

Monitoring of Coastal Sea Turtles: Gap Analysis

5. Flatback turtles, *Natator depressus*, in the Port Curtis and Port Alma region

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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 ambiguity surrounding the taxonomy of the flatback turtle as a distinct species (Williams *et al.* 1967) has been resolved (Limpus *et al.* 1988; Zangerl *et al.* 1988). The flatback turtle is a valid distinct taxon with a long independent evolutionary history from other marine turtle genera extending back millions of years (Bowen *et al.* 1993; FitzSimmons *et al.* 1995).

The flatback turtle, *Natator depressus* (Figure 1), is endemic to the Australian continental shelf, occurring in coastal water of northern Australia and southern New Guinea (Indonesia and Papua New Guinea). Breeding is almost entirely restricted to Australia. The biology and conservation status of flatback turtles have been reviewed within Australia by Limpus (2007).

Status

Within Australia, the flatback 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 flatback turtle breeding in eastern Australia (Limpus, 2007):

- Peak Island (23.333°S, 151.933°E); a major nesting population; mid nesting season tagging and track count census during most years, 1980-2011 (Limpus *et al.* 1981; Parmenter and Limpus, 1995).
- Wild Duck Is (22.000°S, 149.867°E); a major nesting population; mid nesting season tagging and track count census during most years, 1979-2007.
- South End Beach, Curtis Island (23.700°S, 151.300°E); an intermediate sized nesting population; mid season track count and tagging census for two-week peak season, last week of November – first week of December, for most years 1970-2012.
- Woongarra coast (including Mon Repos beach) via Bundaberg (24.790°S, 152.438°E); a minor nesting population; total nightly tagging census for the total nesting season, October-March, during 1968-2012 (Limpus *et al.* 1971; Limpus *et al.* 1984).

Foraging

There are no index foraging areas for monitoring flatback populations in eastern Australia.

Stock identification

The flatback turtle nesting populations of south east Queensland and the north-western Gulf of Carpentaria have been proposed to represent two independent breeding units on the basis of morphology (adult size, clutch counts, egg and hatchling sizes) and out of phase (summer/winter) timing of nesting seasons (Limpus, 1971; Limpus *et al.* 1989; Limpus *et al.* 1993).

A genetic analysis has identified that there is a low level of genetic variability in the species and there is limited gene flow between the rookeries (Dutton *et al.* 2002). This preliminary genetic study identified four management units for the six major aggregations of flatback turtle rookeries for Australia with the greatest genetic difference between the eastern Australian and eastern Gulf of Carpentaria nesting assemblages (Figure 3).

The aggregation of flatback turtles nesting on the beaches between Townsville and Bundaberg is currently accepted as a single genetic stock/management unit.

Nesting population

The flatback turtle population breeding in eastern Australia represents a modest sized but distinct breeding population for the species.

Within eastern Australia, the majority of the flatback turtle nesting has been surveyed by aerial surveys supplemented by examination of selected representative beaches on the ground (Limpus, 1971, 1985; Limpus *et al.* 1981, 2002, 2008; Hodge *et al.* 2007; Clifton and Limpus, 2001; Parmenter and Limpus, 1995).

The majority of eastern Australian flatback turtle nesting occurs on the continental islands between Bustard Head and Ingham and on the adjacent mainland beaches. The flatback turtle is the dominant nesting species of nesting marine turtle in this broad region (19° – 24°S) of eastern Queensland. Low density nesting, as a minimum level, can be expected on any beach on the continental islands and adjacent mainland beaches between Port Douglas and Bundaberg. It is very rare for flatback turtles to nest on beaches fronted by coral reef flats. See Figure 3 for a summary of nesting distribution.

- Nesting by between 100 and 500 flatback turtles annually has been reported for three rookeries: Wild Duck Island, Peak Island and Avoid Island (3 beaches combined).
- Nesting by between 10 and 100 flatback turtles annually has been reported for at least 30 rookeries, including South End Curtis Island.
- Nesting by between 1 and 10 flatback turtles annually has been reported for at least 50 rookeries, including Mon Repos Beach on the Woongarra Coast.

The flatback turtle has a restricted breeding season in eastern Australia: nesting commences in late October and peaks during late November - early December and is completed by late January; hatchlings emergence from nests occurs approximately two months after the respective clutches were laid.

The flatback turtle is the dominant nesting species of marine turtles on beaches within the port limits of Port Alma and Port Curtis, including one index beach: an intermediate sized nesting population on South End, Curtis Island. Low density flatback turtle nesting can be expected on all other seaward beaches within the port limits for Port Alma and Port Curtis. The largest flatback nesting population for the east Australian management unit, Peak Island, lie on the northern side of the port limits for Port Alma.

Nesting census and nesting population trend

A tagging census has been conducted at each of the four index rookeries for the eastern Australian stock for varying periods since 1968 (Limpus, 1971; Limpus *et al.* 1981; 2006). Those data provide the primary measures of the trends for the flatback turtle breeding population in eastern Australia:

- Limpus *et al.* (2002), using annual number of nesting turtles tagged and mid season track counts, concluded that the annual nesting population of flatback turtles at Wild Duck Island, South End Curtis Island and Woongarra Coast had been approximately stable over preceding decades – 1969 to 1999.

Here we present a more rigorous analysis of the population trends at all four index beaches. The long term tagging-recapture data from nesting female flatback turtles at each of the four index beaches are analysed for the first time using the program MARK (White *et al.* 2006) to estimate survival probabilities and to provide annual population abundance estimates across the census period for the turtles associated with each nesting beach (rookery) (See Appendix 1 for a summary of the methodology within this study). The tagging data and results of this analysis are summarised in Table 1 and Figure 3.

This analysis has demonstrated a high annual apparent survival probability for the adult female flatback turtles and a long term, approximately stable population nesting at Wild Duck Island, Curtis Island and Woongarra Coast across four decades of census. In contrast, the nesting population at Peak Island has had a significantly lower annual survival probability and a declining population across the past three decades.

These data provide a conflicting status for the eastern Australian flatback management unit. Three index beaches spread widely across the breeding range for this stock and representing a large, an intermediate and a very minor nesting population are supporting stable nesting populations (Figure 3a, c, d). Peak Island, the largest nesting population for eastern Australia and a rookery from towards the middle of the eastern Australian nesting distribution, supports a declining population (Figure 3b).

This apparent anomalous situation for the status of the eastern Australian flatback turtle management unit will be further explored here.

Otter Trawling was listed under the EPBC Act as a key threatening process (KTP) in 2001 because of the level of by-catch of marine turtles. Across the same period, the compulsory use of Turtle excluder devices (TEDs) was regulated in the Northern Prawn Fishery (NPF) in April 2000, East Coast Trawl Fishery (ECTF) in December 2000 and the Torres Strait Prawn Fishery (TSPF) in March 2002. Bycatch related mortality of loggerhead turtles in the prawn trawls of eastern and northern Australia was identified as the primary cause of the decline in the eastern Australian loggerhead turtle breeding numbers since the 1970s (Limpus, 2008a). Based on data available in 2004, Limpus (2008a) indicated that "the benefits of a greatly reduced trawl bycatch mortality resulting from the use of TEDs in the NPF, ECTF and TSPF in the early 2000s should be detectable as a slowing in the rate of decline of the population at the east coast nesting beaches within a single breeding cycle of about 5 years for a young adult, i.e. by about 2005." Examination of the trends in nesting numbers for loggerhead turtles at each of the six index beaches up to 2011 (See Loggerhead turtle gap analysis), shows that there has been a reversal of the downward trend for loggerhead turtle nesting numbers since 2001. These data indicate that the use of TEDs have been effective in reducing bycatch mortality in prawn trawls of eastern and northern Australia such that the eastern Australian loggerhead turtle nesting population is in a recovery mode.

A comparable decline in eastern Australian flatback turtle nesting population did not occur, even though there were many hundreds to low thousands of flatback turtles captured annually in the Queensland ECTF and TSPF prior to the regulated use of TEDs in these fisheries (Robins and Mayer, 1998). These two trawl fisheries at that time had a very low reported flatback turtle mortality rate of 2% of captures if comatose turtles were treated as potentially dead, then the potential mortality could have been 5% of trawl captures. Since the regulated use of TEDs was introduced to these fisheries, turtle mortality from this source has been reduced to a trivial level (Pears, *et al.* 2012). The lower level of impact of trawling captures of flatback turtles in eastern Australia is consistent with the better breath holding capacity of flatback turtles relative to the breath holding capacity of loggerhead turtles (Sperling, 2007).

With the flatback turtles nesting at each of these index beaches having been identified to a single interbreeding genetic stock (Dutton *et al.* 2004), and given that the foraging ranges of the nesting females from each of these rookeries are distributed approximately uniformly throughout their east Australian foraging range (Figure 4A-D), it is reasonable to assume that the reasons for the declining Peak Island nesting population has not been caused by a general problem impacting the entire foraging range of the eastern Australian flatback management unit. If that is the case then it would suggest the problem(s) associated with the Peak Island nesting population is operating within the adjacent inter-nesting habitat or at the nesting beach.

Given the uniformity of research methodology associated with tagging and measuring of the nesting turtles at all four rookeries, except for the regular rolling of the nesting females on their backs for weighing at Mon Repos, it is unlikely that the research protocols at Peak Island are contributing to its declining population.

There has been a low loss of eggs to terrestrial predators at Wild Duck and Peak Islands that contrasts with the often high loss of eggs to a range of terrestrial predators on Curtis Island over the past four decades (Limpus, 2007). Therefore the decline in the Peak Island nesting population while the other nesting populations are stable can not be attributed to low hatchling production at Peak Island some 20-40 years ago.

There is a paucity of data regarding the distribution, behaviour and threats for flatback turtles within their inter-nesting habitat offshore of Peak Island. It is suggested that the following questions warrant investigation:

- Has there been an unrecognised in-water mortality factor(s) operating off shore from Peak Island e.g. some unrecognised fishery bycatch mortality in the Peak inter-nesting habitat or some currently unrecognised disturbance from adjacent coastal development?
- Has there been an impact of runoff from the largest river system in eastern Qld (Fitzroy River Catchment) that enters the sea adjacent to Peak Island. This river system has experienced increased flooding over recent decades (Agnew P&F Association, 2011)?

Gonad examinations using laparoscopic examination of adult female flatback turtles nesting on the Woongarra Coast have been used to determine breeding status (n = 18). During this procedure, all were observed to have empty digestive tracts (Limpus, unpublished data). This indicates that, like other marine turtles, adult female flatback turtles do not feed during the breeding season and hence do not use food resources within their inter-nesting habitat.

Courtship and mating systems

There are no records of where flatback turtle courtship occurs in eastern Australia.

Limpus (1971) identified that courtship occurs before the commencement of nesting for individual females, presumably during October and November, based on scars from claw marks on the carapaces of nesting females.

Mating by the female with multiple partners and sperm storage at courtship followed by use of this sperm during the ensuing nesting season to fertilise multiple clutches of eggs has been investigated using genetic markers and found to be common for flatback turtles (Theissinger *et al.* 2009).

There is a lack of information on the breeding biology of adult male flatback turtles at courtship and their associated breeding migrations.

Embryology and temperature dependent sex determination

Miller (1985) has provided a comprehensive description of flatback turtle embryological development.

The flatback turtle of eastern Australia, typical of marine turtles displays temperature dependent sex determination (TSD) (Limpus, 2007; Hewavisenthi and Parmenter, 2000, 2002a):

- This population has a pivotal temperature of 29.3°C;
- Cooler nests producing mostly male hatchlings and warmer nests producing mostly female hatchlings.
- Sex determination is independent of the hydric environment of the nest.

Hewavisenthi and Parmenter (2001, 2002b, c) reported on additional incubation studies addressing impact on the developing flatback turtle embryo by environmental characteristics of the nest.

During an investigation of microbial invasion of incubating flatback turtle eggs, it was established that embryo mortality may occur by over-growth of the respiratory surface (egg shell) by fungal hyphae, by deprivation of calcium to the developing embryo or from embryo mortality resulting from fungal penetration of the eggs (Phillott, 2004; Phillott *et al.* 2006).

There has been recent interest in the transfer of toxins and heavy metals between the nesting females and the eggs and hence the developing embryo for the flatback turtle.

- Muusse *et al.* (2006) and Hermanussen (2009) established maternal transfer of organohalides (dioxins and PCBs) to the eggs and developing embryos of a first time breeding flatback turtle at Mon Repos.
- Ikonmopoulou *et al.* (2011) examined metal concentrations in the nesting flatback turtles at Curtis Island.

These studies, within the scope of their methodologies, have not identified any negative impacts from these toxins on the females, the eggs or the embryos. Given that the nesting females do not forage within the inter-nesting habitat while they are producing their eggs, there is no link between the presence of these toxins in the nesting females or their eggs and the adjacent inter-nesting habitats.

Sperling (2007) using satellite telemetry technology investigated habitat use by gravid flatback turtles off shore from the Curtis Island nesting beach during their inter-nesting phase (during the two-week periods in which clutches of eggs are prepared for laying). Although the sample size was small and she used the less precise PPT technology, she established that gravid female flatback turtles that lay their eggs on the seaward beach of Curtis Island travel south around Facing Island and enter the Gladstone Harbour area during part of their inter-nesting period. This study warrants being repeated for both the Curtis Island and the Peak Island nesting females using the more productive and more accurate GPS satellite tag technology to establish detailed inter-nesting habitat use by these turtles.

Sperling *et al.* (2007b) studied the dive profiles of flatback turtles in the inter-nesting habitat off the Curtis Island rookery using time-depth recorders (TDRs). Dive durations of up to 98 min were recorded with maximum dive depths of 29 m recorded, probably reflecting, in part, the bathymetry of this coast.

Migration

Figures 4A-E summarise the distribution of foraging areas that have been recorded to supply nesting female flatback turtles to eastern Australian rookeries.

While adult females can migrate to breed at eastern Australian rookeries from up to 1,300 km distant (Limpus *et al.* 1983), the majority migrate from widely dispersed foraging areas across 14° of latitude along the eastern Queensland Coast from southern Torres Strait (10°S) to Rodds Bay (24°S) (Figure 5).

Turtles that live within the same foraging area, e.g. within the vicinity of Gladstone, can be expected to disperse to widely scattered breeding sites (Figure 4F). The available migration tag recoveries indicate that the flatback turtles nesting at the one rookery will have migrated from numerous foraging areas and that individual females display fidelity to their respective foraging areas and nesting beaches (QTC Turtle Database).

Almost all existing migration data for the eastern Australian flatback population (Figure 4) were obtained from flipper tag recoveries with turtles captured in prawn trawls. Since the regulated introduction of turtle exclusion devices (TEDs) into the Torres Strait and East Coast Prawn Trawl fisheries in the early 2000s, there have been no further reports of tagged flatback turtles from this source.

Any further investigation of the migratory behaviour of flatback turtles would appear to be dependent on the use of satellite tracking technology. Satellite telemetry tracking of post-breeding migrations of four flatback turtles nesting at Peak Island and Curtis Island are part of unpublished studies (JCU PhD study, supervised by Professor H. Marsh; Australian Conservation Volunteers).

Oceanic pelagic post-hatchling dispersal

Flatback turtle hatchlings are among the largest marine turtle hatchlings and as a consequence are subject less intense predator pressure from ghost crabs and some species of seabirds during their dash from the nest to the seas, when compared to hatchlings of other species (Limpus, 1973, 1985).

On entering the sea, hatchling flatback turtles engage in a swimming frenzy to disperse from their natal nesting beaches out to coastal waters. During this swimming frenzy, the hatchling does not feed but utilises the internalised yolk reserves left over from embryonic development in the egg. This phase

in the flatback turtle life history has been investigated mostly via laboratory experiments examining blood properties/chemistry and hatchling locomotor performance. Flatback turtles have a shorter highly vigorous swimming period on entering the sea compared to green and loggerhead turtle hatchlings (Pereira *et al.* 2011, 2012a). During four-day laboratory trials during the “swimming frenzy” phase, flatback turtle hatchlings maintained a more stable swimming speed than occurs with other turtle species which have an oceanic dispersal phase (Salmon *et al.* 2009). The swimming frenzy of flatback turtles was predicted to not take the hatchling as far off shore as occurs with green and loggerhead turtles.

In a field study with laboratory reared hatchlings (1–7 weeks of age), each towing a small TDR, released in shallow (< 12 m) turbid shelf waters mostly made short and shallow dives (<100 seconds; < 4 m), but some could dive to the bottom (Salmon *et al.* 2010). These authors hypothesized that, as neonates, flatback turtle hatchling dives enable them to 1) search efficiently for prey throughout the water column under conditions of limited visibility, 2) minimize surface time so that even in murky water the turtles can return to previously attractive locations, and 3) swim rapidly to evade their predators.

Limpus (2007) defined the post-hatchling life history phase to span the period from when the hatchling commences feeding (ceases dependence on the internalised yolk sac) to when the turtle ceases dependence on planktonic food and shifts to foraging on benthic organisms.

In contrast to the other species of marine turtle, the flatback turtle post-hatchlings do not generally disperse into oceanic pelagic waters. Rather, this age class has been recorded frequently from GBR and south-Queensland waters and is believed to follow a surface water dwelling, planktonic life over the continental shelf (= neritic pelagic habitat) (Figure 6) (Limpus *et al.*, 1994; Walker, 1991a, b, 1994; Walker and Parmenter, 1990). A high proportion of the post-hatchling records for this species are of small turtles collected from the feeding stations of marine raptors, especially white-bellied sea-eagles, on the continental islands within the central and southern GBR.

Hamann *et al.* (2011) used simulation modelling of tidal currents and hatchling swimming behaviour to investigate the fate of hatchling flatback turtles during the first two weeks of their dispersal starting at Wild Duck Island. The model confirmed that dispersal from eastern Queensland flatback turtle rookeries is restricted to coastal waters and that dispersion was controlled by water circulation and the hatchling’s swimming.

There have been no specific studies at sea addressing this pelagic foraging life history phase of the flatback turtle. Limited observations of this size class feeds on macro zooplankton (including *Vellela*, *Lepas*, lobster larvae) in the Arafura Sea (Limpus, 2007). The duration of the post-hatchling life history stage is unknown. There have been no studies to quantify survivorship of post-hatchlings during this neritic pelagic dispersal phase for the flatback turtle.

Coastal foraging population

The foraging range of immature and adult flatback turtles in eastern Queensland encompasses the continental shelf from Torres Strait south to Moreton Bay, based on post-nesting migration tag recoveries (Figure 4a) and prawn trawl capture records (Robins and Mayer, 1998). The isolated records of foraging immature flatback turtles from Hervey Bay and Moreton Bay have not been assessed to determine whether or not there is a year round residency of the species at this southern limit to their foraging distribution. Flatback turtles forage in the sub-tidal deeper soft bottom habitats between the coral reefs of the GBR and the mainland and have been most frequently trawled at 6-35 m depth and less frequently to depths up to 55 m (Robins and Mayer, 1998). They are not associated with rocky or coral reefs for foraging.

The limited diet data for large immature and adult flatback turtles in eastern Australia indicates that they are carnivorous, feeding principally on soft-bodied invertebrates including soft corals and sea pens (QTC marine turtle database).

There are no data identifying the size range at which flatback turtles change from pelagic foraging in coastal neritic waters to benthic foraging.

In the absence of tagging-recapture studies of foraging flatback turtles, there are no data available on the population structure of the species with respect to age and size structure, sex ratio, maturity ratio, annual breeding rates, growth rates, recruitment rates or survivorship for any age class.

Flatback turtles have an oxygen carrying capacity at the high end of the range in diving reptiles (Sperling *et al.* 2007a). This study indicated that flatback turtles have a respiratory physiology particularly suited to sustain prolonged shallow dives.

Diet

There have been formal studies of flatback turtle diet in eastern Australia. Incidental observations of food items include sea pens and soft corals (QTC marine turtle database).

Ageing studies

A study to determine the age at which flatback 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, 1985): over seven breeding seasons, 3276 hatchling flatback 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.

Only one flatback turtle “tagged” as a hatchling has been recaptured subsequently as an adult. She returned for her first breeding at 21 years of age, CCL = 93.0 cm, in the 2001–2002 breeding season (QTC marine turtle database). She had been originally marked as hatchling at the Mon Repos rookery and was recorded nesting on Kelly’s Beach, approximately 5km from where she was hatched. This study is still in progress.

The size at which flatback turtles reach sexual maturity (1st breeding season) has been quantified for nesting turtles at Mon Repos based on long term tagging-recapture and gonad examination to identify recruits to the breeding population:

- Nesting beach, Mon Repos: CCL = 92.03 cm (SD = 2.585; range = 88.0 – 97.7 cm; n = 25. QTC marine turtle database).

Growth of adult flatback turtles is extremely slow, at 0.012 cm per year (Parmenter and Limpus, 1995).

Parmenter and Limpus (1995) estimated a reproductive half-life of 10.1 yr and a minimal estimate of adult female longevity = 30.5 yr. The longest time span of reproductive activity recorded for an adult female flatback turtle on the Woongarra Coast has been 32 years based on 43 yr of total annual tagging of this nesting population (QTC marine turtle database).

Anthropogenic mortality in coastal waters

Prior to the regulated use of turtle exclusion devices (TEDs) into the Queensland East Coast Trawl Fishery and the Torres Strait Prawn Fishery in the early 2000s (Limpus, 2007) there were many hundreds to low thousands of flatback turtles captured annually in these two trawl fisheries with a very low reported mortality rate of 2% of captures (Robins and Mayer, 1998). If comatose turtles were treated as potentially dead, then the potential mortality could have been 5% of trawl captures. These trawl bycatch mortality data have not been reported via StrandNet.

EHP annual stranding reports (Greenland *et al.* 2004; Greenland and Limpus, 2004; Biddle and Limpus, 2011; Meager and Limpus, 2012) have summarised the incidence of marine turtle strandings and mortality in coastal waters of eastern Queensland from StrandNet records. The data for flatback turtles from these reports are summarised in Table 2. Given that the strandings summarised in StrandNet are not a complete record of turtle mortality in Queensland, the data in Table 3 can provide only an index of relative importance of mortality factors. None of the causes of mortality with flatback turtles identified via StrandNet appear to be sufficient to account for the declining nesting population at Peak Island.

Climate change impacts on marine turtle

There has been concern regarding the potential impacts of climate change on marine turtle populations for some two decades (Limpus, 1993). 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 flatback turtles in eastern Australia.

There have been no management actions implemented to compensate for climate change impacts on the species, however there have been some studies investigating particular aspects of climate change impacts on flatback turtles in eastern Australia:

- Flatback turtles have made radical changes in distribution of nesting beaches, foraging areas and migratory pathways in the last 12 thousand years (Limpus, 2007b). The species is capable of adjusting nesting distribution with each generation when each female chooses her nesting beach at the commencement of her adult life. Therefore these types of spatial changes can be made immediately in response to climate change. However, the changes in physiology required to make temporal changes in breeding cycles are more likely to occur in response to progressive selection across several to many generations and hence occur slowly.
- Fuentes *et al.* (2011) found that the nesting distributions of marine turtles along the eastern Queensland coast, including flatback turtles occur in areas of the coast with a lower historical incidence of tropical cyclones. With predicted changes in the distribution and intensity of cyclone activity, monitoring of cyclone impacts on nesting populations was recommended and management options discussed.
- The relationship between marine nesting distribution and the exposure of coastal areas to wind and wind-generated waves was analysed using a Relative Exposure Index (REI) developed for an extensive area in north eastern Australia. Values of the index for nesting sites of five different sea turtle species, including flatback turtles, and randomly selected non-nesting sites were compared (Garcon *et al.* 2010). Although there were differences between species, the results show that sea turtles nest in areas of higher REI values suggesting that wind exposure is related to the spatial distribution of sea turtle nesting sites. The authors hypothesised that REI may influence nest site selection in female turtles and/or the dispersal of hatchlings towards oceanic currents. Within the southern GBR region flatback turtles nest at significantly less exposed sites than loggerheads, green and leatherback turtles.

Collaborative studies investigating sand temperature impacts on flatback turtle incubation and hatchling health and performance at Mon Repos are in progress between EHP and UQ post graduate students supervised by Dr David Booth.

Conservation management

There is an excellent record of habitat protection for the eastern Australian flatback turtle population (Limpus, 2007):

- “Most nesting for this eastern Australian stock (>70%) is contained in protected habitat of National Parks or Conservation Parks declared under the *Nature Conservation Act 1992*.”
- 97% of the coastal waters of eastern Queensland contained in Australian and Queensland Marine Protected Areas,

With the vast majority of the nesting, foraging and post-hatchling pelagic dispersal within neritic waters occurring within the Great Barrier reef world Heritage Area and associated Marine Parks and National Parks, this flatback turtle population that breeds in eastern Australia has the most comprehensive habitat protection afforded any turtle population globally.

A range of management actions have continued since the late 1980s that have substantially increased hatchling production from the mainland rookeries and Curtis Island. The increased numbers of hatchlings produced through these projects have a strong female sex ratio bias because there are brown sands on the mainland beaches that have nest temperatures that are generally warmer than the pivotal temperature for this population (Limpus *et al.* 1983, 1985; Maloney *et al.* 1990; Reed, 1980).

- The reduction on fox predation of turtle eggs on the Curtis Island (Limpus, 2007; Limpus *et al.* 2006) and mainland beaches to the south, including the Wreck Rock beaches (Limpus, 2008a), from approximately 90% loss of eggs during the late 1970s – early 1980s to less than 5% egg loss in recent years. These activities are continuing.
 - EHP and NPRSR staff in collaboration with QTC Volunteers conduct annual baiting for foxes (Fox-off 1080 baits) along mainland beaches of the Woongarra Coast, Skyringville, Moore Park, and Wreck Rock beaches and Curtis Island where fox exclusion screens are also used to protect some clutches.

- QTC staff and volunteers rescue doomed eggs along the Woongarra Coast, Moore Park and Curtis Island to increase hatchling production (Pfaller *et al.* 2008). This project increases flatback turtle hatchling production with a few thousand extra hatchlings being produced annually.

An emerging threat to successful flatback turtle breeding within the Rockhampton region (23° latitude block) from north of Yeppoon to Rodd's Bay is the escalating alteration to coastal light horizons and its potential to cause a decline in flatback turtle nesting on this coast and the disruption of hatchling ocean-finding behaviour.

There is unambiguous evidence that flatback turtle hatchlings can have their ocean finding behaviour disrupted by changed light horizons associated with artificial lighting in proximity to the nesting beaches (Limpus, 1971; Limpus and Kamrowski, 2013). It is now apparent that it is not only the artificial lighting that is directly visible to the turtles on the beach but also the reflected light from clouds and salt-spray over the coast that can cause disruption to ocean finding behaviour. In this context, nesting flatback turtles returning to the sea on Hummock Hill Island have been disoriented by the brightly illuminated salt-spray above the Queensland Alumina Limited alumina refinery located on Boyne Island. This illuminated industrial site is located approximately 18km north of the Hummock Hill Island turtle nesting habitat (Hodge *et al.* 2007).

Light horizons at the turtle nesting beaches of Curtis and Facing Islands were quantified in September 2011 during the new moon phase to survey and quantify existing ambient night-time light levels and changes to the night-time light horizon as perceived by marine turtles. These images were collected to provide baseline data prior to the construction of the then proposed LNG plants within the Gladstone harbour area (Pendoley Environmental, 2012). This study has identified that the skyline at the turtle nesting beaches on Curtis and Facing Islands is highly modified by artificial light pollution. The combined glow from the town of Gladstone, the coal plant and the Alumina Plant was the biggest source of light in the images at all the locations. At South End Beach (Curtis Island) and Ocean Beach (Facing Island), lighting from some offshore vessels was visible.

Kamrowski *et al.* (2012), using satellite imagery of night illumination from the earth's surface, have identified the flatback turtle nesting area of eastern Australia as the second most light polluted flatback breeding area along the Australian coast and hence posing a threat to successful marine turtle breeding in the area. This same study identified that the majority of the Australian light pollution originated from industrial development.

There has been expanding urban and coastal development at the coastal strip from Yeppoon to Boyne Island in recent decades in addition to the expansion of industry within Port Alma and Port Curtis. Studies in the Caribbean with hawksbill turtle hatchlings, *Eretmochelys imbricata*, (Harewood and Horricks, 2008) have demonstrated that beach front lighting can negatively interfere with the swimming performance of hatchlings dispersing out to sea. In addition, they found that hatchlings released from dark beaches were attracted by lights from neighbouring beaches, which only became visible after they were a substantial distance from shore. This illuminated-skyline-trapping of hatchlings in inshore coastal waters and on the beaches parallels the observations made in the past with loggerhead, flatback, and green turtle hatchlings in south Queensland.

Concern should be held for the future successful functioning of the flatback turtle nesting populations in the immediate vicinity of Port Alma and Port Curtis with respect to increasing light pollution and its potential for negatively impacting on flatback turtle hatchling dispersal and survivorship and nesting population stability. No lighting mitigation measures have been formally implemented to the greater Gladstone and Yeppoon areas.

Collaborative studies investigating light horizon impacts on flatback turtles are in progress between EHP and a JCU post graduate student supervised by Dr Mark Hamann.

There has been no population model developed for evaluating the population dynamics of flatback turtles.

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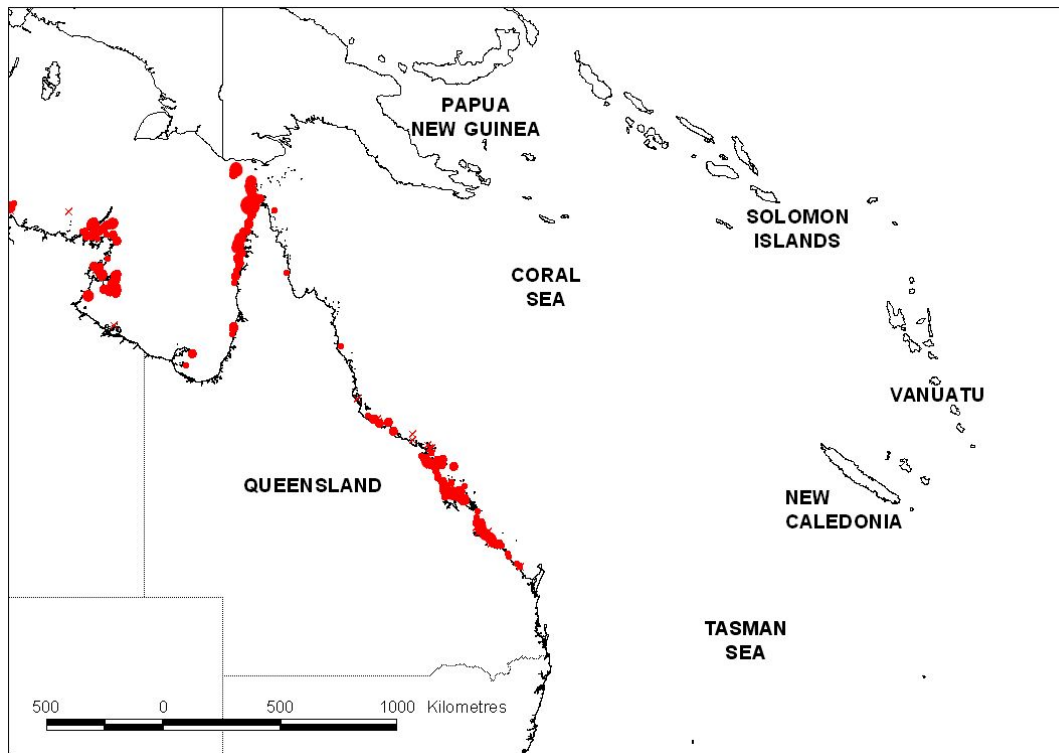


A. Adult flatback turtle (K42651) ashore nesting on the Woongarra Coast, December 2006.

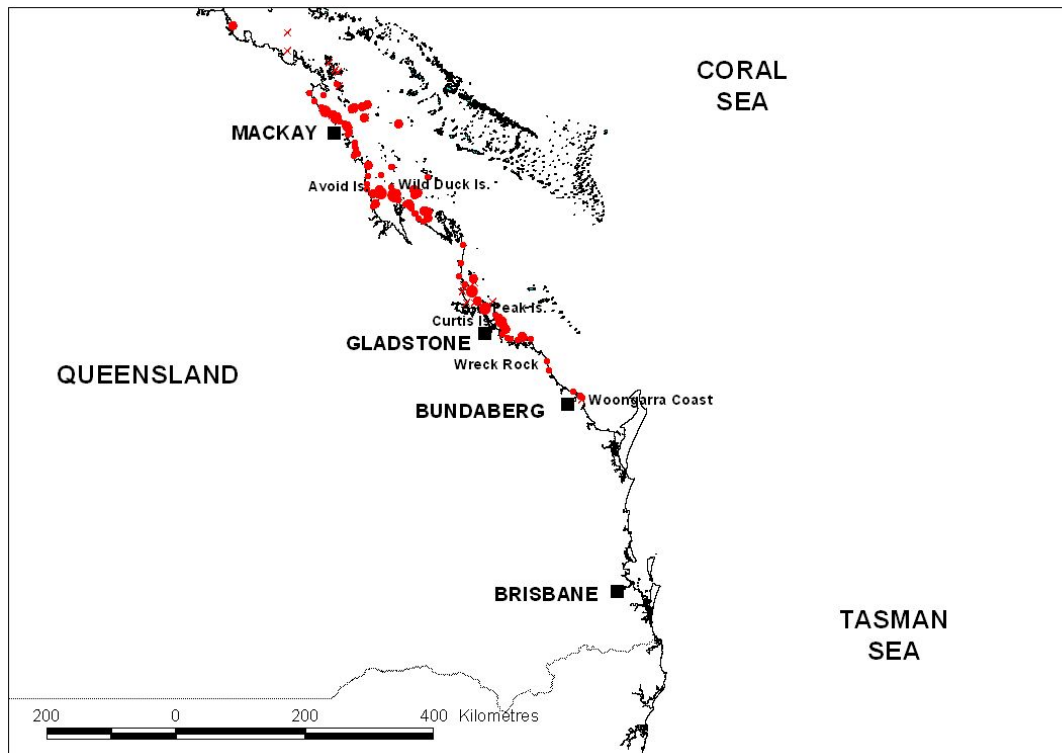


B. Hatchling flatback turtle at Mon Repos.

Figure 1. Flatback turtle, *Natator depressus*, in eastern Australia.

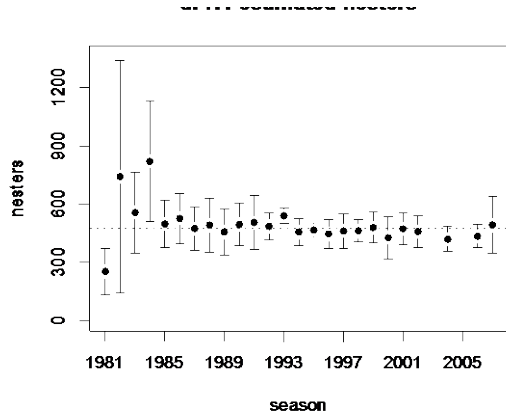


A. Nesting distribution within the Gulf of Carpentaria and eastern Australia.

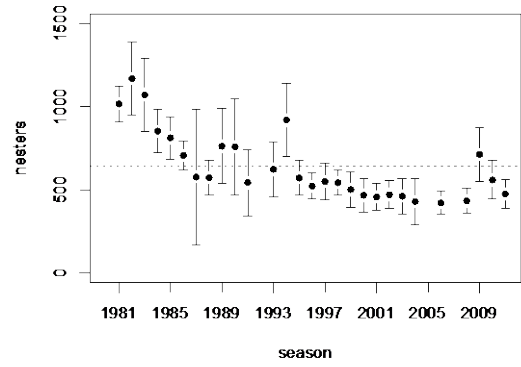


B. Nesting distribution for the eastern Australian management unit.

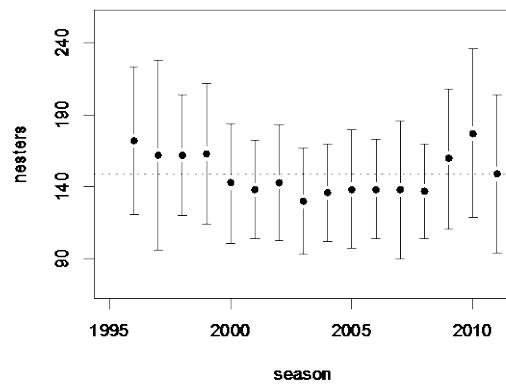
Figure 2. Flatback turtle, *Natator depressus*, nesting distribution within eastern and northern Australia. Red dots denote recorded nesting localities.



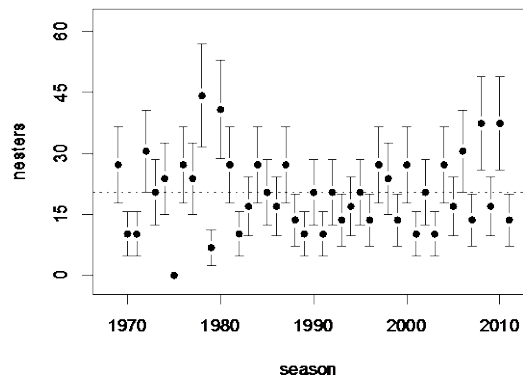
A. Wild Duck Island



B. Peak Island

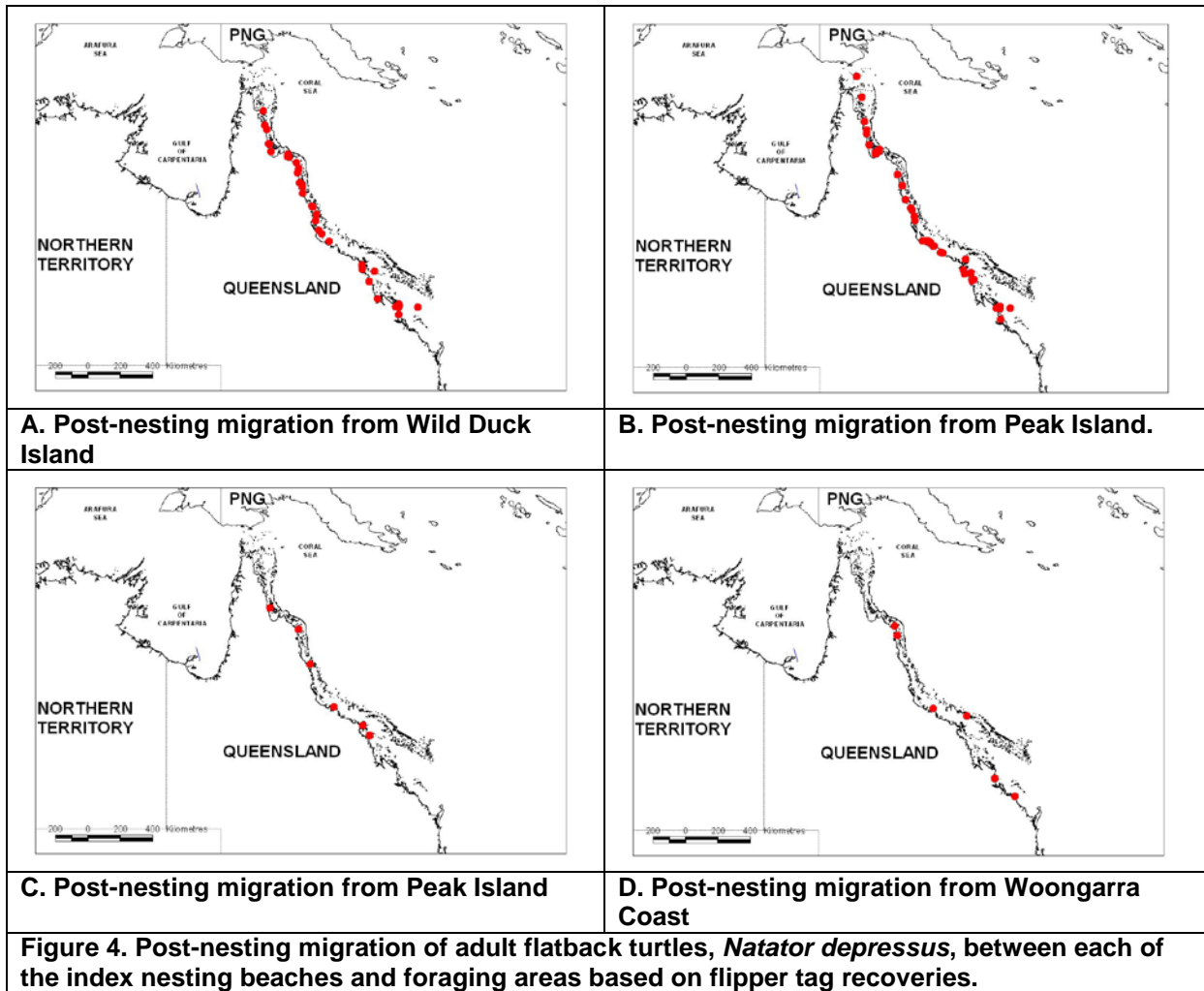


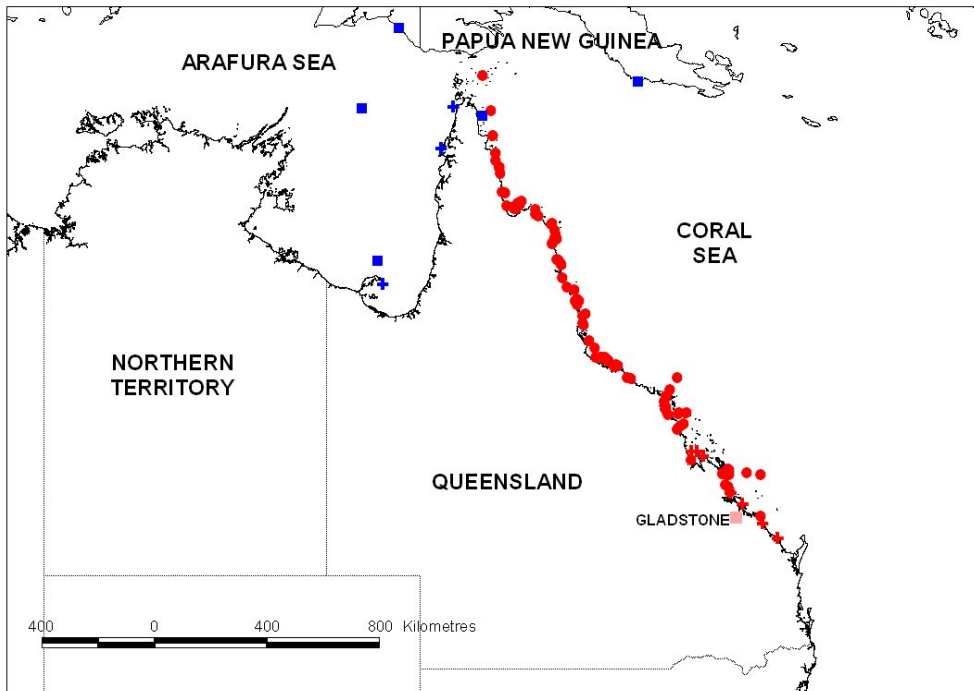
C. Curtis Island



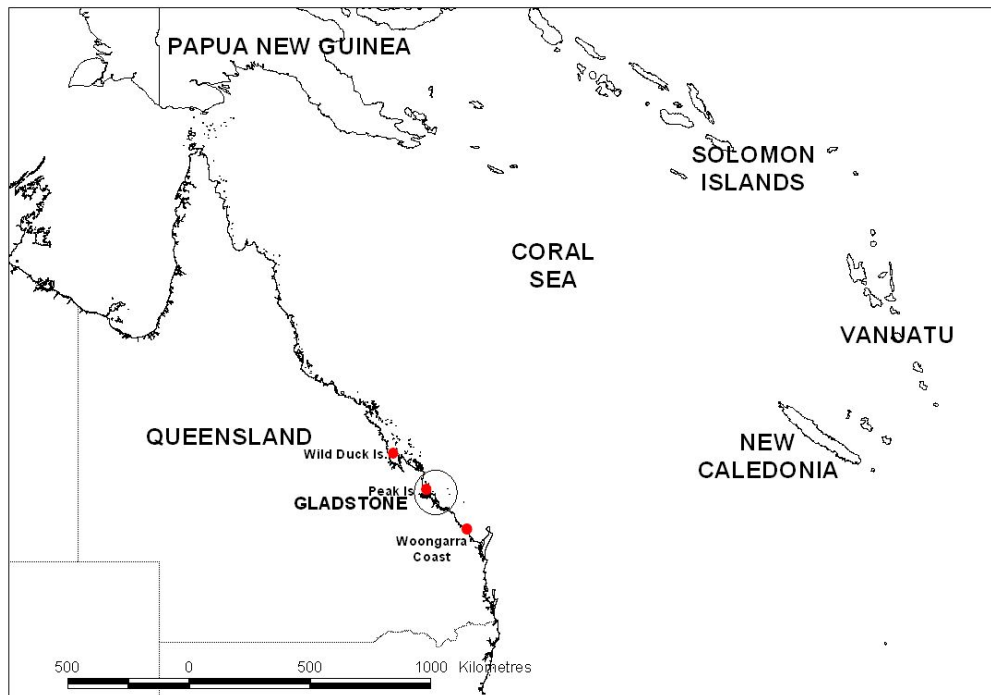
D. Woongarra Coast

Figure 3. Estimated total annual female populations associated with flatback turtle, *Natator depressus*, index rookeries in eastern Australia, based on CJS capture-mark-recapture analyses.





E. Migration to/from breeding areas within Queensland rookeries and distant foraging areas. Eastern Australian stock: nesting = red crosses; foraging = red dots. Eastern Gulf stock: nesting = blue crosses; foraging = blue squares.

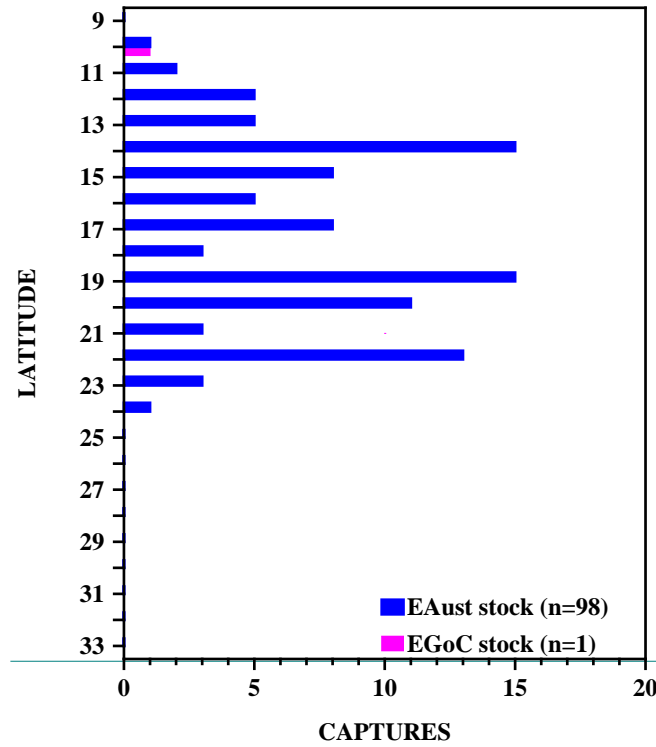


F. Migration between foraging areas adjacent to Gladstone and distant breeding sites (red dots).

Figure 4. Continued.

***Natator depressus* STOCK DISTRIBUTION :
EASTERN AUSTRALIA**

**RECAPTURES FROM FEEDING-NESTING
MIGRATION (n=99)**



Torres Strait and east Australian captures only

Figure 5. Distribution of foraging area records by 1° latitude blocks along the eastern Australian coast for flatback turtles, *Natator deprssus*, recorded at nesting sites in Australia, based on flipper tag recoveries.

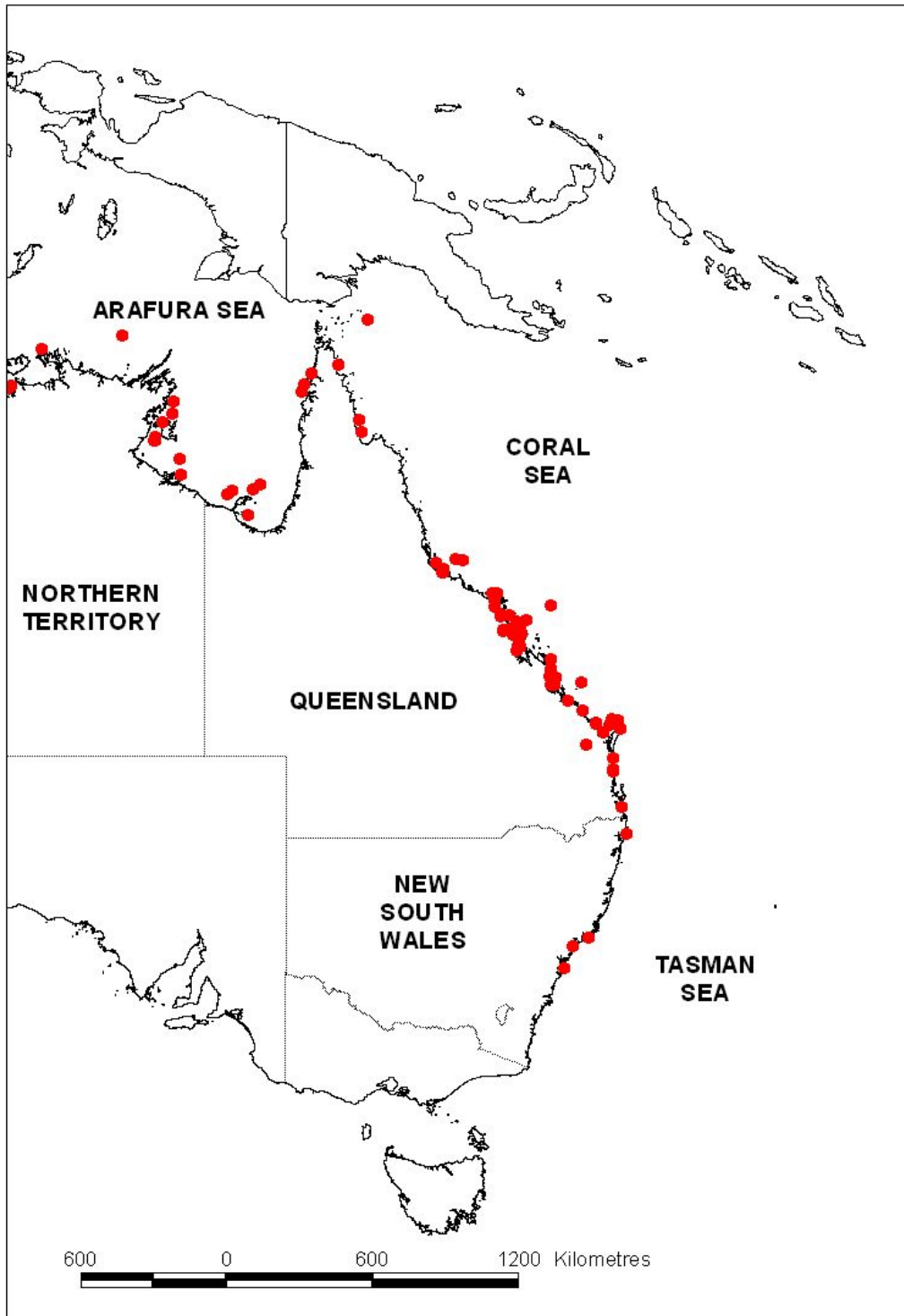


Figure 6. Distribution of flatback turtle, *Natator depressus*, post-hatchling records from the QTC Marine Turtle data base.

Table 1. Summary of tagging data and the results of Cormack-Jolly-Seber (CJS) capture-mark-recapture analysis for adult female flatback turtles, *Natator depressus*, nesting at the four index nesting beaches (Wild Duck Island, Peak Island, Curtis Island and Woongarra Coast) for the east Australian management unit for this species.

	FLATBACK TURTLE INDEX BEACHES			
	Wild Duck Island	Peak Island	Curtis Island South End Bch	Woongarra Coast
Commencement tagging census	1979	1980	1995	1968
Last year of tagging census	2007	2011	2011	2011
Study duration	29 yr 3 seasons missed - 1980, 2003, 2005	32 yr	17 yr	44 yr
Tagged females across all years	1265	2686	271	90
Long-term mean recorded nesters annually	163; significant fluctuations	201; significant fluctuations	56; significant fluctuations	6; significant fluctuations
Annual apparent survival probability	0.93 95% CI: 0.92-0.94	0.844; 95% CI: 0.82-0.87	0.956; 95% CI: 0.94-0.97	0.923; 95% CI: 0.89-0.95
Annual recapture probabilities	mean = 0.35; range=0.08 to 0.61; generally increasing since early 1990s	mean = 0.32; range=0.02-0.56; generally fluctuating around the mean	mean = 0.38; range =0.254-0.502; slowly increasing until mid 2000s & decreasing since	mean = 0.294; 95% CI: 0.25-0.34; constant
Mean adult female population	473; stable long term but fluctuating	642; 1980s: significantly declining nesting population; 1990s: slowing rate of decline mid-late 2000s: slight increase	149; stable long term but fluctuating	20; stable long term but fluctuating

Table 2. A summary of reported flatback turtle, *Nattator depressus*, strandings and mortality by year from anthropogenic sources in Queensland.
 See Greenland and Limpus (2004, 2008) 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. R denotes turtles released alive.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Boat Strike					1			1				1	1	4 (0.3/yr)
Dredging														0
Shark Control Program						2		1	1					4 (0.3/yr)
Crab pot entanglement														0
Fishing line/rope entanglement	1									2+1 ^R	1+1 ^R			6 (0.5/yr)
Gill netting							1+1 ^R							2 (0.2/yr)
Ghost net entanglement				3	3		5			1				12 (0.9/yr)
Ingestion of foreign bodies					1					1 ^R				2 (0.2/yr)
Undetermined						21						59 ^R		-
Total	1	0	0	3	5	23	7	2	1	5	2	60	1	

APPENDIX 1

Long-term capture-mark-recapture (CMR) study of adult female flatback turtles, *Natator depressus*, nesting on wild Duck Island, Peak Island, Curtis Island and Woongarra Coast in central and southeast Queensland.

Tagging methodology:

Nesting turtles were tagged with standard flipper tags applied to the front flippers following the Queensland Turtle Conservation Project standard methods (Limpus, 1971; Limpus et al. 1983; Limpus, 1992; Parmenter, 1993). Turtles were tagged with monel tags prior to 1982 and with titanium tags from 1982 onwards (Limpus, 1992). Prior to 1978, flatback turtles were single tagged on the front flipper. Most nesting flatback turtles were double tagged on the front flippers from 1978, onwards (See flatback turtle gap analysis, Figure 1). PIT Tags (Parmenter, 1993) have been injected into nesting flatback turtles at all of the index sites, commencing at Wild Duck Island in 1989, at progressively at the other sites at different dates after that.

Statistical Methodology:

Within this analysis, we used a random effects Cormack-Jolly-Seber (CJS) statistical modelling approach that accounts for individual heterogeneity in survival and/or recapture to estimate key demographic parameters for a CMR study (Gimenez & Choquet 2010) and an *ad-hoc* approach based on comparison with various fixed effects CJS-type models (Lebreton et al. 1992) that have well-known goodness-of-fit metrics to help assess random effects CJS model fit.

CJS model assumptions such as transience (seen once and never again) and capture heterogeneity (known as trap-dependence) were evaluated using program U-CARE (Choquet et al. 2009) while CJS goodness-of-fit was assessed using U-CARE and the median \hat{c} approach implemented in program MARK (White et al. 2006). The median \hat{c} estimate for the best-fit CJS model to adjust the model selection metric (Akaike Information Criterion, AIC) was used for the random effects CJS model fits. We used a time-since-marking model structure to account for transient behavior (Chaloupka & Limpus 2002) and the random effects model approach (Gimenez & Choquet 2010) to account for capture heterogeneity and individual variability in survival. All random and fixed effects CJS models were fitted using program MARK (White et al. 2006) while model selection was based on the AIC corrected for sample size and over-dispersion (QAICc, Anderson et al. 1998).

The best-fit model based on QAICc was then used to estimate apparent survival and recapture probabilities. This modelling approach also enabled us to estimate derived parameters for the population such as annual abundance by applying a Horwitz-Thompson-type estimator using the recapture probabilities derived from the best-fit model (Chaloupka & Limpus 2001).

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