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Anthropogenic impacts on green turtles *Chelonia mydas* in New Zealand

Daniel A. Godoy*, Karen A. Stockin

Coastal-Marine Research Group, Institute of Natural and Mathematical Sciences, Massey University, Albany, Auckland 0745, New Zealand

ABSTRACT: Conservation strategies to sustain endangered green turtle *Chelonia mydas* populations must categorise and mitigate a range of anthropogenic threats. This study provides first insights into some of the adverse effects of anthropogenic activities on green turtles at a foraging area in New Zealand. Gross necropsies were conducted on 35 immature and sub-adult green turtles that were stranded in northern New Zealand between 2007 and 2013. Results revealed 54% (n = 19) of individuals exhibited human-related trauma, and 63% of these (n = 12) had ingested synthetic marine debris. The predominant plastic items ingested were soft plastics (e.g. single-use food packaging, plastic bags), and white, clear or translucent items. No correlation was observed between curved carapace length and the volume or number of synthetic debris items ingested. Propeller strike injuries were identified in 26% (n = 5) of turtles exhibiting human-related effects, while 10% (n = 2) had evidence of incidental capture in recreational fishing activities. Importantly, within New Zealand waters, anthropogenic effects predominantly associated with plastic ingestion are impacting the green turtle aggregation, and may be an important contributory factor to the stranding of immature and sub-adult green turtles in this region. Consequently, the threats identified in this study should be considered when developing population-specific conservation strategies.

KEY WORDS: Marine debris ingestion · Single-use plastics · Propeller strike · Incidental capture · Fisheries bycatch · Species conservation

INTRODUCTION

In recent history, human activities have led to a substantial decline in marine biodiversity worldwide (Lewison et al. 2004, Crowder & Norse 2005, Pereira et al. 2012). These activities include overexploitation and harvesting, bycatch, habitat loss and degradation, pollution, and climate change (Derraik 2002, Newson et al. 2009, Block et al. 2011, Burrows et al. 2011, Gilman 2011). In addition, of increasing concern is the significant and wide-ranging environmental impact of synthetic marine debris, especially plastic pollution (Gregory 2009, Law et al. 2010, Carson 2013). Knowledge of the impact of anthropogenic threats on threatened marine species across temporal and spatial scales is therefore a critical component of any conservation management plan (Wallace et al. 2011, Koch et al. 2013).

Marine turtles are widely distributed throughout tropical and temperate regions, (Pritchard 1997). These highly migratory species exhibit complex life history patterns that encompass coastal nesting areas, neritic foraging grounds, oceanic habitats, and long-distance migratory pathways (Balazs 1976, Hirth 1997, Lohmann & Lohmann 1998, Bolten 2003, Luschi et al. 2003, Boyle & Limpus 2008). Accordingly, marine turtles are exposed to numerous anthropogenic effects across their distributional range and life cycle (Eckert 1995). Thus, although historically abundant, 6 of 7 species have experienced significant declines glob-

*Corresponding author: d.a.godoy@massey.ac.nz

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ally and are now considered Threatened or more under the Red List of the International Union for Conservation of Nature (Seminoff 2004, Abreu-Grobois & Plotkin 2008, Mortimer & Donnelly 2008, Wallace et al. 2013a, Casale & Tucker 2017). Given the complex life history, wide ranging distribution, and significant anthropogenic threats marine turtles are exposed to throughout their lives, conservation managers need an understanding of the types and extent of anthropogenic mortality to formulate appropriate population-specific mitigation (Seminoff et al. 2002, Wallace et al. 2011, Wallace et al. 2013b).

Marine turtles occupying coastal foraging habitats are at risk of adverse anthropogenic effects including fisheries bycatch, vessel collision, and entanglement in and ingestion of synthetic marine debris (Denkinger et al. 2013, Wallace et al. 2013b, Lewison et al. 2014, Schuyler et al. 2014, Nelms et al. 2016). Marine turtles ingest synthetic marine debris inadvertently if mixed or attached to natural diet items, or if mistaken for natural prey or forage (Carr 1987, Hoarau et al. 2014, Casale et al. 2016). Ingested synthetic debris can accumulate and obstruct, harm, or cause inflammation of the digestive tract, leading to reduced digestive ability, reduced fitness, and even possible mortality (Bjorndal et al. 1994, Casale et al. 2016, Nelms et al. 2016, Schuyler et al. 2016). Other lesser-known consequences of synthetic debris ingestion are dietary dilution (McCauley & Bjorndal 1999) and the sublethal effects of desorbed or leached organic contaminants from plastics (Moore 2008, Teuten et al. 2009, Engler 2012, Nelms et al. 2016). Schuyler et al. (2012) reported that neritic foraging marine turtles selectively consumed soft clear and white plastics, which resembled their natural prey, such as jellyfish (Carr 1987, Bugoni et al. 2001, Campani et al. 2013). In this regard, Plotkin & Amos (1990) suggested that small turtles (particularly pelagic stage juveniles) were more likely to ingest plastics, while older neritic phase sub-adults and adults exhibited a size-correlated decrease in plastic consumption. Conversely, Tomás et al. (2002) concluded that the volume of plastic ingested correlated with an increase in curved carapace length (CCL) in loggerhead turtles *Caretta caretta* in the Mediterranean Sea.

Entanglement in synthetic marine debris (including discarded or lost fishing gear) and bycatch in fisheries activities poses a major threat to marine turtles worldwide (Laist 1997, Lewison et al. 2004, Jensen et al. 2013, Wallace et al. 2013b, Wilcox et al. 2013, Clarke et al. 2014). Incidental capture of marine turtles in pelagic longline, trawl, and coastal gillnet fisheries has also been widely reported (Crowder et al. 1995, McCracken 2000, Robins et al. 2002, Tomás et al. 2008, Donoso & Dutton 2010, Wallace et al. 2013b). In addition, for many air-breathing vertebrates (e.g. marine mammals and turtles), vessel-related injuries such as propeller strike and blunt force trauma caused by vessel collision may also represent a major cause of injury and mortality (Stockin et al. 2009, Work et al. 2010). For example, in populated coastal communities, such as southeast Florida, up to 60% of stranded loggerhead turtles exhibit propeller strike injuries (Work et al. 2010).

Monitoring free-ranging marine turtles for anthropogenic impacts at coastal foraging grounds is logistically challenging and therefore often overlooked (Seminoff et al. 2003, Chaloupka et al. 2008, Nelms et al. 2016). However, examinations of stranded turtles from coastal foraging grounds can be used to elucidate key threats to a foraging aggregation (Chaloupka et al. 2008, Cole et al. 2011, Koch et al. 2013). For instance, Casale et al. (2016) suggested that stranded turtles are a good representative of neritic coastal foragers, and thus can reveal important information on the threats and risks to resident populations (Chaloupka et al. 2008). In turn, information derived from such studies can highlight specific population-level impacts and inform future mitigation and conservation strategies (Crowder et al. 1995, Wallace et al. 2011, Casale et al. 2016, Nelms et al. 2016).

In New Zealand, recent research has identified a temperate neritic foraging aggregation of immature green turtles (Godoy et al. 2016, Godoy 2017). The aggregation comprises a mixed-stock foraging ground with links to several genetically distinct management units that span the Pacific Ocean region (Godoy 2017). Although bycatch data suggest green turtles are at risk of incidental capture in commercial fisheries waters around New Zealand (Godoy 2016), other potential threats have not been investigated. Here, we assessed the frequency of anthropogenic effects on green turtles in New Zealand by undertaking post mortem examinations of stranded carcasses. Stranded turtles were assessed to (1) investigate the ingestion of synthetic marine debris and ascertain whether there was a correlation between size (CCL) and number or volume items ingested, (2) determine the type and colour of synthetic debris ingested, (3) identify evidence of entanglement, vessel collision, and bycatch, and (4) describe any other significant contributing factors to green turtle mortality.

MATERIALS AND METHODS

Between 2007 and 2013, a total of 48 stranded green turtles were reported in New Zealand (Godoy et al. 2016). Of these, 35 were recovered and assessed for anthropogenic impacts using standard necropsy techniques (Wolke & George 1981, Flint et al. 2009b). Stranding date, location, and standard CCL (±0.1 cm SD) measurements were recorded (Limpus et al. 1994, Bolten 1999). Sex and maturity status were determined by visual or histological examination of the gonads and associated ducts following Rainey (1981) and Limpus & Reed (1985). Gross lesions, abnormalities, and other potentially relevant indicators were recorded, measured, and photographed.

To investigate whether synthetic debris had been ingested and where it had accumulated, the entire gastrointestinal track was removed and divided into anterior (oesophagus and stomach) and posterior (small and large intestine) sections. The gut was examined for areas of impaction, haemorrhaging, or lesions caused by ingested synthetic debris (as per Flint et al. 2009b). The location of any impaction or related observation within the gastrointestinal tract was recorded and photographed. The contents were then collected and rinsed through a 0.5 mm fine mesh sieve. Any recovered synthetic debris was washed and dried at room temperature for processing, while all diet items or natural debris (e.g. wood, pumice, feathers) were separated for diet component analysis (Godoy 2017). For each turtle sampled, synthetic debris items were identified and categorised according to type as described in Schuyler et al. (2012): hard plastic, soft plastic, synthetic rope or twine, non-synthetic rope, fishing items, balloons, other rubber, foam, other (e.g. tar or oil, metal, glass, cloth); and according to colour: white, clear or translucent, red, orange, yellow, green, blue, brown, black, other. The total number of each type and colour of synthetic debris within each turtle was recorded, weighed (±0.01 g), and volume measured using the volume displacement method with ethanol in a graduated cylinder (±0.1 ml) (Schuyler et al. 2012, Santos et al. 2015a). The total frequency of occurrence (FO) of each type and colour was subsequently quantified (Schuyler et al. 2012). The relative percent abundance of each type and colour of ingested synthetic debris was also calculated for each turtle and expressed as the mean percentage (%A ± SE) for the entire sample (Schuyler et al. 2012). To investigate the relationship between CCL and the number of synthetic debris items ingested per turtle, a generalised linear model (GLM) was fitted to the data (McCullagh & Nelder 1989). A linear regression analysis was performed to determine the relationship between CCL and the ingested volume of synthetic debris items. Volumes were log transformed for regression analysis and alpha was set at 0.05. Analyses were performed using R software (R Development Core Team 2014).

During gross necropsy, turtles were examined for evidence of entanglement in synthetic marine debris, fishing interaction, or vessel strike injuries. Categories were defined as (1) entanglement: turtles presented with evidence of interaction with either discarded fishing gear or other type of synthetic marine debris (i.e. linear rope marks, external lesions, and indentations); (2) fishing interaction: turtles presented with evidence of interaction with active fishing-related gear (e.g. set nets, crayfish pots) or hooks were observed embedded externally (e.g. mouth cavity or flipper) or internally (e.g. swallowed hook and line); (3) vessel or propeller strike: identified as catastrophic blunt trauma (e.g. fractures, haemorrhaging), as multiple evenly spaced parallel lacerations (propeller), or single linear laceration (skeg) (Norem 2005, Flint et al. 2009b, Work et al. 2010, Martinez & Stockin 2013). A catastrophic injury was defined as any wound that fractured or penetrated the carapace or body, compromising the coelomic cavity, thus presumably causing immediate or delayed mortality via infection (Work et al. 2010).

For each turtle examined, the likely cause or significant contributing factor to mortality was determined based on the most significant and severe finding. For example, where a catastrophic vessel collision injury was identified, and no other external or internal gross pathology observed, vessel strike was considered the most likely cause of mortality. Given the small sample size overall, seasonal, sex, and size class effects could not be statistically tested, therefore only a descriptive summary for each factor is presented.

RESULTS

All turtles were found stranded (alive or dead) on the coastline of the North Island between ca. 38° and 34° S. Stranded turtles were recorded in slightly higher abundance during austral spring (n = 15) compared with summer (n = 6), autumn (n = 10), and winter (n = 4). Turtles ranged in size from 37.3 to 94.6 cm CCL ($\bar{x}$ = 51.9 cm, SD = 12.3, n = 35). All turtles were immature juveniles to large sub-adults of both sexes (19 female, 12 male, 4 undetermined). Of the 35 carcasses assessed for anthropogenic trauma, 54% (n = 19) exhibited evidence of human impacts. Twelve individuals (34%) had ingested synthetic debris.

All but one turtle (ID: 064) contained natural digesta in their gastrointestinal tract. The one exception was also devoid of synthetic debris. In total, 791 pieces of synthetic debris were ingested by 12 turtles, with a mean of 65.9 ± 37.0 (SE) pieces per turtle, although ingestion rate was highly variable between individuals (range = 1–432). Similarly, ingested volumes also varied greatly between individuals (range = 0.1–45 ml, $\tilde{x}$ = 8.6 ml, SE = 4.6). The GLM revealed no correlation between CCL and the number of pieces ingested (χ^2_{10} = 1.74, p = 0.187). Similarly, linear regression analysis revealed no correlation between CCL and the volume of synthetic debris ingested ($F_{1,10}$ = 1.03, p = 0.334).

Soft plastic was the most frequent type of plastic consumed (FO = 91.7%) and in the largest relative quantity (%A = 56.7 ± 9.8; Table 1, Fig. 1). In addition, white (FO = 66.7, %A = 24.5 ± 8.9) and clear or translucent categories (FO = 83.3, %A = 49.6 ± 10.3) were most frequently consumed and in the highest relative quantities (Table 2, Fig. 1). Synthetic debris types identified included single-use plastics such as food packaging, balloons, and bags, while fishing line and synthetic 'soft bait' lures were also recorded (Fig. 1, Fig. S1 in the Supplement at www.int-res.com/articles/suppl/n037p001_supp.pdf). Of the 12 turtles with ingested synthetic debris, 9 contained synthetic debris only in the posterior tract (small and large intestines), while 3 contained synthetic debris in the anterior (stomach) and posterior tract. Four turtles contained significant amounts of ingested synthetic debris leading to severe impaction of the gastrointestinal tract, with perforation of the intestinal wall recorded in 1 individual (ID: 076). In addition, 1 turtle had ingested fishing line measuring 122.5 cm that

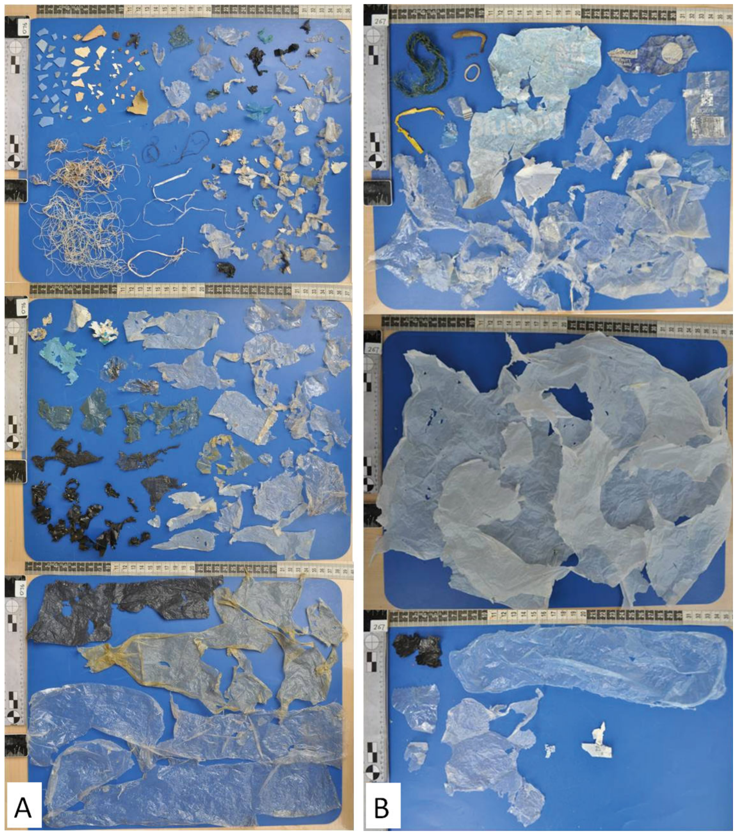

Fig. 1. Examples of synthetic debris ingested by 2 stranded turtles in New Zealand. (A) Turtle A (ID: 076, 43.7 cm CCL, 7.7 kg) and (B) turtle B (ID: 267, 66.4 cm CCL, 28.3 kg) exemplifying the prevalence of soft, white and clear or translucent plastics ingested

Table 1. Frequency of occurrence (FO, %) and relative percentage abundance (%A ± SE) of synthetic marine debris types observed in the gastrointestinal tract of stranded immature and sub-adult green turtles in New Zealand (n = 12)

Synthetic debris colour	n	FO	%A ± SE
Soft plastic	11	91.7	56.7 ± 9.8
Plastic rope or twine	8	66.7	21.3 ± 6.4
Hard plastic	5	41.7	10.2 ± 4.8
Fishing items	1	8.3	8.3 ± 8.3
Other rubber	3	25.0	2.9 ± 2.8
Balloons	2	16.7	0.6 ± 0.4
Total			100

Table 2. Frequency of occurrence (FO, %) and relative percentage abundance (%A ± SE) of synthetic marine debris colours recorded in the gastrointestinal tract of stranded immature and sub-adult green turtles in New Zealand (n = 12)

Synthetic debris colour	n	FO	%A ± SE
Clear or translucent	10	83.3	49.6 ± 10.3
White	8	66.7	24.5 ± 8.9
Blue	6	50.0	7.8 ± 4.1
Black	5	41.7	1.6 ± 0.8
Green	4	33.3	3.3 ± 1.7
Yellow	4	33.3	4.9 ± 4.1
Orange	2	16.7	0.2 ± 0.1
Red	1	8.3	2.8 ± 2.8
Brown	3	25.0	1.5 ± 1.1
Other	3	25.0	3.7 ± 2.8
Total			100

had become lodged in the small intestine, causing severe plication and granulomatous inflammation of the surrounding tissue.

Of the 35 turtles assessed for vessel-related injuries, 5 (14 %) exhibited clear evidence of catastrophic propeller strike injuries (e.g. Fig. 2). A further 2 turtles (6 %) had been categorised as incidentally caught given that recreational hooks were embedded in the oesophagus anteriorly between the tongue and the glottis (Fig. S2 in the Supplement). No turtles exhibited injuries or marks consistent with entanglement either in active or discarded fishing gear, or other synthetic debris.

In the absence of forensic examination, the cause of death could not be conclusively determined, although significant contributing factors were evident in 11 cases. Four turtles exhibited significant gut impaction or intestinal plication; 5 were presented with catastrophic propeller strike injuries; and 2 exhibited evidence of incidental capture in recreational fishing activities.

DISCUSSION

Gross necropsies were conducted on stranded green turtles found on New Zealand's northern coastline between 2007 and 2013 to identify and describe the anthropogenic impacts that may threaten green turtles in New Zealand waters. Overall, 54 % (n = 19) of stranded turtles exhibited anthropogenic impacts, suggesting human activities may have a substantial influence on the stranding rate of green turtles in the New Zealand aggregation. Observed impacts include the ingestion of synthetic marine debris (of terrestrial and marine origin), vessel strike injuries, and incidental capture in recreational fishing activities. The size range of turtles observed in this study was markedly similar to those seen in Godoy et al. (2016), and thus we consider the turtles sampled here as an accurate reflection of the broader population structure (Fig. S3 in the Supplement).

Synthetic debris ingestion

The extent of synthetic debris ingestion identified here was similar to the amounts reported for benthic foraging green turtles in Australia (Schuyler et al. 2012) and fell mid-range within the levels reviewed from studies worldwide by Nelms et al. (2016). Similarly, studies at other foraging grounds, including the Mediterranean (Casale et al. 2016), southern Brazil (Bugoni et al. 2001), and eastern Australia (Schuyler et al. 2012), showed that soft plastics and white or clear or translucent items are the most prevalent synthetic debris types ingested. It is unclear whether the items consumed by green turtles in New Zealand proportionally reflect the quantity of synthetic marine debris discharged (and therefore available for incidental consumption) or whether they are selectivity consumed i.e. mistaken for natural forage or prey.

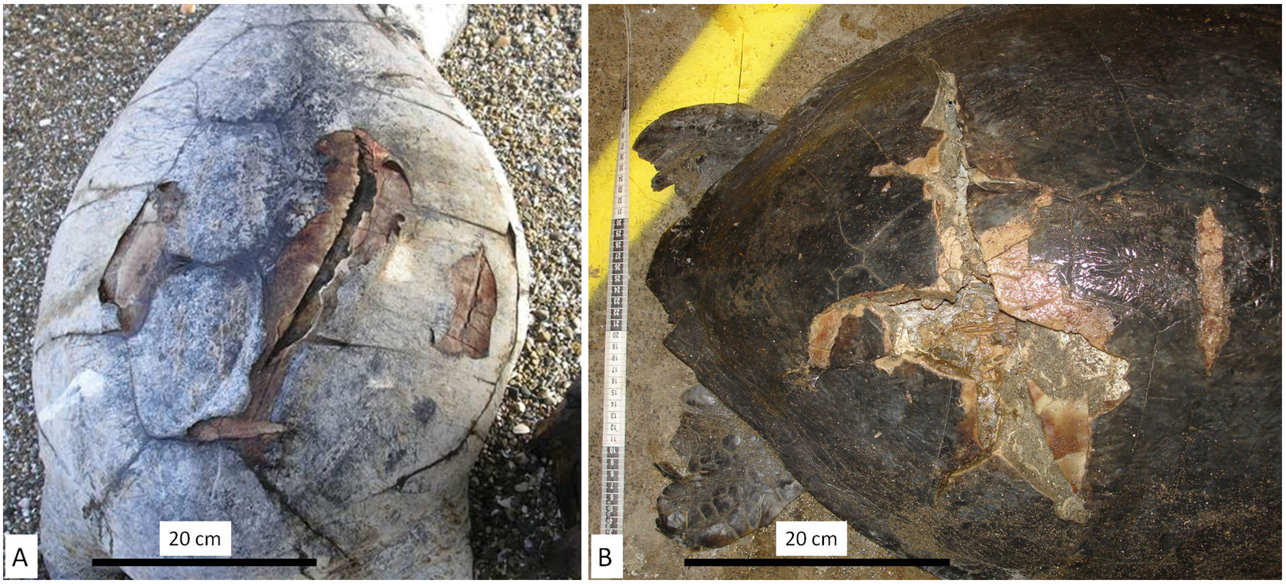

Fig. 2. Examples of 2 stranded green turtles exhibiting catastrophic propeller strike injuries. Note the evenly spaced parallel lacerations causing severe fracture and penetration of the carapace in both (A) turtle A (ID: 094, 77.3 cm CCL) and (B) turtle B (ID: 267, 76.2 cm CCL)

However, Schuyler et al. (2012) reported that when compared with marine litter abundance (as a measure of availability) in eastern Australia, neritic turtles selectively consumed white and clear soft plastics over hard and coloured items. In addition, of particular note was a prevalence of single-use plastics (e.g. food packaging and plastic bags) recorded in the gastrointestinal tracts of several turtles. The pervasiveness of single-use plastics observed in this study and others (e.g. Santos et al. 2015b) is concerning given that this category of plastic has been shown to be the fastest-growing component of waste today (Moore 2008).

The adverse impact of discarded land-based plastic waste on marine species is often further intensified where large urban centres are located near coastal zones, as opposed to non-urban or rural regions, because they often generate and discharge relatively higher volumes of plastic pollution out to sea (Moore 2008). For marine turtles occupying neritic foraging grounds near these highly urbanised areas, the impact of discharged waste may therefore have a considerable negative effect (Nelms et al. 2016). Auckland, New Zealand's largest urban and industrialized centre, is located adjacent to the Hauraki Gulf, where compared with other national centres, relatively high discharged concentrations of marine litter have been recorded (Gregory 1991, Backhurst & Cole 2000, Bayley & Goodyear 2004, Young & Adams 2010). Accordingly, because this region also overlaps a core neritic habitat for green turtles in New Zealand (Godoy et al. 2016), we consider individuals occupying this region may be at higher risk of marine debris ingestion than turtles from other parts of New Zealand. In addition, given the lack of correlation between the size of turtles examined and the volume or number of pieces ingested, the data suggest that the risk of synthetic debris ingestion is uniform across the aggregation, which is in accordance with other studies of similar-sized neritic foraging green turtles (e.g. Bugoni et al. 2001, Schuyler et al. 2012).

Vessel collision and fisheries interactions

Given that post-pelagic green turtles often recruit to occupy shallow embayments, estuaries, and harbours (Hirth 1997, Limpus et al. 2005, Koch et al. 2007, Bresette et al. 2010), they are also at risk of vessel collision injuries and bycatch, particularly in areas adjacent to densely populated coastal regions (Limpus et al. 1994). Our results support this, since 86% of all turtles exhibiting vessel collision injuries (propeller strike) or captured in recreational fisheries, were recovered near Auckland (Waitemata) or Whangarei harbours. These highly urbanised regions have high levels of recreational and commercial vessel traffic and have been shown to also have higher incidences of fatal vessel collisions for marine mammals (Martinez & Stockin 2013, Dwyer et al. 2014). Although there was evidence of incidental capture in recreational fisheries, commercial fisheries interactions were not identified. Despite this, recent research suggests that green turtles occupying this northeastern region of New Zealand are at risk from inshore commercial fisheries activities (Godoy 2016).

Entanglement was not identified as a cause of injury or mortality in this study; however, mortality caused by entanglement (mainly via asphyxia and drowning) in fishing nets is difficult to identify due to an absence of visible lesions and is, therefore, often underestimated (Bugoni et al. 2001). Despite a lack of evidence of entanglement of green turtles in the present study entanglement of other marine species in fishing gear in New Zealand has been observed, including leatherback turtles *Dermochelys coriacea* (D. A. Godoy et al. unpubl.), marine mammals (Slooten & Dawson 1995, Boren et al. 2006, Stockin et al. 2009), and seabirds (Abraham & Thompson 2011, Bell 2014). Furthermore, entanglement in active or discarded fishing gear is a significant issue for marine turtle mortality in other regions (e.g. northern Australia and the Mediterranean) and therefore its potential risk in New Zealand cannot be overlooked (Nelms et al. 2016, Schuyler et al. 2016).

Causes of mortality

Conclusively diagnosing the cause of mortality in stranded marine animals is difficult and requires comprehensive histopathological post-mortem examinations of fresh carcasses (Chaloupka et al. 2008, Flint et al. 2009a, Stockin et al. 2009). It should be noted, therefore, that comprehensive histopathological or toxicological samples were not collected during gross necropsies, and therefore other effects (e.g. disease, anthropogenic related chemical toxicity) were not examined here. While this was not logistically feasible in the present study, in several cases reported herein, gross necropsies still revealed incidences of ingested synthetic debris, incidental capture, and catastrophic propeller strike trauma severe enough to conclude that these factors were the leading probable cause of mortality. For example, propeller strike was deemed the leading probable cause of mortality in at least 2 cases given that (1) antemortem body condition was good (absence of muscle or adipose atrophy), (2) there was an absence of any obvious gross pathology (abnormalities, lesions, epibiont or parasite load), and (3) significant hemorrhaging and trauma was evident around the wound sites, indicating the turtles were alive at the time of impact. In addition, fresh digesta in the stomach and crop suggested they had been foraging immediately prior to death. Therefore, evidence suggests that in both cases, these turtles died because of the injuries sustained.

In relation to mortality due to ingested synthetic marine debris, 4 turtles exhibited severe gut impaction of the intestinal tract due to the accumulation of synthetic debris. This resulted in severe inflammation, perforation, or plication of the intestinal tract, leading to the conclusion (based on gross analysis) that these turtles most probably died because of ingesting synthetic marine debris. Such an inference is plausible given that Santos et al. (2015b) quantified that amounts as low as 0.5 g are sufficient to block the digestive tract and cause death in juvenile turtles. In their study, synthetic debris-induced mortality was estimated at 39.4% compared with 42% reported here.

CONCLUSION

This study provides the first description of the predominant sources of anthropogenic impacts affecting green turtle populations within northern New Zealand. The range and magnitude of impact observed herein reflects the threats reported globally, with ingested synthetic debris and propeller strike being the most important precursors to stranding and mortality. However, the present work suggests that the risk of such impacts will be considerably higher for turtles inhabiting neritic habitats adjacent to densely populated urban centres of northeastern New Zealand. Importantly, the focal aggregation comprises a mixed-stock foraging ground with links to genetically distinct populations from across the Pacific Ocean (Godoy 2017). Thus, this study identifies several adverse human impacts that may impact those distant source populations of this wide-ranging endangered species. In turn, this underscores the need to consider all potential threats across a population's entire distributional range and congruent jurisdictions to appropriately scale conservation strategies.

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