Monitoring of Coastal Sea Turtles: Gap Analysis

2. Green turtles, *Chelonia mydas*, in the Port Curtis and Port Alma region

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This report has been produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. The study was undertaken under a Consultancy Agreement (CA120021) between Gladstone Ports Corporation and the Department of Environment and Heritage Protection to review all relevant literature on marine turtles for the Port Curtis and Port Alma regions.

This publication has been compiled by the Queensland Department of Environment and Heritage Protection (EHP).

Background

This study has been undertaken to provide a review and summary of available scientific literature and data on marine turtles in Central Queensland, particularly the Port Curtis and Port Alma region, and if required, expand the extent to consider turtle information for Queensland:

- Identify and update baseline data for suitable turtle habitat in the Port Curtis and Port Alma region at a distance of 500km north of Port Alma and south of Port Curtis
- Assess whether the available historical survey data are sufficiently robust to permit trend analyses. If so, undertake a trend analysis; undertake a formal power analysis of the reviewed data, if appropriate;
- Conduct a quantitative analysis of the historical trends in marine turtle numbers for the Port Curtis and Port Alma region; and
- Identify the migratory links between resident foraging turtles in the Port Curtis and Port Alma region and their nesting areas.

The green turtle, *Chelonia mydas* (Figure 1), has a global distribution, occurring in all oceans. The biology and conservation status of green turtles have been reviewed at a global scale by Parson (1962), Hirth (1997) and IUCN SSC Marine Turtle Specialist Group (2004) and within Australia by Limpus (2008).

Status

Within Australia, the green turtle is scheduled as a vulnerable species under both the Queensland and Federal conservation legislation and associated regulations, *Nature Conservation Act 1992* and *Environment Protection and Biodiversity Conservation Act 1999*, respectively.

Data sources

This gap analysis has drawn on information available in the published literature and in the two primary computerised data bases with the Queensland Department of Environment and Heritage Protection (EHP).

Queensland Turtle Conservation (QTC) database

EHP maintains a database that incorporates all tagging records for Queensland, incidental sighting records, nesting distribution and migration data for marine turtles in Queensland.

StrandNet

EHP maintains a database collating reports of sick, injured and dead marine wildlife (Cetaceans, dugong, turtles, threatened sharks and grouper) in Queensland (Biddle and Limpus, 2011). This data base includes turtle mortality from the Queensland Shark Safety Program.

These data sets have been supplemented with data sets managed by Dr Limpus which summarise international nesting and migration.

Index study sites

Nesting:

There are four index nesting beaches for monitoring green turtle breeding in the southern Great Barrier Reef (GBR) (Limpus, 2008) (Figure 2B).

Southern GBR Stock

- Heron Island (23.433°S, 151.917°E); a minor nesting population but the primary index site; total nightly tagging census for the nesting season, December-February, during most years, 1964-2012.
- Wreck Island (23.300°S, 151.917°E); a major nesting population; mid season (last 2 weeks of December) track count census for the nesting season during most years, 1977-2012.
- North West Island (23.300°S, 151.700°E); a major nesting population; mid season (last 2 weeks of December) track count census for the nesting season during most years, 1977-2012.

- Lady Musgrave Island (23.900ºS, 152.383ºE); a minor nesting population; mid season (last 2 weeks of December) track count census for the nesting season during most years, 1972-2012.

Northern GBR stock

- Raine Island (9.817ºS, 144.017ºE) and Bramble Cay (11.600ºS, 143.867ºE) are index nesting beaches within the northern GBR management unit in the northern GBR and Torres Strait which are not addressed in this current gap analysis.

Foraging

There have been three primary index foraging areas for monitoring population dynamics of the southern GBR green turtle management unit in eastern Australia. At each site, the sex, maturity and breeding status of the turtles has been determined by gonad examination:

- Moreton Bay (27.35ºS, 153.40ºE); annual tagging-recapture sampling of this foraging population in temperate waters during 1990-2012 (Limpus et al. 1994a).
- Southern GBR - Heron & Wistari Reef (23.433ºS, 151.917ºE); annual tagging-recapture sampling of the foraging population during 1984-1999 (Limpus and Reed, 1985a).
- Western Shoalwater Bay (22.333ºS, 150.200ºE); annual tagging-recapture sampling of the foraging population in most years during 1986-2012 (Limpus *et al*. 2005).

There are additional subsidiary index foraging sites where tagging-recapture studies have been conducted with varying duration and or intensity:

- Clack Reef (14.067ºS, 144.250ºE); annual tagging-recapture sampling of the foraging population during 1988-1991 and 1997 (Limpus *et al*. 2009).
- Northern Repulse Bay (20.450ºS, 148.800ºE); intermittent tagging census during 1988-1992 (Limpus, 2007).
- Green Island Reef (16.750ºS, 145.983ºE); intermittent tagging census during 1988-2012.

Stock identification

There have been a series of on going analyses investigating the genetic relationship of green turtle breeding aggregations at a global scale and within the Australasian region:

- Bowen *et al*. (1992) established that the green turtle population that breeds in southern Queensland (represented by Heron Island specimens) was genetically distinct from all other tested green turtle populations.
- Norman *et al*. (1994) demonstrated multiple genetic stocks of green turtles breeding in Australia.
- Fitzsimmons *et al*. (1997a, b) established that adult male and female green turtles displayed comparable levels of fidelity to their respective natal breeding areas. These results contradicted the hypothesis of Karl *et al* (1992) that nuclear gene flow between genetic stocks was the result of lower fidelity of males to breed within their natal area.
- Moritz *et al*. (2002) and Dethmers *et al*. (2006) provide the definitive separation of green turtle genetic stocks in Australia with only the western Arnhem Land, Cocos-Keeling and Christmas Island and central Coral Sea nesting populations remaining unresolved:

Figure 2B summarises the distribution of green turtle genetic stocks in the eastern Australia - Coral Sea region based on Dethmers *et al*. (2006). Stocks are identified by the region in which breeding occurs, irrespective of where the turtle lives.

Nesting population

The green turtles that breed within the southern GBR region are therefore assigned to the southern GBR genetic stock (management unit) (Figure 2). This green turtle management unit represents a globally significant population for the species.

There is a well defined breeding season for southern GBR management unit:

- Courtship commences in about mid September, reaches a peak in October and ceases by about mid November (Limpus, 1993). Booth and Peters (1972) have described green turtle courtship behaviour at Fairfax Island lagoon. The study warrants reinvestigation using more rigorous quantification of data.
- Nesting commences in mid to late October, reaches a peak in late December to early January and ends in about late March–early April (Bustard, 1972). Nesting behaviour was described and defined by Bustard and Greenham (1969).

- Hatchlings emerge from nests from late December until about May with a peak of hatching in February and March – emerging approximately two months following laying of the respective clutches (EHP QTC turtle database).

Within the southern GBR region, there are numerous green turtle nesting sites (Figure 2B). The primary focal area for green turtle nesting in this region encompasses the islands of the Capricorn-Bunker Groups (Bustard, 1972; Limpus *et al*. 1984; Limpus, 1985; Limpus and Nicholls, 2000; Limpus, 2008). The largest breeding aggregations occur on three islands: North West, Wreck and Hoskyn Islands, each supporting thousands of nesting females annually in an average nesting season. Smaller but still major nesting aggregations occur on Tryon, Heron, Lady Musgrave, Masthead, Erskine, Fairfax, North Reef, Wilson Islands and the northern part of Fraser Island, each supporting hundreds of nesting females annually in an average nesting season. Minor breeding aggregations occur at Bushy Island, the Percy Islands, Bell Cay, Lady Elliott Island, and the mainland coast from Bustard Head to Bundaberg, each beach supporting tens of nesting females annually in an average nesting season. Very low-density nesting can occur on almost any other beach within this area.

Isolated green turtles nest on beaches within the port limits of Port Alma and Port Curtis, but not on an annual basis.

Nesting census and nesting population trend
No attempt has been made to conduct a total tagging census (count of the number of nesting females) of the southern GBR *C. mydas* rookeries apart from at Heron Island (Figure 3). The size of the annual female breeding population has been monitored at four index rookeries for the southern GBR stock for varying periods since 1964 (Bustard, 1972; Limpus, 1980; Limpus *et al*. 1984; Limpus, 1985; Limpus and Nicholls, 2000; Limpus, 2008). These data (Figures 3, 4) provide the primary measures of the trends for the green turtle breeding population in the southern GBR:

- During the late 1800s until 1950 green turtles nesting at islands within the Capricorn-Bunker Group of islands in the southern GBR and turtles foraging in coastal waters from Moreton Bay to at least as far north as Mackay were harvested for soup manufacture and meat production. This commercial harvest of green turtles in the southern GBR ceased in August 1950 and was not resumed (Limpus, 1980, 1985, 2008; Limpus *et al*. 1994; Daley *et al*. 2008).
- Limpus and Nicholls (2000) documented synchronous fluctuations in the size of the green turtle nesting population on multiple islands within southern GBR. The census data from the four index beaches (Figures 3, 4) have demonstrated a general synchrony of fluctuations in green turtle nesting numbers across more than four decades.
- Based on mid-season nightly track counts, the total nesting population for the southern GBR green turtle stock was expected to be approximately 8,000 females in an average breeding season in the early 1980s (Limpus *et al*. 1984; Limpus, 1985).
- This nesting population is one of a few green turtle populations globally that has maintained a robust population recovery across several decades (Chaloupka *et al*. 2008).

These census data demonstrate that the southern GBR green turtle nesting population has been increasing steadily across more than four decades at an average of about 3% per year.

Green turtle breeding abundance is regulated by El Nino Southern Oscillation climate variation
The highly variable size of the annual nesting population, often in successive years is a characteristic of green turtle nesting populations globally (Chaloupka *et al*. 2008). Limpus and Nicholls (1988, 2000) and Limpus *et al*. (2003) have demonstrated a strong correlation between the El Nino southern Oscillation (ENSO) climate signal and the size of the annual green turtle nesting populations as measured at index nesting beaches in eastern Australia, some 18 months after the climate event. Very high density nesting occurs about 18 months following a major El Nino event (a drought in eastern Australia) while very depleted nesting numbers occur about 18 months following a major La Nina event (high rainfall seasons in eastern Australia). ENSO controls the proportion of adult females present in the foraging areas that prepare for breeding (Limpus and Nicholls, 1994).
There is approximately a year of preparation for an adult female to develop the necessary fat deposition required before vitellogenesis commences, culminating in the female migrating to her breeding area on completion of vitellogenesis (Miller and Limpus, 2003). Initiation of this preparation for breeding is hypothesised to be regulated by the quality and/or quantity of food in the foraging areas.

Courtship and mating systems

Limpus (1993) identified that courtship aggregations occurred in the lagoon habitats of coral reefs with in the southern GBR:

- Within any one breeding season, individual males were sexually active for about a month.
- It was not unusual for an individual male to mount a series of different females.
- Breeding male green turtles at any one courtship area mate with females that will nest on rookeries spread throughout the region.
- In comparison with the breeding females from the same breeding unit, the males are smaller in curved carapace length.
- A higher proportion of males than females remigrate for additional breeding seasons at short (1-2 year) intervals.
- Like adult females, adult males are slow-growing, averaging 0.046 cm/year.
- Males display fidelity to their respective courtship areas, to which they return in successive breeding migrations, a finding subsequently supported by mtDNA genetics studies (Fitzsimmons *et al*. 1997a).
- At the conclusion of the courtship period, males disperse to widely scattered feeding areas.
- From each of the courtship areas, individual females did not necessarily nest at the rookery closest to the respective mating aggregation but dispersed throughout the green turtle rookeries within the southern GBR, with females being recaptured nesting up to 92 km from a recorded mating site.

FitzSimmons *et al*. (1997b) demonstrated that there is high fidelity for both the adult male and females to return to their natal region for breeding. At the same time they proposed that there can be gene flow between management units resulting from adult females on breeding migrations being mated by males encountered when the females migrate through courtship areas of a different management unit.

Females mating with multiple partners, sperm storage at courtship and using this sperm during the following nesting season to fertilise multiple clutches of eggs has been investigated using genetic markers (FitzSimmmons, 1998). However, this study indicates that single paternity within entire clutches may be the norm with the southern GBR management unit. This issue warrants further investigation.

Endocrinology and gonad morphology have been studied with courting green turtles from the southern GBR management unit (Hamann *et al*. 2003; Jessop *et al*. 1999, 2004; Miller and Limpus, 2003; Wibbels *et al*. 1990)

Embryology and temperature dependent sex determination
Miller (1985) has provided a comprehensive description of green turtle embryology.

Parmenter (1980) investigated movement induced mortality on green turtle embryos resulting from rotation of the eggs and defined a methodology for safe transportation of eggs to distant incubation sites and laboratories.

The green turtle, typical of all marine turtles, displays temperature dependent sex determination (TSD) (Miller and Limpus, 1981):

- This population has a pivotal temperature of 27.6°C (Limpus, 2008);
- Cooler nests produce mostly male hatchlings and warmer nests produce mostly female hatchlings.

Temperature data from nest depth within the turtle nesting habitat of the Capricorn Group islands indicate that the northern (sunny) aspect beaches are consistently warmer that the southern (shaded) aspect beaches on the same island. As a consequence, the northern aspect beaches produce mostly female hatchlings and the southern aspect beaches and shaded habitats can produce mostly males (Limpus *et al*. 1983, 1984). Hatchling sex ratio has not been measured for the entire population. However, it is anticipated that it will be strongly biased to females in most seasons, based on sand temperatures at nest depth (Bustard, 1972; Bustard and Greenham, 1968; Limpus *et al*. 1983, 1984; Booth and Astill, 2001a). Metabolic heat production within natural green turtle nests at Heron Island was predicted to have little effect on hatchling sex ratio because the heating occurred after the sex-determining period (Booth and Astill, 2001a). In this same study, the location and degree of shading of nests had little effect on mean nest temperature, but deeper nests were generally cooler and therefore were predicted to produce a higher proportion of males than shallower nests.

With growing concerns regarding climate change and rising temperatures, attention is now being focussed on the role of temperature on hatchling quality.

- Based on the results of constant temperature incubation experiments, green turtle hatchlings from male producing incubation of 26^{o}C were of greater mass and had smaller residual yolks than hatchlings from female producing incubation of 30^{o}C (Booth and Astill, 2001b).

- Booth *et al*. (2012) found that "both maternal origin and nest environment influence (green) turtle hatchling morphology and locomotor performance in some but not all field nests. By using egg mass (maternal origin effect) and nest temperature (nest effect) in multiple regression analysis, ……. maternal origin had a greater influence than nest temperature on the morphological attributes of hatchling mass and carapace size, but nest temperature had a greater influence than maternal origin on the performance attributes of self-righting time, self-righting propensity, swim thrust during the first 30 min of swimming, and power stroke rate during the first 30 min of swimming".

Migration

Figure 5 summarises the distribution of foraging areas in Papua New Guinea, Vanuatu, New Caledonia, Fiji, Northern Territory, Queensland and New South Wales to supply adult green turtles to southern GBR breeding sites that have been recorded from flipper tag recoveries. Limpus (2008) has summarised a number of principles underlying green turtle migration:

- There is no one path followed by all turtles on their breeding migrations.
- While some individuals migrate in excess of 3,000 km, most migrate less than 1000 km to their rookeries.
- Each adult migrates with a high degree of fidelity to its particular feeding area and its rookery (Limpus *et al.* 1992, 1994a, 2005, 2009).
- Turtles nesting at the one rookery will have migrated from numerous foraging areas (Limpus *et al*. 1992, 2003).
- Similarly, turtles that live within the same foraging area can be expected to disperse to widely scattered breeding sites (Limpus *et al*. 2005, 2009) (Figure 6).

Breeding migrations are physiologically demanding for the breeding females (Kwan, 1994; Hamann *et al*. 2002, 2003; Jessop *et al*. 2004a) because of greatly reduced or absence of foraging during migration and egg production.

Breeding males make comparable migrations to those undertaken by the breeding females (Limpus, 1993) (Figure 5a, b). Breeding migrations are physiologically demanding on the males also (Jessop *et al*. 2004b).

Studies by Lohmann and Lohmann (1996) indicate that adult turtles use a large-scale, bi-coordinate magnetic map sense to guide their migration back to the region of their birth.

Adult females can migrate to breed at eastern Australian rookeries from up to 3,000km distant but the majority appear to migrate from foraging areas within a limited area of the eastern Queensland coast spanning only 14^{o} of latitude (14^{o} to 27^{o} latitudinal blocks) (Figure 7) and from New Caledonia (Figure 5a).

Green turtles living within the 23^{o} latitude block of the eastern Australian (in the vicinity of Port Alma and Port Curtis) have been recorded to migrate to breed at many different rookeries in south and central Queensland (Figure 6):

- Capricornia Section of the Southern GBR (North West Island, Wreck Island, Heron Island, Lady Musgrave Island),
- the adjacent mainland coast (Wreck Rock beaches) and
- Fraser Island and
- multiple islands in north western New Caledonia.

Building on previous satellite telemetry studies, there are current collaborative studies between EHP and a JCU post graduate student supervised by Dr Mark Hamann investigating foraging area home ranges using GPS satellite tags. These tags have been deployed on adult green turtles foraging in Shoalwater Bay, Sandy Strait and Moreton Bay.

Data not addressed in the above analysis include one unpublished telemetry study of habitat use and migration for green turtles foraging in Port Curtis. This study is part of a JCU PhD study (Supervised by Prof. H. Marsh).

Oceanic pelagic post-hatchling dispersal
Hatchling green turtles engage in a swimming frenzy to disperse from their natal nesting beaches out to open ocean waters. This phase in their life history has been poorly investigated in eastern Australia.

Survivorship of hatchling green turtles leaving the beach and swimming across the reef flats has been quantified at Heron Island:

- Survivorship of hatchling crossing the reef flat averaged at 0.4 (Gyuris, 1994). Fish and sharks are the primary predators of the hatchlings as they cross the reef flats.
- Smaller hatchlings have a lower survivorship than larger hatchling (Gyuris, 2002).

The methodology used in these studies, while suited to relatively calm weather conditions, may not be appropriate for quantifying hatchling predation under all sea states and hence turbidity conditions. There would be value in repeating these hatchling survivorship studies using alternate technologies that are now available.

Once offshore of the eastern Australian rookeries, the post-hatchling green turtles initially travel south in the East Australian Current, past sea mounts outside the continental shelf and on to offshore of northern New South Wales (Limpus and Walker, 1994; Walker 1994; Boyle and Limpus, 2008). During this dispersal the post-hatchlings feed on macro zooplankton (Boyle and Limpus, 2008).

The subsequent temporal and spatial aspects of the dispersal of these post-hatchling green turtles after they leave the East Australian Current and disperse within the Coral Sea – Tasman Sea region of the south-west Pacific Ocean (Robins *et al*. 2002, 2007) has not been quantified.

There have been no studies to quantify survivorship of post-hatchlings during this oceanic dispersal phase. A large proportion of sampled small post-hatchling green turtles travelling south in the East Australian Current have ingested synthetic debris, particularly those that wash ashore as debilitated or dead in south Queensland and northern New South Wales (Boyle and Limpus, 2008).

Coastal foraging population
Limpus *et al*. (2005) defined a methodology for identifying juvenile green turtles that have recently recruited to benthic foraging in coastal waters. The size of immature green turtles from the southern GBR management unit that have recently recruited to residency in coastal waters from the post-hatchling pelagic foraging life history stage have been sampled at three widely separated foraging area (Table 1). When pooled across these foraging areas, a juvenile green turtle recruits from pelagic habitats to shallow coastal foraging areas with a mean curved carapace length (CCL) = 43.96cm (SD = 3.257, range = 36.5 – 73.4; n = 417). The size by sex of turtles that had recently recruited to coastal waters are summarised in Table 1. When compared across the three foraging areas, no significant differences were detected among the female recruits to coastal foraging (Table 1). In contrast there were significant differences among the sizes at which males recruited to the various coastal foraging areas (Table 1). Larger males were recorded as recruits to Moreton Bay than to the other two foraging areas. Within each foraging area, no significant difference was detected between the sizes of the sexes as they recruited to coastal foraging (one way ANOVA: $p > 0.25$ at each site). Limpus (2008) indicates that these recent recruits to coastal residency should be in the 5-10 yr age range.

Limpus *et al*. (2008) have summarised habitat use by green turtles from the southern GBR management unit: After recruiting from the pelagic post-hatchling phase to benthic foraging over the eastern Australian continental shelf, immature and adult green turtles feed in range of “tidal and sub-tidal habitats including coral and rocky reefs, sea grass meadows and algal turfs on sand and mud flats throughout an area bounded by the eastern Arafura Sea, Gulf of Carpentaria, Torres Strait, Gulf of Papua, Coral Sea, Great Barrier Reef, Hervey Bay, Moreton Bay and NSW coastal waters” (Limpus and Reed, 1985; Limpus *et al*. 1994a, 2005; Speirs, 2002; Strydom, 2009; QTC turtle database). Based on tag recoveries of adults, the major part of the southern GBR stock can be assumed to occupy feeding areas south of Princess Charlotte Bay to northern New South Wales and in New Caledonia (Figures 5, 7). Green turtles are year-round foraging residents to at least as far south as northern New South Wales (Speirs, 2002).

Green turtles also forage in the deeper soft bottom habitats between the coral reefs of the GBR and the mainland and have been most frequently trawled at 1-30 m depth and less frequently to depths up to 60 m (Robins and Mayer, 1998).

The green turtle population is structured similarly at the index foraging sites and all other sites sampled in coastal waters (Shoalwater Bay: Limpus *et al*. 2005; Capricorn Reefs: Limpus and Reed, 1985; Hervey Bay: Strydom, 2009; Moreton Bay: Limpus *et al*. 1994a; Julian Rocks, NSW: Speirs, 2002):

- Consisting of all size classes from small immature turtles to adults.
- Strongly biased to females, approximately 1 males to 2 females, across all age classes at all index foraging areas (Limpus, 2008)

Survivorship, calculated from tagging-recapture analysis for green turtles resident on coral reefs in the southern GBR, is high (Table 2) (Chaloupka and Limpus, 2005). This is a study site with little direct anthropogenic impact on the turtles:

- "There were no significant sex-specific differences in either survival or recapture probabilities for any age class."
- "Mean annual adult survival was estimated at 0.9482 and was significantly higher than survival for either subadults or juveniles."
- "Mean annual subadult survival was 0.8474, which was not significantly different from mean annual juvenile survival estimated at 0.8804."
- "The time-specific adult recapture probabilities were a function of sampling effort but this was not the case for either juveniles or subadults. The sampling effort effect was accounted for explicitly in the estimation of adult survival and recapture probabilities."

Adult female green turtles typically do not breed annually but skip two years or more between breeding seasons (Limpus *et al*. 1994b; Limpus, 1993; Limpus, 2008). Whether or not a turtle prepares for breeding is determined back in its home foraging area more than a year prior to the breeding season. The proportion of adult females that prepare for breeding in any one year from the index foraging areas (Figure 8) displays some synchrony across the foraging area. However, the proportions of females preparing to breed from each foraging area (Table 3) are significantly different (One way ANOV: $F_{2,65} = 4.78$; $0.1>p>0.05$). The mean annual adult female breeding rate recorded within these samples = 0.167 (SD = 0.125, range = 0 – 0.63, n = 68 samples). Within this small sample of study sites, Moreton Bay which has the highest female breeding rate (Table 3) also was recorded with the highest growth rates (Chaloupka *et al*. 2004), while western Shoalwater Bay which has the lowest female breeding rate also was recorded with the lowest growth rates. These data are indicative of a significant role of habitat condition, possibly forage abundance or quality in regulating at least these two major demographic parameter: growth rate and annual breeding rate. This warrants further investigation. Typically there is a higher proportion of the adult males than females that prepare for breeding from their respective foraging areas in any one year (Figure 8, Table 3).

Based on a tagging-recapture analysis of the green turtle population resident on Heron-Wistari Reefs of the southern GBR between 1985–1992, Chaloupka and Limpus (2001) identified that the resident green turtle population increased over the 8 years by 11% pa and comprised 1300 individuals in 1992. This study site was minimal exposure of the resident turtles to human related impacts. The female nesting population on Heron island which draws on females from widely distributed foraging areas (Figure 5) also increased but more slowly at 3% pa, presumably the result of some foraging areas having lower survival and/or recruitment rates.

Diet

Green turtles are long-lived marine reptiles that undergo shifts in diet during their development through diverse habitats. During their early oceanic pelagic post hatching life history phase, juvenile green turtles in the southwestern Pacific feed omnivorously on planktonic material (Boyle and Limpus, 2008). At approximately CCL = 44 cm, they recruit to inshore foraging habitats where they become primarily herbivorous.

There have been numerous studies investigating the diet of green turtles from the southern GBR management unit at multiple coastal foraging areas:

Moreton Bay:

- Arthur *et al*. (2008) investigated the shift in diet and habitat using changes in stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) composition of epidermal tissue sampled throughout their life history in the southwestern Pacific Ocean. The recently recruited turtles to foraging grounds in Moreton Bay had significantly higher $\delta^{15}N$ isotopic signatures when compared with all other life history groups examined and significantly lower $\delta^{13}C$ when compared with all age classes other than pelagic juveniles. Adult and large immature turtles had similar isotopic signatures and were both significantly enriched in ^{13}C when compared with hatchlings and small immature turtles.
- Brand-Gardner *et al*. (1999) and Brand *et al*. (1999) studied the diet of immature green turtles using gastric lavage in the gutter on the southwestern side of Moreton Island, Moreton Bay.
  - While these turtles fed on both seagrass and algae, most fed selectively on algae, primarily *Gracilaria*.
  - *Gracilaria* was not abundant within the study area but was the most frequently selected food item.
  - The seagrass, *Zostera capricorni*, was the most abundant microphyte within the study area but was one of the least selected food items.
  - There was a negative correlation between fibre level and the preferred food species, with the species with lower levels of fibre being selected more frequently. The preferred species had higher nitrogen levels also.
  - Ascidian and anemone accounted for approximately 5% of the food items.
  - The time taken for food to pass through the gut was measured for three turtles at 6.5-13.5 days.
- Read and Limpus (2002) examined the diet of immature green turtles on the Moreton Banks. These turtles foraged on the available seagrass species, but principally *Halophila ovalis*; algae, principally red algae (*Gracilaria cylindrica* and *Hypnea spinella*); and lesser amounts of grey mangrove fruit (*Avicennia marina*) and some animal material.
- Arthur *et al*. (2007) using crittercam technology recorded adult green turtles feeding on gelatinous animals (ctenophores, jellyfish, nudibranchs) from the water column. This prey source was previously not documented in Moreton Bay using traditional gastric lavage (Forbes and Limpus, 1993). This study has demonstrated that green turtles may have a more flexible diet than previously described, indicating they could potentially supplement their diet with alternate prey items when seagrass quality or quantity is compromised.

Hervey Bay:

- An investigation of the diet of 40 immature green turtles in the basking assemblage within the mangroves in western Hervey Bay using gastric lavage and stable isotope analysis during samplings in April, June and August identified a diet that varied seasonally (Cameron, 2007):
  - 43% mangrove (*Avicennia marina*) leaf, fruit and flower;
  - 39% algae (*Gracilaria, Hypnea, Sargassum, Laurencia, Catenella, Rhizoclonium, Ulva, Caloglossa*);
  - 15% seagrass (*Zostera capricorni, Halophila ovalis, Halodule uninervis, Cymodocea serrulata*).
  - Animal food items (fish eggs and sponge) were identified in the samples of one turtle each.

Heron Island Reef:

- Forbes examined the diet on 518 immature and adult green turtles resident on Heron Reefs over a two year study using gastric lavage,
  - These turtles were foraging on almost exclusively algae.
  - They fed on a diverse range of algae: 38 species of Rhodophyta (red algae), particularly *Turbinaria*; 21 species of Chlorophyta (green algae), particularly *Caulerpa, Codium, Enteromorpha*; and 10 species of Phaeophyta (brown algae), particularly *Galidiella, Polysiphonia, Laurencia*.
  - Animal items occurred in some samples, particularly hydrozoan jellyfish and *Physalia* which were consumed in quantity on the occasions when they were present over the reef.
  - The algal turf, which comprised of a mix of brown and red algae was heavily exploited by these turtles but there would be sudden diet shifts when green algal blooms such as *Enteromorpha* occurred.

Shoalwater Bay:

- Arthur *et al*. (2006) investigated the diet of 46 immature and adult green turtles during a toxic cyanobacterium, *Lyngbya majuscula*, bloom along 18 km of western Shoalwater Bay and covering more than 11 km^2 of inter-tidal habitat during June–July (winter) 2002:
  - *L. majuscula* was found in 51% of the samples but contributed only 2% of the diets.
  - In bloom samples, lyngbyatoxin A was found to be present in low concentration, but debromoaplysiatoxin was not detected.
  - *L. majuscula* contribution to turtle diet was found to increase as the availability of the cyanobacterium increased.
  - The bloom appeared to have no immediate impact on turtle body condition, however, the reduced quality of the seagrass in the diet in conjunction with decreases in plasma concentrations of sodium and glucose suggest that the turtles had been exposed to a substandard diet as a result of the bloom.
- During a collaborative study between Queensland Parks and Wildlife Service and UQ Marine Botany (See studies by Arthur *et al*. below for additional diet summaries), Limpus et al. (2006) investigated immature green turtle diet in western Shoalwater Bay during winter 2001:
  - Green turtles foraging in western Shoalwater Bay are primarily herbivorous but were highly variable between habitats in which the turtles were feeding.
  - The diets of juvenile and sub-adult turtles were predominantly of seagrasses with smaller amounts of red algae, white mangrove fruit and seedling cotelydons, blue green algae and animal matter.
  - The majority of turtles captured were from the seagrass meadows and the seagrass component of the crop sample for these animals was approximately 70%.
  - The most frequently observed species in the diet was the seagrass *Halodule sp.* (96.6% of samples), followed closely by other seagrass species *Zostera muelleri* and *Halophila ovalis*.
  - Mangrove material was found in animals from the mangrove forest where they may have been opportunistically feeding on the submerged plants at high tide.
  - Red algae contributed a significant wet weight component of the diet, particularly in turtles caught on rocky reef or basking on rocks at low tide. Although turtles caught among mangroves during the upper tidal cycles had a low proportion of red algae in the crop sample, the mangroves was the only habitat where *Bostrychia tenella* was observed in crop samples. This red alga grows on mangrove roots and trunks.

  This study reinforced the importance of mangrove fruit in the winter diet of green turtles in western Shoalwater Bay. *Avicennia marina* fruit was in diet samples from 13.3% of turtles when there was abundant fruiting by mangroves in 2001. In 2002, *A. marina* were not heavily in fruit and was absent from turtle diets. When mangroves fruited again in 2003, 13.5% of turtles fed on the fruit in that winter. When the fruit is available, it is commonly eaten by the turtles (Limpus and Limpus 2000).

  It was concluded that as different habitats become available for the turtles through the tidal cycle, the major food types consumed may change. Overall, the study identified variability in diet for green turtles in this area by year, by specific foraging site and during the tidal cycle.
- Arthur *et al*. (2009) examined the diet of both adult and immature green turtles using gastric lavage and longitudinal examination of gut content in a necropsied adult with associated stable isotope analysis:
  - Green turtles in Shoalwater Bay appear to be primarily herbivorous, but opportunistic in their foraging behaviour.
  - All turtles in this study ingested seagrass, but many also consumed mangrove material and red algae.
  - Only 1% of turtles had consumed significant amounts of animal material, based on gastric lavage.
  - The break down and assimilation of seagrass and mangrove leaves appear to occur at different locations through the alimentary tract.
  - The composition of diets was significantly different between sampling years, primarily due to the quantity of the seagrass *Halodule* sp. in the diet and the presence of *L. majuscula*.
  - Red algae and mangrove material were commonly observed in green turtle diet samples but did not contribute as much volumetrically to diet as seagrasses.

- Red algae may provide an alternate food source when seagrass is limited, and could potentially provide a nutritional advantage for those turtles able to access areas in which the algae grows.
- Seagrass as the main diet of green turtle contributes most to tissue production, however mangrove leaves and propagules provide an opportunistic food source from which nutrients are released faster than from seagrass.
- The continuous presence of seagrass interspersed with clumps of mangrove material throughout the alimentary tract in a necropsied adult female suggests transitory feeding behaviour where a turtle moves to the mangroves with the high tide and forages on mangrove propagules and leaves while are accessible at the top of the tide and then moves back to seagrass beds with the receding tide.

Ageing studies and relevance to management time scales

A study to determine the age at which green turtles reach sexual maturity, to determine philopatry to natal beaches and to quantify survivorship to sexual maturity was commenced at Mon Repos during the 1973-1974 nesting season (Limpus, 1885): Over seven breeding season, approximately 105,000 hatchling green turtle hatchlings were tagged using mutilation tagging (carapace notching) such that each was identified to the beach of its birth and the season in which it was born. Some green turtles "tagged" as hatchlings have been recaptured as immature turtles in their foraging areas (Limpus *et al*. 1994). The first adults that had been marked as hatchlings at the Heron Island rookery have returned for their first breeding at 32 years of age in the 2010–2011 breeding season (C. Limpus, unpublished data). This study is still in progress.

As summarised above, green turtles recruit to coastal residency from the post-hatchling oceanic pelagic dispersal life history phase at CCL = 44 cm.

The size at which green turtles from the southern GBR management unit reach sexual maturity (1st breeding season) has been quantified for turtles foraging on the southern GBR coral reefs using gonad examination to determine commencement of breeding (Once a female turtle reaches maturity and commences breeding, a corpus luteum is formed on the ovary with each ovulation of a mature follicle. Each corpus luteum heals to leave a permanent scar (corpus albicantium) on the surface of the ovary (Miller and Limpus, 2003). The presence or absence of corpora albicantium on the ovary can be used to differentiate between a female in her first breeding season and a female that has bred in a previous season. This criterion can be applied for identifying first time breeding females when studying foraging females in vitellogenesis as they prepare for a breeding season or when studying nesting females at a rookery. There are no comparable morphological characters that can be used to identify a male in his first breeding season.).

There are significant differences in the mean size at which a female from the southern GRB green turtle stock commences her breeding life, depending on the foraging area at which the female lives (Table 4): one way ANOVA, $F_{3,148} = 25.205$; $p < 0.001$, significant).

Among these foraging areas (Table 4), the females that matured at the largest average size were those foraging in the area where green turtle have the highest growth rates (Chaloupka *et al*. 2002), *viz*. Moreton Bay. Similarly, the females maturing at the smallest average size were in the foraging area where green turtles had the lowest growth rate, *viz*. Shoalwater Bay. From these data it is concluded that when southern GBR green turtle stock females grow rapidly throughout their lives, they will grow to a larger size when compared with turtles growing up in a habitat which supports slower growth rates. Therefore large adult green turtles are not necessarily older than smaller adults. Their large size may well be the result of them having grown faster and hence larger to mature at similar ages to slow growing turtles that mature at a smaller size.

The mean size of a female laying eggs for her first breeding season, based on gonad maturation, and recorded when they have migrated to at the nesting beaches within the southern GBR stock area has been CCL = 102.05 cm (SD = 5.681, range = 86.6 – 117.6, n = 159; spanning nesting seasons 1989-2007. QTC Turtle Database). This mean size at first breeding is towards the middle of the range of sizes at first breeding recorded at various foraging areas for the stock (Table 4) and further supports the view that rookery-based samples of adult females represent pooled samples from multiple foraging areas.

Growth rates of wild green turtles have been quantified using tagging-recapture studies at multiple index foraging areas.

- Limpus and Walters (1980) refuted the long held folklore that green turtles commenced breeding at about 10 years of age using growth data from a small sample immature green turtles resident on Heron-Wistari Reefs. They estimated that green turtles in this population would be in excess of 30 years of age at first breeding.
- Chaloupka (2001) developed a system-of-equations growth model to describe and summarise sex-specific growth for green turtles in the southern GBR foraging area. Based on this analysis, an average adult female or male southern GBR management unit green turtle would commence breeding about 35 years after recruiting to benthic foraging.
- Limpus and Chaloupka, (1997) and Chaloupka et al. (1994) investigated the growth dynamics of green turtles of the southern GBR genetic stock resident in four separate foraging grounds (Clack Reef, western Shoalwater Bay, Heron-Wistari Reefs, eastern Moreton Bay), spanning 13º of latitude, using tagging recapture data collection and a nonparametric regression modelling approach for data analysis:
    - Juveniles recruit to these foraging areas at the same size, but grow at foraging-ground-dependent rates that result in significant differences in expected size or age at first breeding.
    - The average age at first breeding will be variable between foraging areas and was estimated to vary from 25–50 years.
    - The variability in growth was not a function of latitudinal variation in environmental conditions or whether the forage was dominated by seagrass or algae.
    - Given the similarity of genetic background across these foraging areas, the geographic variability in growth rates is most likely due to local environmental conditions.
    - Temporal variability in growth rates was evident in response to local environmental stochasticity, so geographic variability might be due to local food stock dynamics.
    - Despite such variability, the expected size-specific growth rate function at all grounds displayed a similar nonmonotonic growth pattern with a juvenile growth spurt at CCL = 60–70 cm or 15–20 years of age.
    - Sex-specific growth differences were also evident with females tending to grow faster than similar-sized males after the juvenile growth spurt.
    - This slow sex-specific growth displaying both spatial and temporal variability and a juvenile growth spurt are distinct growth behaviours of southern GBR management unit green turtles.
    - The fastest growth was recorded at Clack Reef (14ºS latitude, seagrass-algal forage) and Moreton Bay (27ºS, predominately seagrass forage). The slowest growth was recorded at Shoalwater Bay (20ºS, primarily seagrass forage). The intermediate growth was recorded at Heron-Wistari Reefs (23ºS, entire algal forage)

Growth of adult male and female green turtles is extremely slow, of the order of a few millimetres per year (Limpus, 1993, 2008).

There is no evidence of further developmental migration of green turtles once they recruit to a foraging area in eastern Australia. Rather, tagging studies indicate that the turtles continue to maintain fidelity to their respective foraging areas even after they reach maturity and for the remainder of their adult lives.

A species with such an extreme delay in age at first breeding will be difficult to manage within the time frames of normal Government conservation agency organisation. For example:

- Changes in the mortality of small immature green (pelagic oceanic post-hatchling life history phase) by oceanic long-line and purse seine fisheries bycatch will not be detectable at the nesting population for more than 25 years after the changes occur with the fishing fleets.
- Similarly, changes in egg mortality and associated hatchling production at the nesting beaches will not be detectable in the next generation of nesting turtles for some 30 years or more.

When other aspects of green turtle life history complexity are considered such, as their large oceanic dispersal distances, adult breeding migrations and the associated occupancy of a diversity of habitats throughout the life history, implementation of successful conservation management for the species will be complex.

On the basis of these timing estimates, impacts of some recent past conservation management will not be detectable in the adult nesting population at this time. If early warnings of population malfunction are to be effective, there is a need for a range of bench mark parameters to be quantified that give a measure of the performance of each life history phase. Some of these parameters include: size of the annual nesting population, recruitment rate to the adult population; annual breeding rate of adults from their foraging areas; rates of clutch loss and incubation success of the remaining clutches; recruitment from pelagic to benthic foraging life history phase; survivorship of immature and adult turtles in representative foraging areas and as breeding adults.

Basking

Basking by green turtles was wide spread and commonly reported from the southern GBR during the early 1900s (Limpus, 2008). However, the mass basking phenomenon at Heron Island in 1910 has ceased to occur since at least the mid 1900s. In recent decades, basking has been reported from an increasing number of sites.

Hervey Bay:

- Strydom (2009) and Twaddle (2012) have described a large basking population of green turtles ranging from small immatures to adults. Basking peaks in a by-monthly cycle coinciding with the lunar-tidal cycles associated with spring tides. Nocturnal basking was consistently more frequent than diurnal basking.

Sandy Cape, Fraser Island:

- QTC turtle research teams have been tagging the basking turtles at night on the sandy beaches in the vicinity of Sandy Cape since the mid 190os. While it is mostly adult male and female green turtles, particularly courting adults that are encountered during these studies, small numbers of basking immature green turtles, immature and adult loggerhead turtles and occasional hawksbill turtles are encountered in this basking assemblage.

Shoalwater Bay:

- Limpus *et al*. (2005) has described widespread diurnal basking by immature and adult green turtles.
    - Basking on the intertidal flats at low tide is common in the winter. These turtles are not stressed and do not attempt to re-enter the water.
    - Basking turtles have a body temperature that is elevated by 0.9^{o}C above the temperature of the substrate on which they are stranded.
- Shimada *et al*. (2013) using satellite telemetry to track habitat usage by adult female green turtles documented that while they basked by day, they basked more frequently by night.

Gladstone:

Immature green turtles were captured from the intertidal flats by day and night at the Boyne Estuary during 8-10 July 2011 and by day on the Pelican Banks during 7-9 December 2011 for investigation of the health of turtles in the port (Limpus *et al*. 2012) (Figure 9). The circumstances of these captured resembled the capturing of basking turtles in Hervey Bay and Shoalwater Bay.

Given the frequency of basking turtles recorded on inter-tidal flats and within mangrove forests at Hervey Bay and Shoalwater Bay, a specific survey for diurnal and nocturnal basking green turtles within port limits of Port Alma and Port Curtis would be warranted.

Green turtles foraging within Port Alma and Port Curtis

Green turtles have been recorded regularly within the port limits of Port Alma and Port Curtis. However, no long term or large scale studies have been conducted with this species with these ports.

Foraging green turtles occur widely within Port Curtis. Figure 10A summarised the size distribution of green turtles tagged during short term sampling of turtles within Port Curtis. Immature turtles are regularly encountered in the shallow water habitats while larger turtles are found in the deeper sub-tidal water. Figure 10B summarises the size range of tagged green turtles rescued from entrapment in land reclamation projects within the Western Basin of the Port.

Low density courtship activity has been recorded within the lower Fitzroy Estuary within Port Alma.

Anthropogenic mortality in coastal waters
EHP annual stranding reports (Greenland *et al*. 2004; Greenland and Limpus, 2004; Biddle and Limpus, 2011; Meager and Limpus, 2013) have summarised the incidence of strandings and mortality of marine turtles in coastal waters of eastern Queensland from StrandNet records. The data for green turtles from these reports are summarised in Table 5. Given that the strandings collated in StrandNet are not a complete record of turtle mortality in Queensland, the data in Table 5 provides only an index of relative importance of mortality factors. Mortality from legal and illegal hunting which is very incompletely imported is expected to be the primary cause of mortality of green turtles from anthropogenic sources. The highest recorded mortalities from reported anthropogenic sources are, on average: boat strike and propeller cuts (50.2 green turtles/year); entanglement in crab pot float lines (20 green turtles/year); ingestion of synthetic debris (7.2 green turtles/year); entanglement in fishing line and rope (5.5 green turtles/year).

Entrapment in Queensland Shark Control Program gear is low (2.3 green turtles/year. Table 5).

The Brisbane Ports Corporation which manages most of the dredging within ports in Queensland introduced changes to reduce turtle morality in dredging operations in 1999. The annual reported mortality of green turtles in port dredging operations since 1999 has been low (0.5 green turtles/year. Table 5)

Climate change impacts on marine turtle
There has been concern regarding the potential impacts of climate change on marine turtle populations for some two decade (Limpus, 1993b). In recent years, there have been two comprehensive reviews of the potential for climate change to impact on marine turtle biology and population dynamics with an emphasis on Australian populations (Hamann *et al*. 2008; Poloczanska *et al*. 2009). Both these studies have addressed the issues relevant to green turtles in eastern Australia.

Any changes in regional temperature will have direct impact on the southern GBR green turtle populations because temperature plays a major role in incubation of eggs:

- Nest temperature during mid incubation determines the sex of the hatchling (See above);
- Nest temperature determines incubation period and incubation success (Miller, 1985);
- Nest temperature is a regulating factor in the timing of emergence of hatchlings from their nests (Gyuris, 1993);
- Nest temperature determines the size and fitness of hatchlings (Booth and Askill, 2001a, b; Booth *et al*. 2012).
- Temperature will play an indirect role in hatchling survivorship because the size of hatchlings influences predation rates by fish and birds (Gyuris, 2000; Limpus, 1973)

Weather through the ENSO climate cycles has a significant impact on rainfall and cyclone frequency in the Coral Sea region. These in turn have a direct impact on the quality and stability of coastal habitats, particularly seagrass pastures and coral reefs, via flooding and erosion. Direct links between the condition of the coastal habitats as foraging areas have been identified in the preceding discussion of green turtle population dynamics:

- ENSO climate cycles regulate the proportion of the adult green turtles preparing to breed annually from their foraging areas. There is an approximate 18 month delay between the climate event and the turtles arriving at their breeding sites (Limpus and Nicholls, 2000. See above discussion).
- The condition of the foraging area determines the growth rates of green turtles and hence the size and age at which they mature (Chaloupka *et al*. 2004. See above discussion).
- The condition of the foraging area plays a significant role in determining turtle mortality in the dispersed foraging areas (Meager and Limpus, 2013).

Impacts of the extreme weather of 2010-2011 on the southern GBR green turtle management unit illustrate some of these issues. There was a record number of marine turtle and dugong strandings reported from eastern Australia (Meager and Limpus, 2012, 2013) following the impact of a category 5 cyclone, Tropical Cyclone *Yasi*, on coastal habitats in the Cardwell-Townsville region in February 2011 and the extreme flooding across multiple catchments (Fitzroy, Burnett, Mary and Brisbane) of south and central Queensland (Agnew P & F Association, 2011). There were extreme elevations of turtle strandings associated with these localities concentrated on latitude blocks 19ºS, 23ºS, 25ºS, 27ºS

(Figure 11A). The primary megafauna species impacted by these extreme weather events have been the herbivorous species, dugong (Meager and Limpus, 2012) and green turtles (Figure 11B).

Limpus *et al*. (2012), comparing green turtle foraging populations in Shoalwater Bay, Port Curtis and Moreton Bay, reported that immature green turtles living in habitats that had been under the flood plume footprint of early 2001 were in poorer body condition following these events. More detailed analyses of the green turtle blood samples and pathology samples collected during part of this study within the Boyne Estuary are in progress at the University of Queensland School of Veterinary Science and School of Toxicology (studies led by Professor P. Mills and Dr. C. Gaus, respectively).

The pulsed localised strandings during 2011 for the Rockhampton area (Figure 11) are consistent with the expected increased mortality of herbivorous megafauna associated with loss of marine vegetation (seagrass and algae) following a major flood event (Preen *et al*. 1995).

Conservation management
Protected habitat
Greater than 90% of all southern GBR *C. mydas* nesting occurs within the protected habitat of National Parks and Conservation parks (Nature Conservation Act 1992, Regulations 1994) (Limpus, 2008a), including:

- Capricornia Cays National Park and Capricornia Cays National Park Scientific (Northwest,
- Tryon, Wilson, Wreck, Heron, Erskine, Masthead, Hoskyn, Fairfax, Lady Musgrave Islands) (Anon, 1999; Limpus *et al*. 1984);
- Great Sandy National Park (Fraser Island);
- Swain Reefs National Park (Bell Cay);
- Percy Island National Park (South Percy and Pine Peak Islands);
- Bushy Island National Park.

At Heron Island, approximately 25% of the beach length is outside of the National Park. North Reef Island is a Commonwealth Lighthouse Reserve.

Limpus (2008b) reported that 97% of the coastal waters of eastern Queensland lie within Australian and Queensland Marine Protected Areas.

There have been a number of additional concerted actions taken that have directly improved the conservation outlook for the southern GBR green turtles management unit:

- Closure under the Fisheries Act of commercial fishing of green turtles in Queensland, August 1950 (Limpus, 1980; Daly *et al*. 2008). This closure of the commercial fishing of green turtles for soup and meat production has not been repealed for the area south of Cooktown since that date.
- Compulsory regulation of the use of turtle exclusion devices (TEDs) in otter trawls in the Queensland East Coast Trawl Fishery, Torres Strait Trawl Fishery and Northern Prawn Fishery through 2001-2002 (Limpus, 2008a). This regulated use of TEDs has resulted in at least a 95% reduction in turtle capture in prawn trawl fisheries and hence a reduction in associated turtle mortality.
- Declaration of Dugong Protection Areas (DPAs) to reduce gill net fishing in the prime seagrass habitats between Cardwell and Hervey Bay to reduce dugong mortality (Anon, 1999). These regulation restricting gill net fishing in prime seagrass habitats, also reduce the probability of capture and resulting drowning of green turtles in gill nets in these areas.
- Marine Park Go-slow Zones. The extensive use of Go-slow zones in areas of high use vessel traffic over shallow habitat in Moreton Bay and Great sandy marine Parks will contribute to reductions in vessel interaction with turtles in these areas.
- Development of a Dredging Code of Practice by the Port of Brisbane, with associated dredge head gear modifications for reducing turtle mortality during dredging operations in Queensland Ports.

There are a number of health issues that are causing public concern for our green turtle population in south and central Queensland, including biotoxin links to green turtle fibropapillpma disease (Arthur et al. 2008; Aeriel, 2011); organohalide pollution and green turtle health and mortality (Hermanussen, S., 2009; Hermanussen et al. 2004, 2006, 2008); blood fluke infection of green turtles (Gordon *et al*. 1998; Flint *et al*. 2010); protozoan infection (coccidiosis) infection of green turtles (Gordon *et al*. 1993). However, these impacts have been operating on the southern GBR green turtle stock throughout its dispersed foraging areas over recent decades and the population is still showing signs of strong recovery. A continued monitoring of these issues would be warranted.

This extreme level of nesting habitat protection and marine habitat management provides the southern GBR green turtle management unit (a turtle population that breeds in the southern GBR and forages predominantly south of 14ºS) with some of the most extensive habitat protection afforded any turtle population globally.

Concern should be held regarding the probable excessive mortality of post hatchlings with in the southwestern Pacific Ocean from ingestion of synthetic debris (Boyle and Limpus, 2008; C&C consulting, 2009) and potential for unsustainable mortality and hence future population decline for the vulnerable southern GBR green turtle management unit. This issue warrants direct monitoring and management response to improve their conservation status.

There have been no direct management actions implemented to compensate for climate change impacts on green turtles in eastern Australia.

Population modelling

Dr M. Chaloupka, University of Queensland, was commissioned by the Federal and State Government conservation agencies to develop a population model for the southern GBR green turtle management unit that could be used to guide policy and management planning for conservation of this turtle stock.

"A stochastic simulation model was developed for the southern Great Barrier Reef green sea turtle stock to foster better insight into regional metapopulation dynamics. The model was sex- and age class-structured linked by density-dependent, correlated and time-varying demographic processes subject to environmental and demographic stochasticity. The simulation model was based on extensive demographic information derived for this stock from a long-term sea turtle research program established and maintained by the Queensland Parks and Wildlife Service. Model validation was based on comparison with empirical reference behaviours and sensitivity was evaluated using multi-factor perturbation experiments and Monte Carlo simulation within a fractional factorial sampling design. The model was designed to support robust evaluation of the effects of habitat-specific competing mortality risks on stock abundance and also on the sex and age class structure. Hence, the model can be used for simulation experiments to design and test policies to support the long-term conservation of the southern Great Barrier Reef green sea turtle stock." (Chaloupka, 2001).

The model was designed to be run using Berkeley Madonna V8.0.l software. Copies of the model software can be obtained from GBRMPA or EHP but users have to obtain their own licences for use of Berkeley Madonna software.

This is a powerful tool for testing green turtle policy and management scenarios (Chaloupka, 2002, 2004; Dobbs and Limpus, 2006).

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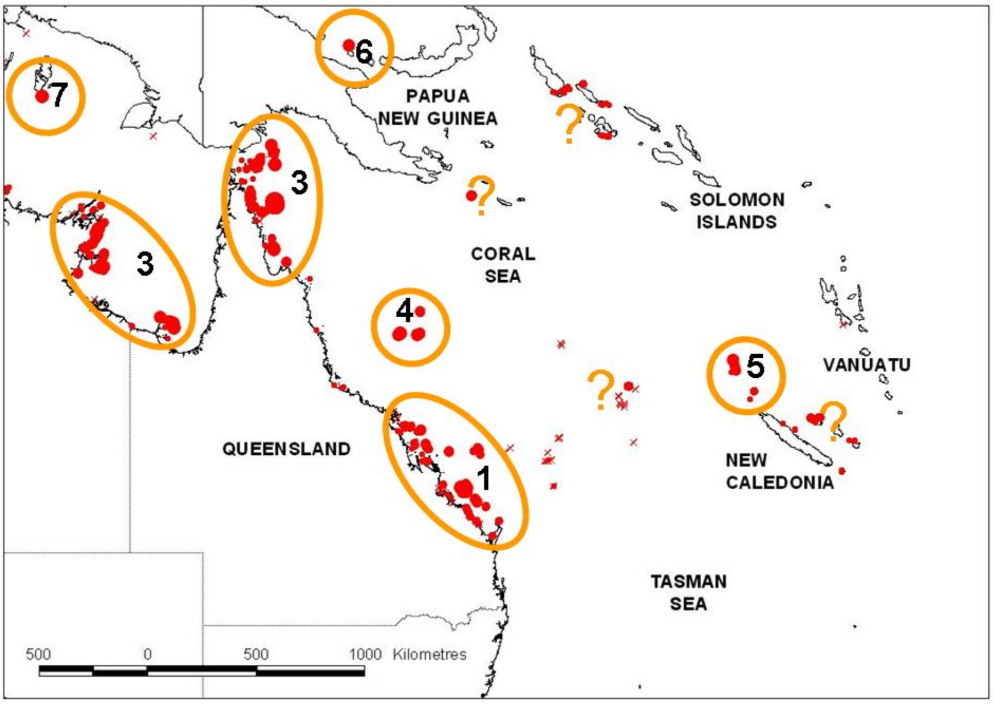
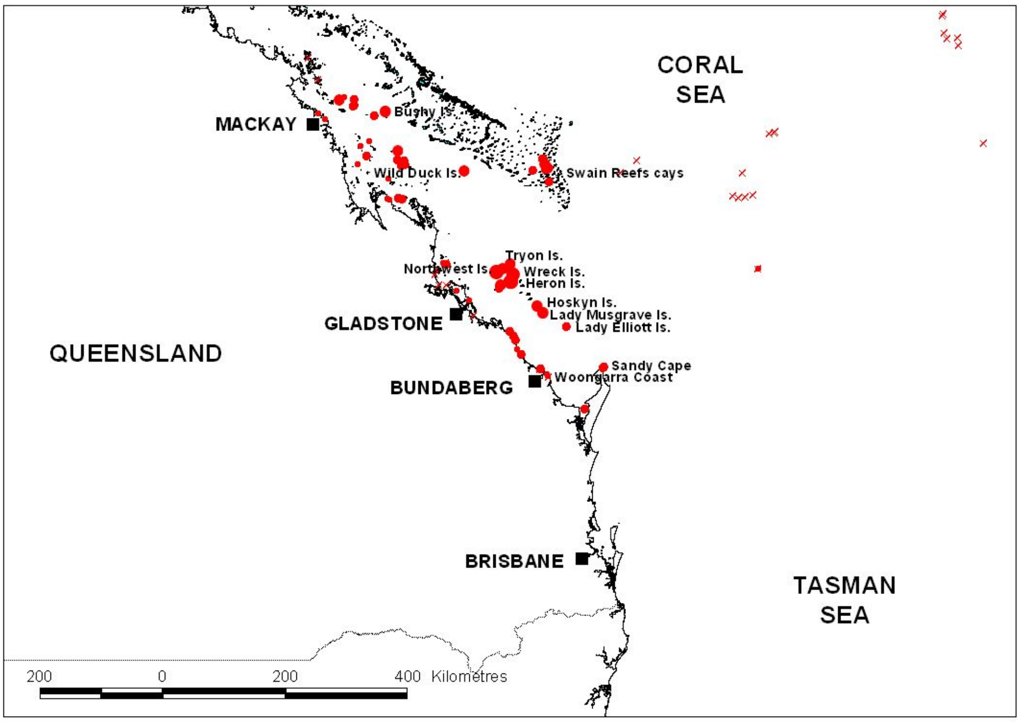
A. Adult green turtle ashore after nesting at Mon Repos.

B. Hatchling green turtle at Mon Repos

Figure 1. Green turtle, *Chelonia mydas*, in eastern Australia.



A. Green turtle nesting distribution by identified genetic stocks within the south-Pacific Ocean and in north-eastern Australia: 1 = southern GBR; 2 = northern GBR; 3 = Gulf of Carpentaria; Coral Sea platform; 5 = NE New Caledonia; 6 = Northern PNG; 7 Aru island, Indonesia. ? denotes stock identity has not been assessed.



B. Distribution of green turtle nesting beaches for the southern Great Barrier Reef management unit.

Figure 2. Green turtle, *Chelonia mydas*, nesting distribution within the south-Pacific Ocean and in north-eastern Australia identified to management units (genetic stocks). Red dots denote recorded nesting localities.

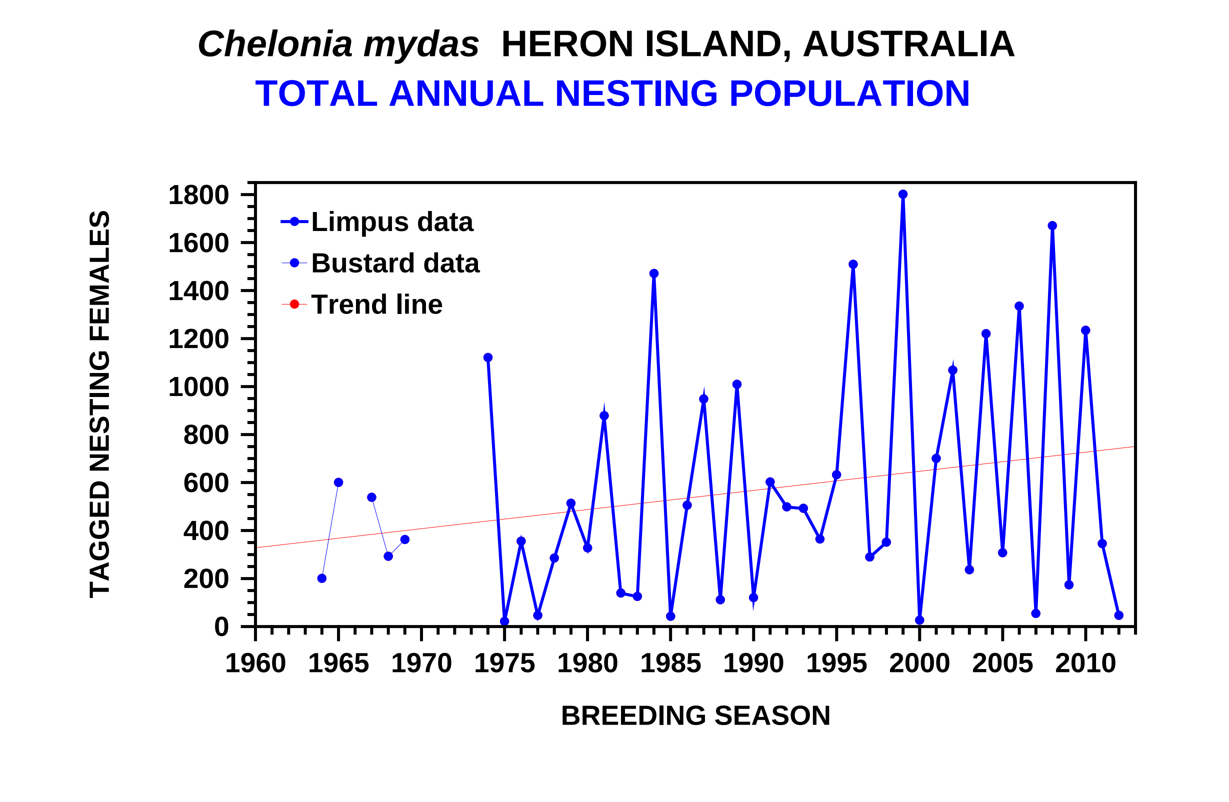
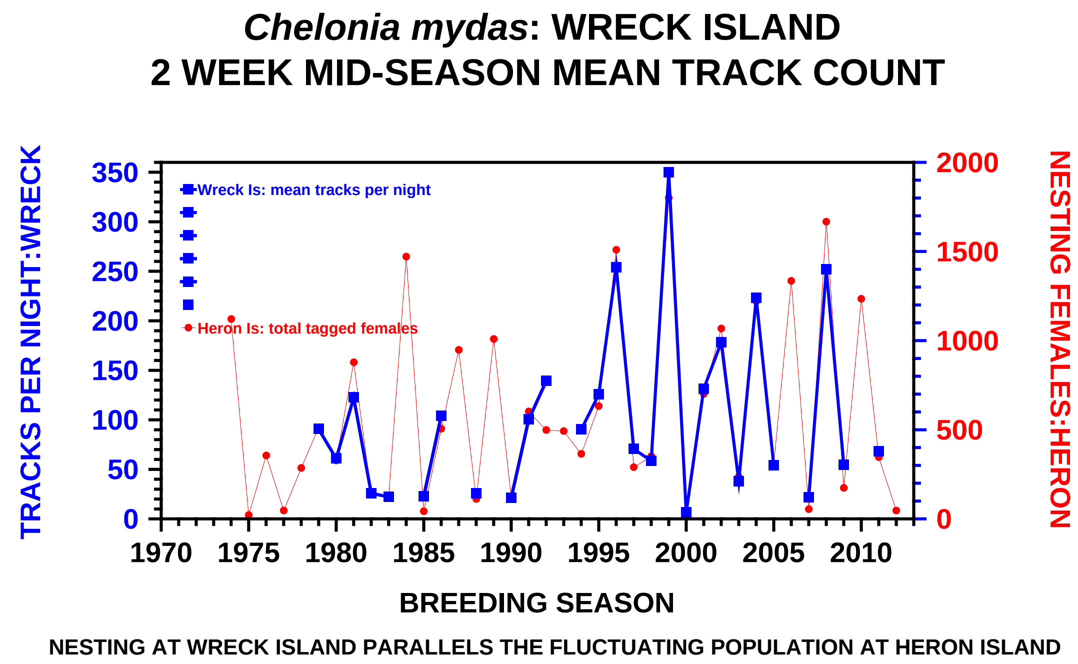
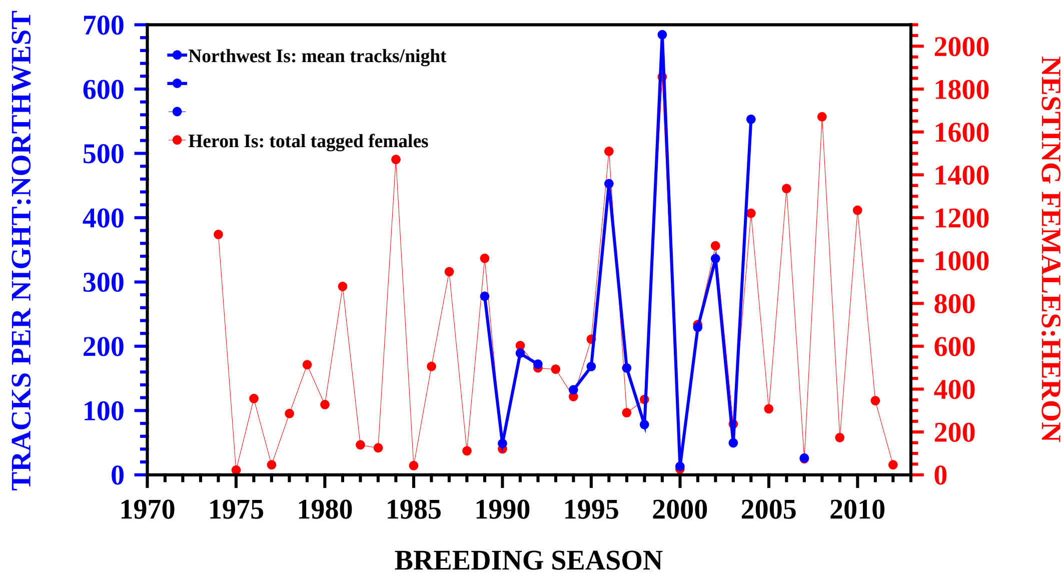


Figure 3. Number of nesting female green turtles at Heron Island, tagged during the annual three months of total tagging census, December-February annually.



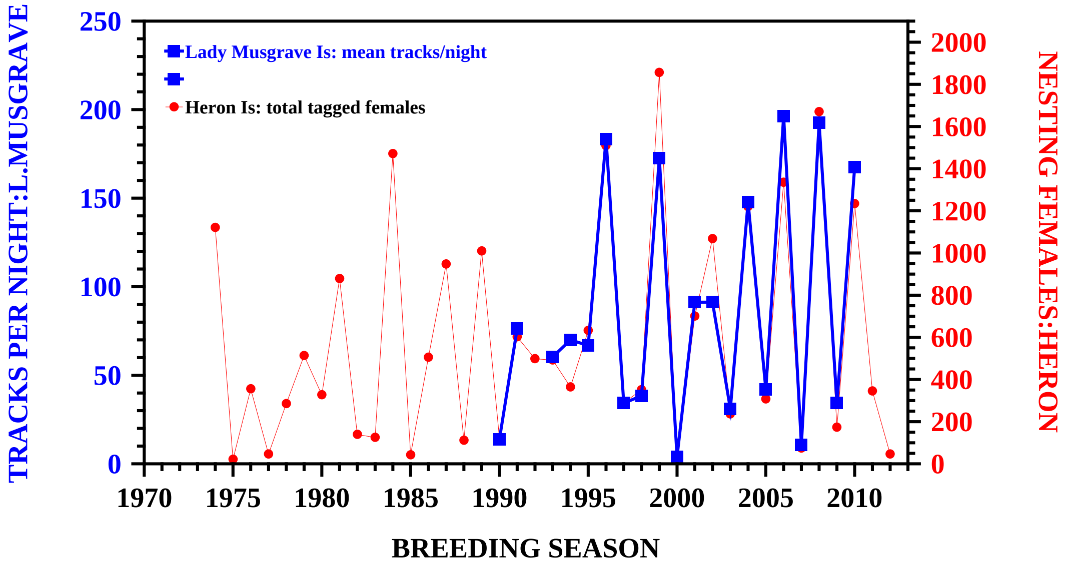
A. Wreck Island



B. Northwest Island

Figure 4. 2 Annual mean track census data recorded for nesting green turtle, *Chelonia mydas*, during the annual two week mid-season census during the last two weeks of December.

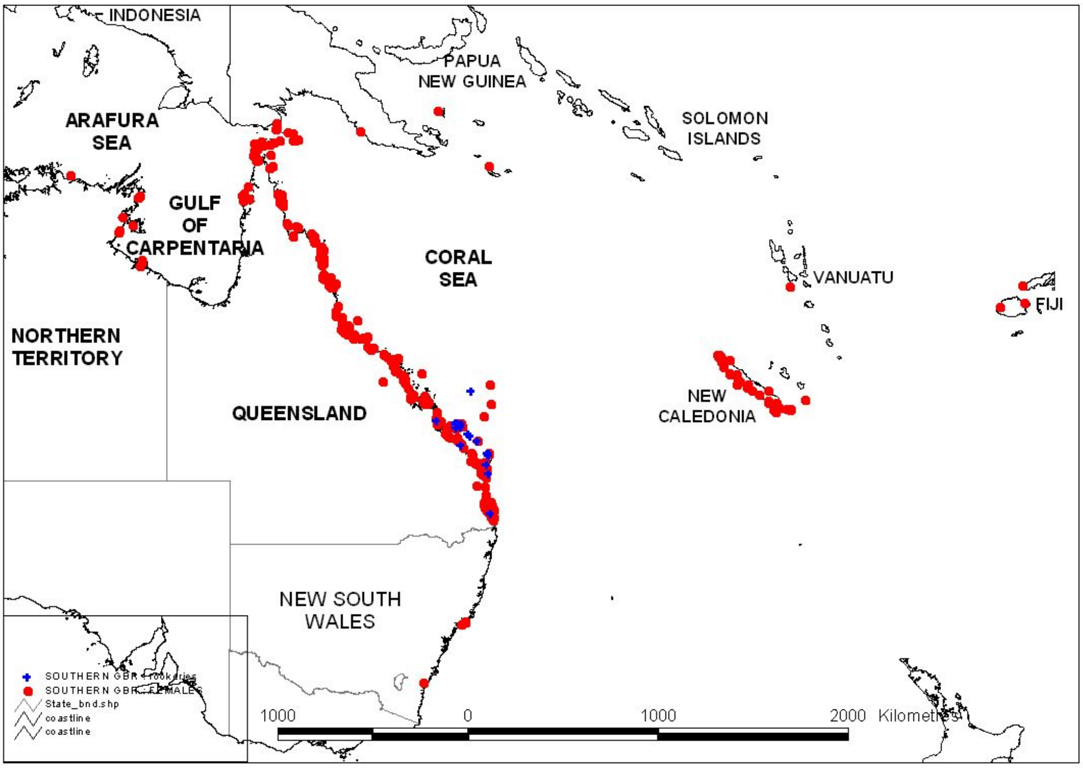
Chelonia mydas: LADY MUSGRAVE ISLAND
2 WEEK MID-SEASON MEAN TRACK COUNT



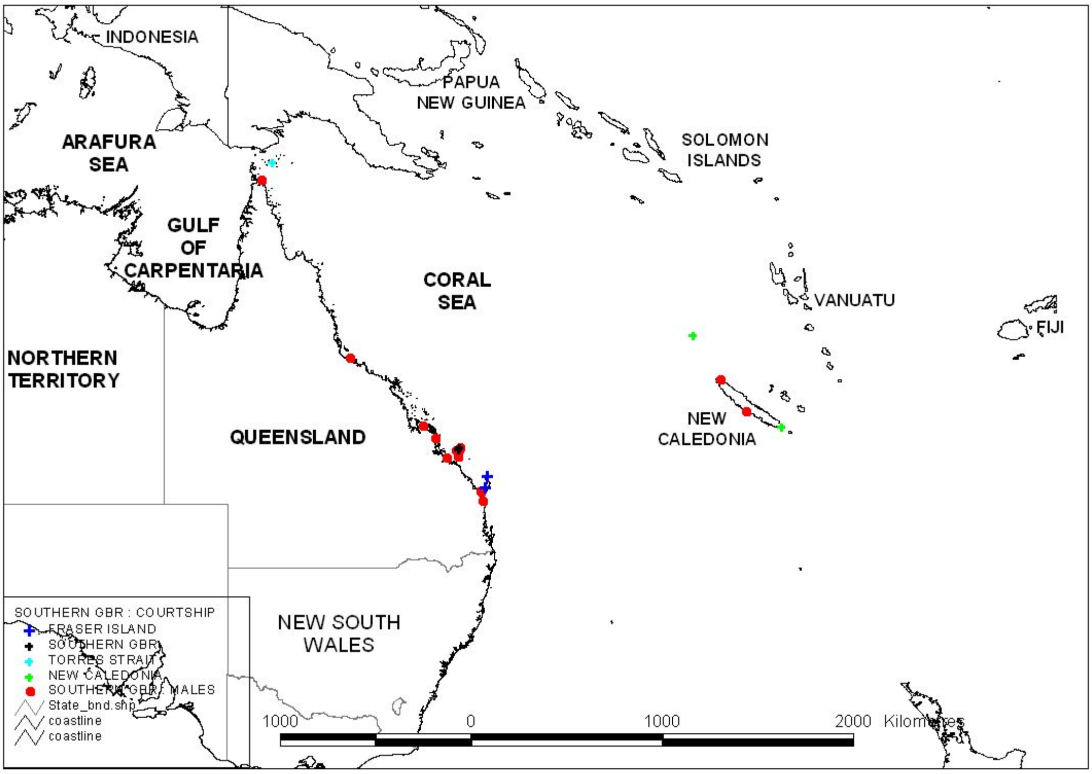
NESTING AT LADY MUSGRAVE ISLAND PARALLELS THE NESTING AT HERON ISLAND

C. Lady Musgrave Island

Figure 4. Continued



A. Adult females.



B. Adult males

Figure 5. Migration of adult green turtles, *Chelonia mydas*, between breeding areas (crosses) and foraging areas (dots) based on flipper tag recoveries and satellite telemetry.

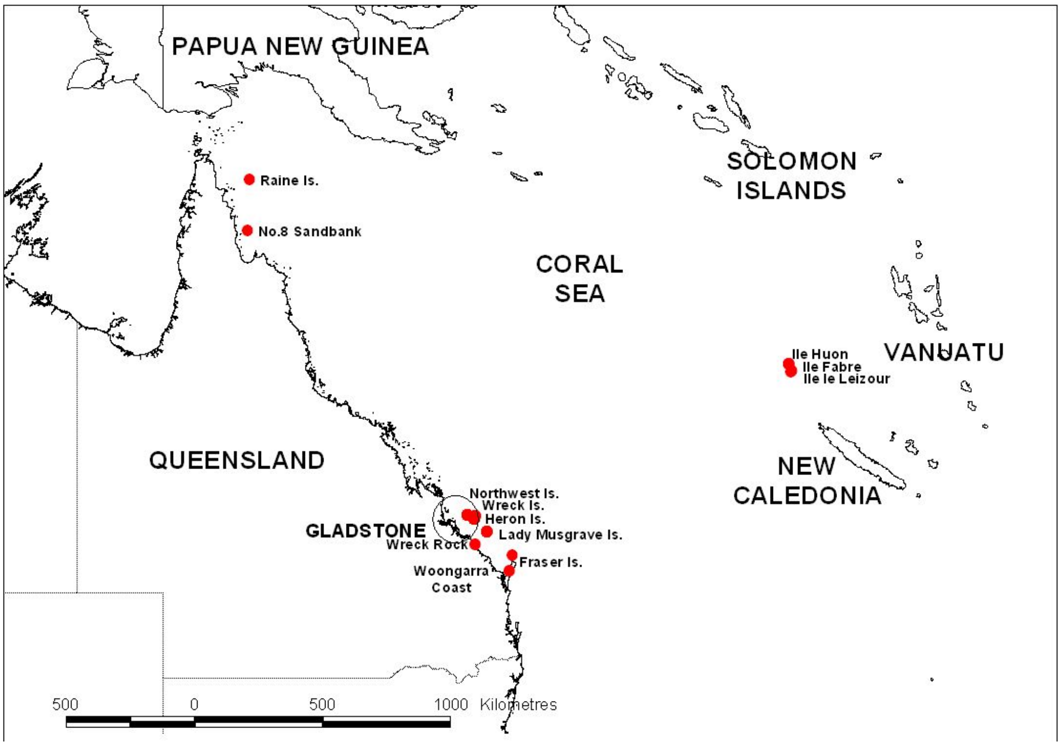


Figure 6. Nesting beaches (dots) to which green turtles, *Chelonia mydas*, migrate to breed from foraging sites within the Gladstone area.

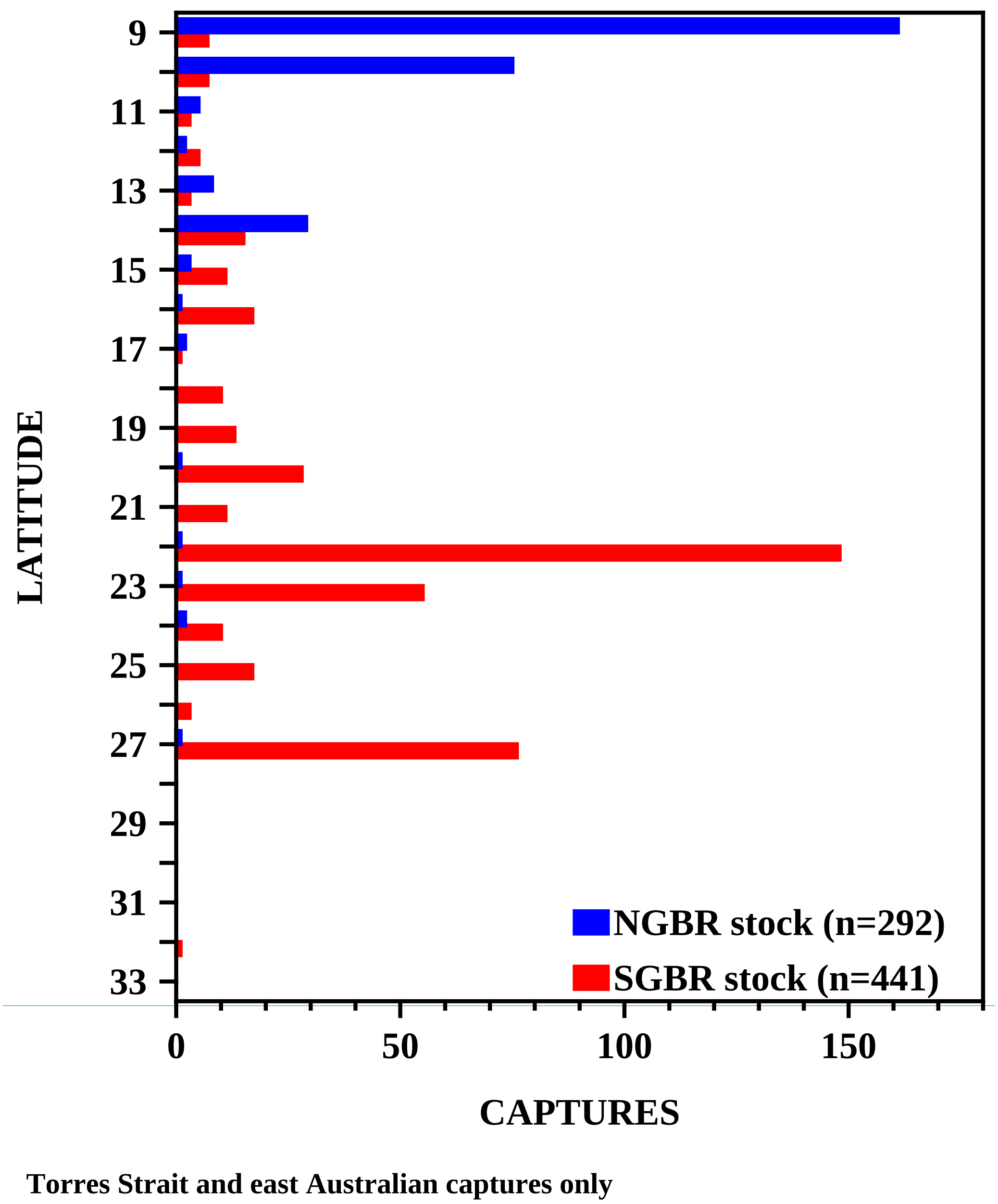


Figure 7. Distribution by genetic stocks (northern and southern Great Barrier Reef management units) of green turtles recorded in foraging areas (n = 733) by 1° latitude blocks along the eastern Australian coast (After Limpus et al. 2003).

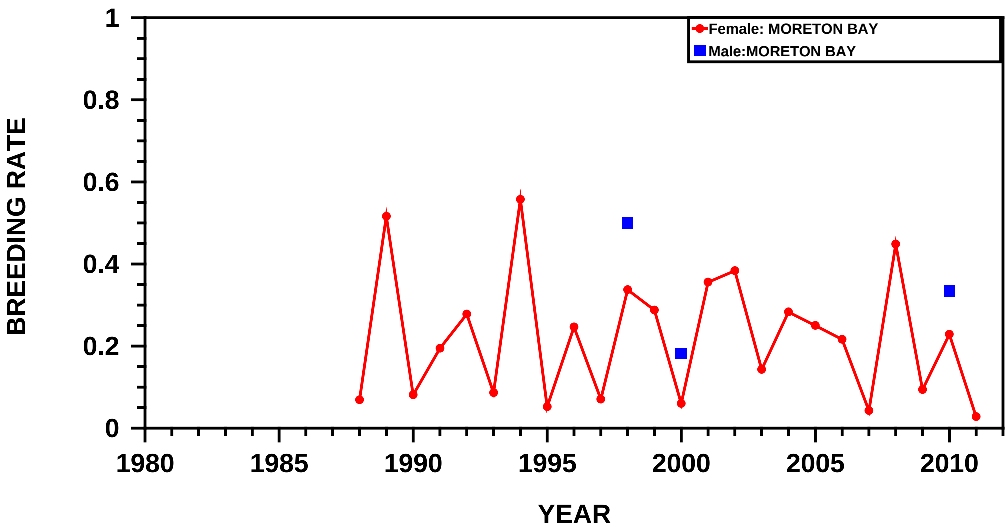


Figure 8A. Moreton Bay.

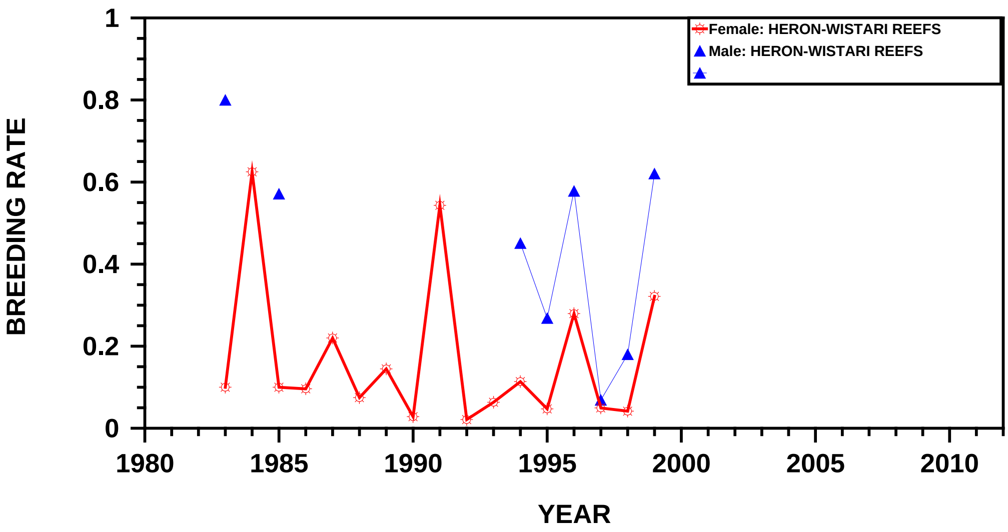


Figure 8B. Heron and Wistari Reefs, southern GBR.

Figure 8. Annual proportion of adult green turtles, *Chelonia mydas*, in a foraging area that prepared for breeding, Breeding activity was determined from gonad examination or by presence of the turtle on a nesting beach or participating in courtship activity (QTC Turtle data base).

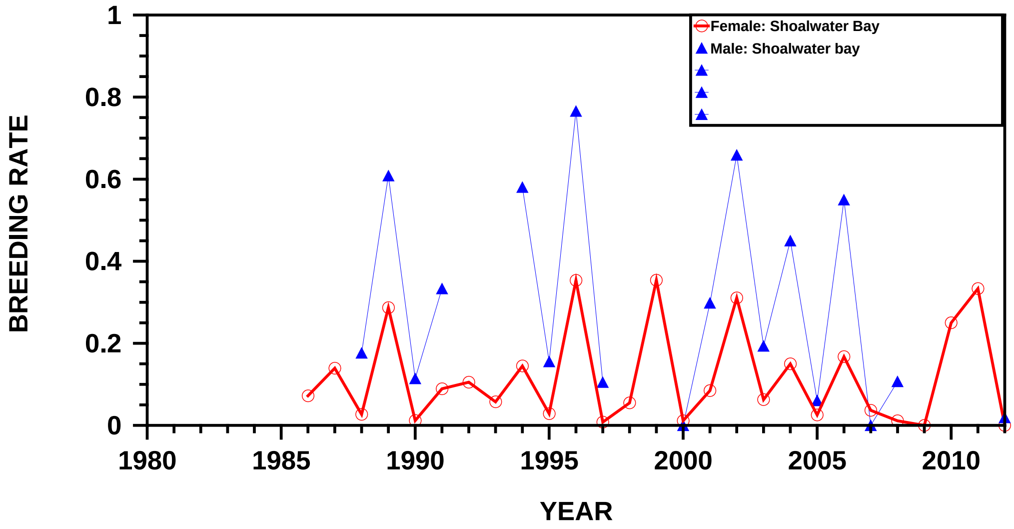


Figure 8C. Western Shoalwater Bay (QTC Turtle data base).


A. Foraging immature green turtle at night on the intertidal flats.

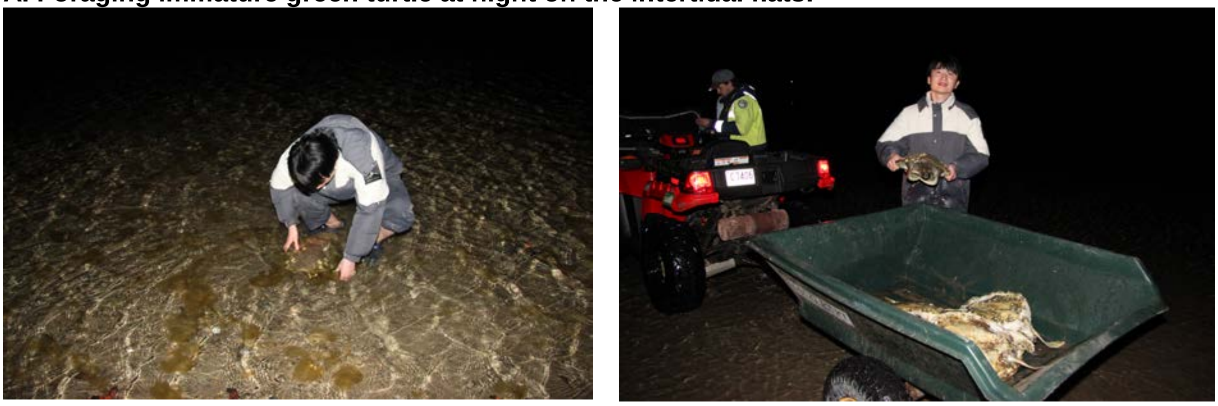
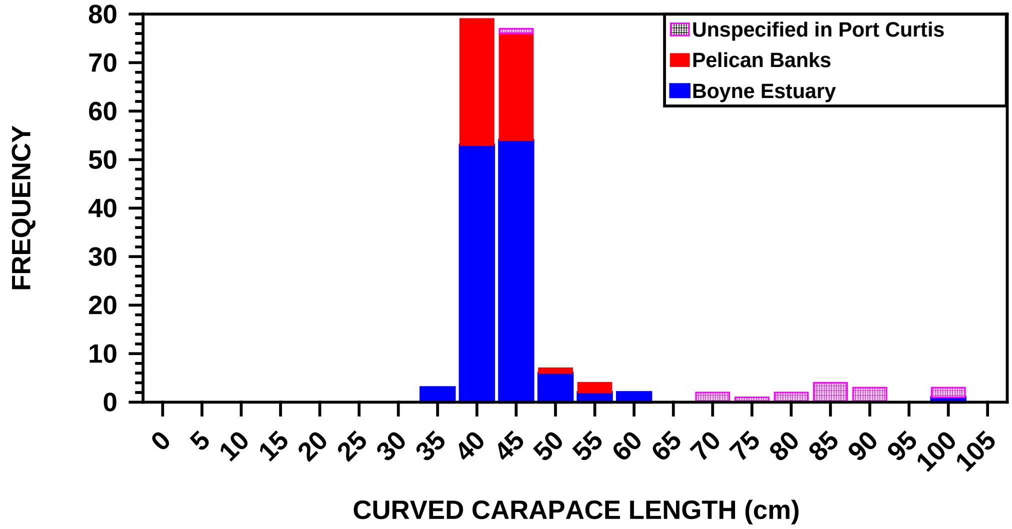
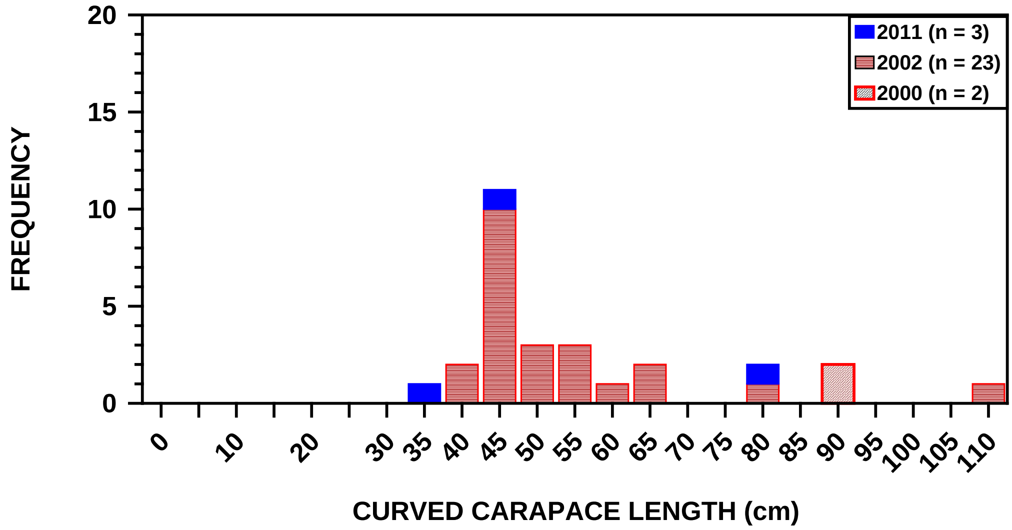

B. Capturing immature green turtles in the intertidal flats at night.

Figure 9. Capturing immature green turtles on the intertidal flats of the Boyne Estuary, 9 July 2011.

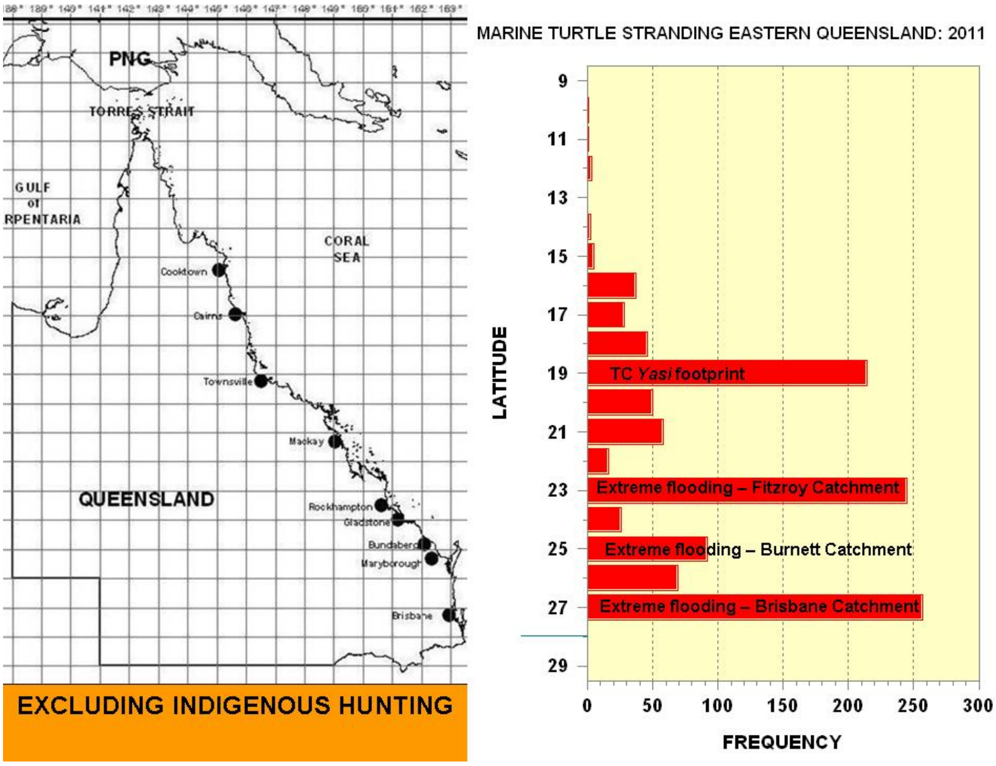


A. Summary of sizes of green turtles tagged during short term studies within Port Curtis.

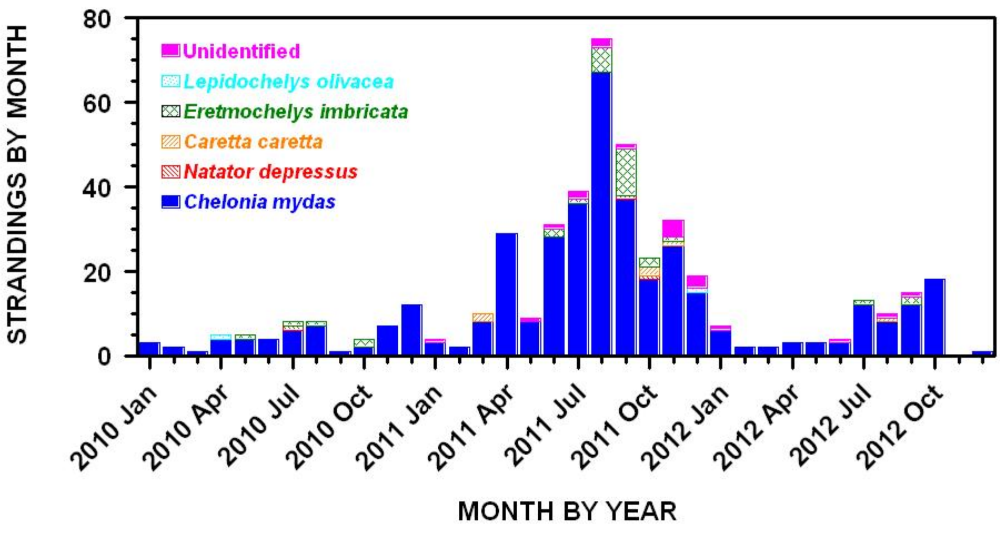


B. Summary of size distribution of green turtles tagged when rescued from land reclamation projects in the Western Basin of Port Curtis.

Figure 10. Size distribution of green turtles, *Chelonia mydas*, tagged within Port Curtis.



A. Distribution of reported marine turtle strandings by 1º latitude blocks along the east Australian coast during 2011.



B. Frequency distribution of reported marine turtle strandings by species and month for the Rockhampton area (latitude 23ºS block) during 3 years, 2010-2012.

Figure 11. Distribution of marine turtle strandings in response to the extreme weather events of late 2010 – early 2011.

Table 1. Summary of the curved carapace length (cm) for male and female green turtles (*Chelonia mydas*) recorded as recent recruits to coastal foraging areas in central and eastern Queensland (QTC turtle database). * denotes significant difference.

Locality	Females			Males		
	Mean ± SD	Range	N	Mean ± SD	Range	N
Shoalwater Bay	43.58 ± 2.705	37.7 – 67.3	77	43.10 ± 2.179	38.8 – 47.5	39
Heron-Wistari Reefs	43.58 ± 2.705	37.4 – 48.6 50	50	43.67 ± 2.463	36.5 – 49.3	41
Moreton Bay	44.23 ± 3.966	38.2 ± 73.4	98	45.06 ± 3.236	39.4 – 55.4	54
ANALYSES						
One way ANOVA	$F_{2,222}$ = 0.657;p > 0.25, NS			$F_{2,131}$ = 6.46;0.001< p < 0.0025 *.		

Table 2. Summary of annual survivorship estimates for green turtle, *Chelonia mydas,* resident in coral reef habitats of the southern Great Barrier Reef (Chaloupka and Limpus, 2005) where there is very little anthropogenic impact on the turtles. All turtles in this study were assigned to sex and maturity categories based on gonad examinations.

Life history stage	Size range (CCL)	Annual survival rate		
		Mean	SE	95% confidence interval
Adult	85-120 cm	0.9482	0.0151	0.919–0.978
Sub-adults	65-90 cm	0.8474	0.0302	0.790–0.908
Juveniles	< 65 cm	0.8804	0.0234	0.835-0.927

Table 3. Summary of the annual proportion of adult green turtles, *Chelonia mydas*, that were recorded preparing to breed from their respective foraging areas, measured from gonad examination or observations of nesting behaviour (QTC turtle research data base).

Sampled subsets	Annual breeding rate			
	Mean	SD	Range	Sample size
Moreton Bay				
Female	0.2212	0.1551	0.028 – 0.557	24
Male	0.338	0.159	0.182 – 0.500	3
Heron-Wistari Reefs				
Female	0.1688	0.1786	0.021 – 0.625	17
Male	0.4423	0.2489	0.069 – 0.800	8
Western Shoalwater Bay				
Female	0.1177	0.1186	0 - 0.354	27
Male	0.2877	0.2517	0 – 0.766	18

Table 4. Size of adult female green turtles from the southern GBR management unit recorded as they prepared for their first breeding seasons, at eastern Queensland foraging areas (QTC turtle research data base).

Foraging area (latitude; years)	**Curved carapace length (cm)**			
	Mean	**SD**	**Range**	**N**
Repulse Bay (20°S; 1987-1989)	103.66	4.940	96.2-107.8	5
Shoalwater Bay (22°S; 1987-2007)	98.75	5.790	87.1-115.5	92
Heron-Wistari Reefs (23°S; 1984-1999)	102.72	3.225	96.0-109.6	35
Moreton Bay (27°S; 1990-2007)	108.69	4.555	95.1-116.6	32

Table 5. A summary of reported green turtle, *Chelonia mydas*, strandings and mortality by year from anthropogenic sources in Queensland. See Greenland and Limpus (2008a, b, and c) and Biddle and Limpus (2011) for a description of the stranding database from which these records are drawn. These turtles are presumed to represent only a portion of the total mortality from these sources. Some of these turtles were released alive. *: known gross under reporting. #: Brisbane Ports Corporation which manages most dredging in Queensland's ports commenced management practices to reduce mortality of turtles during dredging operations in 1999.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total	annual mortality per year
Boat Strike	57	66	55	48	65	45	49	57	75	49	52	52	602	50.2
Dredging #	1	3	nr	1			1						6	0.5
Shark Control Program	1	2	4	2	4		8		3	1	1	2	27	2.3
Crab pot entanglement	7	14	18	15	22	16	18	22	34	29	26	14	234	19.8
Entanglement in nets				3	1	9	2	2				15	32	2.7
Entanglement in ghost nets	nr	3	3	nr	7	2	3	4	2			2	26	2.6
Fishing line/rope entanglement		7	3	3	3	4	8	8	8	6	7	9	66	5.5
Ingestion of foreign bodies	11	3	7	12	4		8	13	9	9	4	6	86	7.2
Hunting, legal*											1	2	-	-
Hunting, illegal	nr	9	4	8	3	6	2	2	2	8	3		47	4.3
Undetermined	nr	nr	nr	5	5	1	2	6	13	12	15	2	61	6.8
Total	-	-	-	97	114	73	101	114	146	114	109	105	1187	-