turtles						
Pre-ECTMP	0	16	12	24	14	18
Pre-current zoning	0	27	32	25	14	55
Current zoning	0	62	47	40	31	72
Total area (km^2)	0	8573	9331	22901	24163	282734
Olive Ridley turtles						
Pre-ECTMP	0	43	11	21	23	16
Pre-current zoning	0	43	42	23	24	52
Current zoning	0	51	48	28	38	70
Total area (km^2)	0	1365	13855	12408	16487	299446

The increases in protection are ecologically significant because the GBRWHA has internationally significant nesting populations of four marine turtle species. Of the four species, loggerhead turtles and hawksbill turtles have undergone population declines over the last 10–20 years (Limpus and Reimer 1994; Dobbs *et al*. 1999; Limpus and Miller 2000), and green turtles in the northern half of the GBR have shown early signs of a declining population (Limpus *et al*. 2003). The flatback turtle population appears to be stable (Limpus *et al*. 2000; Limpus 2007). Although the mandatory introduction of turtle-excluder devices (TEDs) in trawl nets has reduced the likelihood of marine turtle by-catch, trawling activities still have the potential to impact marine turtles during the nesting season through disturbance to their internesting behaviour and benthic habitats. Marine turtles are vulnerable to disturbance during the nesting season owing to many factors, including: large aggregations of breeding males and females, turtles remain in the vicinity of the breeding site for many months (Dobbs *et al*. 1999; Limpus *et al*. 2001; Limpus and Limpus 2001), turtles are generally hypoactive to preserve valuable energy reserves (Hays *et al*. 1999), and premature use of energy can lead to fewer clutches being laid (Hamann *et al*. 2002). Thus, reducing the likelihood of disturbance to turtles from commercial fishing during their internesting period is likely to reduce unnecessary energy use by the animals and permit higher rates of reproductive output.

Protection of foraging habitats

Fulfilment of conservation goals is often hindered by a lack of knowledge of the distribution and ecology of species such as marine turtles. Protective measures can only be based on what is known about marine turtle life history, behaviour and habitats, such as their long-distance migrations and high fidelity to foraging and nesting sites. While we know that protecting certain foraging areas such as Shoalwater Bay will benefit the several species that forage there (Limpus *et al*. 1992, 2005), it is difficult to set a benchmark for the level of protection that will serve to adequately conserve all marine turtle species in the GBRWHA. Despite these inherent difficulties, we found that the GBRMPA fulfilled its aim to protect a minimum of 20% of each turtle species' known foraging habitat in selected inshore and offshore marine turtle foraging areas.

While there are obvious caveats with the use of marine turtle by-catch data to indicate the abundance of marine turtles, such as reporting accuracy and the bias towards data collected in waters <30 m deep, they provide the best available data on broad-scale distribution and abundance of marine turtles in the GBRWHA, especially for the less easily studied flatback and Olive Ridley turtles. Since the initial by-catch data were collected, the East Coast Trawl Management Plan of 1999 has incorporated the mandatory use of TEDs, and this has ensured physical protection for marine turtles from trawlers. However, there are numerous recent accounts of the broader-scale impacts of trawling on benthic ecology, both in Australia (Wassenberg 2002; Burridge 2003; Stobutzki 2003; Burridge 2006) and overseas (Hiddink 2006; Kumar 2006; Vergnon 2006). The reported impacts of trawling include: changes to species abundance, diversity, life-history traits, species recruitment and bottom condition. Although there are good data on the foraging ecology of green and loggerhead turtles from a few sites in the GBRWHA, there are substantial information gaps for these and other species. Nevertheless, marine turtles show strong site fidelity to particular foraging areas (Limpus and Limpus 2001) and environmental and dietary factors influence breeding intervals, breeding rates and growth (Limpus and Nicholls 1988; Balazs 2004; Chaloupka 2004). Thus it is reasonable to assume that significant alterations to benthic ecology will have a substantial impact on dietary ecology, distribution and abundance and life-history traits of long-lived species such as marine turtles.

At the scale of the GBRWHA there is a lack of information on the distribution and abundance of marine turtles. Most of what is known is derived from fisheries by-catch data whereby the assumption is made that higher rates of by-catch per unit area equates to higher abundance (Robins 1995, 2002). In our study, using the fisheries by-catch dataset as a proxy of marine turtle abundance, in the GBRWHA we found a stepwise improvement in protection of all marine turtle foraging habitats, regardless of species that can be attributed to the sequential implementation of the East Coast Trawl Management Plan in 2000, the rezoning of the GBRWHA in 2004 and, to a lesser degree, the implementation of Dugong Protection Areas in 1998. However, our data indicate that areas of higher by-catch rates, and thus higher marine turtle abundance, received significantly less protection from trawling than areas of lower by-catch and lower marine turtle abundance. This essentially means that although turtle by-catch is better managed by the inclusion of TEDs, trawling is still likely to impact the abundance, distribution and life-history traits of marine turtles in important foraging areas through impacts to benthic habitats. Nevertheless, the combination of a widespread increase in protection over the GBRWHA from commercial fishing and by-catch reduction at sites of high marine turtle abundance are very positive steps towards maintaining healthy populations of marine turtles in the GBRWHA and the broader region.

Creating the balance

Quite clearly, the GBRMPA sought to create a balance between use and conservation when the current zoning plan was designed and implemented. While most of the biophysical operating principles as they related to marine turtles were met, there were some shortfalls with regard to the protection of marine turtles in internesting habitats. First, a 5-km buffer may not accurately represent the internesting habitat, and, second, trawling is still permitted within 5 km of both very-high-priority and two of the high-priority nesting sites for the southern GBR green turtle population. Given the advances in the accuracy of vessel-monitoring systems in determining trawl effort in areas open for trawling (Deng 2005) and the ability to track fine-scale movements of marine turtles during the breeding season (Hays *et al*. 1999) it would be possible to identify and manage current overlaps between habitat use by marine turtles and trawler activity.

Overall

Our findings are instructive because they show that by counteracting the risk posed by the lack of knowledge of appropriate minimum-protection levels, larger, more comprehensive reserves created at the scale of bioregions can substantially improve preservation of specific habitats known to be important to species of conservation concern. It has recently been shown

that recovery of depleted marine turtle populations is possible (Balazs and Chaloupka 2004; Chaloupka *et al*. 2007) and the use of protective zoning can be one tool that can ultimately enable a rebound in populations of exploited (Allison *et al*. 1998; Gell and Roberts 2003) and possibly long-lived species. However, while species-specific protection measures may be seen as side benefits of an ecosystem approach it is important to ensure preservation of significant habitat types for key species, such as marine turtles. This is because making 'popular' species a centre point of an MPA that can demonstrate positive conservation values can inadvertently attract support, funding and research into the area and assist in raising awareness among the general public.

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