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Marine turtles in Moreton Bay

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Abstract

Six species of marine turtle from two families have been recorded foraging within the waters of Moreton Bay. Of those species, two (green turtle, *Chelonia mydas* and loggerhead turtle, *Caretta caretta*) are resident in substantial foraging populations that contribute annually to nesting populations of their southern Great Barrier Reef and South Pacific Ocean genetic stocks, respectively. Capture-mark-recapture studies of resident foraging populations in Moreton Bay commenced in 1990, serving as a platform supporting a wide range of additional studies of turtles in Moreton Bay that have garnered valuable insights into the diet, habitat use, physiology, toxicology, genetics and population dynamics of the resident turtle populations. This paper provides a summary of the research completed over the past few decades on turtle biology within Moreton Bay and highlights areas of future research.

Keywords: capture-mark-recapture, diet, health, physiology, toxicology, population dynamics

Introduction

The shallow coastal waters of Moreton Bay have supported marine turtle populations since sea levels rose following the last ice age. They were hunted for food by the local Indigenous people and, following the arrival of European settlers, hunted commercially from 1824 to 1950 (Fig. 1) (1, 2).

In recent times, six species of marine turtle from two families have been recorded foraging in the waters of Moreton Bay. Five species of the family Cheloniidae are year-round foraging residents: loggerhead turtle, *Caretta caretta,* (3); green turtle, *Chelonia mydas* (4); hawksbill turtle, *Eretmochelys imbricata* (5); olive ridley turtle, *Lepidochelys olivacea* (6); flatback turtle, *Natator depressus* (6). Leatherback turtles (*Dermochelys coriacea*), from the family Dermochelyidae, are migratory visitors (6, 7). Marine turtles within Australian waters are afforded protected under the Australian Government's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and by state and territory legislations. Two species (green and loggerhead) migrate into the Moreton Bay waters and nest annually at low density on the ocean beaches of the Bay islands (6). Small post-hatchling loggerhead and green turtles travelling south with the East Australian Current from the nesting beaches of the southern Great Barrier Reef (GBR) region pass through the waters offshore Moreton Bay on their way south and east into the South Pacific Ocean (8). This review does not address biological data associated with debilitated or dead marine turtles that have washed in from the pelagic waters of the Coral or Tasman seas.

Figure 1. Green turtle (*Chelonia mydas*) harvest in Moreton Bay circa 1934 (49).

Immature marine turtles recruit from a pelagic foraging life-history phase in the open ocean to benthic foraging in coastal waters at different sizes: loggerhead turtles recruit to benthic feeding in Moreton Bay at a mean curved carapace length (CCL) of 78.2 cm (SD=3.75, n=52) at approximately 16 years of age (9); green turtles similarly recruit to benthic feeding in Moreton Bay at CCL = 44.2 cm (SD=3.97, n=98) and CCL = 45.1 cm (SD=3.24, n=54.0) for females and males respectively. Hawksbill turtles are believed to recruit to Moreton Bay benthic foraging areas at approximately CCL = 36.0 cm (10).

Large immature and adult leatherback turtles are not permanent residents of Moreton Bay; they are transient visitors to Moreton Bay during the autumn and winter months. The frequency of encounters with leatherback turtles in the Moreton Bay region has substantially declined in recent decades (11).

Most green turtles foraging in Moreton Bay are from the southern GBR genetic stock as defined by FitzSimmons and Limpus (12): > 90% of adult females based on flipper tag recoveries (13), 95% of adults and 85% of immature green turtles based on population genetics analysis (14). A small proportion of the foraging green turtles in Moreton Bay originate from the northern GBR, New Caledonia, Vanuatu, French Polynesia and the eastern Pacific (14). Only loggerhead turtles from the south-west Pacific genetic stock that breed in eastern Australia and New Caledonia have been recorded in eastern Australia, including Moreton Bay (12). There is no clear definition of the genetic stock of origin for hawksbills that forage in Moreton Bay.

Systematic Department of Environment and Science (DES) capture-mark-recapture (CMR) studies of foraging marine turtles in Moreton Bay commenced in 1990 and identified that the most abundant species in the Bay were green, loggerhead and hawksbill turtles (3–6). These studies contributed to the development and implementation of the Moreton Bay Marine Park, with the identified high use areas for foraging turtles designated within Marine National Park green zones and mandatory go slow areas for recreational and commercial vessels. Turtles are most commonly encountered on the shallow seagrass-dominated Eastern Banks adjacent to Dunwich on North Stradbroke Island northwards along the western face of Moreton Island. Turtles are also encountered along the fringing mangroves and shallow muddy flats at the southern extent of the Bay and throughout Deception Bay in the north-west.

The green turtle population in the Moreton Banks has approximately tripled during the 25 years of the CMR study from 1990–2014 (15). Satellite telemetry studies have demonstrated that green turtles maintain long-term fidelity to their respective foraging sites in Moreton Bay (16). Based on satellite telemetry, the home range of green turtles foraging in eastern Moreton Bay was 128.8 km^2, 23.7 km^2 in southern Moreton Bay and 121.8 km^2 in north-western Moreton Bay (17). Adult female green turtles resident in Moreton Bay commenced breeding during 1990–2007 at a mean CCL = 108.7 cm (SD=4.56, n=32) (13). The green turtles in Moreton Bay are on average amongst the largest and fastest growing in eastern Australia (18).

Once recruited to benthic foraging residency, the loggerhead turtles show high fidelity to their respective foraging areas across decades (19, 20). These recruited turtles retain fidelity to their foraging areas following displacement (21). Based on satellite telemetry, the home range of loggerhead turtles foraging in eastern Moreton Bay was 155.8 km^2, 32.7 km^2 in southern Moreton Bay and 15.6 km^2 in western Moreton Bay (17). Adult female loggerhead turtles of the south-west Pacific breeding stock nesting at Mon Repos commence breeding at a mean CCL = 93.65 cm (SD=4.25, n=69) (9).

Marine turtles that forage in Moreton Bay migrate to breed at widely dispersed and usually distant nesting beaches, with most green turtles that forage in Moreton Bay migrating to breed on the islands of the Capricorn-Bunker Group in the southern GBR between North West Island and Lady Elliot Island. Small numbers of the Moreton Bay green turtles have been recorded nesting at Raine Island in the northern GBR, on islands within the Recifs d'Entrecasteaux in north-western New Caledonia and Vanuatu (Fig. 2a). Most loggerhead turtles that forage in Moreton Bay migrate to breeding grounds on the mainland beaches between Bundaberg and Agnes Water (Woongarra coast being the major breeding site). Smaller numbers of Moreton Bay loggerhead turtles have been recorded on the islands of the southern GBR between the Swain reefs and Lady Elliot Island; isolated nesting records have occurred in northern New South Wales and eastern New Caledonia (Fig. 2b).

The CMR studies have been a platform to support a wide range of additional studies of turtles in Moreton Bay, including but not limited to diet, habitat use, physiology, toxicology, genetics and population dynamics. DES CMR studies from the early 1990s to the present demonstrated a robustly increasing green turtle foraging population on the eastern banks of Moreton Bay but a declining population of loggerhead turtles for the same area. The successes for green turtles are attributable to a consistently increasing green turtle nesting population in the southern GBR since strong protection of the species and their habitats commenced in 1950. Recruitment of new immature green turtles taking up residency is a regularly observed feature.

The problem for the declining loggerhead population originates from excessive mortality of small post-hatchlings ingesting plastic debris as they travel in the East Australian Current and

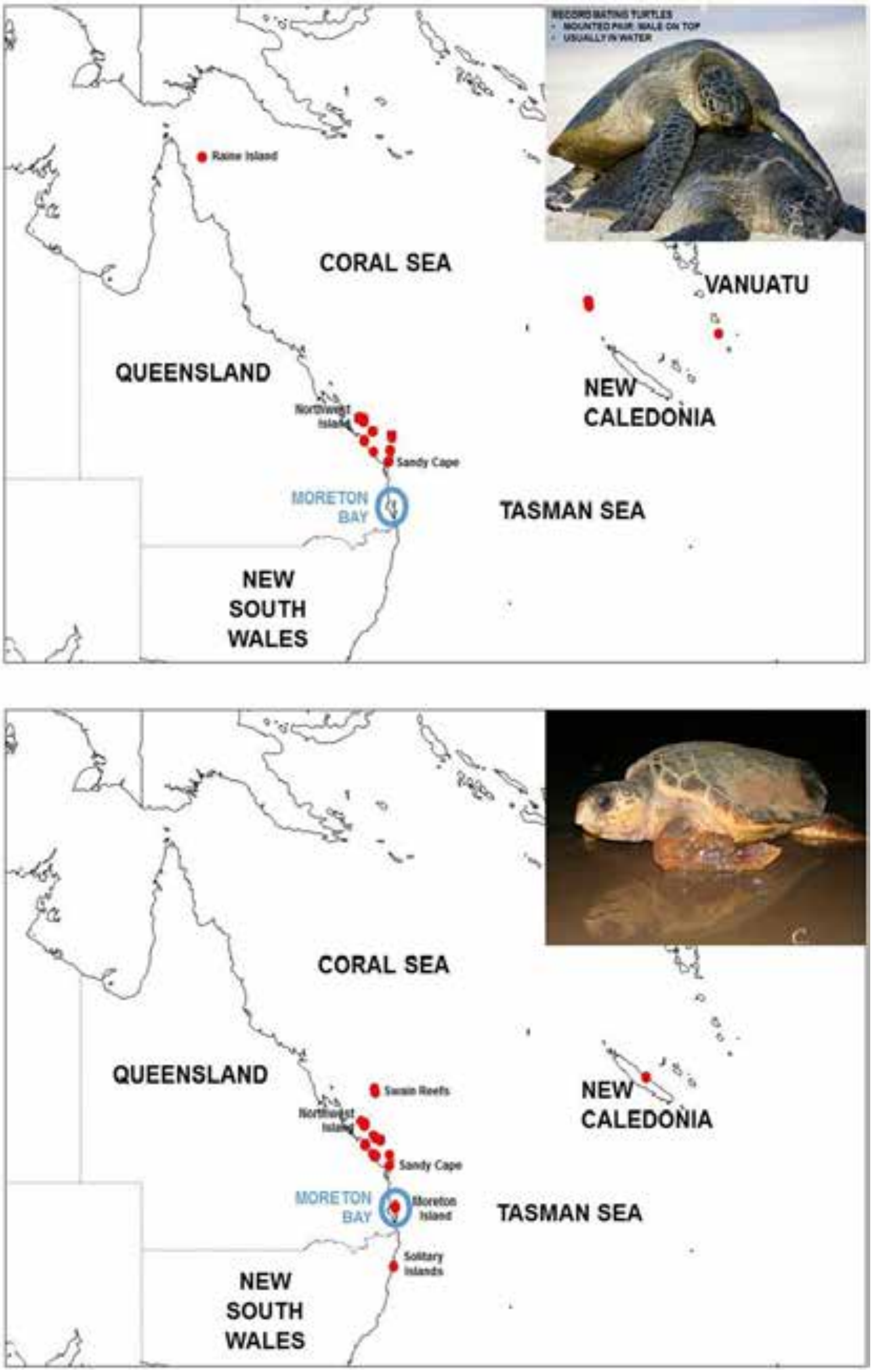

Figure 2 Recorded nesting rookeries of the South Pacific (a) green (*Chelonia mydas*) and (b) loggerhead (*Caretta caretta*) turtles that forage in Moreton Bay. Photos by Col Limpus.

additional mortality from fisheries bycatch in the eastern Pacific. These post-hatchling mortalities have resulted in a severely depleted recruitment of young loggerheads into residency in Moreton Bay since the early 1990s.

Diet and habitat use

Marine turtles undergo a number of distinct life stages accentuated by changes in foraging habitat and diet (22). For most marine turtle species this begins with a protracted open-ocean foraging period post hatching. Marine turtles exhibiting this oceanic-neritic development pattern subsist on a predominantly carnivorous diet borne of pelagic macro-zooplankton; they then shift foraging strategy and diet composition upon recruitment to neritic foraging habitats (23). Boyle and Limpus (8) have documented the diet, including ingested plastic, of the small post-hatchling green and loggerhead turtles passing Moreton Bay on the East Australian Current.

Loggerhead turtle (*Caretta caretta*)

Following recruitment to benthic foraging in Moreton Bay, loggerhead individuals occupy a range of habitats including intertidal and subtidal seagrass meadows, coral and rocky reefs, and the soft-bottom, deeper, subtidal habitats. While foraging loggerheads in South East Queensland have been reported feeding on over 100 taxa, in Moreton Bay they are most commonly found to forage on species of portunid crabs and a range of benthic gastropod and bivalve molluscs (Table 1). While loggerheads feed extensively on epifaunal species they will also mine the substrate to obtain infauna prey items (24, 25) and take prey items from the mid-water column and at the surface (26).

Table 1. Summary of findings from dietary studies on the loggerhead turtle (*Caretta caretta*) in the Moreton Bay region.

Loggerhead turtle (*Caretta caretta*)		
Preen (24)	1996	– 'Infaunal mining' foraging method observed (n=13) – Polychaeta, thin-walled Mollusca and Bivalvia
Limpus *et al.* (26)	2001	– Gut and faecal content (n=53) – 94 benthic and near-benthic taxa – Predominantly Mollusca or Crustacea, Echinodermata, Porifera, Cnidaria and Osteichthyes – Diet a function of feeding area not sex or size
West (25)	2005	– Faecal contents (n=24) – Predominantly Crustacea and Mollusca
Boyle and Limpus (8)	2008	– Gut content (n=7) of oceanic post-hatchlings – Pelagic Cnidaria, Crustacea and Mollusca – > 50% of sampled individuals observed to have ingested synthetic materials
Limpus and Limpus (51)	2008	– Mortalities from predation on porcupine fish (n=12)
Coffee (52)	Unpubl. data	– Faecal contents (n=12) – Predominantly Crustacea and Mollusca

Green turtle (*Chelonia mydas*)

Within the Moreton Bay area, foraging populations of green turtle have been observed to feed within tidal and subtidal habitats, grazing primarily on algae (*Gracilaria* sp. and *Hypnea* sp.) and seagrass (*Zostera capricorni* and *Halophila ovalis*) and opportunistically on mangrove (*Avicennia marina*) leaves and propagules (Table 1). At higher trophic levels, observations of opportunistic foraging on gelatinous animal material in Moreton Bay (27–29) are consistent with findings from other foraging populations (Fig. 3) (30–33).

Figure 3. Neritic-foraging immature green turtle prey on jellyfish, northern NSW. Image by Owen Coffee (50)

Table 2. Summary of findings from dietary studies on the green turtle (*Chelonia mydas*) in the Moreton Bay region

Authors	Year	Dietary observations
Brand, Lanyon and Limpus (53)	1999	– Digestive retention and dietary compositions (n=3) – Predominantly seagrass *Halophila ovalis* and algae *Gracilaria* sp. – Digestive retentions of 6.5–13.5 days
Brand-Gardner, Limpus and Lanyon (54)	1999	– Oesophageal lavage (n=20) – Observed preference for *Gracilaria* sp. – Inverse relationship with fibre levels and preferred species
Read and Limpus (55)	2002	– Oesophageal lavage (n=240) – Predominantly seagrass *Halophila ovalis* and red algae *Gracilaria cylindrica* and *Hypnea spinella* – Animal material and cotyledons of mangrove *Avicennia marina* observed
Arthur et al. (27)	2007	– Animal-borne imaging (n=6) – Individuals foraged upon gelatinous animal material in the water column – One sampled individual recorded foraging on seagrasses
Arthur, Boyle and Limpus (28)	2008	– Stable isotope analysis (SIA) (n=64) at distinct life stages (hatchlings, pelagic juveniles, small immature, large immature and adult) – Elevated $\delta^{15}N$ in recent recruit neritic juveniles consistent with individuals foraging at higher trophic levels
Boyle and Limpus (8)	2008	– Gut contents (n=31) of oceanic post-hatchlings – Observed pelagic Cnidaria, Crustacea (predominantly Malacostraca) and Mollusca – Over 65% of sampled individuals observed to have ingested synthetic materials
Brine (29)	2008	– Oesophageal and SIA (n=24) – Lavage identified seagrasses *Halophila* sp. and *Halodule* sp. as largest contributors to diet – SIA identified elevated $\delta^{15}N$ in recent recruits and larger size classes, indicative of higher trophic feeding
Townsend et al. (56)	2012	– Necropsy (n=2) – Multi-stage mass spectrometry identified envenomation from accidental ingestion of blue-ringed octopus (*Hapalochlaena fasciata*) as cause of death

Hawksbill turtle (*Eretmochelys imbricata*)

While there are no studies on the foraging ecology of the resident hawksbill turtles of Moreton Bay, individuals foraging off the coast in the Northern Territory and the northern GBR have been recorded foraging on algae (Rhodophytes, Chlorophytes and Phaeophytes), with a significant contribution of sponges and soft corals to their diet (34, 35). These observations are consistent with those from foraging individuals sampled in the Caribbean and the Indian Ocean (36, 37). There have been observations of individual adult size hawksbills selectively feeding on large sea anemones on the subtidal rocky reef on the seaward side of North Stradbroke Island (6).

Leatherback turtle (*Dermochelys coriacea*)
Unlike cheloniid marine turtles, the leatherback turtle does not recruit to a benthic, life-history phase. Instead they retain a surface-water foraging habitat whether they are in oceanic or neritic waters throughout their life. In the north-west Pacific and the Atlantic their diet is primarily large, gelatinous, macro-zooplankton (cnidarians, ctenophores and colonial tunicates such as *Pyrosoma* sp.) (38–41). While limited data exist on their foraging ecology in the south-west Pacific, they have been regularly reported to feed on the blue blubber jellyfish (*Catostylus mosaicus)* in Moreton Bay (11).

Olive ridley turtle (*Lepidochelys olivacea*)
Following an oceanic developmental period, olive ridley turtles in Australia have been reported recruiting to neritic foraging environments (42). While there is a paucity of data on the foraging ecology of recruited immature and adult olive ridleys, they are thought to subsist on a carnivorous diet composed primarily of gastropods, cnidarians and benthic crustaceans (42, 43), consistent with observations on the diet of adult olive ridley sampled off the coast of Mexico (44).

Flatback turtle (*Natator depressus)*
Forgoing a pelagic developmental period, flatback turtles spend their post-hatchling through to their adult life stages in neritic foraging environments (22). While limited observations exist on the foraging ecology of flatback turtles, it is posited that foraging individuals in the Moreton Bay region have diets consistent with those reported in individuals throughout the east and west coasts of Australia. They subsist on carnivorous diets, composed primarily of soft-bodied invertebrates such as sea pens, soft corals, holothurians and jellyfish (43–46).

Health, physiology and toxicology

A substantial marine turtle population lives within the semi-enclosed waters of Moreton Bay, which receives the outflow of five rivers (Albert, Logan, Brisbane, Pine and Caboolture). These rivers receive the chemical discharge associated with more than two million human inhabitants and their urban development, agricultural and pastoral activities, and industry. As such, the turtles of Moreton Bay are more likely to be impacted by river outflow than any other population of marine turtles in Queensland. Elevated levels of heavy metals and organo-halide compounds have been detected in marine turtles resident in Moreton Bay; to date no studies have demonstrated a detrimental impact of these substances on turtle biology (Table 3). The

associated health, toxicology and physiology related studies on marine turtles within Moreton Bay are summarised in Table 3.

Boat strike, entanglement in crab pots and fishing gear and to a lesser extent, the ingestion of synthetic debris, were the primary sources of anthropogenic mortality for turtles within Moreton Bay (9, 13, 47, 48). Indigenous harvest of marine turtles in Moreton Bay is not quantified.

Summary

Since the start of capture-mark-recapture studies in 1990, research, in tandem with the state's tertiary institutes, has determined which species inhabit the Bay, their genetic stocks and population dynamics, and has worked toward the conservation and management of the resident populations. This paper has outlined some of the research achievements of the past few decades, however, as identified, many questions remain. The large numbers of resident foraging turtles within Moreton Bay are ideally situated for ongoing studies by research institutes in the vicinity of the Bay, allowing new research techniques to be developed and the anthropogenic impacts on these species to be quantified into the future.

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Table 3. Summary of findings from health, physiology and toxicology studies on marine turtles in the Moreton Bay region. See footnote for abbreviations.

Authors	Year	Observations
(57) Gordon, Kelly and Lester	1993	– 1991, of a cohort of 70 green turtles which died in Moreton Bay, n = 24 stranded green turtles were euthanised and examined by necropsy – Severe enteritis or encephalitis was prevalent in the examined turtles, associated with *Caryospora cheloniae*, a coccidial pathogen – At the time of study such infections had only been observed in captive- reared hatchling green turtles – Concluded that *C. cheloniae* was pathogenic for all life stages of green turtle
(58) Gordon Kelly and Cribb	1998	– n = 96 stranded green turtles were examined by necropsy – Spirorchid fluke infection (spirochetosis) was identified as the cause of mortality in ~ 10% of necropsied turtles – Spirochetosis was diagnosed in 98% of examined turtles with flukes observed in 45% of stranded turtles – Spirorchids were likely to contribute to the strandings of green turtles with concurrent disease
(59) Gordon, Pople and Ng	1998	– 1990–91, n = 50 (38 green turtles, 8 loggerheads, 3 hawksbills and 1 olive ridley) stranded turtles were sampled for trace metal concentrations – Arsenic (As), cadmium (Cd), mercury (Hg), selenium (Se) and zinc (Zn) concentrations were sampled from the kidneys and livers of the sampled individuals – Cd concentrations in all turtle species (1.7–75.9 $\mu g\ g^{-1}$ wet weight) were amongst the highest recorded for marine vertebrates globally at the time of publication – Decreasing concentrations of Cd, Se and Zn were associated with increasing curved carapace length (CCL) in kidney tissue, whilst Zn concentrations increased with CCL in liver tissue
(60) Hermanussen *et al.*	2004	– No information existed at the time of the study on the sensitivity of reptiles to dioxins and dioxin-like compounds – The carapace fat tissue was sampled from stranded immature to adult green turtles (n=4) – Concentrations of PCDD/F and TEQs were on average 10 times higher in green turtles when compared to dugongs – PCDD/F and TEQ concentration in sediments in Moreton Bay could be considered negligible compared to polluted areas in the Northern Hemisphere, concentrations in green turtles are comparable to those found in reptiles of the Great Lakes and St Lawrence basins – Sediment retention of these pollutants is up to 15 times higher in seagrass beds compared to bare sediment – A trend of increasing concentration with decreasing degree of chlorination was observed in the turtles when compared to the sediments
(61) Hamann *et al.*	2005	– 1996–99, blood samples from (n=25) non-vitellogenic female green turtles – The highest plasma triglyceride concentration and lowest plasma cholesterol concentration were found in the non-vitellogenic female green turtles in Moreton Bay during the El Niño year of 1997 – These same Moreton Bay females in 1997 had higher plasma triglyceride and lower cholesterol concentration than those recorded in non-vitellogenic females foraging on Heron Reef and in Shoalwater Bay in 1997 – Turtles feeding during El Niño years could obtain higher levels of body condition
(48) Gordon	2005	– 1990–96, n=108 green turtles were examined for cause of morbidity and mortality – Direct anthropogenic causes (including trauma, ingestion of marine debris and drowning) accounted for 34% of mortalities in sampled turtles – Fibropapillomatosis accounted for 7% of mortalities – Naturally occurring diseases accounted for the remaining 59% of stranding

(62) Hermanussen *et al.*	2006	– Total dioxin/furans (POPs) concentrations ranged from 14–213 pg/g lipid for greens, 93–137 pg/g lipid for hawksbills and 151–319 pg/g lipid in loggerhead turtles from Moreton Bay – Trophic level influenced the bioaccumulation of certain POPs and the highest TEQ levels are present in carnivorous loggerheads and lowest in herbivorous green turtles – A trend of increasing tissue concentrations and TEQs was observed with increasing habitat contamination zones
(63, 64) Muusse; Muusse *et al.*	2006	– 2004–05, blood and eggs were sampled for total PCDD/F and PCB concentrations from n = 6 (5 loggerheads and 1 flatback) Moreton Bay foragers nesting at Mon Repos, Qld – Blood data were consistent with other turtle studies from Moreton Bay – Total PCB concentrations were higher in blood than in egg samples – PCB TEQs were higher and transferred in higher percentages in experienced breeders
(65) Hermanussen *et al.*	2006	– Sediment samples (n=100) and blood samples (n=29) from green turtles were collected to analyse for PCDD/F exposure – Average PCDD/F concentrations were higher for turtles in sub- populations proximal to river inputs – PCDD/F congener profiles in green turtles reflected that observed in sampled sediments – It is uncertain whether the levels found have the potential to result in adverse effects for green sea turtles
(66) Flint *et al.*	2010	– 2007, n = 125 green turtles were assessed from Moreton Bay to determine health status using blood samples – 18 blood chemistry and 8 haematology variables were investigated – 7% of turtles were classified as clinically unhealthy – Clinically unhealthy turtles were biased towards small immature males – Small immature turtles with > 20 *Chelonibia* barnacles on the plastron were 3 times more likely to be unhealthy than those with no barnacles
(67) Flint *et al.*	2010	– 2007–08, n = 101 loggerhead turtles were assessed to determine health status using blood samples – 13 blood chemistry variables and 3 haematology variables were investigated – 66% of turtles were classified as clinically healthy and 23% as unhealthy – Neither sex nor maturity influenced the risk of being clinically unhealthy – Loggerhead turtles in Moreton Bay required separate reference intervals for immature and mature turtles for thrombocyte counts and for male and female turtle for lymphocyte, heterophil and total white cell counts – A single reference interval for other parameters can be used regardless of age or sex
(68) Flint *et al.*	2010	– 2008, a subset of n = 155 green turtles from Moreton Bay and a further n = 569 from Shoalwater Bay were examined during annual monitoring – Corneal fibropapillomatosis was observed in four (0.5%) of examined individuals – The corneal lesions were deemed to have detrimental effect on the vision of the affected turtles – Documented the occurrence of corneal fibropapillomas in the South Pacific green turtle population, a condition previously restricted to observations in Hawaii, mainland USA and Florida
(69) Flint *et al.*	2010	– 2006–09, n = 100 stranded green turtles were examined from southern Queensland to assess causes of disease and mortality – Parasitism from spirorchid flukes was most commonly attributed to cause of mortality (41.8%) – Spirochetosis was observed most frequently in summer when compared with other seasons (P=0.029) and in immature turtles (n=70) more severely than in mature (n=19) turtles (P=0.032)

		– Disease (spirochetosis, gastrointestinal impaction etc.) were considered to contribute to cause of death in 92.8% (n=142) of examined green turtles, with 7.2% (n=11) of mortalities assigned to anthropogenic misadventure
(70) Schuyler *et al.*	2012	– 2006–11, n =115 marine turtles were examined by necropsy – 54.5% (n=12) of post-hatchling pelagic foraging immature turtles had ingested marine debris, in contrast to 29.0% (n=27) of benthic foraging turtles with marine debris ingestion – Approximately 90% of ingested debris was plastic in origin – Pelagic foraging turtles ingested significantly more rubber and hard plastic than benthic foraging turtles, which exhibited selectivity for white and clear soft plastics
(47) Meager and Limpus	2012	– 2011, n = 1793 marine turtle stranding and mortalities were reported – The regions between the Gold Coast and Hervey Bay (28°S to 25°S) accounted for 41% of records (n=728) – Within Moreton Bay n = 51 marine turtles were recorded as killed or injured by vessels – Marine strandings were close to twice those reported the previous year for the Queensland coastline – Elevated strandings were likely influenced by extreme weather events in late 2010 to early 2011 which affected seagrass availability
(15) Limpus, Jones and Chaloupka	2016	– Fibropapillomatosis was observed in the foraging population of green turtles in Moreton Bay at the commencement of capture-mark-recapture studies – The highest frequency of green and loggerhead turtles with fibropapillomatosis is from the eastern banks of Moreton Bay – Hawksbill turtles have only been recorded with fibropapillomatosis at low frequency on the eastern banks of Moreton Bay
(71) Flint *et al.*	2017	– Investigated the relationship between extreme weather events and marine turtle strandings – Rated most influential, freshwater discharge was associated with increased marine turtle strandings 10–12 months later for events with a cumulative effect (multiple months) and 7–9 months later for non-cumulative events (single month only) – Increased strandings post extreme freshwater discharge were attributed to reduced seagrass coverage in foraging areas

Note: PCDD/F – polychlorinated dibenzo(p)dioxins and furans (‘dioxins’), TEQ – toxic equivalent, PCB – polychlorinated biphenyl, POP – persistent organic pollutant, pg/g – pictogram/gram, PCDD – polychlorinated dibenzodioxins