Review of commercial fishing interactions with marine reptiles

Prepared for Department of Conservation

July 2022

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NIWA CLIENT REPORT No:	2022147WN
Report date:	July 2022
NIWA Project:	INT2021-03

Revision	Description	Date
Version 1.0		Day Month Year
Version 1.1	Amendments to …	Day Month Year

Quality Assurance Statement		
	Reviewed by:	Owen Anderson
	Formatting checked by:	Chloe Hauraki
	Approved for release by:	Richard O'Driscoll

Dunn, M.R.; Finucci, B.; Pinkerton, M.H.; Sutton, P. (2022). Review of commercial fishing interactions with marine reptiles. NIWA Client Report 2022147WN. 78 p.

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Executive summary

This project has updated and characterised protected marine reptile fishery captures in New Zealand waters to the 2021 fishing year. Five species of sea turtle (leatherback, green, hawksbill, loggerhead, and olive ridley) and four species of sea snake and kraits (yellow-lipped, Saint-Girons, blue-lipped, and yellow bellied) are known to occur in New Zealand waters and all are protected under the Wildlife Act 1953

Between 2007–08 and 2020–21, there were a total of 273 reported captures of turtles, an average of 19.5 per year, and one capture of a sea snake. Of these, 49 were recorded by Ministry observers. In commercial fishing returns, five species of turtles were reported, with leatherback being the most frequently captured (n = 217; 79.5%), following by green turtles (n = 25; 9.2%). In the observed records, 37 (76%) were leatherback turtles. Most captures, across all species, were made in the surface longline fisheries targeting bigeye tuna or swordfish in FMA 1 (northeast North Island), where such fishing effort was also greatest, largely between January and April. The single sea snake, a banded sea krait, was caught during bottom longline fishing targeting tarakihi. The turtle captures varied between 2–34 per year until 2020–21, when they increased to 58.

For the main turtle capture area and season, FMA 1 and January to April inclusive, between 2007–08 and 2020–21, most of the reported turtle captures (86.6%) were made by vessels which did not have an observer aboard. Of the 53 vessels in the selected fishery, 10 (18.9%) had reported turtle bycatch, and just five of the 10 reported 90.7% of the turtle captures, with one vessel alone reporting 38.7% of all captures. This vessel was only observed in 2020, when it accounted for 33.0% of the observed events, and 2021, when it accounted for 47.3% of the observed events. That observers were on this vessel in 2021, and the times and places that it fished, may partially explain why the observer turtle capture total was so much higher in 2020–21.

Evaluation of the environmental variables and the captures of leatherback turtles suggested the primary influence on turtle capture was likely to be water temperature, followed by frontal zones, ocean currents, and water clarity, with primary productivity having relatively little influence. Leatherback turtle captures were predicted to be most likely when sea surface temperatures were between about 14–22°C, when subsurface temperature at 200m was relatively warm, in the first two-thirds of the calendar year, when the mixed layer depth was relatively shallow, when time varying eastward currents were either negative or relatively strong, at latitudes south of about 42°S (i.e., west coast South Island), and when vessels were targeting swordfish.

Given the IUCN “vulnerable to critically endangered” status of these species, there is a need to reduce turtle captures in New Zealand fisheries. Overseas recommendations propose that an achievable turtle capture rate (all species combined) should be less than 0.019 turtles per 1000 hooks for surface longline fisheries. Averaged between 2008 and 2021, leatherback turtle capture rates alone were at least 0.019 turtles per 1000 hooks in FMA1 between January and April. A previous iteration of this work provided recommendations to better monitor marine reptile captures in New Zealand and to date, little progress has been made on any of these. It is highly recommended that these proposals are adopted, including the implementation and monitoring of a minimal sea turtle interaction rate; guidelines to reduce sea turtle mortality; revision of observer coverage allocation; improved data quality and reporting; and improved population information and research. Additional recommendations made here include the implementation of set capture limits (absolute captures) rather than catch rate limit, further collection of biological information, improved estimation of capture rates through communication with skippers, and further investigation of alternative data sources.

1 Introduction

1.1 Scope of report

Five species of sea turtle and four species of sea snake and kraits have been recorded from New Zealand waters and all are protected under the Wildlife Act 1953 (Table 1). All sea turtle species are listed on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species as threatened species (Critically Endangered, Endangered, or Vulnerable). The sea snake and krait species recorded in New Zealand are all listed as Least Concern on the IUCN Red List. Leatherback and green turtles have been the marine reptiles most frequently reported as bycatch in commercial fisheries, likely reflecting a higher occurrence in New Zealand waters (Godoy, 2016).

Table 1: Marine reptiles found in New Zealand waters. Since 1996, all marine reptiles have been fully protected out to 200 nautical miles under the Wildlife Act 1953. IUCN Red List regional status (www.iucnredlist.org) for the western and/or southern Pacific population is reported where available, otherwise the IUCN Red List classification shown is global. *previously *Pelamis platura*.

Common name	Scientific name	NZ Status; IUCN Red List Status
Leatherback turtle	*Dermochelys coriacea*	Protected; Critically Endangered
Green turtle	*Chelonia mydas*	Protected; Endangered
Hawksbill turtle	*Eretmochelys imbricata*	Protected; Critically Endangered
Loggerhead turtle	*Caretta caretta*	Protected; Critically Endangered
Olive ridley turtle	*Lepidochelys olivacea*	Protected; Vulnerable
Yellow-lipped sea krait	*Laticauda colubrina*	Protected; Least Concern
Saint-Girons' sea krait	*Laticauda saintgironsi*	Protected; Least Concern
Blue-lipped sea krait	*Laticauda laticaudata*	Protected; Least Concern
Yellow-bellied sea snake	*Hydrophis platura**	Protected; Least Concern

The last review of bycatch of marine reptiles covered the period to 2015 (Godoy 2016). That report found no fisheries bycatch of sea snakes, and that most turtle bycatch events were from surface longlines fishing off northeast New Zealand in summer. Godoy (2016) also found Ministry observer coverage was very low in the places and times at which turtle bycatch was most likely, and in some years the turtle bycatch rate in surface longlines fisheries exceeded the level recommended by the Western and Central Pacific Fisheries Commission.

Reporting of turtle bycatch by commercial fishers has been considered unreliable and incomplete (Godoy 2016). Thus, the turtle bycatch rate in New Zealand surface longline fisheries has been estimated by Abraham et al. (2021) by scaling Ministry observed captures to overall commercial fishing returns using a statistical model. The model included coefficients such as number of hooks, vessel size, area and month fished, and estimates of sea surface temperature and chlorophyll a. Abraham et al. (2021) estimated 53 (95% CI 27–86) captures of all turtle species for the fishing year 2017–18 (New Zealand fishing years start on 1 October), just over an order of magnitude higher than was actually observed. High uncertainty in bycatch estimates was estimated, and is expected, because observer coverage has been low. Godoy (2016) reported the proportion of turtle captures seen by observers to be about 9%.

The objectives of the research presented here was essentially to update the Godoy (2016) report, specifically to:

1. Characterise commercial fishery interactions with marine reptiles, particularly sea turtles, within New Zealand fishery waters.

2. Report on total numbers of captures and fate of bycaught marine reptiles by species, fishery, and year.

3. Identify species most at risk from commercial fishing and fisheries with the highest observed or reported catches of marine reptiles.

1.2 Status of populations

The most encountered and vulnerable marine reptile in New Zealand waters would appear to be the leatherback turtle (Godoy, 2016). Leatherback turtles suffered a sharp global population decline of over 95% in the last two decades of the 20th Century, and by the late 1990s were described as facing imminent extinction in the Pacific (Spotila et al., 2000). The Malaysian leatherback stock (subpopulation), where historically at least 3000 nests per year had been reported, has become functionally extinct (Dutton et al., 2007; Benson et al., 2011; Tapilatu et al., 2013). The largest remaining nesting aggregation in the western Pacific, which is a metapopulation with nesting all year, is at Papua Barat in Indonesia, with additional nesting also in the Solomon Islands, Papua New Guinea, and Vanuatu (Dutton et al., 2007). To estimate the number of animals remaining, the number of nests observed is scaled to the number of nesting females, and the number of nesting females to the number of adults. Using information between 1999 and 2004, Dutton et al. (2007) estimated the western Pacific to have between about 5000–9200 nests a year, and assuming leatherbacks lay five nests per season, this would indicate about 1000–1840 females nesting per year. With an assumption that nesting takes place every 2.5 years, the population would be about 2700–4500 breeding females. Uncertainty in this estimate was not quantified but is likely to be high (Dutton et al., 2007). The sex ratio and number of males does not seem to have been quantified. Leatherback turtles encountered around New Zealand are most likely to be from the western Pacific population, and from the nesting beaches at Papua Barat and the Solomon Islands in particular (Benson et al., 2011). The Papua Barat nesting females were estimated to be declining at an average rate of 5.9% per year between 1984 and 2011, and the number of females nesting annually was estimated to be 464–612 in 2011 (Tapilatu et al., 2013). At the same location, Martin et al. (2020) estimated an annual declining trend of 6.1% based on 2001–2017 nesting data, estimating the number of annual nesting females in 2017 to be 787. These estimates are thought to cover about 75% of the western Pacific nesting turtles and are therefore likely indicators of trend, although underestimates of absolute abundance, which in 2017 might have been just over 1000 females nesting annually (Martin et al., 2020). Perhaps 30 to 50 females are thought to nest at the Solomon Islands, but data for this region are sparse (Pilcher, 2021). Martin et al. (2020) predicted extinction of Pacific leatherbacks to be about as likely as not by the end of the 21st Century.

The green turtles encountered around northern New Zealand are thought to originate from several different stocks that span the Pacific, within which many nesting locations are known (Pilcher, 2021), with New Zealand being a temperate and persistent mixed-stock nursery ground (Godoy et al., 2016; Godoy 2017). It has been speculated that juvenile green turtles around New Zealand arrive primarily by following the subtropical Tasman Front (East Auckland current), and based upon the sizes observed, they leave New Zealand waters prior to the onset of puberty (Godoy & Stockin 2018). New Zealand climatic conditions fall outside of the preferred thermal envelope for green turtles during winter, and it is possible that turtles may leave coastal areas and resume offshore pelagic foraging in winter (Williard et al., 2017). The Australian Great Barrier Reef (GBR) region hosts some of the largest nesting populations of green turtles (variable, but up to around 25,000 nesting females per year; Seminoff 2004; Maison et al., 2010) and are a plausible source of juvenile green turtles found in New Zealand. Therefore, although listed as Endangered, green turtle abundance from the GBR alone has been estimated to be more than an order of magnitude higher than leatherback abundance. Other Pacific stocks of green turtles are known to nest in Hawaii, Indonesia, Philippines, Malaysia, Thailand, Mexico, and Ecuador (Seminoff 2004). The IUCN recognises that the green turtle population and threat assessment is getting old (2004) and needs to be updated.

Leatherback and green turtles are the species most frequently caught around New Zealand. Other marine reptiles are encountered less often and include loggerhead, hawksbill, and olive ridley turtles, and sea snakes. There are few data on the status of the South Pacific stock of loggerhead turtles, but the stock is known to have declined and thought to be small, accounting for only about 1% of global loggerhead numbers, with most loggerheads occurring in the northwest Atlantic and Indian Oceans (Casale & Tucker 2017; Pilcher, 2021). Loggerheads in the South Pacific nest on northern Australia and New Caledonia beaches, and hatchlings may travel large distances, reaching the west coast of South America and New Zealand (Godoy 2016; Madden Hof et al., 2020). Although numbers of nesting loggerhead females in the South Pacific may have increased after declines through the 1980s and 1990s, so have threats to post-hatchlings, hampering population recovery (Limpus & Limpus 2003; Madden Hof et al., 2020). Whilst there has been circumstantial evidence for nesting of loggerheads in northern New Zealand, it is highly unlikely that eggs could successfully incubate to produce hatchlings (Limpus & Limpus 2003).

There are six stocks of hawksbill turtles assumed for the Pacific, with the largest being in the Indo-Pacific and eastern Australia, but population numbers have dramatically declined (by about 75% over the last three generations) and the stocks are considered Critically Endangered (Groombridge & Luxmoore 1989). The southwest Pacific stock size may be around 1000–2000 nesting females per year (Pilcher, 2021). Hawksbill turtles are associated with tropical and subtropical waters, and are less common in New Zealand's temperate waters, but strandings of juveniles and sub-adults have been reported around northern New Zealand in winter (Godoy, 2016). Some records of hawksbill turtles are suspected to be misidentification (Godoy 2016).

Olive ridley turtles are a tropical to warm temperate species, and around New Zealand they are most often seen as beach strandings, and very rarely seen as fisheries bycatch even though capture by trawl and longline fisheries is known elsewhere (Abreu-Grobois & Plotkin 2008; Godoy 2016). The olive ridley turtles around New Zealand are most likely to originate from the western Pacific population, which has nesting sites in northern Australia and Indonesia, with New Zealand waters used as a foraging or migratory area (Abreu-Grobois & Plotkin 2008). Very little information is available on the size and status of the west Pacific olive ridley stock (Picher, 2021). Olive ridley turtles are considered globally Vulnerable and in decline, although more abundant than most turtle species (Abreu-Grobois & Plotkin 2008). Information about the population that occurs in New Zealand waters is lacking.

There are 19 species of sea snakes known in Oceania and four are known from New Zealand (Godoy 2016). Sea snakes in New Zealand have been found beach stranded, predominantly in northern New Zealand, and all have been thought to be adult (Godoy 2016). There are no previous records of sea snakes as fishery bycatch in New Zealand (Godoy 2016), although their presence as an unwanted bycatch in Australian prawn fisheries is well-described (Milton 2001; Udyawar et al., 2020) and snakes can be a valuable bycatch in some trawl fisheries across southeast Asia (Van Cao et al. 2014). The population structure and trends for sea snake populations that use New Zealand waters is unknown, and sea snakes are relatively poorly known (Udyawer et al., 2018) but the IUCN considers the populations to be globally stable.

1.3 Bycatch in fisheries

The two main challenges to turtle conservation are egg harvesting at nesting beaches and capture in fishing gear. There have been efforts to reduce and eliminate leatherback egg harvesting at western Pacific nesting beaches (Dutton et al., 2007). No turtle nesting has been confirmed in New Zealand. Commercial surface longline fisheries have been identified as the major source of turtle bycatch (Lewison et al., 2004; Wallace et al., 2010). James et al. (2005) noted that the persistent focus on pelagic fisheries for turtle bycatch has been, in part, because of the relative ease of availability of the data. In New Zealand, surface longline fisheries for tunas and swordfish have been identified as capturing most turtles (Godoy, 2016). The threat from coastal fisheries, including recreational fisheries, may be underestimated because of the sparsity of data and observer coverage, and in some cases may be the primary threat to turtles (James et al., 2005; Peckham et al., 2007; Wallace et al., 2010; Roe et al., 2014). In New Zealand, Godoy & Stockin (2018) found two of 35 (6%) stranded green turtles showed signs of capture by recreational hooks, and five (14%) showed evidence of catastrophic propeller strike, suspected to be most likely from recreational fisheries. Godoy & Stockin (2018) also found four green turtles had gut impaction or intestinal plication (folding) with plastic waste.

Bycatch estimates of turtles in New Zealand have been completed by Godoy (2016) and Abraham et al. (2021). Godoy (2016) collated Ministry observer and industry reported records, and Abraham et al. (2021) scaled observer reports to the whole surface-longline fishery level using a statistical model. Godoy (2016) found the highest reported turtle bycatch in 2012–13 (n = 21), which was lower than estimated for that year by Abraham et al. (n = 34; scaled up from n = 2 observed). The scaling factors estimated by Abraham et al. (2021) were large, although Godoy (2016) noted that the observer data did not cover the times and areas when bycatch was highest. Abraham et al. (2021) estimated turtle captures were relatively high in 2015–16 (n = 57; n = 6 observed) and 2017–18 (n = 53; n = 4 observed), and increased back in time from 2007–08 (n = 28; n = 1 observed) to 2002–03, the earliest year estimated (n = 127; n = 0 observed). Babcock et al. (2003) suggested that at least 50% observer coverage might be required for rare species, like turtles, to derive a good estimate of bycatch.

Interactions with pelagic longlines may not result in mortality from capture itself, because the turtles can still reach the surface to breathe. For example, of 323 leatherback interactions with U.S. longlines in the Atlantic, only one turtle (0.3%) was found dead (Garrison 2003). Within pelagic longline fisheries, turtles are more vulnerable to shallower longline sets rather than deeper-set tuna target lines because turtles forage most actively in the epipelagic zone (Roe et al., 2014). Turtles may also suffer fatal interactions from other fixed gear, such as gill nets; off eastern Canada, in 83 records of leatherback interactions with fixed gear, 18% were reported dead at hauling, and free-swimming leatherback turtles trailing attached gear were also seen (James et al., 2005). Lee Lum (2003) estimated an at-vessel mortality rate of 28–34% for leatherbacks caught in coastal artisanal gill net fisheries off Trinidad.

Ryder et al. (2006) concluded the risk of post-release mortality to sea turtles caught by surface longlines was about 27% for those hooked externally or entangled with line left on the animal, and about 42% for those hooked in the mouth or if the hook was ingested. Further studies reviewed by Swimmer & Gilman (2012) found mortality rate estimates between zero and 44%, with a median of 25%. Acute mortality was defined as death <30 days from capture, with the most lethal interaction caused by ingestion of fishing gear where hooks then punctured the stomach, lower esophagus, heart, or lung. In general, in was concluded that a turtle hooked in the lower esophagus would have very little chance of surviving. A second period of chronic mortality was also observed, with death perhaps 3–9 months later, resulting from slow organ failure, compromised feeding, or secondary infections, e.g., to hook-damaged flippers. It was thought that leatherbacks could suffer a slightly higher mortality rate than other turtle species.

The reduction of sea turtle bycatch in other jurisdictions has often involved setting limit reference points (LRP), where hitting the LRP triggers a management action such as a fishing vessel move-on rule, or closure of the fishery. Two types of limits seem to be used, (1) an absolute amount, e.g., if more than *n* turtles are captured management action is required, or (2) a relative amount, meaning relative to the amount of effort or target species catch, e.g., the catch rate should remain below *n* turtles per *y* hooks. Both measures should be linked to knowledge of the turtle population dynamics, but this seems to be rare because such population information is generally lacking. Whilst (1) can be related directly to a mortality on the population, to have the same relevance (2) would rely upon fishing effort levels and turtle catchability (influenced by e.g., hook and bait type) remaining constant over time.

There is currently no LRP for turtle captures in New Zealand. New Zealand authorities have previously argued that turtle captures were minimal, and no measures were necessary. Details can be found in the Scientific Committee report for the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, 10–21 August 2009, paragraphs 303–310. This states that the catch rates (per hook) were low:

"307. In New Zealand's shallow-set swordfish fishery, the observed sea turtle catch rates are as follows: nominal CPUE: 0.00057 sea turtle per 1000 hooks, and average 0.0013 sea turtles per 1000 hooks."

And no action specific to turtles was therefore required:

"309. New Zealand considers that its shallow-set swordfish longline fisheries have had minimal observed sea turtle interaction rates over the preceding three-year period. National observer coverage rates meet the requirements of CMM-2008-03 para 7b, and existing practices and provisions in these fisheries are considered by New Zealand to adequately avoid and minimize the effects of fishing on sea turtle populations in New Zealand's fishery waters. As a result, New Zealand requested that the SC recognize New Zealand as having a minimal sea turtle interaction rate as per para 7b of CMM-2008-03."

The catch rates in article 307 came from Brouwer & Griggs (2009), who used Ministry observer data from 2003–04 to 2007–08, noting that only 15 turtle (11 leatherback) captures had been observed since 2000. Godoy (2016) concluded that the observer coverage of the surface longline fisheries was generally in the wrong time and place to measure turtle bycatch. The form for commercial fishers to report turtle captures (Non-Fish Protected Species) was only introduced in late 2008.

The catch rates estimated for New Zealand by Brouwer & Griggs (2009) were substantially lower than the "minimal catch rate" suggested by Brouwer & Bertram (2009), which was a catch rate of 0.019 (all species combined) turtles per 1000 hooks or less, in shallow-set longline fisheries targeting swordfish. The intention of "minimal catch rate" was that fisheries with catch rates higher than this would be required to implement measures aimed at reducing sea turtle bycatch. Brouwer & Griggs (2009) did not define 'fishery' but appeared to use annually aggregated data to calculate rates. The meaning of "minimal catch rate" was of a catch rate that should "be achievable" with mitigation measures, therefore it could be taken to mean finer spatial and temporal scales. By following the catch rate approach to an LRP, Brouwer & Griggs (2009) recognised that the intention of the minimal catch rate limit was to reduce mortality, but whether the actual mortality reduction would be sufficient for conservation purposes was unknown. Godoy (2016) found the Brouwer & Griggs (2009) minimal catch rate was exceeded in annual surface longline data for 5/7 years between 2008–09 and 2014–15 in Fisheries Management Area (FMA) 1, for 2/7 years in FMA 9, and for 1/7 years in FMA 2.

Elsewhere, an absolute limit on turtle bycatch has been advocated or applied. Curtis et al. (2015) estimated a LRP of 7.7 leatherback turtle deaths per five years for the Western US Exclusive Economic Zone (EEZ) was required to prevent further decline of the Western Pacific leatherback population. The size of the Western US EEZ (825,549 km^2) is somewhat smaller than the combined size of the FMAs surrounding the North Island; FMAs 1, 2, 8, and 9 (1,082,000 km^2). In Hawai'i, an annual limit of 16 leatherback turtle captures is used for the shallow-set pelagic longline fishery, and when this is reached the fishery is closed for the remainder of the calendar year (NOAA 2020). There is 100% observer coverage of the fishery. There is also a limit on individual vessel bycatch, and if a vessel catches two leatherback or five loggerhead turtles in a trip, then it must stop and return to port, and not engage in shallow-set longline fishing for five days. If that vessel hits the turtle bycatch limit again, it is banned from the fishery for the remainder of the calendar year. Further, Hawai'i prohibits fishing within a 50–75 nautical mile radius of the centres of each island and an atoll in the northwest, has mandatory use of circle hooks and mackerel-type bait, and dehooking and resuscitation training; the combined measures are estimated to have reduced turtle bycatch by 90% (Work et al., 2020).

The complete observer coverage in Hawai'i mitigates potential non-reporting of bycatch by fishers. Hurtubise et al. (2020) evaluated reporting of turtle bycatch in Atlantic Canadian fisheries, and concluded that in the absence of observers, the government logbooks were likely an underestimate of the true rate of turtle-fishery interactions ("potentially high under-reporting"), and might not correctly identify the relative risk posed by different fisheries. They stated "non-compliance with monitoring programs that depend on self-reporting is a common challenge".

1.4 Factors influencing turtle distribution

The most frequently captured marine reptile in New Zealand has been the leatherback turtle (Godoy, 2016), and in this report we examined the potential influence of environmental conditions on capture probability. Because this report focused on leatherbacks, our introduction here focuses on that species.

Satellite tagging has shown that adult leatherback turtles migrate directly from breeding beaches into offshore areas of high planktonic productivity, and a few winter nesters from the tropical southwest Pacific migrate to northern New Zealand where they may remain in or close to New Zealand waters for more than a year (Bailey et al., 2012a,b; Benson et al., 2011; Roe et al., 2014; Shillinger et al., 2011). Leatherback turtles in the eastern Pacific make southward post-nesting migrations towards the South Pacific Gyre, bounded by Australia to the west, South America to the east, the equator to the north, and Antarctic circumpolar current to the south (Shillinger et al., 2011). Western Pacific leatherbacks may travel through the central Pacific and as far as the west coast United States (Benson et al., 2011).

Bailey et al. (2012a) tagged 55 leatherbacks from the western Pacific (135 in total), and none travelled closer to New Zealand than the east coast of Australia or just south of Tonga. Benson et al. (2011) tagged 126 turtles from the western stock, and three travelled to the Tasman Front region north of New Zealand, with one travelling into the Bay of Plenty, presumably following the East Auckland Current (an extension of the Tasman Front). The turtles off New Zealand were migrating throughout the year and foraging between January and July. The relatively cool waters may be beneficial for foraging leatherbacks as they may need to spend less time thermoregulating (Okuyama et al., 2021), and better foraging opportunities have been linked to subsequent nesting (Saba et al., 2008). The southern limit of tagged turtles occurring off Australia (off Tasmania) was roughly equivalent in latitude to the New Zealand west coast South Island (Benson et al., 2011).

Leatherbacks exhibit 'gigantothermy' and extend into cooler waters than other turtles, with tag-derived data showing a wide thermal range between 3.6 and 34.4°C (McMahon & Hays 2006; Shillinger et al., 2011). In the eastern Pacific, the southern limit of the turtle tag tracking range was at about 14°C, which might represent the lower thermal limit for prolonged exposure (Shillinger et al., 2011). McMahon & Hays (2006) found a similar temperature limit of about 15°C for leatherbacks in the Atlantic. Leatherbacks move throughout the water column, and spend most of their time in surface waters with an average depth of around 50 m, with dives of around 20–30 minutes whilst foraging, although leatherbacks can dive for up to around 90 minutes and to depths of nearly 900 m (Shillinger et al., 2011). Dives may be deeper but shorter during the day, and Shillinger et al. (2011) hypothesized that foraging was more active at night. McMahon & Hays (2006) discussed that temperature may be aliasing for food availability in some cases, rather than direct physiological constraints on leatherbacks; Bailey et al. (2012b) suspected both food and temperature determined movements. It has been hypothesized that leatherbacks show foraging site fidelity (James et al., 2005; Benson et al., 2011; Shillinger et al., 2011).

The factors determining leatherback movements and behaviour have been found to vary between populations and studies. Western Pacific leatherback foraging behaviour was found to have a strong positive response to chlorophyll and temperature (Bailey et al., 2012). However, in the Tasman Front region, foraging of western leatherbacks was associated with lower chlorophyll and low eddy kinetic energy (Benson et al., 2011). Eastern Pacific leatherbacks foraging grounds were characterised by relatively low temperature and weaker productivity (Shillinger et al., 2011; Willis-Norton et al., 2015). Benson et al. (2011) reported two turtles arriving in the Tasman Sea during April-June, and foraging in an area of low current velocity and potential plankton retention just south of the Tasman Front, prior to passing the North Cape of New Zealand, and that the foraging behaviour occurred within areas of lower chlorophyll adjacent to a region of higher chlorophyll (Benson et al., 2011). It was hypothesized that leatherback prey may accumulate in gyres or fronts having low physical energy, formed by frontal regions, headlands, and points. Leatherback foraging is expected to be particularly active, as they may need to consume an estimated 20–30% of their body mass daily (Davenport & Balazs, 1991).

Environmental variables used in previous analyses of leatherback behaviour have included sea surface temperature (from e.g., AVHRR Pathfinder v5.0), chlorophyll-a (SeaWiFS), sea surface height (AVISO; root mean square used to indicate amount of mesoscale variability), wind velocity (SeaWinds/QuikSCAT processed into wind stress and wind stress curl components, used to calculate vertical movement relative to horizontal - Ekman pumping), and eddy kinetic energy (Benson et al., 2011; Shillinger et al., 2011; Bailey et al., 2012).

In contrast to leatherbacks, in New Zealand juvenile green turtles recruit to coastal habitats, harbours, and rocky reefs in Northland from the pelagic phase and potentially remain in New Zealand waters for up to five or six years before migrating to adult habitats in tropical regions (Godoy et al., 2016). Green turtles recruit from oceanic to neritic (0–200 m depth) habitats as juveniles, shifting diet from mesopelagic invertebrates to benthic seagrass and algae (Reich et al., 2007). In temperate latitudes, cold-stunning is triggered at less than 10°C, dormancy at less than 15°C, and there is continued foraging (albeit at reduced levels) at temperatures above 15°C (Williard et al., 2017). In the North Atlantic, juvenile green turtles of 20 to 35 cm (straight carapace length) arrive in nearshore waters of North

Carolina (about 34-36°N) in spring, as early as late March, and leave for offshore waters in the fall, by early December (Williard et al., 2017). The juvenile green turtles off North Carolina were expected to remain within neritic habitats all year, but 73% were found to leave for open ocean habitat, where they were likely to resume their pre-recruitment diet of epi-pelagic invertebrates (Williard et al., 2017). This resumption of pre-recruit foraging habits during winter has also been shown for loggerheads (McClellan et al., 2010).

Satellite telemetry data for 11 rehabilitated immature green turtles between 2004 and 2016 found nine remained within New Zealand’s waters (Godoy unpubl. data, cited in Work et al., 2020). Tagging data also exist for juvenile loggerheads released from Lord Howe Island (D. Godoy, pers. comm. via C. Duffy, DOC).

2 Methods

2.1 Observer data

The Centralised Observer Database (*COD*) contains data collected by observers on fishing vessels and is managed by NIWA for Fisheries New Zealand (FNZ). The databases were searched for all records containing the three-letter species codes for the following species and associated fishing event data up to the end of 30 September 2021:

- Leatherback turtle (*Dermochelys coriacea*, LBT);
- Green turtle (*Chelonia mydas*, GNT);
- Hawksbill turtle (*Eretmochelys imbricata*, HBT);
- Loggerhead turtle (*Caretta caretta*, LHT);
- Olive ridley turtle (*Lepidochelys olivacea*, ORT);
- Unidentified turtle (TLE);
- Banded sea snake (*Laticauda colubrina*, BSS);
- Yellow-bellied sea snake (*Hydrophis platurus*, YSS); and
- Unidentified sea snake (SSN).

These records are hereafter referred to as 'observed' marine reptiles and sets. The Observer Programme also provided photographs and diary notes taken by observers. These sources were searched for relevant observations and data, particularly for information relating to species identification and condition.

All observer records were checked ('groomed') by hand, evaluating each record for plausibility by comparing the consistency of data provided for that event (e.g., location consistent with depth), and then also consistency with adjacent records (usually having no protected species catch). Photographs taken by the observers were also obtained, and used to evaluate record accuracy, including species identification.

2.2 Commercial data

The Enterprise Data Warehouse database (previously *Warehou*) contains catch and effort data received from commercial fishers, and is managed by FNZ. The database was searched for all records containing protected marine reptiles noted above up to the end of 30 September 2021. Associated data extracted included date, latitude, longitude, Fisheries Management Area (FMA), Fisheries General Statistical Area, fishing method, target species, fishing depth, fishing duration, and total hook count. Gear location was taken as the reported start location. The same data fields were extracted for all fishing events, regardless of whether a marine reptile was caught, to allow comparison between events that caught marine reptiles and events that did not. These records are hereafter referred to as 'reported' marine reptiles and sets. Since late 2008, fishers have been reporting protected species captures mainly on Non-Fish Protected Species Catch Returns (NFPS), with the first marine reptile record being dated 18 February 2009.

Commercial fishery catch and effort data were groomed to replace obviously incorrect or missing values. The grooming of the commercial fisheries data did not exclude any records, but set specific data fields to NA if they were found to be erroneous and could not be estimated. Estimates were set to be the median value for the vessel for missing or erroneous total hook numbers, fishing duration, and set, and to the median for that vessel on that day for missing or erroneous sea surface temperature. The latitude and longitude of records having a fishing position that was on land were set to NA. Procedures to groom positional data in more detail are available, for example based upon sequential fishing locations within a trip, but this was not run here because of the excessive time needed for the large number of records (about 10.1 million fishing events). For bottom trawl and bottom longline records, bottom depth was set to fishing depth if the latter was provided but the former was missing, or the values were reversed if fishing depth was deeper than bottom depth. Where bottom depth was missing, or was <3 m or >2000 m, it was estimated as the median of all records within one nautical mile of that location.

2.3 Combined reptile capture data set

The commercial and observer reports of marine reptile captures were combined to provide a single groomed data set containing all records. Any duplication between the commercial fisher and observer data was then removed. Where a capture was reported by both the commercial fisher and the observer, and those records were not the same (e.g., in turtle species identification), primacy was given to the observer data.

2.4 Other data sources

The *trawl* database managed by NIWA contains all data collected on research trawl surveys and was also searched for any marine reptile records. No records were reported.

The Auckland Zoo hospital has also received sick and injured marine reptiles. Some of this information is summarised briefly in Appendix A, but the collation and analysis of these data was beyond the scope of the current project.

The Department of Conservation herpetofauna database (Amphibian and Reptile Distribution Scheme (ARDS)) allows the public to report sightings of amphibians and reptiles. All marine reptile sightings were extracted from this database and summarised in Appendix B.

Additional miscellaneous records were reported in Appendix C. These include published and unpublished data, recreational sightings reported during ad-hoc surveys of recreational marine fishers (diary surveys, boat-ramp surveys, and shellfish harvest surveys) and held in the Ministry for Primary Industries *rec_data* database, museum collections records, data held by the Department of Conservation and not on ARDS, public sightings reported on iNaturalist (www.inaturalist.org), and records from the recently established DOC Protected Species Catch app, which allows recreational fishers to report accidental captures of protected species (https://docnewzealand.shinyapps.io/protectedspeciescatch/). Because these may or may not be fisheries interactions, these records are not commented on further for the purpose of this report.

2.5 Analyses of leatherback turtle captures and environmental conditions

The variables that might influence leatherback capture were investigated using a dataset consisting of surface longline catch and effort records over the fishing years 2007–08 to 2020–21, with all fishing events sampled by Ministry observers, and additional commercial records for eight vessels selected because they each reported at least one leatherback capture in every year fished; these were considered vessels 'inclined to report turtle bycatch'.

The collated environmental variables are summarised in Table 2. Trial analyses evaluated all variables, but the final analyses excluded water clarity (*kd490*) and SST gradient (*sstgrad*) because they were unavailable for some records and would have reduced the number of leatherbacks included in the final data set by 15. Records were removed from the data set where any of the remaining variables were missing, either because they were not available for that time and location, or the record was missing data fields required to link to the environmental data. This includes some turtle captures being in too shallow water to be included in the Roemmich and Gilson Argo climatology (Roemmich & Gibson 2009). A possible solution to this would have been to use a different climatology (e.g., CSIRO Atlas of Regional Seas, CARS), but any inshore product would be based on no data, and so could lead to spurious results and false confidence.

The total leatherback captures across all fishing methods and regions between 2007–08 and 2020–21 was 217; the total included in the northeast New Zealand longline data set was 203 (out of 5727 events, a capture rate of 3.54%); the total included in the final analysis data set after exclusions of data due to missing variables was 178 out of 5098 fishing events (11% of events removed, but a similar capture rate of 3.49%).

The capture of turtles was modelled using a binomial generalised linear model (GLM). The model was of occurrence only, meaning information on the number of leatherbacks captured were excluded, with each event that captured more than one turtle treated as if it was the capture of a single turtle. This was because the number of records where more than one leatherback was captured was considered too small to analyse; of the 178 leatherback turtle captures, 141 were of single turtles, and 16 were of two to four turtles. The proportion of positive capture records was therefore 157/5098 events (3%).

Variables were tested for inclusion in the model in a stepwise manner and the best predictor chosen using the Akaike information criterion (AIC) estimator. Variables were retained in the model only if their coefficients were statistically significant and improved the AIC, and the predicted effect was considered plausible. The variables *chla*, *vgpm*, *cbpm*, *eppley*, and *café*, were log transformed (Table 2). If the model chose a variable highly correlated (R^2>0.9) with another already included in the model it was excluded. Highly correlated variables were *vgpm* and *eppley*, *temp100m*, *temp200m*, *MeanDynamicHeight* and *TimeVaryingDynamicHeight*, and mixed layer depths. Continuous variables were tested for inclusion as first, second, or third order polynomials. Year was not a variable in the model, but the predicted probability of capture was estimated separately for each year because a focus of the study was to evaluate possible reasons for the increase in turtle captures in recent years.

Results of the final GLM are shown as:

(1) The predicted effect plotted over the observed range of each variable in turn, made with all other variables fixed at their median or modal values.

(2) The influence of each variable, calculated as the mean predicted value from its coefficient for each year divided by the overall mean for that coefficient (Bentley *et al*., 2012). The model coefficients were constant, therefore any trend over time was a result of changes in the associated variables over time (i.e., if the variables were also constant, the predicted trend would be flat).

(3) The distribution of each variable over time, shown as box and whisker or stacked-bar plots, for continuous and factor variables respectively.

(4) Because the focus on the analyses was to evaluate factors influencing captures, and explain any trend over time, the predicted trend by year was plotted against the observed catch rates, and as the correlation between the two. As in (2), because the model did not include a year coefficient, any trend over time was a consequence of changes in the selected model coefficients (i.e., environmental conditions). The model predictions used the variables as in the data set, i.e., as encountered by the fishing fleet, so this analysis will not distinguish between a systematic change in environmental conditions (e.g., climate change), and a change of fishing location, where the fleet simply moved to an area with different environmental conditions.

(5) The effect of adding sequential coefficients into the model on the predictions by year is shown as step plots. The predictions are scaled to have the same geometric mean.

Two version of the GLM analysis were conducted, one using only environmental coefficients (i.e., excluding the FNZ variables), and the other including all coefficients.

Table 2: The variables included in analyses of leatherback turtle (LBT) capture probability for the surface longline fishery. Form in GLM is either as a categorical factor, or as a continuous variable fitted as a polynomial (order shown; if variables were logged this is indicated). AVISO data were at a 0.25 degree latitude and longitude resolution. The Roemmich and Gilson Argo climatology were at a 1 degree latitude and longitude resolution (Roemmich & Gilson 2009).

Variable label	Source	Form in GLM	Description
chla	Chlorophyll-a concentration between 1997–2021 (monthly, 9 km) produced by blending SeaWiFS (NASA, 2018a) and MODIS-Aqua (NASA, 2018b) observations using the overlap period (Pinkerton et al. 2021).	Log(3rd)	Open ocean chlorophyll-a (mg/m3). This will be dubious close to the shore (within ~5 km). Correlation with *kd490*.
SST	Optimal-interpolation ocean product (OI-SST v2.1; Reynolds et al., 2007; Huang et al., 2021) at 0.25°lat x 0.25°lon, monthly	2nd	Sea surface temperature (°C)
kd490	Open-ocean Kd490 product from MODIS-Aqua and SeaWiFS (Clark, 1997) (9km, monthly) blended as Pinkerton et al. (2021)	3rd	Diffuse attenuation at 490 nm (proxy for water clarity) (m^{-1}). Excluded from final models as no data for 2021.
par	Open-ocean PAR product (9km, monthly) from MODIS-Aqua and SeaWiFS (Frouin & Pinker, 1995; Frouin et al., 2012) blended as Pinkerton et al. (2021)	Log(3rd)	Average daily incident irradiance at sea surface (Einstein/m^2/d). Correlated with *temp*.
vgpm	Vertically Generalised Production Model (VGPM, Behrenfeld & Falkowski 1997) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly) and blended as Pinkerton et al. (2021).	Log(3rd)	Model of primary production (mgC/m^2/d). *Chla* preferred in final models. Correlated with *eppley* and *mld*.

Table 2 (continued):

Variable label	Source	Form in GLM	Description
café	Carbon, Absorption, and Fluorescence Euphotic-resolving model (CAFE, Silsbe et al., 2016). based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], (9km, monthly) and blended as Pinkerton et al. (2021).	Log(3rd)	Models of primary production (mgC/m^2/d). *Chla* preferred in final models
cbpm	Carbon Based Production Model (CBPM, Behrenfeld et al., 2005; Westberry et al. 2008) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly) and blended as Pinkerton et al. (2021).	Log(3rd)	Models of primary production (mgC/m^2/d). *Chla* preferred in final models
eppley	Eppley-modified VGPM (Eppley, 1972; Behrenfeld & Falkowski 1997) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly)) and blended as Pinkerton et al. (2021).	Log(3rd)	Models of primary production (mgC/m^2/d). *Chla* preferred in final models
SSTgrad	Magnitude of the 2-dimensional spatial gradient of OI-SST v2.1 (Reynolds et al., 2007; Huang et al., 2021)	3rd	Spatial gradient in *SST* as indicative of fronts (because this was calculated from data on a lat-lon grid it will have biases across large areas but may be useful). Inclusion resulted in reduced data set. Excluded from final models because reduced LBT occurrences by *n* = 15.
mld0p030	Depth at which there is potential density difference of 0.030 kg m^{-3} from the surface. Based on GLBu0.08 hindcast results (using hycom, fnmoc, soda, tops: Metzger et al., 2007; Chassignet et al. 2007; Wallcraft et al. 2009) sourced from Oregon State University ocean productivity (9km, monthly)	2nd	Mixed layer depth (m) on two different criteria for changes in potential density (0.03 kg/m^3 and 0.125 kg/m^3). Correlated with other mld, and vgpm.
mld0p125	As for *mld0p030* but with potential density difference of 0.125 kg/m^3 from the surface (9km, monthly)	3rd	Mixed layer depth (m) on two different criteria for changes in potential density (0.03 kg/m^3 and 0.125 kg/m^3). Correlated with other *mld*, and *vgpm*.
temp100m	Roemmich and Gilson Argo climatology	2nd	Temperature at 100m. Correlated with other temp.
temp200m	Roemmich and Gilson Argo climatology	2nd	Temperature at 200m. Correlated with other temp.

Table 2 (continued):

Variable label	Source	Form in GLM	Description
TimeVaryingEastwardCurrents	AVISO	3rd	Zonal current (u) (time-varying eastward currents). Positive values indicate stronger to the east.
TimeVaryingNorthwardCurrents	AVISO	2nd	Meridional current (v) (time varying northward currents). Positive values indicate stronger to the north.
TimeVaryingSpeed	AVISO	3rd	Time varying speed
MeanEastwardCurrent	AVISO	3rd	Mean u (mean eastward current); variable over space but not time
MeanNorthwardCurrent	AVISO	2nd	Mean v (mean northward current); variable over space but not time
TimeVaryingDynamicHeight	AVISO	2nd	Time-varying dynamic height. Correlated with temperature.
MeanDynamicHeight	AVISO	3rd	Mean dynamic height. Correlated with mean temperature. Variable over space but not time
Vessel	Fisheries New Zealand	Factor	Unique vessel identifier
Hook_num	Fisheries New Zealand	1st	Reported number of hooks per set
Target_species	Fisheries New Zealand	Factor	Reported target species
Day of year	Fisheries New Zealand	3rd	1st January = 1
Month	Fisheries New Zealand	Factor	Calendar month
lat	Fisheries New Zealand	3rd	Start latitude, full resolution
long	Fisheries New Zealand	3rd	Start longitude, full resolution

1. Oregon State University Ocean Productivity project, http://sites.science.oregonstate.edu/ocean.productivity/index.php.

3 Results

3.1 Summary of captures

Between 2007–08 and 2020–21 there were a total of 273 reported captures of turtles, an average of 19.5 per year, and one capture of a sea snake (Table 3). Most captures were reported on NFPS forms used by commercial fishers. The number of captures reported by Ministry observers was five or less per year until 2020–21, when one green and 19 leatherback turtles were reported. Five species of turtles were reported, with leatherback being the most frequently captured (n = 217; 79.5%), followed by green (n = 22; 8.1%); the snake was reported as a banded sea krait.

For the observer data, grooming removed one record of a leatherback capture from 2020–21 because the NFPS form reported two turtles, whereas photos taken by the observer showed only a single turtle. This left 49 observed records.

Examination of observer photos also allowed one unidentified turtle to be assigned to loggerhead, one leatherback turtle to be added (the observer reported two, the fisher one), and one green turtle to be corrected to olive ridley.

Table 3: Marine reptile commercial fishery captures by data source, species code, and fishing year, after data grooming. Fishing years start 1 October. Ob, Ministry observers; Co, commercial NFPS forms. Final capture estimates were made by merging the observer and commercial data sets, see Table 4.

Fishing year	Leatherback		Green		Hawksbill		Olive Ridley		Loggerhead		Unidentified Turtle		Sea Snake	
	Ob	Co	Ob	Co	Ob	Co	Ob	Co	Ob	Co	Ob	Co	Ob	Co
2007–08	1	0	0	0	0	0	0	0	0	0	0	1	0	0
2008–09	2	4	1	2	0	0	0	0	0	0	0	0	0	0
2009–10	0	2	0	1	0	0	0	0	0	0	0	3	0	0
2010–11	3	16	1	3	0	1	0	0	0	1	0	3	0	0
2011–12	0	18	0	0	0	5	0	0	0	0	0	0	0	0
2012–13	0	20	0	1	0	0	0	0	0	0	2	3	0	0
2013–14	0	7	0	2	0	0	0	0	0	1	0	0	0	0
2014–15	1	13	1	1	0	0	0	0	0	0	0	0	0	0
2015–16	5	23	0	1	0	0	0	0	1	1	1	3	0	0
2016–17	2	4	0	1	0	0	0	0	0	1	0	0	0	0
2017–18	2	28	1	3	0	0	0	0	1	3	0	0	0	0
2018–19	0	16	0	0	0	0	0	0	0	0	0	0	0	0
2019–20	2	12	0	3	0	0	1	0	1	2	0	1	0	1
2020–21	19	50	1	5	0	1	0	0	0	0	0	2	0	0
Total	37	213	5	23	0	7	1	0	3	9	3	16	0	1

Forty-three observed captures were matched to reported turtle captures (Table 4). Six observed captures were matched to fishing events where no turtle was reported by the fisher, and these were mostly in the first half of the time series. There was no obvious correlation between the percentage of turtles seen by observers, and the overall estimate of turtle captures (Figure 1). The overall percentage of the observed turtle captures reported was 17.9%, and this was relatively high in 2007–08 and 2008–09 (recently after the new forms were introduced), and in 2016–17 and 2020–21 (Table 4).

Godoy (2016) was able to identify slightly more turtle captures than we were, between 2008–09 and 2014–15 he estimated 118 turtle captures, whereas we estimated 112. Estimates by year will be slightly different because Godoy used a 1 July year (we used the fishing year starting 1 October).

The groomed and combined observer and commercial data estimates of marine reptile captures were relatively high during 2010–11 to 2012–13, 2015–16, 2017–18, and 2020–21, with 2020–21 being the highest in the time series, at 58 turtles (Table 5).

Between one and four turtles were caught per event, with 90% being single captures. Most captures, across all species, were made in the surface longline fisheries targeting bigeye tuna or swordfish (Table 6). The single sea snake was caught during bottom longline fishing targeting tarakihi.

Table 4: Sea turtle captures reported on NFPS commercial fisher forms in the absence of a Ministry observer (commercial only), Ministry observed records that could be matched to a commercial turtle capture record (observer matched to commercial), and Ministry observed records where there was no commercial turtle capture record (observer only). % observed, the percentage of the reported turtle captures that appeared in the observer records.

Fishing year	Commercial only	Observer matched to commercial	Observer only	% observed
2007–08	1	0	1	50
2008–09	5	1	2	38
2009–10	6	0	0	0
2010–11	21	3	1	16
2011–12	23	0	0	0
2012–13	23	1	1	8
2013–14	10	0	0	0
2014–15	13	1	1	13
2015–16	23	7	0	23
2016–17	4	2	0	33
2017–18	30	4	0	12
2018–19	16	0	0	0
2019–20	13	4	0	24
2020–21	38	20	0	34

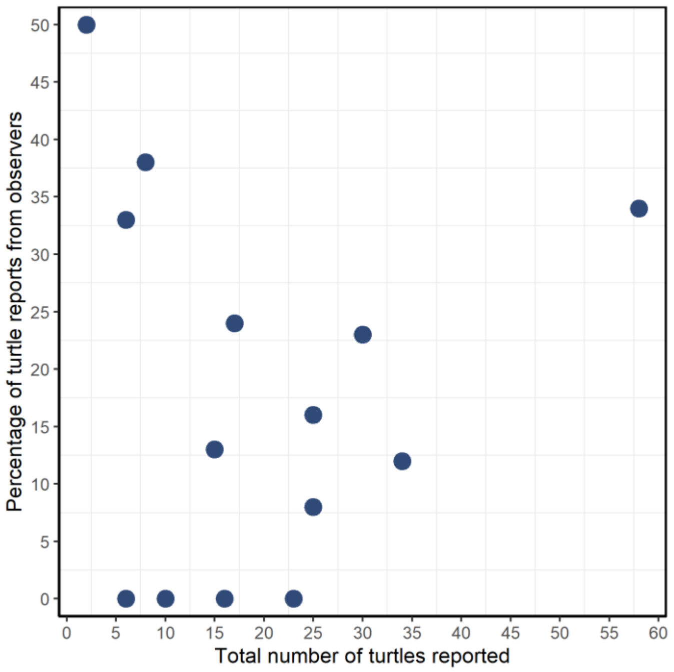

Figure 1: **The percentage of the reported turtles that were in the observer data set and total number of turtles reported (data shown in Table 2).**

Table 5: **Marine reptile commercial fishery captures by species and fishing year, after data grooming and combining Ministry observer and commercial data. Fishing year refers to the year starting 1 October. Numbers in parentheses are captures estimated by Godoy (2016) for a fishing year starting 1 July; both sets of estimates are aligned by year-ending (e.g., 2014–15 means the year ending 30 June 2015, or 30 September 2015).**

Fishing year	Leatherback	Green	Hawksbill	Olive Ridley	Loggerhead	Unidentified turtle	Total Turtle	Snake
2007–08	1	0	0	0	0	1	2	0
2008–09	6 (7)	2 (3)	0	0	0	0	8 (10)	0
2009–10	2 (2)	1 (1)	0	0	0	3 (2)	6 (5)	0
2010–11	17 (17)	3 (2)	1 (1)	0	1 (1)	3 (4)	25 (25)	0
2011–12	18 (18)	0 (1)	5 (2)	0	0	0	23 (21)	0
2012–13	20 (21)	1 (1)	0 (3)	0	0	4 (3)	25 (28)	0
2013–14	7 (7)	2 (2)	0	0	1 (1)	0 (1)	10 (11)	0
2014–15	13 (17)	2 (1)	0	0	0	0	15 (18)	0
2015–16	23	1	0	0	1	3	28	0
2016–17	4	1	0	0	1	0	6	0
2017–18	28	3	0	0	3	0	34	0
2018–19	16	0	0	0	0	0	16	0
2019–20	12	1	0	1	2	1	17	1
2020–21	50	5	1	0	0	2	58	0
Total	217	22	7	1	9	17	273	1

Table 6: **Reported sea turtle captures in commercial fishing gear between 1 October 2008 and 31 October 2021, by fishing method and target species.**

Fishing method Target species	Leatherback	Green	Hawksbill	Olive Ridley	Loggerhead	Unidentified turtle	Total
Surface longline							
Bigeye tuna	104	8	4	0	4	10	130
Swordfish	85	2	2	0	0	0	89
Southern bluefin	19	4	1	1	1	3	29
Pacific bluefin	4	0	0	0	1	0	5
Set net							
Flatfish	1	0	0	0	0	0	1
Grey mullet	0	1	0	0	0	0	1
Trawl							
Flatfish	0	1	0	0	0	1	2
John dory	0	1	0	0	0	0	1
Scampi	0	0	0	0	0	1	1
Snapper	2	1	0	0	0	0	3
Tarakihi	1	0	0	0	0	0	1
Trevally	1	1	0	0	1	1	4
Bottom longline							
Snapper	0	3	0	0	2	1	6
Tarakihi	0	0	0	0	0	0	1
Total	217	22	7	1	9	17	273

Data on the type of bait used by surface longline were available from the commercial turtle capture reports, for 149 fishing events between 2008–09 to 2018–19 (Table 7). Bait choice was recorded as either fish or squid. The sample sizes were small and may therefore be substantially biased compared to the overall fleet. Nevertheless, the data suggested the type of bait was variable, with squid sometimes predominant.

There were no commercial reported reptile captures from FMAs 3–6 (Chatham Rise and Subantarctic), despite fishing effort taking place there (Table 8). Leatherbacks were most often reported in FMA 1 (northeast North Island), where effort was also greatest, largely between January and April. Leatherbacks were also reported in summer, mostly between January and May, but in lower numbers in FMAs 2 (southeast North Island), 7 (west coast South Island) and 9 (southwest North Island). The distribution of green turtle reports was broadly similar, being highest in FMA 1 between January and June, with lower numbers also in summer to early winter in FMAs 2 and 7. Green turtle reports in FMA 9 were infrequent, but included a capture in spring (September). Hawksbill turtles were reported more often from FMA 9 than FMA 1 (west rather than east coast of the northern North Island), despite there being less effort in FMA 9, with reports largely in summer to early winter (February to August). Loggerhead turtles were reported in a similar pattern to hawksbill turtles, from summer to early winter in FMAs 1 and 9 with more in FMA 9 despite lower fishing effort. Unidentified turtles were largely reported in summer in FMA 1, but some also in FMAs 7 and 9 from summer to early winter; it seems likely that leatherbacks would be easily identified (their exceptional appearance), making unidentified reports most likely to be green turtles (especially those from FMA 1). The single olive ridley turtle was reported in FMA 1 in August. The sea snake was reported off the northeast coast of the North Island (FMA 1) in April. Despite substantial fishing effort on Chatham Rise, no turtles were reported (although leatherback turtles have been encountered around the Chatham Island, D.Godoy, pers.comm.).

Table 7: Bait type reported on surface longlines where a turtle bycatch was reported, as recorded by commercial fishers, by fishing year. Bait type was either fish or squid. *n*, the number of observations.

Fishing year	*n*	%squid
2008–09	4	100
2009–10	6	100
2010–11	21	33
2011–12	33	48
2012–13	21	48
2013–14	7	57
2014–15	10	70
2015–16	19	84
2016–17	5	40
2017–18	21	67
2018–19	12	25

Table 8: Number of sea turtle captures in the surface longline fishery by fisheries management area (FMA) and month. A zero means effort but no capture; a dash means no effort. One leatherback turtle and one green turtle were not included because the FMA was listed as "unknown". The cells are shaded according to total hook numbers, with darker red shading indicating greater fishing effort. Only surface longline is shown because this was the main capture method for all species (see Table 5).

Leatherback

Month	FMA1	FMA10	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	Total
1	20	0	20	0	0	0	0	0	0	3	43
2	29	–	8	0	0	0	0	1	0	0	38
3	34	–	14	0	0	0	0	2	1	2	53
4	26	–	7	0	0	0	0	3	0	3	39
5	7	1	5	0	0	0	0	1	0	3	17
6	3	0	3	0	0	0	0	1	0	0	7
7	0	0	1	0	0	0	0	0	0	3	4
8	2	0	0	0	0	0	0	0	0	0	2
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	7	0	0	0	0	0	0	0	0	0	7
12	5	0	1	0	0	0	0	0	0	0	6
Total	133	1	59	0	0	0	0	8	1	14	216

Table 8 (cont.):

Green

Month	FMA1	FMA10	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	Total
1	1	0	0	0	0	0	0	0	0	0	1
2	0	–	2	0	0	0	0	0	0	0	2
3	4	–	1	0	0	0	0	0	0	1	7
4	1	–	0	0	0	0	0	1	0	1	3
5	1	0	2	0	0	0	0	0	0	0	3
6	2	0	1	0	0	0	0	1	0	0	4
7	0	0	1	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	1	1
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
Total	9	0	7	0	0	0	0	2	0	3	21

Hawksbill

Month	FMA1	FMA10	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	Total
1	0	0	0	0	0	0	0	0	0	0	0
2	0	–	0	0	0	0	0	0	0	1	1
3	0	–	0	0	0	0	0	0	0	1	1
4	1	–	0	0	0	0	0	0	0	0	1
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	1	1
8	1	0	0	0	0	0	0	0	0	2	3
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
Total	2	0	0	0	0	0	0	0	0	5	7

Table 8 (cont.):

Loggerhead

Month	FMA1	FMA10	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	Total
1	0	0	0	0	0	0	0	0	0	1	1
2	0	–	2	0	0	0	0	0	0	0	2
3	1	–	1	0	0	0	0	0	0	0	2
4	0	–	1	0	0	0	0	0	0	0	1
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	0	1
7	2	0	0	0	0	0	0	0	0	0	2
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
Total	3	0	5	0	0	0	0	0	0	1	9

Unidentified turtle

Month	FMA1	FMA10	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	Total
1	0	0	0	0	0	0	0	0	0	0	0
2	0	–	0	0	0	0	0	0	0	0	0
3	4	–	2	0	0	0	0	0	0	0	6
4	3	–	0	0	0	0	0	0	0	1	4
5	0	0	0	0	0	0	0	2	0	0	2
6	0	0	0	0	0	0	0	0	0	1	1
7	1	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0	0	1
11	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	1
Total	9	0	2	1	0	0	0	2	0	3	17

The spatial distribution of reported reptile bycatch was broadly similar amongst the species, with most reported in a ‘band’ from the northwest of the North Island down the east coast of the North Island (FMA 1), extending to East Cape (northern FMA 2), with a few reported on the west coast North Island, and a few off the west coast South Island (Figures 2–8). The greatest number of reports for leatherback and green turtles were in the surface longline fisheries off Bay of Plenty and off East Cape. The reports of green turtles from bottom longline and bottom trawl were largely from the Hauraki Gulf.

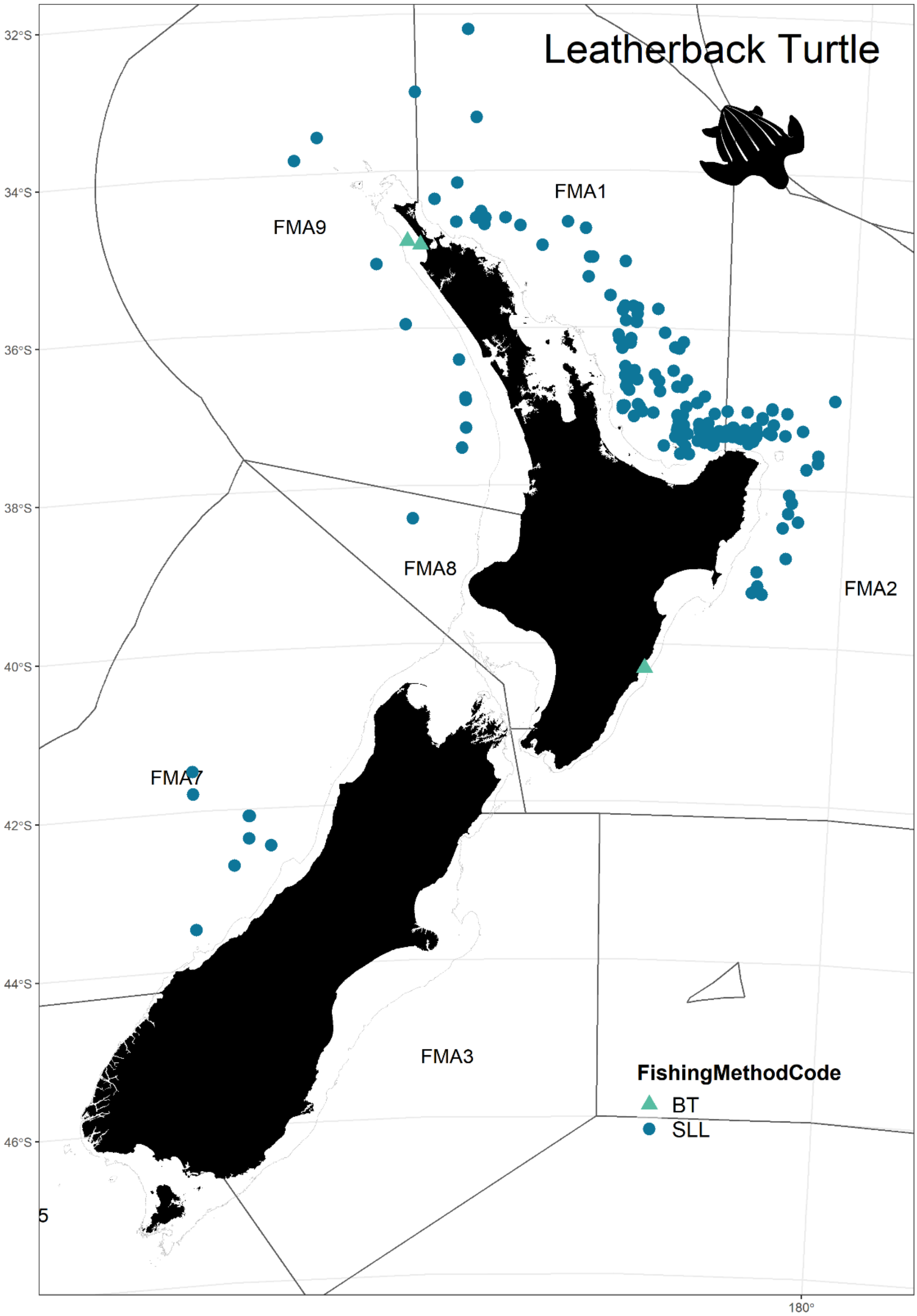

Figure 2: **Distribution of all leatherback turtle capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 217). Symbols indicate gear. Map shows isobath (200m) and FMAs. One leatherback turtle captured in a setnet did not have a position data (reported from stat area 009 (Bay of Plenty) in 2013–14). BT, bottom trawl; SLL, surface longline.**

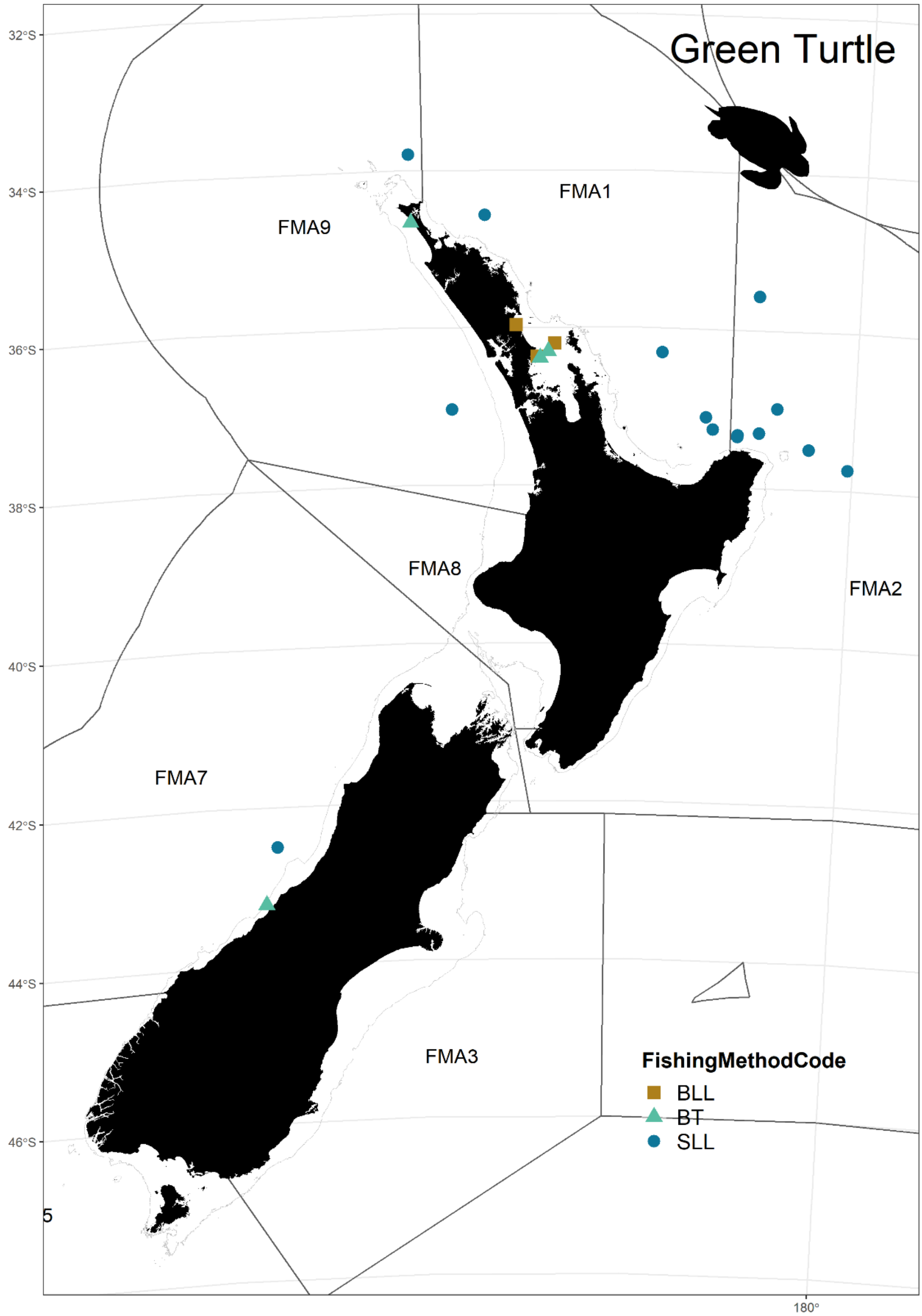

Figure 3: **Distribution of all green turtle capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 22). Symbols indicate gear. Map shows isobath (200m) and FMAs. One green turtle captured in a setnet did not have a position data (reported from stat area 046 in 2008–09). BLL, bottom longline; BT, bottom trawl; SLL, surface longline.**

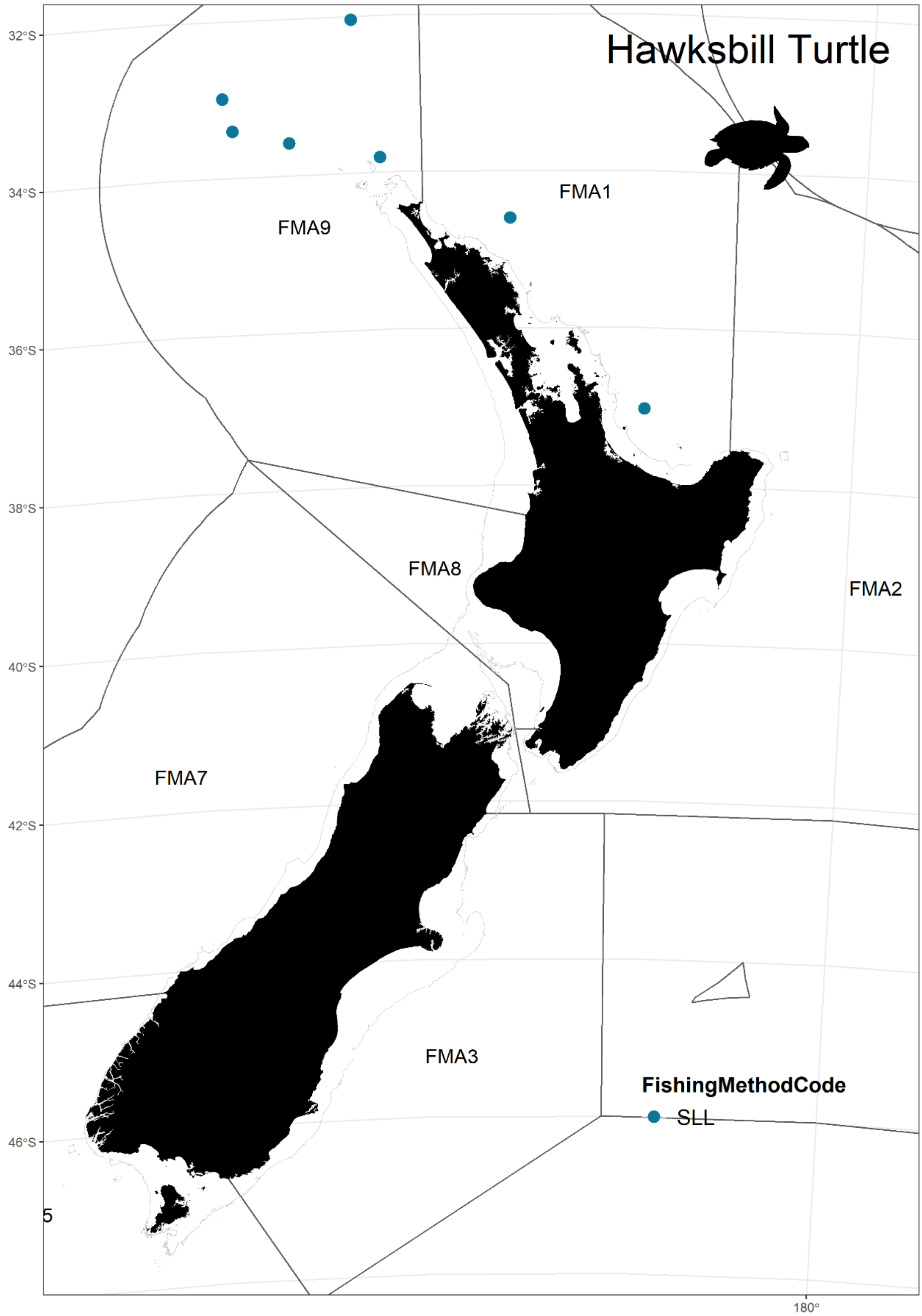

Figure 4: Distribution of all hawksbill turtle capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 7). Symbols indicate gear. Map shows isobath (200m) and FMAs. SLL, surface longline.

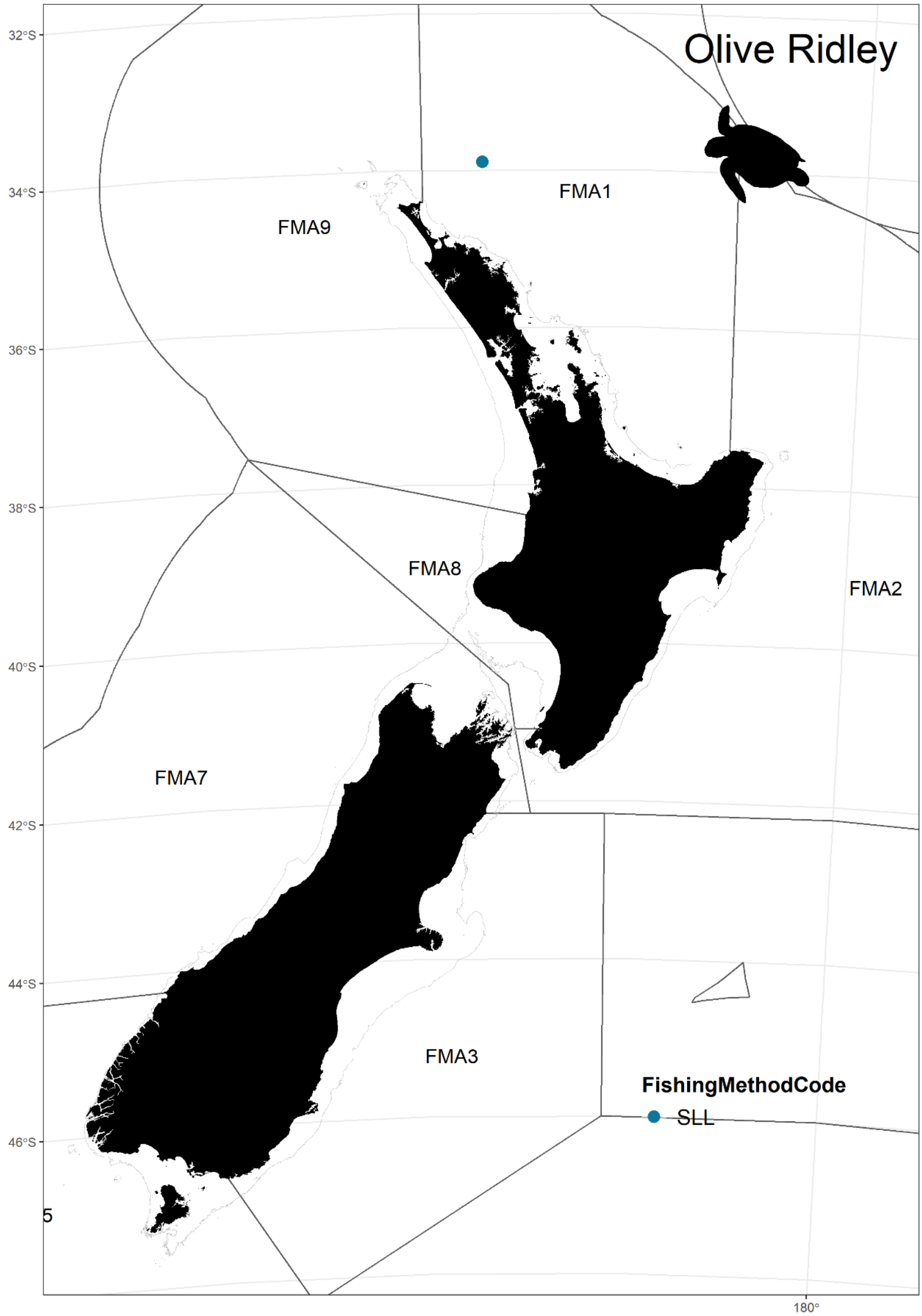

Figure 5: Distribution of all olive ridley turtle capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 1). Symbols indicate gear. Map shows isobath (200m) and FMAs. SLL, surface longline.

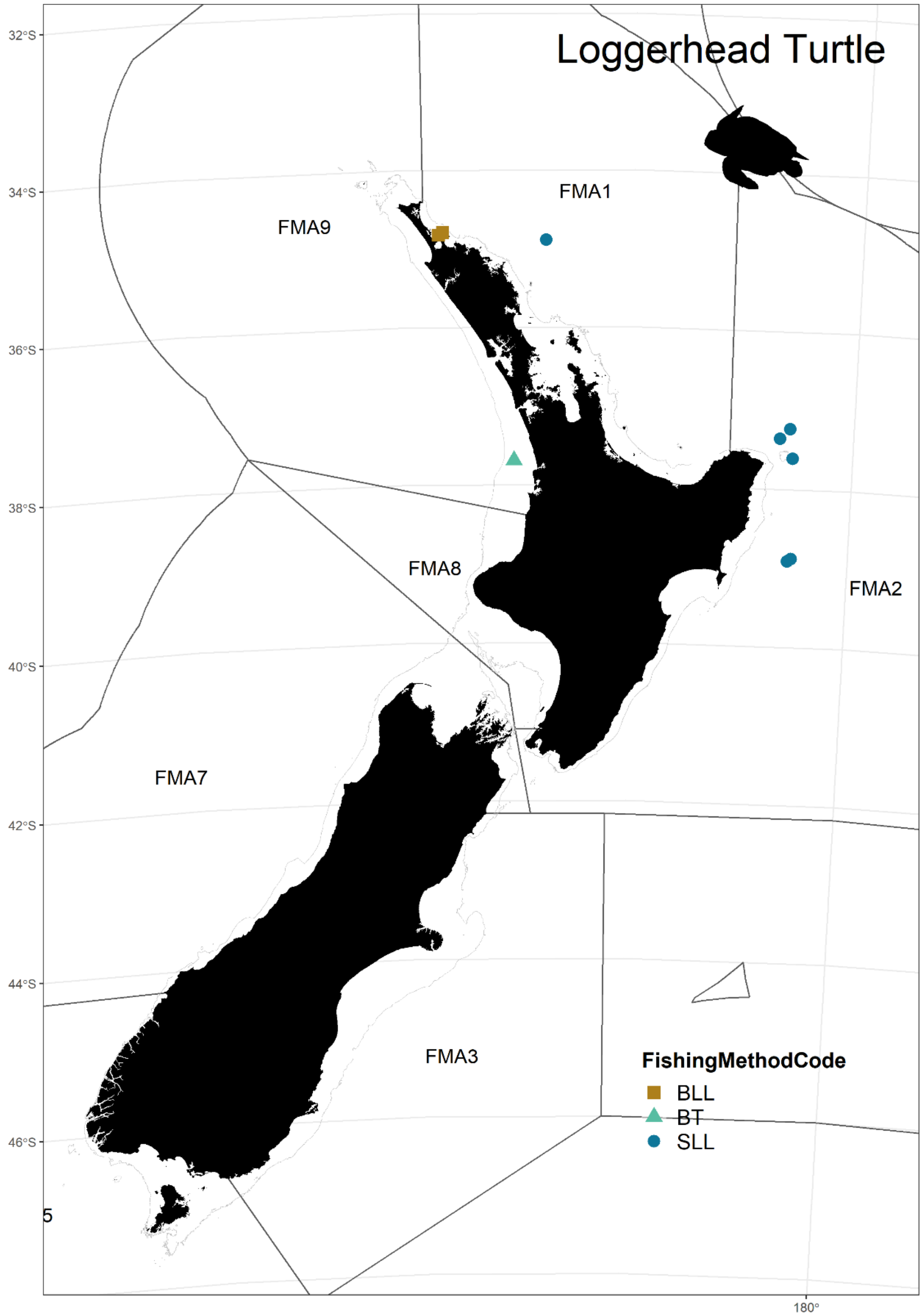

Figure 6: **Distribution of all loggerhead turtle capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 9). Symbols indicate gear. Map shows isobath (200m) and FMAs. BLL, bottom longline; BT, bottom trawl; SLL, surface longline.**

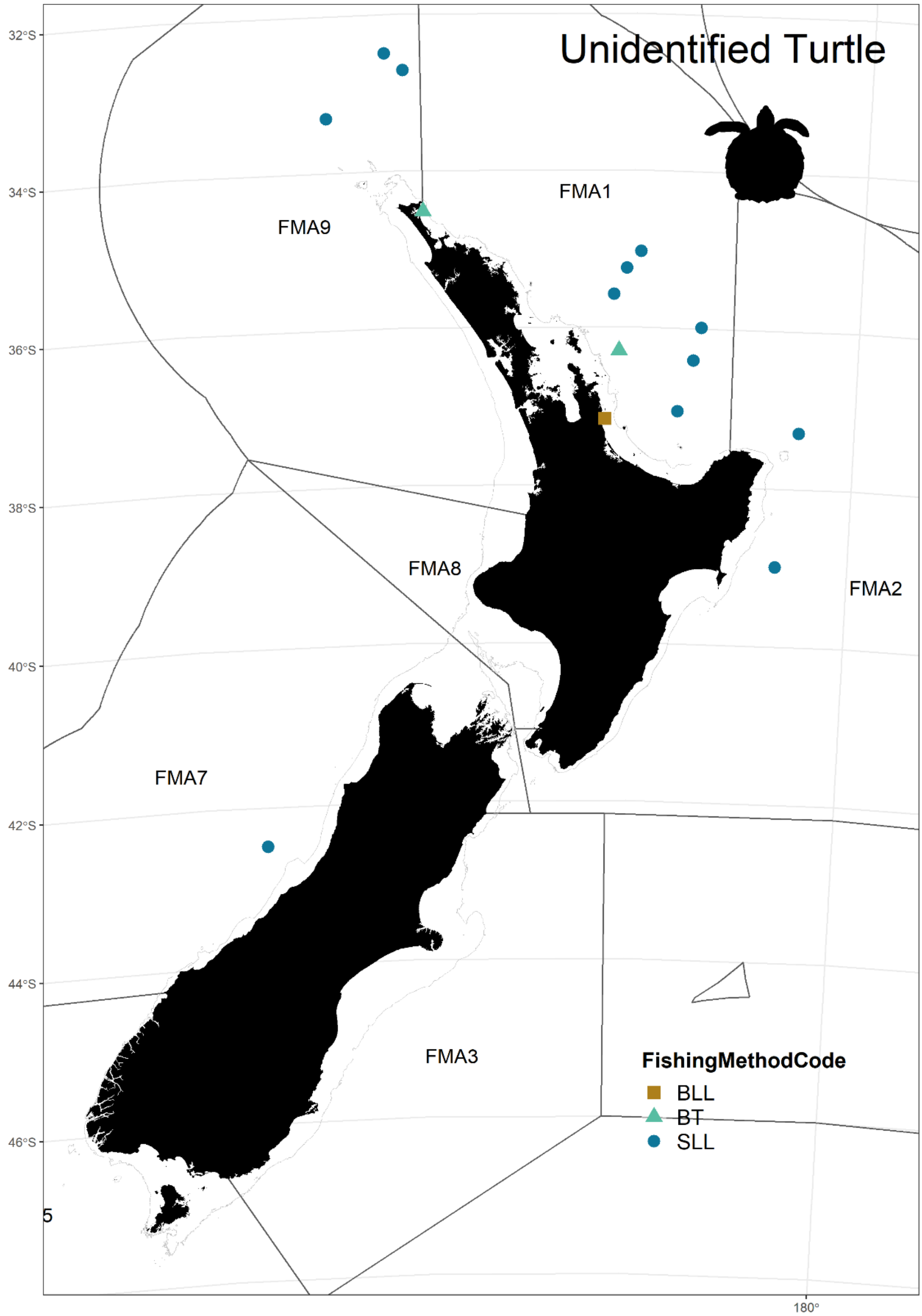

Figure 7: **Distribution of all unidentified turtle capture locations (observer and commercial) data from 2007–08 to 2020–21 (n = 17). Symbols indicate gear. Map shows isobath (200m) and FMAs. BLL, bottom longline; BT, bottom trawl; SLL, surface longline.**

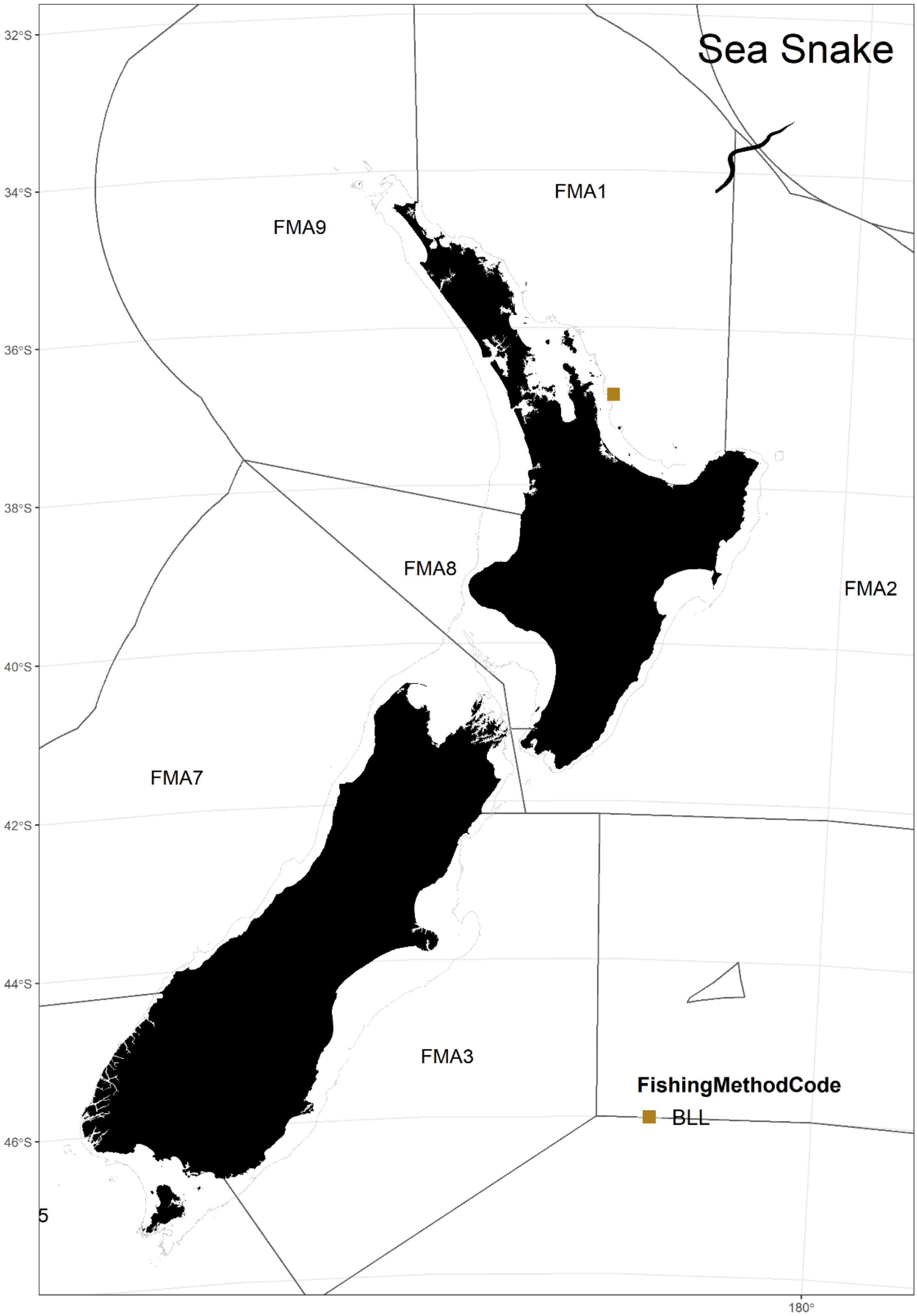

Figure 8: Distribution of all sea snake capture locations data (observer and commercial) from 2007–08 to 2020–21 (n = 1). Symbols indicate gear. Map shows isobath (200m) and FMAs. BLL, bottom longline.

Information on the condition of the turtle, and details of capture, were sometimes reported by Ministry observers. It appears most turtles were alive when captured and were released swiftly; it was apparent from observer notes that the crew attempted to release live turtles as quickly as possible.

Of the observer reports from longlines, two leatherbacks (n = 2/61) and one green turtle (n = 1/5) were reported as dead (n = 3/63). Where information was available, all of two loggerhead turtles and four unidentified turtles were released alive. A subset of the observer records provided further details of the capture. Turtles were most frequently reported as hooked in the flipper or body (n = 12/16), with a few hooked in the mouth (n = 2/16) or tangled in the gear (n = 2/16). Most turtles were released with the hook still embedded (n = 15/17), with removal of the hook only specified for two captures (n = 2/17). For most turtle captures, how the turtle was captured, and whether the hook or other trailing gear (e.g., snood, floats) remained attached after release, was not specified. From the observer notes and photographs, it seemed likely that leatherbacks and other larger turtles were rarely brought aboard but were cut free from the mainline whilst still in the water. In two occurrences, the observer reported that the crew attempted to cut the gear as close as possible to the turtle, and in at least one instance, trailing gear was specified as left on the turtle. Smaller turtles were often hauled onboard and hooks were removed by hand. One turtle broke free during retrieval of the main line and in one instance, a dehooker was reported to be used to release the turtle. In two instances, turtles were reported to be released alive but injured; one turtle was reported to suffer injury to its rear flipper after entanglement with the longline gear, while another had visible marks to its shell and head and the observer suspected that this damage may have been from the fishing gear or attempted predation on the turtle. Three turtle captures by bottom trawl were observed, where one leatherback was dead and two green turtles were released alive; no other details were provided.

The commercial fisher reports also report status, and most turtles were classified as released alive and uninjured (205/267), some were alive and injured (50/267), and 12 as dead (12/267). Based on the observer records, it seems very likely that the classification "alive and uninjured" will include many turtles released with hooks still embedded. The single snake captured was recorded as released alive and uninjured.

The percentage of captures that died was similar in the commercial (4.5%, n = 267) and observer (4.8%, n = 63) data. The fate of released turtles was unknown.

The Ministry observer records rarely provided any further information on the size or sex of the turtles. The available observer photographs (not shown here) suggested most leatherbacks were adults, with observers recording one as a "large specimen" (January 2021 FMA1), and "about 200 kg" (February 2020 FMA 1). A loggerhead was reported as "about 25 kg" (March 2020 FMA 2), which would indicate it was a juvenile. In the commercial catch and effort records, an unidentified turtle was recorded against a green weight of 25 kg (October 2007 FMA 3). The data field for green weight in the NFPS records contained no data. Review of observer logbooks indicated that the current database didn't allow skippers to record a weight on the NFPS forms.

3.2 Capture rates and observations on reporting

For the main turtle capture area, method, and season, surface longlining in FMA 1 between January to April inclusive, between 2007–08 and 2020–21, most of the reported turtle captures (103 of 119; 86.6%) were made by vessels which did not have a Ministry observer aboard. Because 'trip' has a different meaning in the observer and commercial databases, a commercial record was assumed to have an observer aboard if the vessel-year-month-day of the commercial record had a match in the observer database. Of the 53 vessels in that fishery, 10 (18.9%) had reported a turtle bycatch, and just five of the 10 reported 90.7% of the turtle captures, with one vessel alone reporting 38.7% of all captures. The latter single vessel accounted for 9.2% of the fishing effort (by number of hooks). The five vessels reported predominantly leatherback and a few green turtles, with three vessels reporting both species. The 10 vessels reporting turtles captured between 0 and 19 turtles a year (median=0, mean=1.25), and accounted for nearly two thirds (63.5%) of the fishing effort. The 43 vessels (81.1%) that never reported a turtle accounted for 36.4% of the fishing effort (by number of hooks).

Between 2007–08 and 2020–21, 12 (22.6%) of the vessels operating in the fishery in FMA 1 between January and April were observed at some point, covering 5.0% of the fishing events. From the 4.04 million hooks observed, 16 turtles were reported; this was a catch rate of 0.0039 turtles per thousand hooks. The five most active vessels in the fishery, which together accounted for 50% of the effort (number of hooks), included four of the five vessels reporting most turtles, and together reported 94 turtles; this was a catch rate of 0.047 turtles per 1000 hooks, about 12 times higher than reported by the observers. Of the vessel and year combinations that reported the greatest number of turtles (19, 14, and 10 per vessel per year), the first was about 50% observed, and the latter two had no observer coverage.

The single vessel that reported 38.7% of turtle captures, over seven years between 2013 and 2021, was only observed in 2020, when it accounted for 33.0% of the observed events, and 2021, when it accounted for 47.3% of the observed events. That observers were on this vessel in 2021, and the times and places that it fished, may partially explain why the overall observer turtle capture estimate was so much higher in 2021 (Table 3). We also replicated the observation of Godoy (2016) that five hawksbill turtles were reported in five surface longline events between February and August 2012 by a single vessel. This vessel was not one of the five vessels reporting 90.7% of the turtles described above.

Brouwer & Bertram (2009) proposed that turtle capture rates (all species combined) should be less than 0.019 turtles per 1000 hooks for shallow-set (surface) longline fisheries targeting swordfish, and they considered this was an achievable target. Averaged between 2008 and 2021, leatherback turtle capture rates alone were at least 0.019 turtles per 1000 hooks in FMA1 between January and April, in FMA2 and FMA9 in January, and in FMA8 in March (Table 9). For the times of year that leatherbacks were typically caught in FMA1 (November to June) the capture rate for surface longline fishing was at least 0.019 turtles per 1000 hooks in 2015 and 2016, and 2018 to 2021 (Table 9). Similarly, capture rates were above 0.019 turtles per 1000 hooks in surface longline fishing in FMA2 (December to July) in 2018 and 2021, in FMA9 (January to July) in 2020, and over the entire fishery in 2021. Because leatherback turtles dominated the reported captures, including the other turtle species made little difference to these statistics, except that the capture rate was raised above 0.019 in FMA9 in 2012 (Table 9).

Table 9: Surface longline fishing effort (thousands of hooks; all target species), total reported number of turtles caught, and catch rate (turtles per thousand hooks), by Fisheries Management Area (FMA; 'All' means all FMAs within the EEZ), month, and fishing year (shown as year ending). The catch rates in the upper part of the table were calculated for specific FMAs and months using data for all years. * The catch rates by specific FMAs and years in the lower half of the table were calculated only across the months when the majority of turtles were caught: these were FMA1, November to June; FMA2, December to July; FMA7, February to April; FMA9, January to July. The cell has been shaded when the turtle bycatch rate was equal to or above 0.019 turtles per 1000 hooks.

Leatherback

	No. hooks in thousands (no. reported turtles)					Turtles per 1000 hooks				
Month	FMA1	FMA2	FMA7	FMA8	FMA9	FMA1	FMA2	FMA7	FMA8	FMA9
1	1037 (20)	515 (20)	19 (0)	3 (0)	100 (2)	0.019	0.039	0	0	0.020
2	956 (29)	834 (8)	163 (1)	4 (0)	254 (0)	0.030	0.010	0.006	0	0
3	1056 (34)	1299 (13)	809 (2)	14 (1)	408 (2)	0.032	0.010	0.002	0.071	0.005
4	988 (26)	1089 (7)	995 (3)	4 (0)	366 (3)	0.026	0.006	0.003	0	0.008
5	564 (7)	1903 (5)	2372 (1)	14 (0)	264 (3)	0.012	0.003	0	0	0.011
6	757 (3)	2166 (3)	2400 (1)	5 (0)	210 (0)	0.004	0.001	0	0	0
7	1992 (0)	1026 (1)	818 (0)	0 (0)	237 (1)	0	0.001	0	–	0.004
8	2124 (2)	161 (0)	439 (0)	1 (0)	274 (0)	0.001	0	0	0	0
9	640 (0)	45 (0)	24 (0)	0 (0)	143 (0)	0	0	0	–	0
10	257 (0)	2 (0)	0 (0)	0 (0)	32 (0)	0	0	–	–	0
11	787 (7)	14 (0)	0 (0)	0 (0)	17 (0)	0.009	0	–	–	0
12	1008 (5)	90 (1)	0 (0)	0 (0)	19 (0)	0.005	0.011	–	–	0

Year	FMA1	FMA2	FMA7	FMA9	All	FMA1*	FMA2*	FMA7*	FMA9*	All
2008	418 (0)	605 (0)	6 (0)	100 (0)	2247 (1)	0	0	0	0	<0.001
2009	621 (2)	849 (2)	7 (0)	226 (2)	3118 (6)	0.003	0.002	0	0.009	0.002
2010	529 (2)	1100 (0)	9 (0)	146 (0)	2993 (2)	0.004	0	0	0	0.001
2011	868 (11)	913 (5)	33 (0)	129 (0)	3208 (17)	0.013	0.005	0	0	0.005
2012	707 (8)	554 (2)	294 (3)	164 (3)	3099 (18)	0.011	0.004	0.010	0.018	0.006
2013	702 (10)	644 (5)	268 (3)	185 (1)	2872 (20)	0.014	0.008	0.011	0.005	0.007
2014	491 (4)	540 (1)	192 (0)	127 (1)	2542 (6)	0.008	0.002	0	0.008	0.002
2015	435 (10)	407 (2)	237 (0)	149 (0)	2412 (12)	0.023	0.005	0	0	0.005
2016	478 (19)	556 (2)	302 (0)	172 (1)	2358 (22)	0.040	0.004	0	0.006	0.009
2017	424 (2)	423 (0)	238 (0)	202 (2)	2081 (4)	0.005	0	0	0.010	0.002
2018	542 (14)	665 (14)	126 (0)	100 (0)	2292 (28)	0.026	0.021	0	0	0.012
2019	333 (7)	750 (6)	136 (0)	26 (0)	2053 (14)	0.021	0.008	0	0	0.007
2020	309 (7)	524 (4)	81 (0)	20 (1)	2000 (12)	0.023	0.008	0	0.050	0.006
2021	298 (35)	393 (15)	37 (0)	94 (0)	1629 (50)	0.117	0.038	0	0	0.031

Table 9 (cont.)

All turtles

	No. hooks in thousands (no. reported turtles)					Turtles per 1000 hooks				
Month	FMA1	FMA2	FMA7	FMA8	FMA9	FMA1	FMA2	FMA7	FMA8	FMA9
1	1037 (20)	515 (20)	19 (0)	3 (0)	100 (2)	0.019	0.039	0	0	0.020
2	956 (29)	834 (8)	163 (1)	4 (0)	254 (0)	0.030	0.014	0.006	0	0.004
3	1056 (34)	1299 (13)	809 (2)	14 (1)	408 (2)	0.039	0.013	0.002	0.071	0.010
4	988 (26)	1089 (7)	995 (3)	4 (0)	366 (3)	0.029	0.007	0.004	0	0.014
5	564 (7)	1903 (5)	2372 (1)	14 (0)	264 (3)	0.012	0.004	0.001	0	0.011
6	757 (3)	2166 (3)	2400 (1)	5 (0)	210 (0)	0.004	0.002	0	0	0.005
7	1992 (0)	1026 (1)	818 (0)	0 (0)	237 (1)	0.001	0.002	0	–	0.008
8	2124 (2)	161 (0)	439 (0)	1 (0)	274 (0)	0.002	0	0	0	0.011
9	640 (0)	45 (0)	24 (0)	0 (0)	143 (0)	0	0	0	–	0
10	257 (0)	2 (0)	0 (0)	0 (0)	32 (0)	0	0	–	–	0
11	787 (7)	14 (0)	0 (0)	0 (0)	17 (0)	0.009	0	–	–	0
12	1008 (5)	90 (1)	0 (0)	0 (0)	19 (0)	0.006	0.011	–	–	0

Year	FMA1	FMA2	FMA7	FMA9	All	FMA1*	FMA2*	FMA7*	FMA9*	All
2008	418 (0)	605 (0)	6 (0)	100 (0)	2247 (1)	0	0	0	0	0
2009	621 (2)	849 (2)	7 (0)	226 (2)	3118 (6)	0.003	0.002	0	0.009	0.002
2010	529 (5)	1100 (0)	9 (0)	146 (0)	2993 (6)	0.009	0	0	0	0.002
2011	868 (15)	913 (6)	33 (0)	129 (1)	3208 (23)	0.017	0.007	0	0.008	0.007
2012	707 (8)	554 (2)	294 (3)	164 (6)	3099 (23)	0.011	0.004	0.010	0.037	0.007
2013	702 (10)	644 (5)	268 (4)	185 (2)	2872 (25)	0.014	0.008	0.015	0.011	0.009
2014	491 (4)	540 (1)	192 (0)	127 (2)	2542 (7)	0.008	0.002	0	0.016	0.003
2015	435 (10)	407 (2)	237 (0)	149 (0)	2412 (12)	0.023	0.005	0	0	0.005
2016	478 (20)	556 (5)	302 (0)	172 (2)	2358 (27)	0.042	0.009	0	0.012	0.011
2017	424 (2)	423 (1)	238 (0)	202 (2)	2081 (5)	0.005	0.002	0	0.010	0.002
2018	542 (14)	665 (17)	126 (0)	100 (0)	2292 (31)	0.026	0.026	0	0	0.014
2019	333 (7)	750 (6)	136 (0)	26 (0)	2053 (14)	0.021	0.008	0	0	0.007
2020	309 (8)	524 (7)	81 (0)	20 (1)	2000 (17)	0.026	0.013	0	0.050	0.009
2021	298 (37)	393 (18)	37 (0)	94 (0)	1629 (56)	0.124	0.046	0	0	0.034

The number of turtle captures in 2021 was the highest on record, both by Ministry observers and by the commercial fishery (Table 5). In 2021, the proportion of observer effort was unusually high during summer (January to March) and in the Bay of Plenty, where it was associated with the relatively high turtle captures (Figure 9). In most earlier years, the observer coverage was highest in the Bay of Plenty during winter and spring (July to December), when few or no turtles were caught (Figures 9 & 10). However, a change in the spatial and temporal pattern of observer coverage did not seem to explain the high turtle captures alone, as the summer Bay of Plenty fishery was similarly covered by observers in some previous years, e.g., 2020 and 2018, but with lower turtle captures. Nevertheless, in other years, e.g., 2016 and 2017, there was little to no coverage of the Bay of Plenty in summer, consistent with comment by Godoy (2016) that observer coverage had been essentially in the wrong time and place to sample turtle captures. In late summer and autumn (April to June), the observer coverage of the fishery was typically and predominantly off East Cape with little to no coverage in the Bay of Plenty, and 2021 was little different in that respect. In years before 2016, the observer coverage was relatively sparse in summer, increased in summer and late autumn, and peaked during winter and spring, with a similar overall spatial coverage (Figure 10).

In summer 2021, the distribution of commercial fishing effort was more extensive, but broadly similar to the observer records, with a concentration of effort and turtle captures in the Bay of Plenty (Figure 11). Fishing in the Bay of Plenty continued into late summer and autumn 2021, when observer coverage was absent. Overall, the seasonal and spatial coverage of the fishery was not noticeably different in 2021, so a change in fishery activity would not, alone, seem to account for the higher numbers of turtle captures.

The spatial coverage of the fishery, and turtle captures from commercial records, was broadly consistent over time, being primarily off the northeast coast of New Zealand and most often in the Bay of Plenty, but in some years the turtle captures were quite localised (e.g., 2013, 2018) whereas in others they were more widespread (e.g., 2016). The spatial pattern was not clearly linked to numbers of captures reported, as captures in both 2018 and 2016 were relatively high (Table 5). A more spatially widespread capture of turtles was seen in some earlier years, especially 2011, and was present in both summer and late summer to autumn. The commercial fishing effort and turtle captures tended to remain throughout the Bay of Plenty during summer to autumn, whereas the observer coverage tended to shift to the east and south of East Cape during late summer and autumn.

Turtle captures in winter were much lower but not always zero, and occurred off the northeast North Island and in areas where effort was highest.

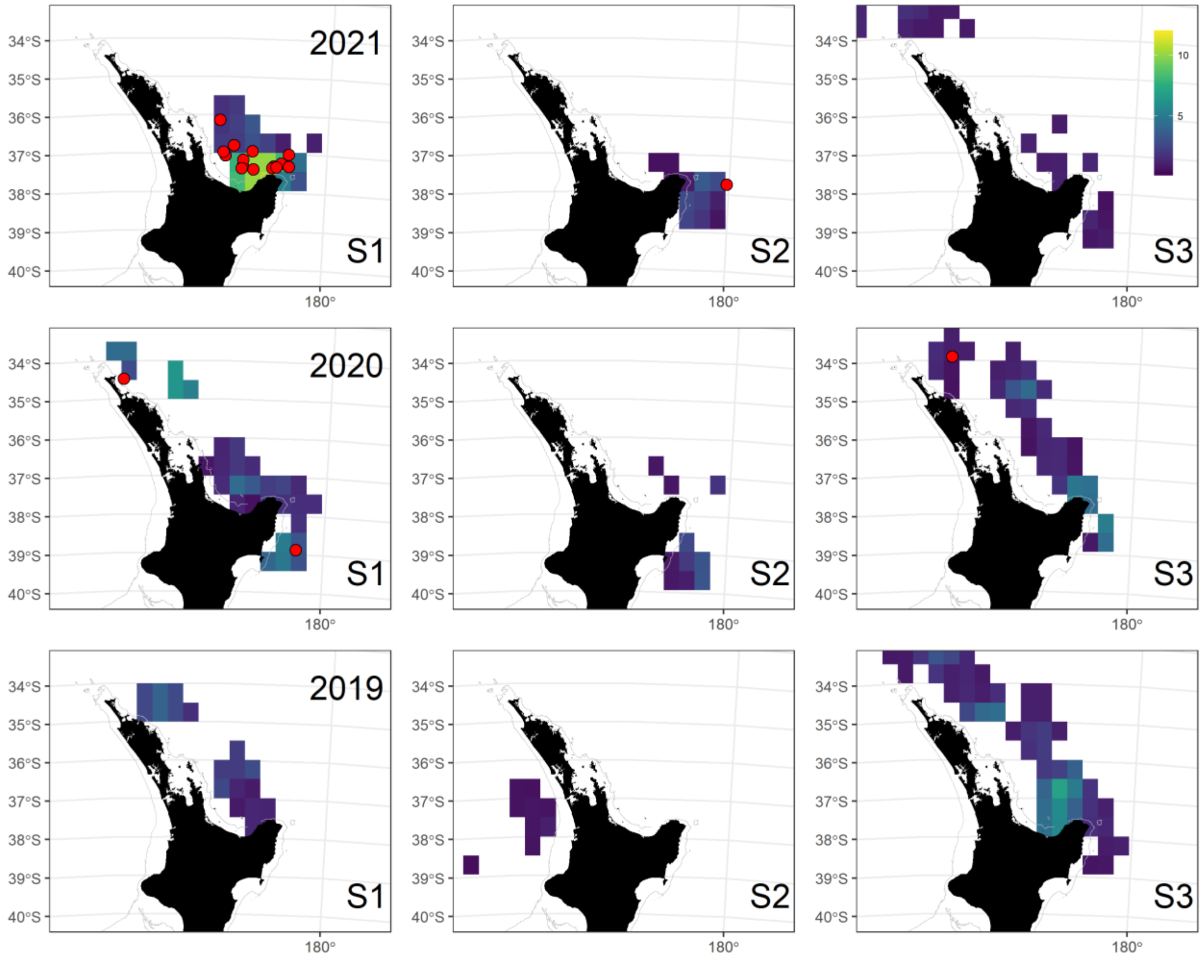

Figure 9: Location of observer reported total turtle captures (red dots), with shaded cells indicating the distribution of observed hooks (in thousands of hooks) in surface longline fisheries (above 40° S), by fishing year and season (S1=January-March, S2=April-June, S3=July-December).

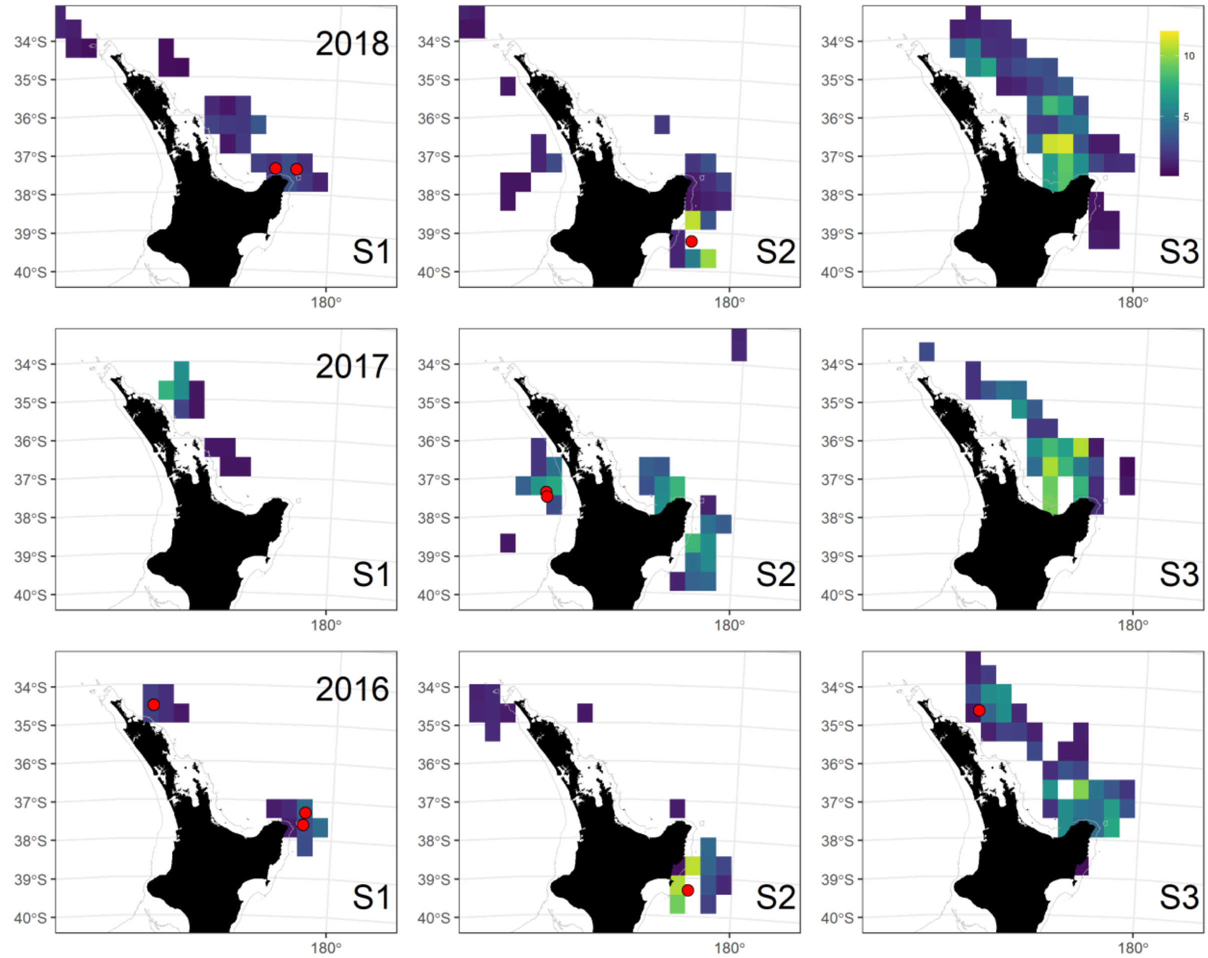

Figure 9 continued:

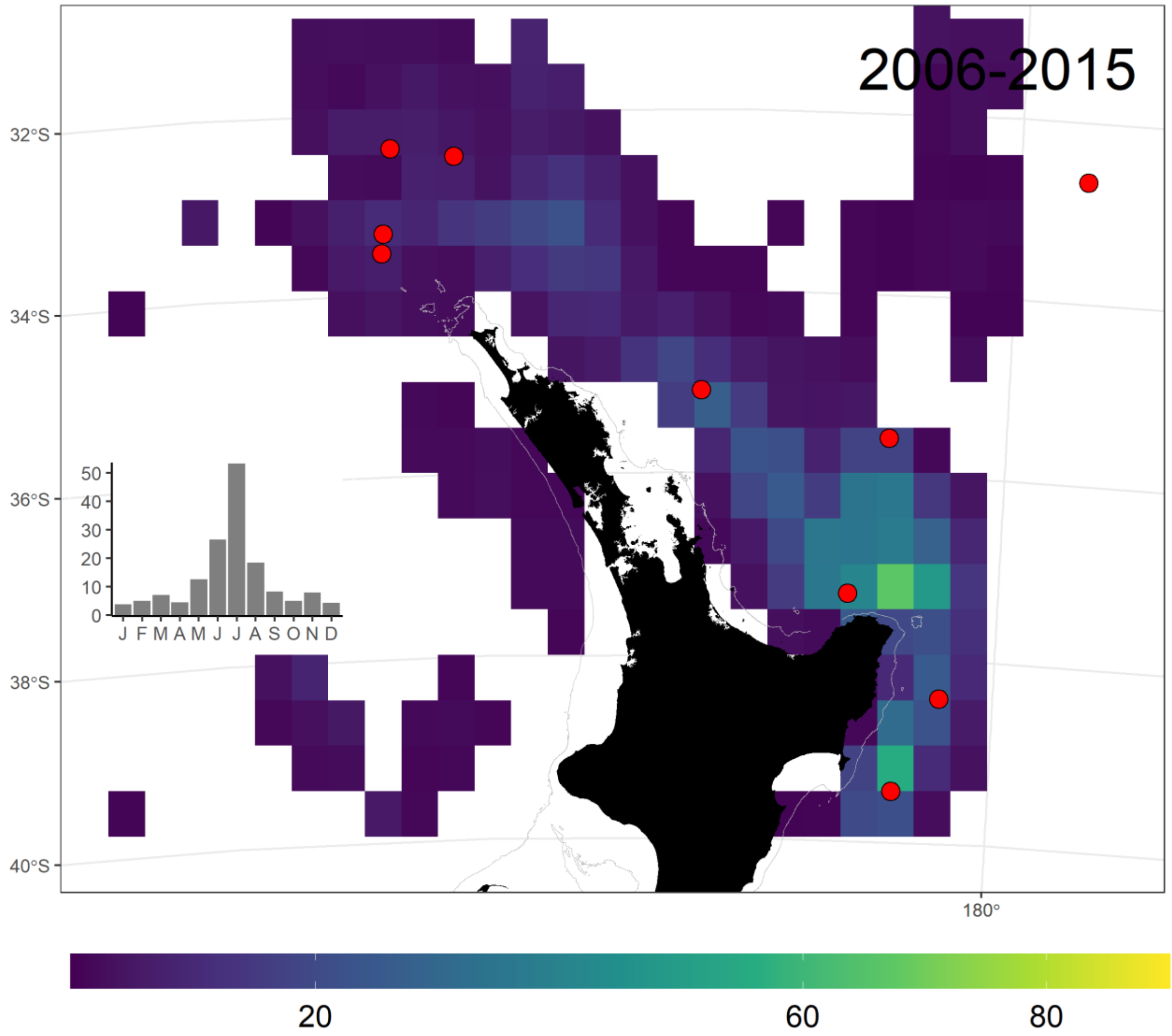

Figure 10: Location of observer reported total turtle captures (red dots), with shaded cells indicating the distribution of observed hooks (in thousands of hooks) in surface longline fisheries (above 40° S) for fishing years 2006–15. Monthly observed hooks inserted.

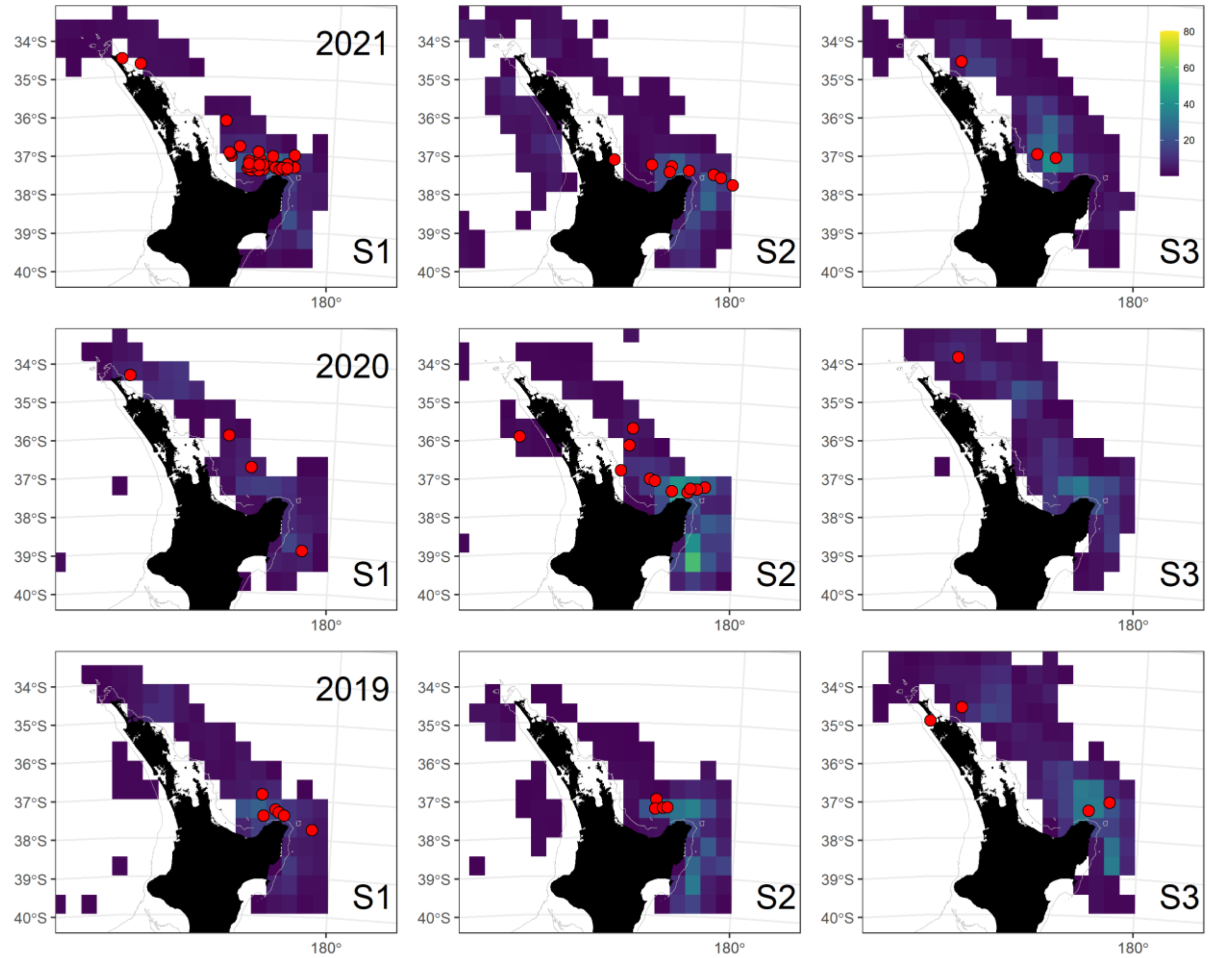

Figure 11: **Location of commercial reported total turtle captures (red dots), with shaded cells indicating the distribution of reported hooks (in thousands of hooks) in surface longline fisheries (above 40° S), by fishing year and season (S1=January-March, S2=April-June, S3=July-December).**

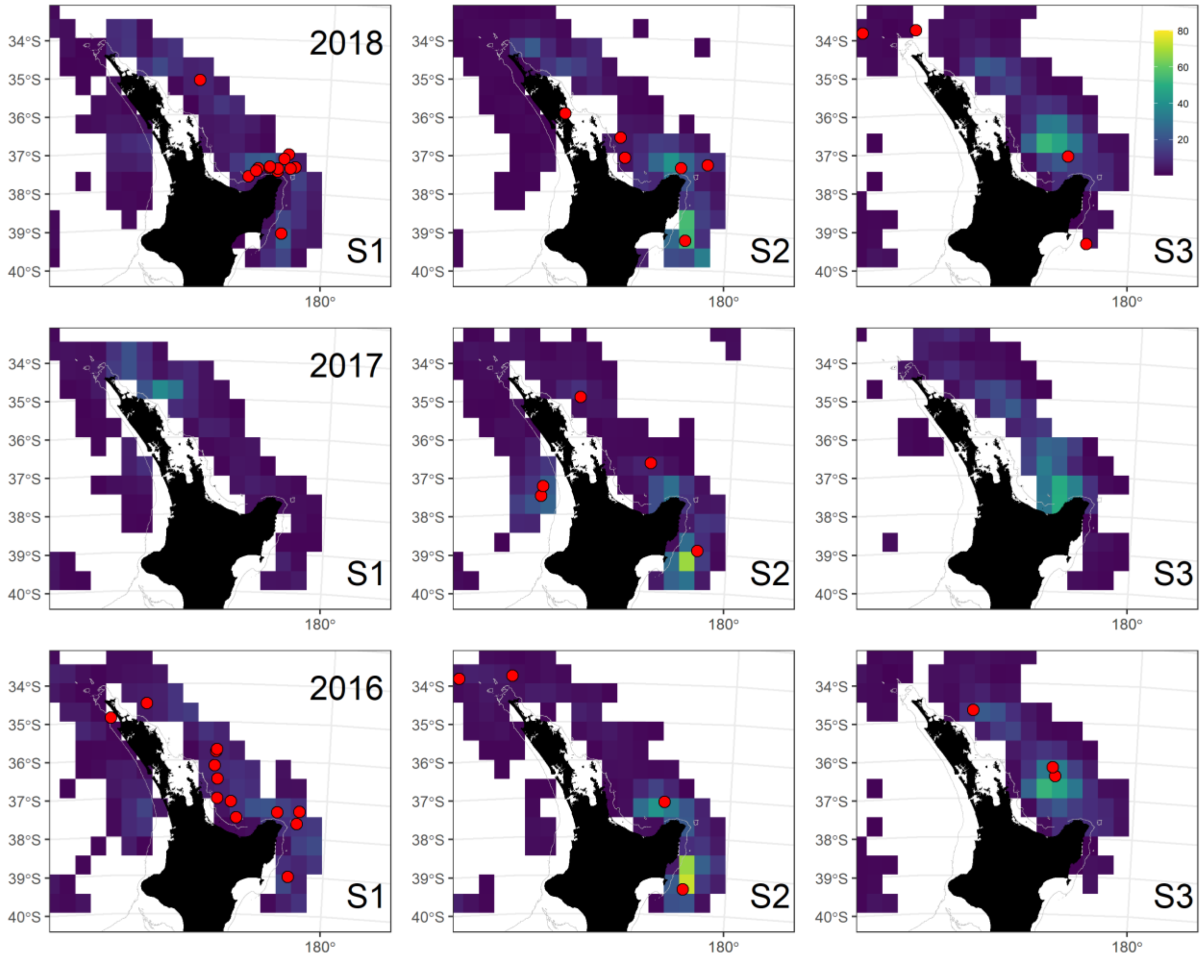

Figure 11 continued:

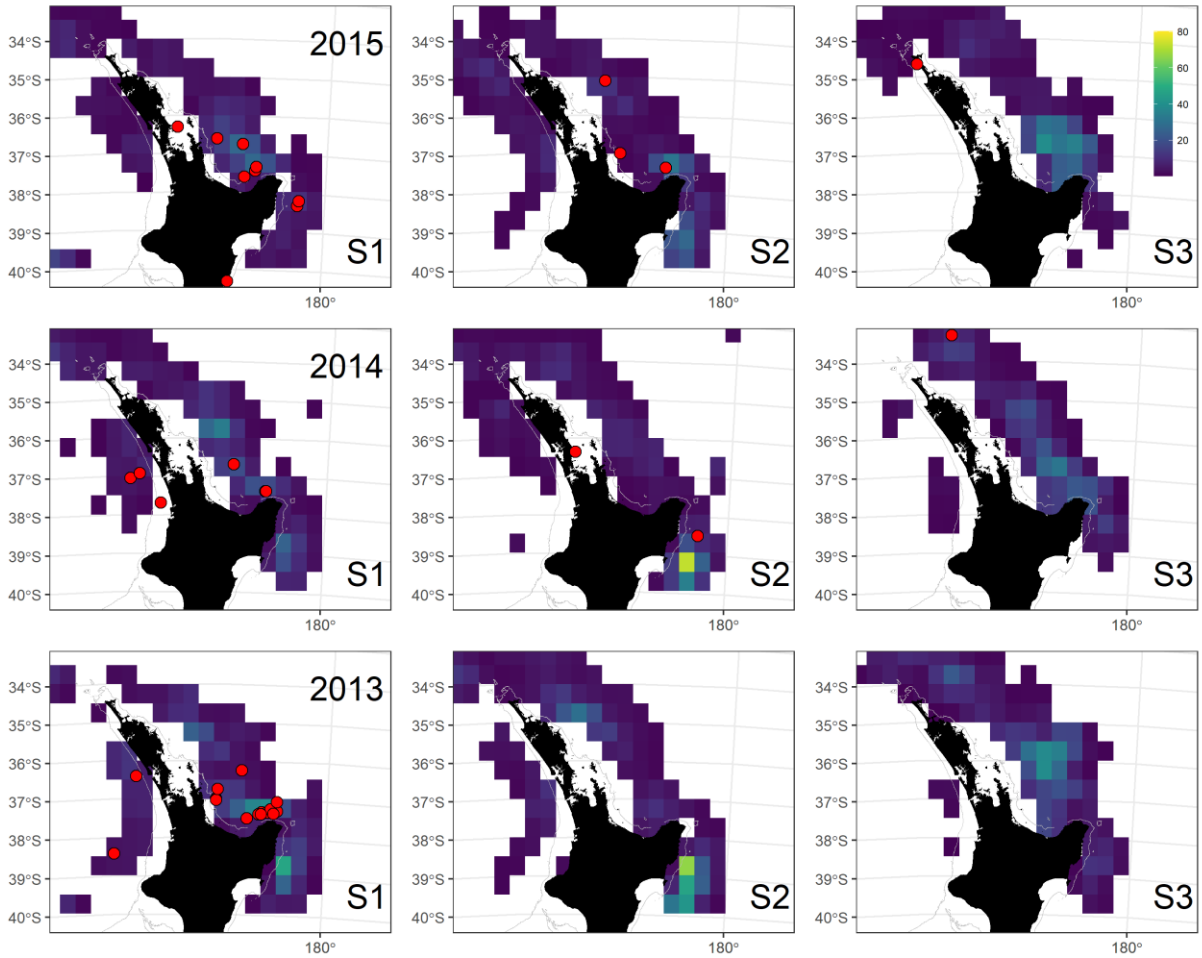

Figure 11 continued:

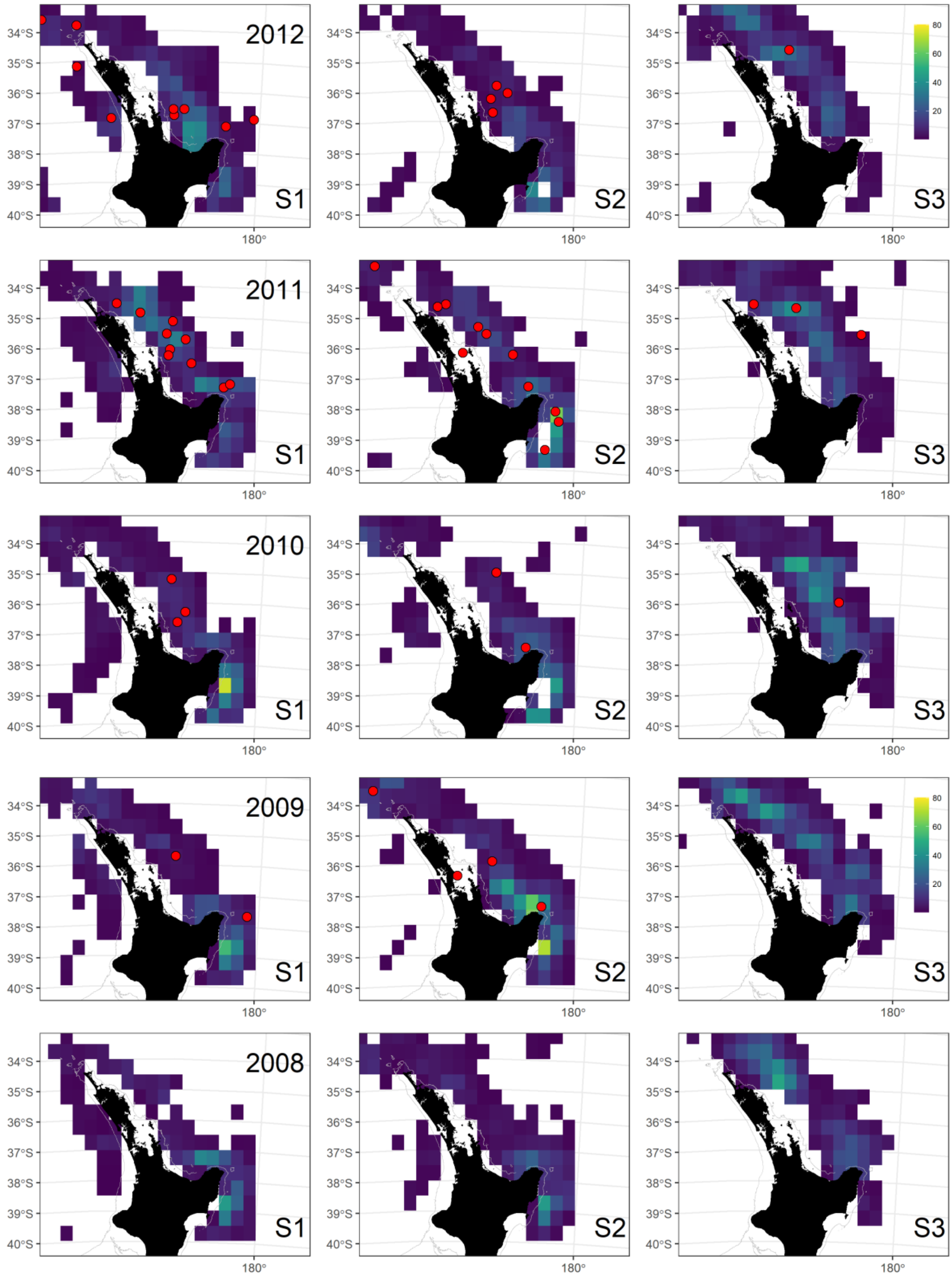

Figure 11 continued:

3.3 Predicting leatherback capture rate from environmental conditions

Graphical evaluation of the environmental variables associated with captures of leatherback turtles suggested the primary influence was likely to be water temperature, followed by frontal zones (dynamic height), ocean currents (mean eastward current, time varying northward current, time varying speed), and water clarity (as *chla* or *kd490*), with primary productivity having relatively little influence (Figure 12). The *kd490* and SST gradient (*SSTgrad*) coefficients were ultimately excluded because including them would have substantially reduced the number of turtle observations in the data set; *kd490* was missing for 2020–21, and SST gradient missing for some inshore areas.

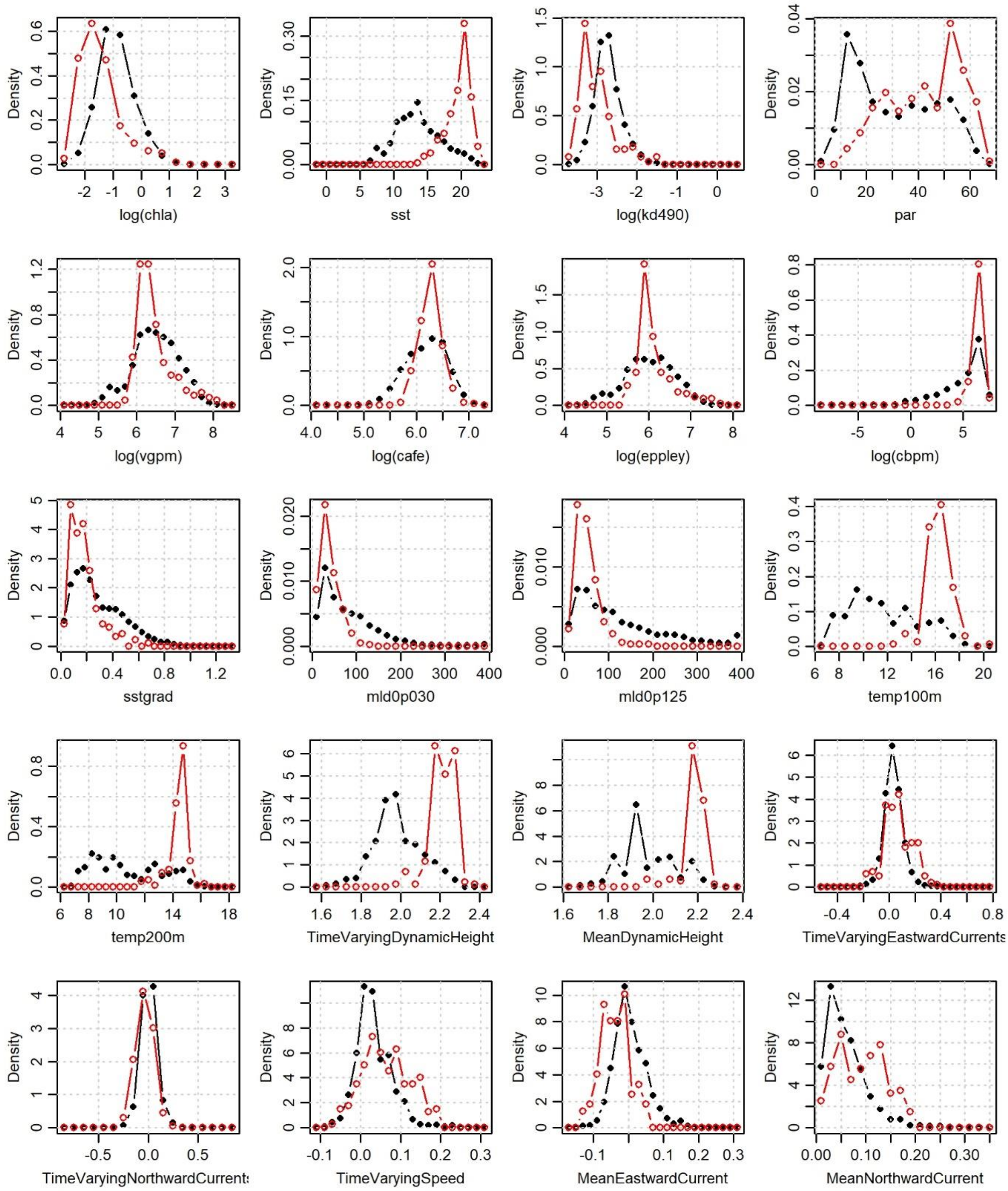

Figure 12: For each variable, the density of fishing events (black) and leatherback turtle captures (red).

The dynamic height calculated from the Roemmich and Gilson Argo climatology can be indicative of eddy structures, although eddies and front areas are not straightforward to identify at the spatial scales likely relevant to biological processes (data here were at 1 degree latitude and longitude resolution). Dynamic height reflects currents: much like a weather map, currents flow along lines of constant height, with anticlockwise flow around a high and clockwise flow around a low (in the southern hemisphere). Visually, the concentration of turtle captures in the eastern Bay of Plenty might be related to an eddy feature (Figure 13).

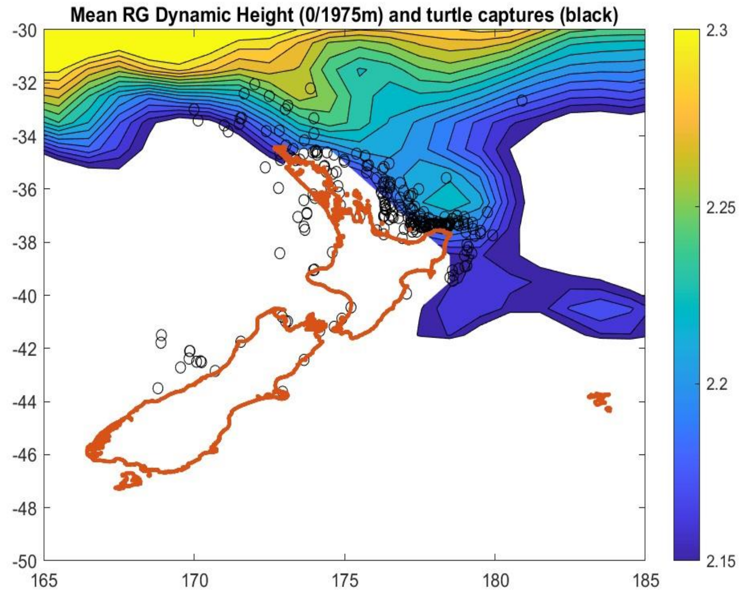

Figure 13: Mean Roemmich and Gilson (RG) Argo climatology dynamic height (surface relative to 1975 m) and location of turtle captures (points) plotted for the northern and east New Zealand region.

An average subsurface temperature of above about 14°C also marks the eastern edge of the Bay of Plenty (Figure 14) and alone was a potentially powerful predictor of leatherback capture; a temperature at 200 m of ≥14°C and ≤ 15.2°C accounted for 7% of the fishing events, but 67% of the turtle captures. Dynamic height is related to water temperature, and both help to identify the core of the East Auckland Current (EAuC) off the east coast North Island (Figure 15). A dynamic height of ≥2.15 and ≤ 2.3°C accounted for 6% of the fishing events, but 72% of the turtle captures. Further offshore the currents move from southward to northward (Figure 15), with northward being indicated here by a negative meridional current (coefficient *MeanNorthwardCurrent*).

3.3.1 GLM with environmental coefficients only

The coefficients included in this binomial GLM were:

Leatherback probability of occurrence ~ poly(*SST*, 2) + poly(*TimeVaryingNorthwardCurrents*, 2) + poly(*TimeVaryingDynamicHeight*, 2) + poly(*temp200m*, 2)

Where ‘poly’ followed by a number indicates a polynomial coefficient and the degree (2nd order). The deviance explained by the final model was relatively low (17.7%), but this was expected given the low number of leatherback occurrences in the dataset (Table 10). Year was not included in the model but a general increase of capture probability was predicted over time, with the highest observed captures in 2020–21, and relatively low captures in 2007–08 to 2009–10, around 2013–14, in 2016–17, and in 2019–20, reproduced by the model (Figure 16). The year trend was largely a response to *SST*, with additional coefficients reducing the expected probability of capture in 2010–11, 2015–16, and particularly 2018–19, and increasing probability in 2020–21 (Figure 17).

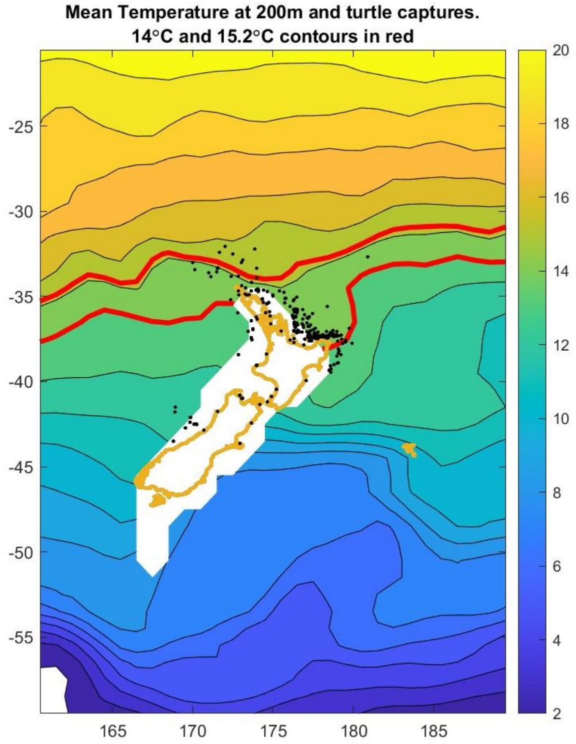

Figure 14: Mean temperature at 200 m and turtle captures (points). The mean temperature field is plotted here, while a time-varying field was used for the analysis. The red lines mark 14 and 15.2° C.

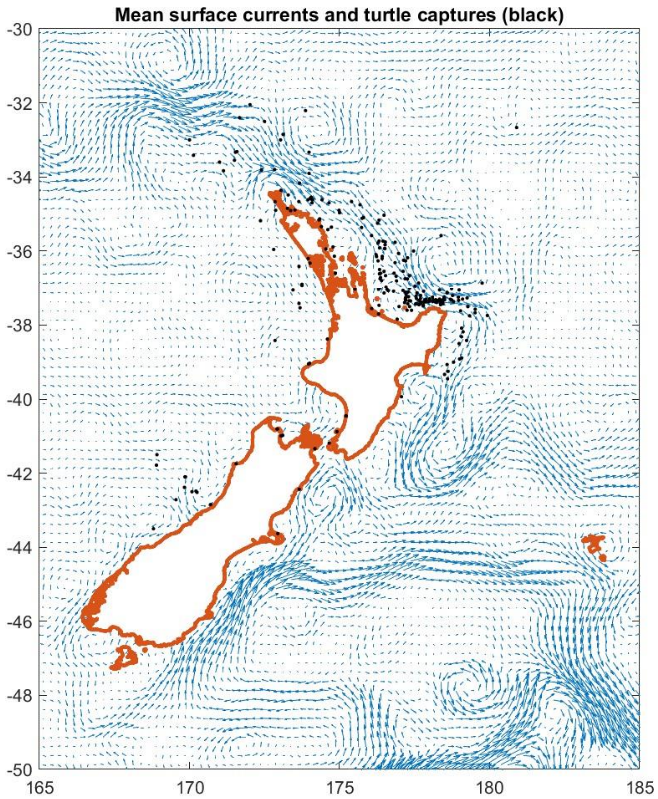

Figure 15: Mean surface currents and turtle captures (points). Arrows indicate current direction, and a larger arrow a faster current speed.

Table 10: Coefficients selected by the binomial generalised linear model (GLM) fitted to leatherback capture in the surface longline fishery, with the degrees of freedom (df), AIC, and amount of deviance explained by each coefficient.

Step	Coefficient	df	AIC	% deviance explained	additional % deviance explained
1	poly(*SST*, 2)	1	1180	16.3	16.8
2	poly(*TimeVaryingNorthwardCurrents*, 2)	2	1177	16.8	0.5
3	poly(*TimeVaryingDynamicHeight*, 2)	2	1176	17.1	0.3
4	poly(*temp200m*, 2)	2	1172	17.7	0.6

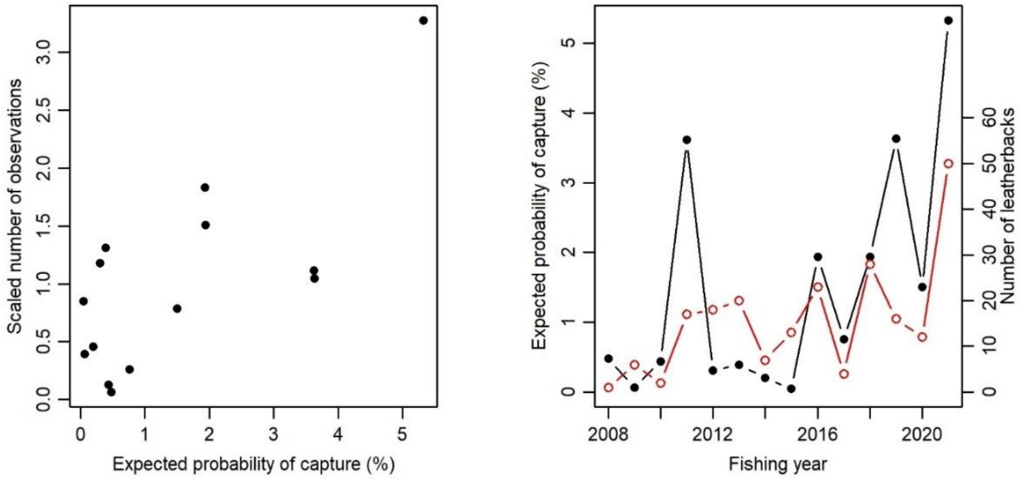

Figure 16: Left panel, the correlation between the annual expected probability of capture from the GLM and the number of leatherbacks observed (scaled to have the same geometric mean). Right panel, the GLM expected probability of leatherback capture (black line and solid points) by fishing year, and the total observed number of leatherback capture (red line and open points; Table 5) by fishing year, with both series scaled to have the same geometric mean.

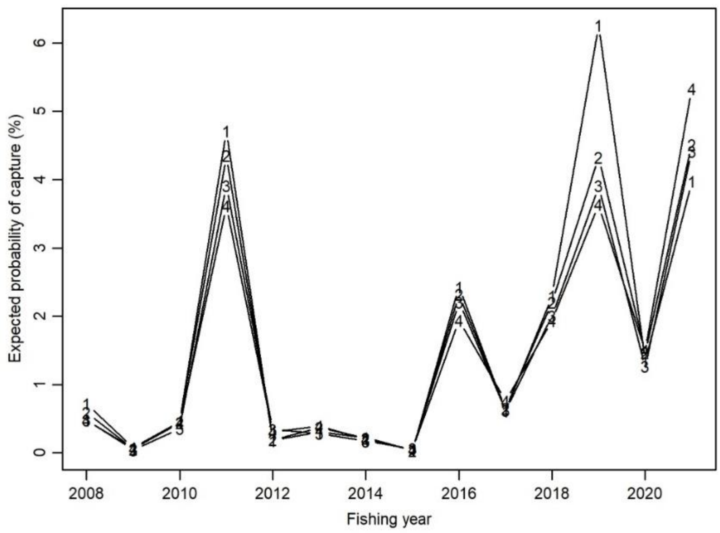

Figure 17: Step plot, showing the expected probability of capture from the GLM after successive terms were added (see Table 10).

Leatherback turtle captures were predicted to be most likely when sea surface temperatures were between about 18–22°C, when subsurface temperature at 200m was between about 12–16° C, when the time varying northward currents were positive, and the time varying dynamic height was less than about 2.1 (Figure 18). Northwards (meridional) current being positive means northwards currents were stronger, so the probability of capture increased as southwards currents got weaker. A lower dynamic height means a lower heat content at that point, which could result from the East Auckland Current moving offshore in that area.

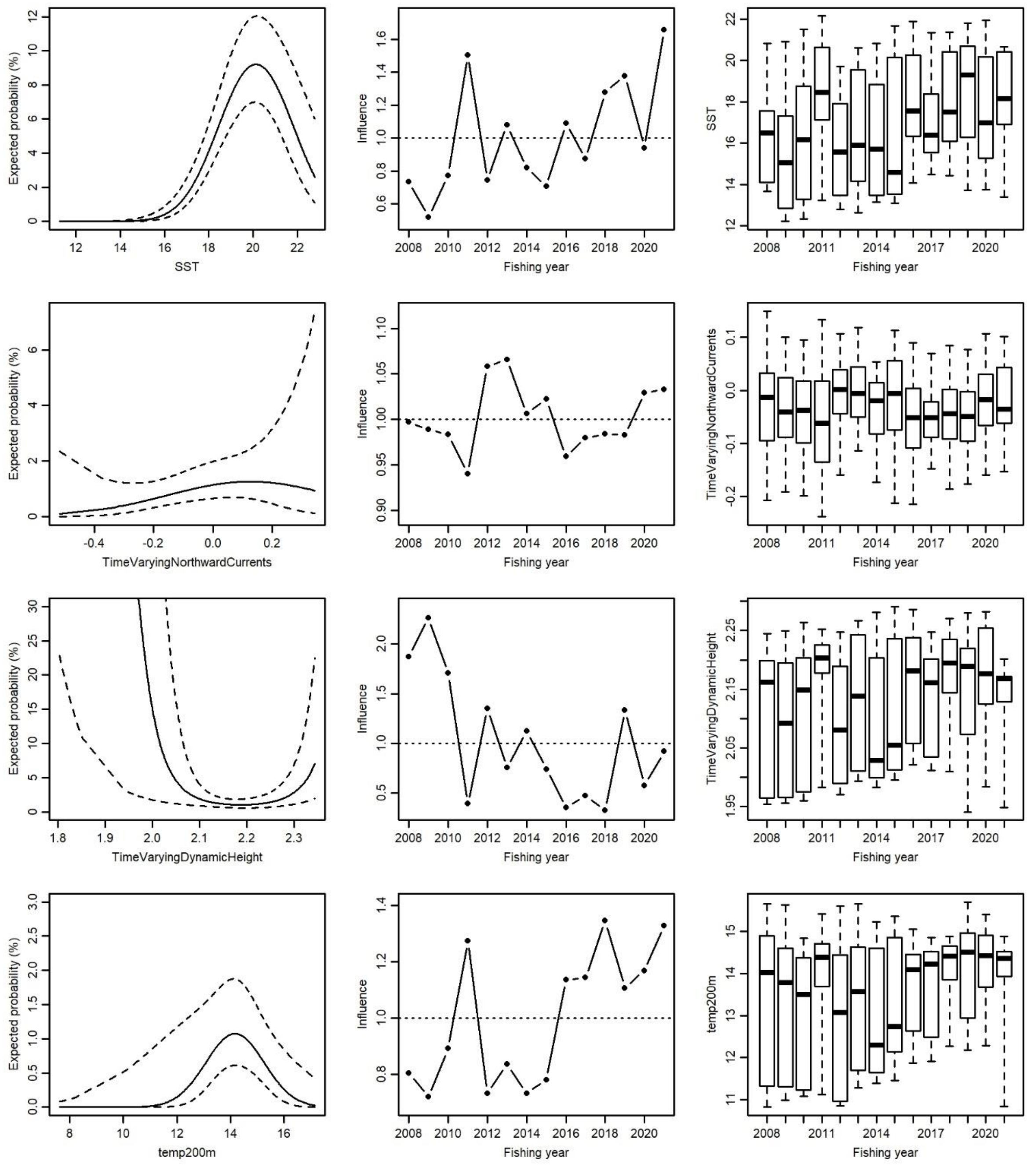

Figure 18: Left panels, the predicted coefficient effect (with 95% CI) estimated with other coefficients fixed at their median values; middle panels, the influence of each coefficient in each fishing year; right panels, the distribution of each variable by fishing year.

3.3.2 GLM with all coefficients

The coefficients included in this binomial GLM were:

Leatherback occurrence ~ poly(*SST*, 2) + poly(*doy*, 3) + poly(*temp200m*, 2) + poly(*mld0p125*, 3) + *target_species* + poly(*lat*, 3) + poly(*TimeVaryingEastwardCurrents*, 3)

The deviance explained by the final model was slightly higher (21.2%; Table 11) than the environmental-only model (17.7%).

Year was not included in the model but a general increase of capture probability was predicted after 2014–15, and the increase was much greater than predicted by the environmental-only model, with 2020–21 about 4-times higher than 2018–19 (Figure 19); in the environmental-only model 2020–21 was only about 40% higher than 2018–19. The year trend was again largely a response to *SST*, with additional coefficients reducing the expected probability of capture in 2010–11, 2015–16, and particularly 2018–19, but almost all coefficients increasing the probability in 2020–21 (Figure 20).

Table 11: Coefficients selected by the binomial generalised linear model (GLM) fitted to leatherback capture in the surface longline fishery, with the degrees of freedom (df), AIC, and amount of deviance explained by each coefficient.

Step	Coefficient	df	AIC	% deviance explained	additional % deviance explained
1	poly(*SST*, 2)	1	1180	16.3	16.3
2	poly(*doy*, 3)	3	1161	18.1	1.8
3	poly(*temp200m*, 2)	2	1156	18.7	0.6
4	poly(*mld0p125*, 3)	3	1150	19.5	0.8
5	*target_species*	4	1149	20.2	0.7
6	poly(*lat*, 3)	3	1147	20.7	0.5
7	poly(*TimeVaryingEastwardCurrents*, 3)	3	1146	21.2	0.5

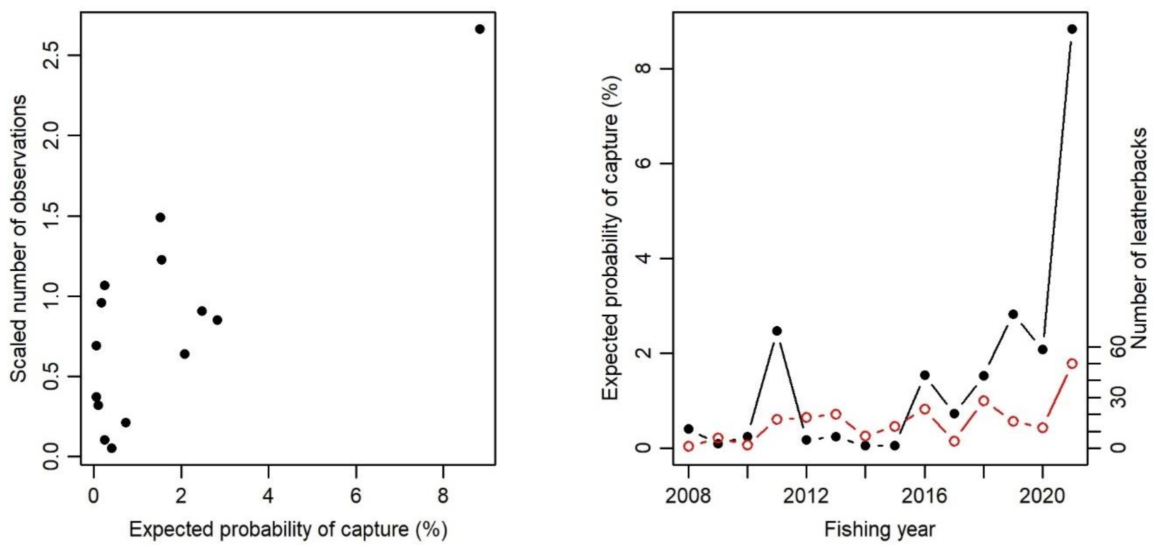

Figure 19: Left panel, the correlation between the annual expected probability of capture from the GLM and the number of leatherbacks observed (scaled to have the same geometric mean). Right panel, the GLM expected probability of leatherback capture (black line and solid points) by fishing year, and the total observed number of leatherback capture (red line and open points; Table 5) by fishing year, with both series scaled to have the same geometric mean.

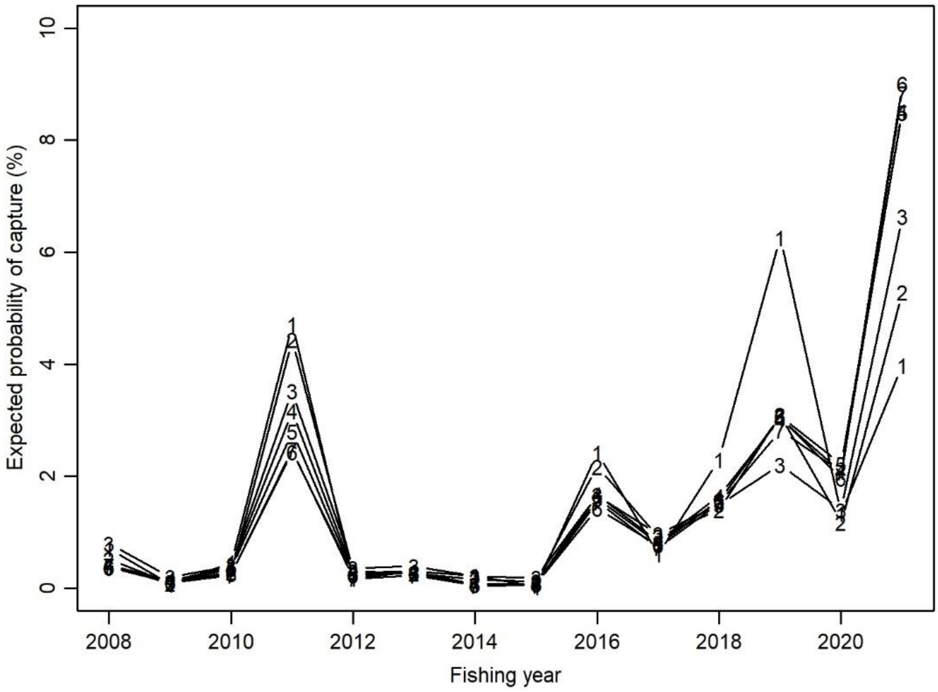

Figure 20: Step plot, showing the expected probability of capture from the GLM after successive terms were added (see Table 10).

Leatherback turtle captures were predicted to be most likely when sea surface temperatures were between about 14–22°C, when subsurface temperature at 200m was relatively warm, in the first two-thirds of the calendar year, when the mixed layer depth was relatively shallow, when time varying eastward currents were either negative or above about 0.1, at latitudes south of about 42°S (i.e., west coast South Island), and when vessels were targeting swordfish (Figure 21). Day of year (*doy*) and latitude (*lat*) were considered plausible even though they might alias for other environmental factors, because it was thought that turtles might arrive at a given time of year, or in a given location, regardless of the environmental conditions.

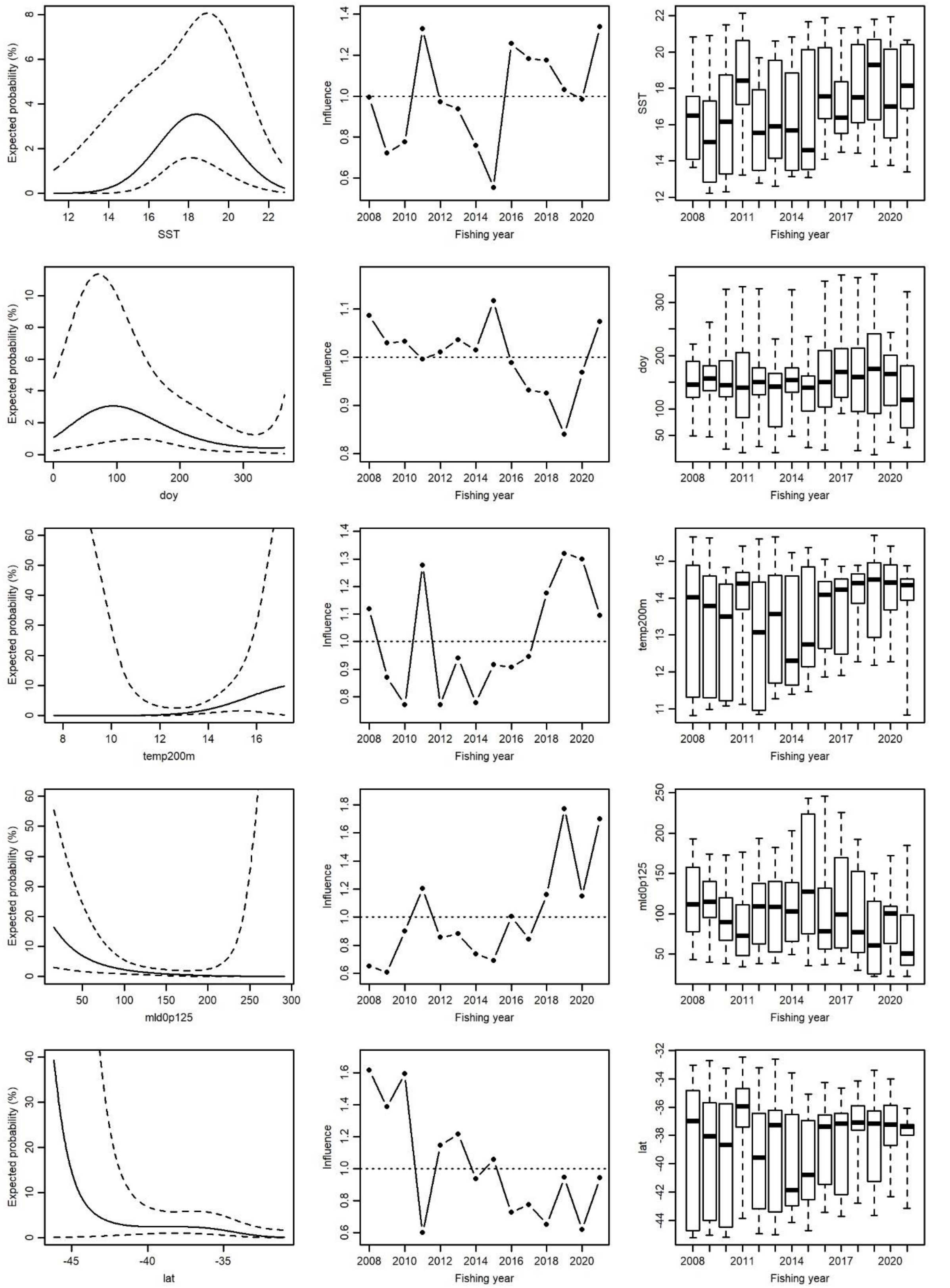

Figure 21: Left panels, the predicted coefficient effect (with 95% CI) estimated with other coefficients fixed at their median values; middle panels, the influence of each coefficient in each fishing year; right panels, the distribution of each variable by fishing year.

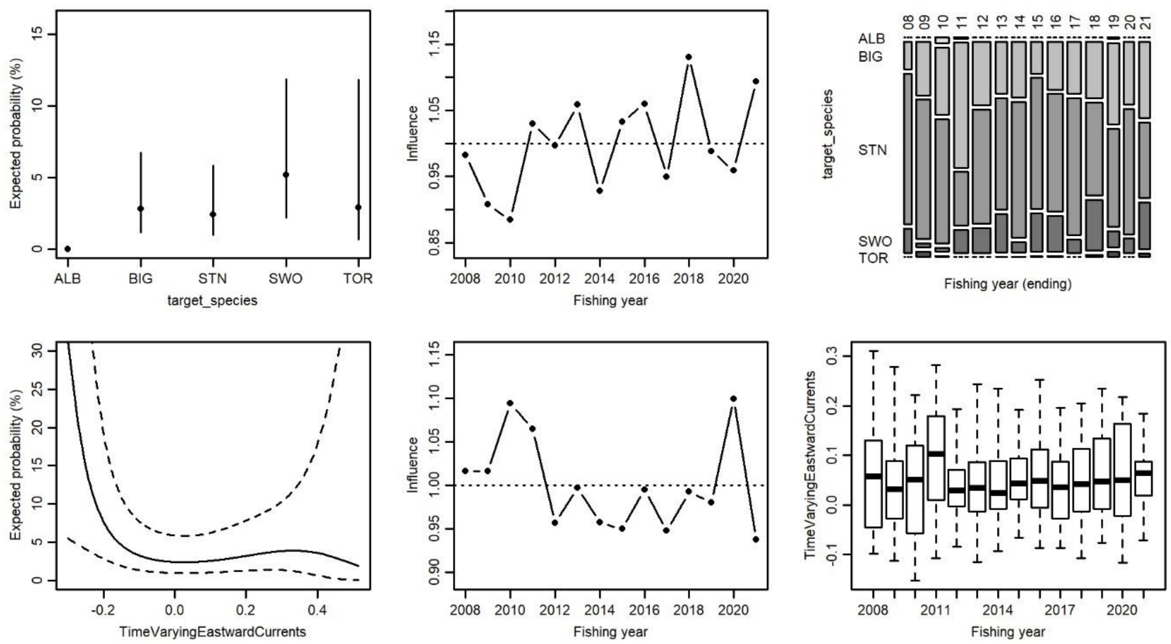

Figure 21 (cont.):

4 Discussion

4.1 Frequency of turtle captures

Godoy (2016) estimated an average 17 turtle captures per year between 2008–09 and 2014–15, and we found a similar level (18 per year) with the time series extended to 2019–20, but there was then a substantial increase for 2020–21, at 58 captures. Most captures (90%) were of single leatherback turtles, but up to four turtles were caught per fishing event, and occasionally two species were caught together. We found the first reported capture of a sea snake, a banded sea krait, in 2019–20.

Most turtle captures were by surface longlines targeting bigeye tuna or swordfish, between January and April, off northeast New Zealand. This was the same as reported by Godoy (2016). Data on bait use were limited, but showed squid were a regular choice. The use of squid rather than fish bait has been shown to catch more turtles (Gilman et al., 2007; Yokota et al., 2009; Swimmer et al., 2017). About 4.5% of captured turtles were reported to be dead, and about 12% were hooked in the mouth and released with the hook still embedded, and such turtles are considered likely to die (Swimmer & Gilman, 2012). Overall, about one quarter of turtles are expected to die following capture based on post-release mortality studies overseas (Ryder et al., 2006; Swimmer & Gilman, 2012).

About 19% of the commercial longline vessels reported about 91% of the turtle captures, with a single vessel reporting 39% of the captures. The latter vessel only seemed to have recently carried Ministry observers in 2019–20 and 2020–21, and in 2020–21 it accounted for nearly half of the observer coverage. This coincided with the highest reported turtle catch. Whilst this might suggest non-reporting in the rest of the fleet, which would be consistent with high scaling-up of observer catch estimates by Abraham et al. (2021), the average turtle catch rate from the non-observed vessels that did report turtles was actually substantially higher than from observed events. This agrees with Godoy (2016), who concluded observer coverage was generally in the wrong place and wrong time to see turtles, and we corroborated this conclusion. An exception was 2020–21, when the proportion of observer coverage was unusually high where turtles were most often reported, during summer and in the Bay of Plenty.

A change in observer coverage did not seem to be the only explanation for higher catches in 2020–21. The correlation of leatherback captures with environmental conditions produced a year pattern that followed reported captures well; in particular, it predicted the large increase in 2020–21. The primary cause of this was sea surface temperature. We estimated lower bounds on leatherback occurrence at 12–16°C, consistent with an estimate of 14°C from tagged eastern Pacific leatherbacks (Shillinger et al., 2011). After temperature, environmental coefficients seemed to be largely describing the position of fishing relative to the East Auckland Current. We did not estimate a primary productivity effect on capture, but productivity and foraging success is thought to determine subsequent nesting success (Saba et al., 2008). Regression analyses allowing further operational coefficients predicted an even greater increase in leatherback captures for 2020–21, implying the increase in that year might have been even higher than reported. Anecdotally, the current year (2021–22) has been another warm year, with prolonged heatwaves on the east coast North Island (see moanaproject.org, news release 21/02/22), and we would therefore predict another year of relatively high turtle captures.

The turtle seen least often in commercial captures was the olive ridley, with only one record, and that record was originally reported as a green turtle (corrected using observer photographs). Nevertheless, olive ridleys were common in Auckland Zoo records (Appendix A) and in beach stranding reports (see Appendix B). Some misidentification of olive ridley turtles by observers is possible (we found one case), and they are certainly caught on longlines elsewhere (Dapp et al., 2013). However, it may be that New Zealand waters are simply too cold for this species, and they routinely suffer cold-shock or dormancy and end up not feeding (i.e., not captured on baited hooks) and stranded as a result. Five hawksbill turtles were reported in five surface longline events between February and August 2012 by a single vessel, and we agree with Godoy (2016) that this is suspicious and was likely species misidentification by the fisher.

Reported captures of turtles outside of the commercial longline fisheries were very low. This is plausible if fisheries do not operate where turtles congregate, but non-reporting may also be occurring. Whilst New Zealand inshore fisheries may interact more frequently with green turtles (Godoy & Stockin, 2018), leatherback turtles might also be impacted (Hamelin et al., 2017; Dodge et al., 2022). Mortality rates from trawls and setnets are expected to be higher than from surface longlines (Wallace et al., 2010).

4.2 Catch rates and limits

In 2009, New Zealand argued historical national turtle bycatch rates were substantially below a recommended minimal catch rate, but that rate was then exceeded in most following years, with no documented management response (Godoy 2016). We found a similar result to Godoy (2016), in that the minimal sea turtle interaction rate of 0.019 turtles per 1000 hooks (as proposed by Brouwer & Bertram 2009) was regularly exceeded in FMA 1 (in 6/7 years since 2014–15), and occasionally elsewhere (in 2/7 years each in FMA 8 and FMA 9). Our catch rates were calculated in a different way to Godoy (2016), as we restricted data to the season over which turtles were usually caught. This avoided including fishing activity in the calculation that would have never encountered a turtle. The estimated catch rates will be sensitive to the definition of the fishery and, for example, increasing the temporal range from a season to all year would include more records when turtles were (always) absent, so reducing the bycatch rate estimates. Conversely, restricting data to the main target species (bigeye tuna and swordfish) would have given a higher turtle bycatch rate. In New Zealand, concerns about the veracity of 'target species' as reported by fishers are regularly raised in science Working Group meetings, and this data field can be relatively unreliable (M. Dunn, pers. obs.). That bycatch rates will be sensitive to fishery definitions is not helpful for their use as an LRP. Further, the minimal bycatch rate is not related to an absolute number of deaths, which is what matters for the turtle population.

The leatherback bycatch in New Zealand has apparently become internationally significant, with captures exceeding the Hawai'i catch limit more than 3-fold in 2020–21. Based upon our results, about 4.5% of turtles might be expected to die during capture, and from literature about one quarter may then die in the period after release. For New Zealand leatherbacks, this would mean for 2020–21: about two turtles die on the lines, and a further 12–13 after release (14–15 deaths); and over the last five fishing years, about five die on the lines, and a further 26–27 after release (31–32 deaths; about six leatherbacks per year). If the catches seen in 2020–21 became the norm, then leatherback deaths on longlines in New Zealand waters would exceed the mortality limit recommended for the Western U.S. EEZ (Curtis et al., 2015). Such estimates are poorly informed and, as a result, highly uncertain, and would also be underestimates if the true number of captures was higher. Some non-reporting of captures seemed likely. Abraham et al. (2021) estimated an average 49 turtles caught per year during 2002–03 to 2017–18, about 2.5-fold higher than our reported estimates (an average 19.5 turtles per year). The extrapolation of observer data by Abraham et al. (2021) was substantial, and accordingly had high uncertainty, but it might also be biased because the observer data (until recently) poorly covered the times and places when most turtles were caught. With more comprehensive observer coverage, the accuracy and precision of estimates from the Abraham et al. (2021) method could be greatly improved, although with inclusion of higher observed catch rates the total estimate of turtle capture and deaths may well increase.

4.3 Marine reptiles and climate change in New Zealand

New Zealand supports a foraging aggregation of immature green turtles, is an important seasonal foraging ground for leatherback turtles, and an occasional foraging ground for loggerhead and hawksbill turtles. Olive ridley turtles and sea snakes may be more vagrant visitors, and New Zealand waters may have less value to their populations. Leatherback, green, and loggerhead turtles likely arrive in New Zealand following the Tasman Front (Boyle et al., 2008; Benson et al., 2011; Godoy 2017), and it would seem likely other marine reptiles do the same. Areas to the north and northwest of New Zealand, which are less frequently fished, may therefore support marine reptiles at similar or perhaps greater densities than seen off eastern New Zealand. Whilst there has been warming of oceans around the New Zealand coast over the last few decades, there has been very little warming in the East Auckland Current, between North Cape and East Cape (Bowen et al., 2017; Sutton & Bowen 2019). The East Australian Current, to which the East Auckland Current is related, has pushed further south bringing pronounced changes in marine conditions off Australia, but there isn't any sign of a similar extension of the East Auckland Current, most likely because of the bathymetric control of the current by Chatham Rise. The subtropical gyre has seen an increase in activity (Roemmich et al., 2016), but that spin-up hasn't seen a corresponding simple acceleration of the boundary currents, which would influence coastal New Zealand (Sloyan et al., 2015; Fernandez et al. 2018). Therefore, although climate is changing around New Zealand, the recent increase in turtle captures may be more related to environmental variability (e.g., ENSO) and/or fishing fleet location in relation to sea conditions, rather than climate change. Nevertheless, turtles are vulnerable to climate change in several ways, notably temperature-dependent sex determination, and their populations may well decline and become more vulnerable in the future (Jensen et al., in press).

5 Recommendations

5.1 Previous recommendations

Godoy (2016) made five broad recommendations, (1) implement and monitor a minimal sea turtle interaction rate; (2) implement the guidelines to reduce sea turtle mortality (studies and regulations of hook type and bait); (3) review the allocation of observer coverage; (4) improve data quality and reporting (better species identification, collect biological data, ask for more data on commercial forms); (5) improve population information and research (particularly on distribution and connectivity). To our knowledge little progress has been made on any of these, although coverage by observers seemed more relevant to turtles in 2019–20 and 2020–21 (whether this was planned we do not know), and study of risk assessment methodology funded by Fisheries New Zealand is underway (although which reptile species are most at risk, where, when and how, and also what might be done in mitigation, would seem to be already known). The Marine Species Programme of the Secretariat of the Pacific Regional Environment Programme (SPREP; www.sprep.org) has for many years provided a comprehensive review and strategy for conservation and management of sea turtles in the South Pacific (see also Pilcher 2021).

We agree with the recommendations of Godoy (2016), with the following suggested revisions and/or additions:

5.2 Set capture limits

A limit reference point (LRP) for turtles would be more relevant if the limit was in terms of absolute captures, rather than a capture rate. To be effective, a capture rate assumes the amount, timing, distribution, and method of fishing effort remains stable over time. An absolute limit does not require this assumption and is therefore preferred, and more consistent with international practice. To estimate an absolute limit will require, as a first step, contact and collaboration with international turtle researchers to obtain the most up-to-date and relevant population estimates, as turtles are all shared stocks nesting outside of New Zealand, and to review best methods for setting limits; methods have been already been developed and applied in the U.S., and New Zealand might usefully follow a similar approach to make national limits internationally consistent.

Secondary to this, of course, is to determine what mitigation might be required once a limit is reached. Whilst science might advise on limits and the potential efficacy of mitigation options, the mandated responses to limits is a management issue and requires stakeholder and partner engagement.

5.3 Collect more information on individual turtles

Many nesting leatherbacks have been fitted with passive integrated transponder (PIT) tags. It is unlikely to be cost effective to tag leatherbacks in New Zealand, but any washed ashore or brought onto the deck of a vessel could be scanned to see if a PIT tag can be recorded. Such data would allow direct confirmation of the origin of the turtle and improve knowledge of life history and population connectivity (Omeyer et al., 2019), as recommended by Godoy 2016, but also potentially provide information on whether a caught turtle survived and was seen nesting again in future years. As above, contact and collaboration with international researchers would be a desirable first step.

It may be practical and useful to fit green turtles in New Zealand with PIT or electronic tags to record movements, to better estimate mortality rates and areas where turtles and fisheries (commercial or recreational) may overlap. Any planned tagging exercise should consider the possible negative effects tagging may have on the turtles (Sherrill-Mix & James 2008).

Biopsy punches might be used at sea (a dart on the end of a pole) to take small muscle samples and allow DNA analyses to be conducted to confirm the likely origin of the turtles. If combined with stable isotope analyses, such samples might also reveal aspects of the turtle behaviour and habitat use in New Zealand waters. A biopsy punch approach might be the most realistic and useful way to collect population data in the short term, especially for leatherbacks, although would still likely take several years to complete.

5.4 Better estimate capture rates

This might be most simply achieved through improving observer coverage (Godoy, 2016), but we also recommend identifying and talking to the skippers, in particular those regularly catching leatherback turtles, to obtain further information on the nature and scale of turtle interactions and capture. Better communication and understanding with fishers would also seem potentially helpful in encouraging compliance with any future mitigation requirements.

5.5 Further investigate Auckland Zoo data

These data should be collated and analysed, as they may provide insight into the nature of turtle injuries and deaths (Orós et al., 2021), the biology and ecology in New Zealand waters, and potentially on frequency of bycatch by inshore and/or recreational fisheries and whether these fisheries need further investigation.

6 Acknowledgements

This project was funded by the Department of Conservation's Conservation Services Programme project INT2021-03. Thank you to the following people for their advice and providing data for this work: Owen Anderson (NIWA), Celine Campana and Mikaylie Wilson (Auckland Zoo), Dan Godoy (Blue Planet Marine), Karen Middlemiss and Clinton Duffy (DOC), and Fisheries New Zealand RDM. The altimeter products (AVISO) were produced by Ssalto/Duacs and distributed by Aviso+, with support from Cnes. Argos data were collected and made freely available by the International Argo Program and the national programs that contribute to it. The Argo Program is part of the Global Ocean Observing System. SeaWiFS and MODIS data were used courtesy of NASA Goddard Space Flight Center (SeaWiFS and MODIS projects) and based on research in NIWA Oceans Programme 4 "Ocean remote sensing" (MBIE-SSIF).

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Appendix A Auckland Zoo data

The hospital at Auckland Zoo has records of “at least 80” turtles (Tables A1 & A2), but the collation and evaluation of these data was beyond the scope of this project. Some data are electronic, whereas others are only on paper. The data report on turtle condition and outcome, but data were not deliberately collected on the potential human/fisheries interaction. Nevertheless, in some cases the cause of harm or death was very likely to be anthropogenic (e.g., Figure A1).

Table A1: Estimated number of turtles received by Auckland Zoo.

	Calendar year										
Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	No date	Total
Loggerhead	0	0	0	1	0	0	0	0	0	4	5
Green	0	1	0	2	3	1	1	2	4	18	32
Hawksbill	1	0	1	2	4	0	1	2	1	2	14
Olive ridley	1	1	1	3	6	2	6	1	4	1	26

Table A2: Estimated status of turtles received by Auckland Zoo.

	Condition			Sex		
Species	Dead	Alive	Unknown	M	F	U
Loggerhead	1	0	4	0	1	4
Green	15	3	14	1	6	25
Hawksbill	12	0	2	1	2	11
Olive ridley	25	0	1	7	4	15

Figure A1: Examples of turtles killed by probable boat strikes. Credit Auckland Zoo.

Appendix B Amphibian and Reptile Distribution Scheme (ARDS) database

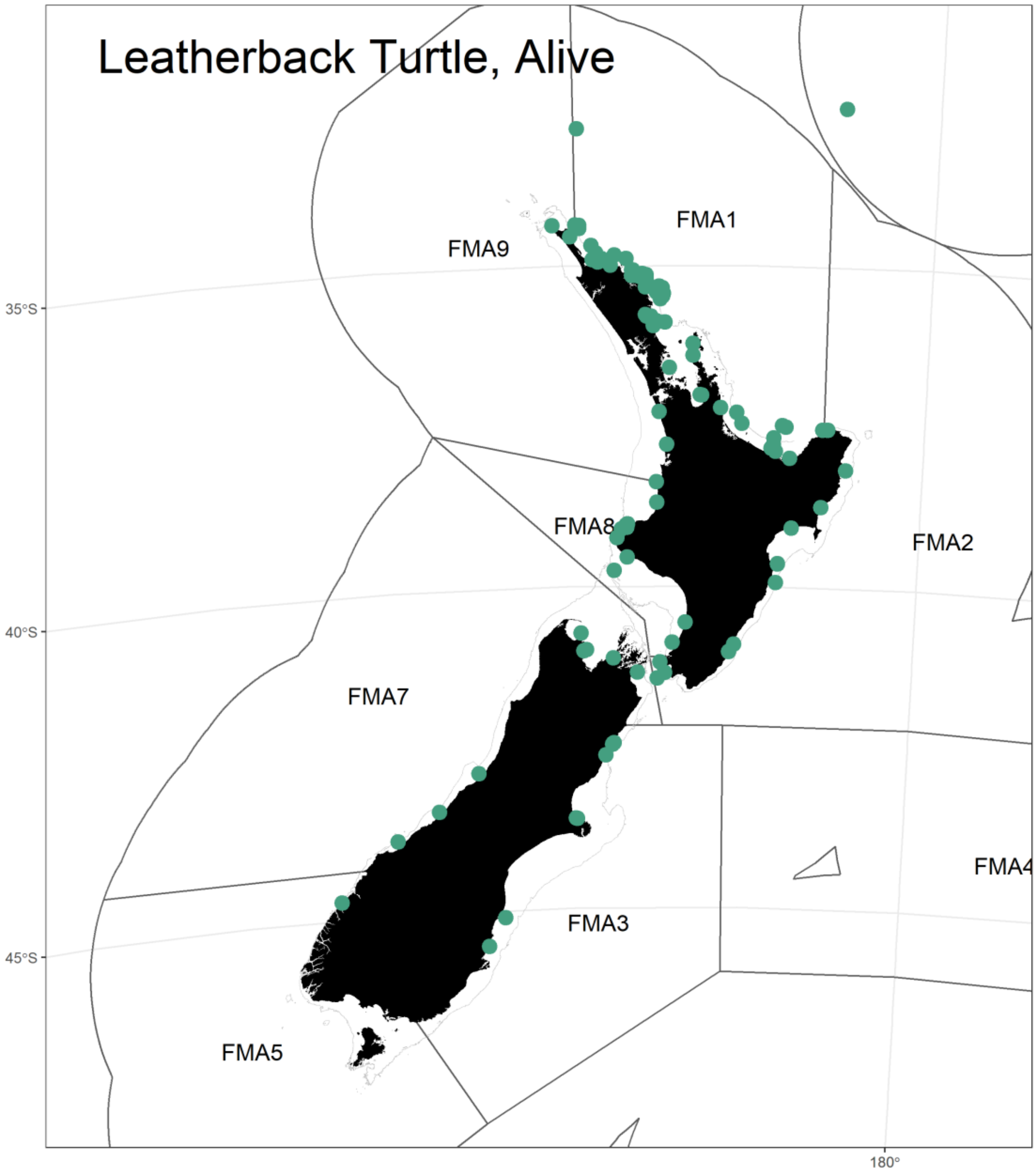

Figure B1: Distribution of leatherback turtle records in the Amphibian and Reptile Distribution Scheme (ARDS) database from 1837–2020 and by individual status (alive records, n = 105).

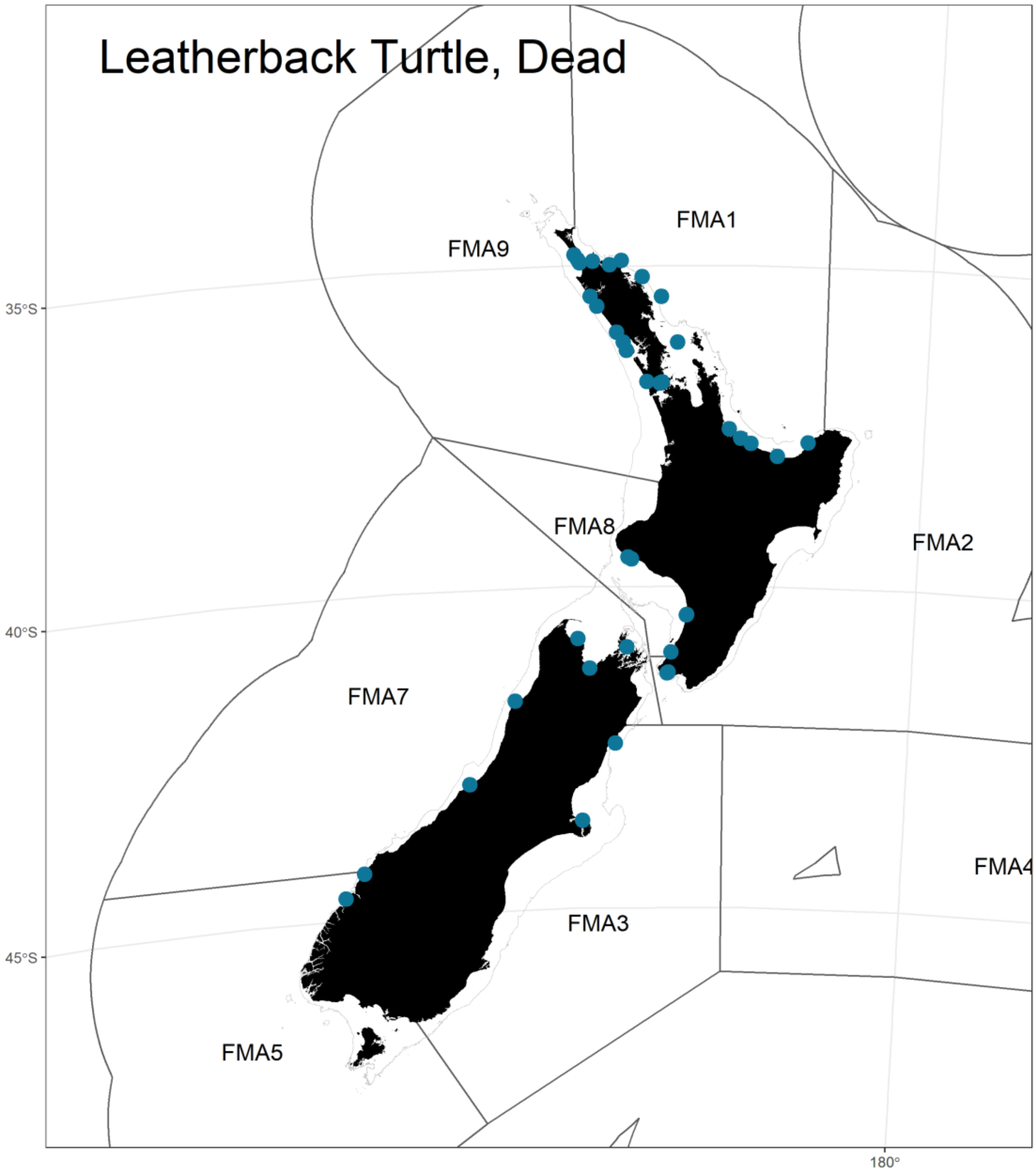

Figure B1: Distribution of leatherback turtle records in the Amphibian and Reptile Distribution Scheme (ARDS) database from 1837–2020 and by individual status (dead records, n = 42). Dead=”Dead specimen” or “Bone”.

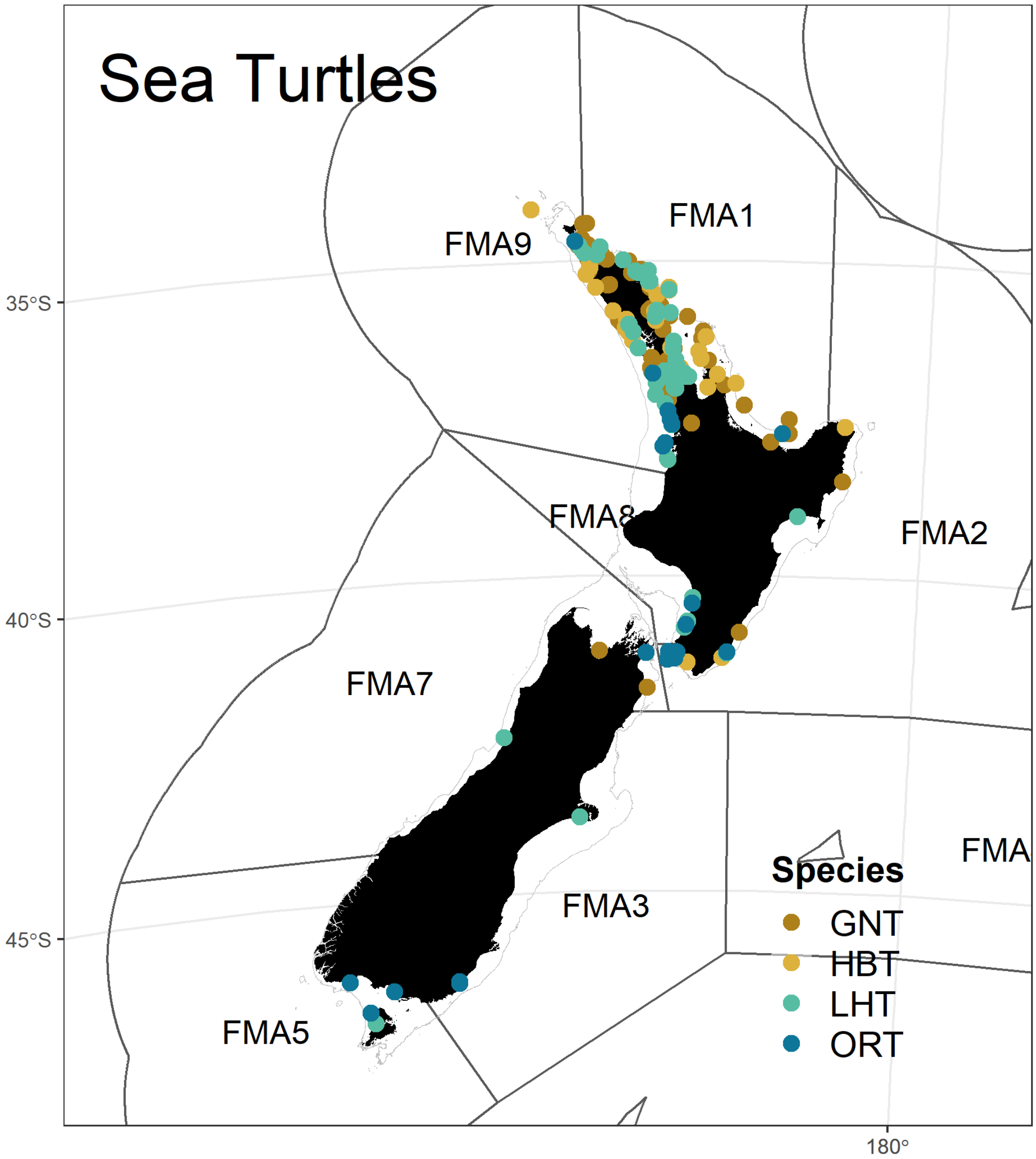

Figure B2: Distribution of all other sea turtle records in the Amphibian and Reptile Distribution Scheme (ARDS) database from 1837–2020. GNT: green turtle (n = 101); HBT: hawksbill turtle (n = 36); LHT: loggerhead turtle (n = 48); ORT: olive ridley turtle (n = 22).

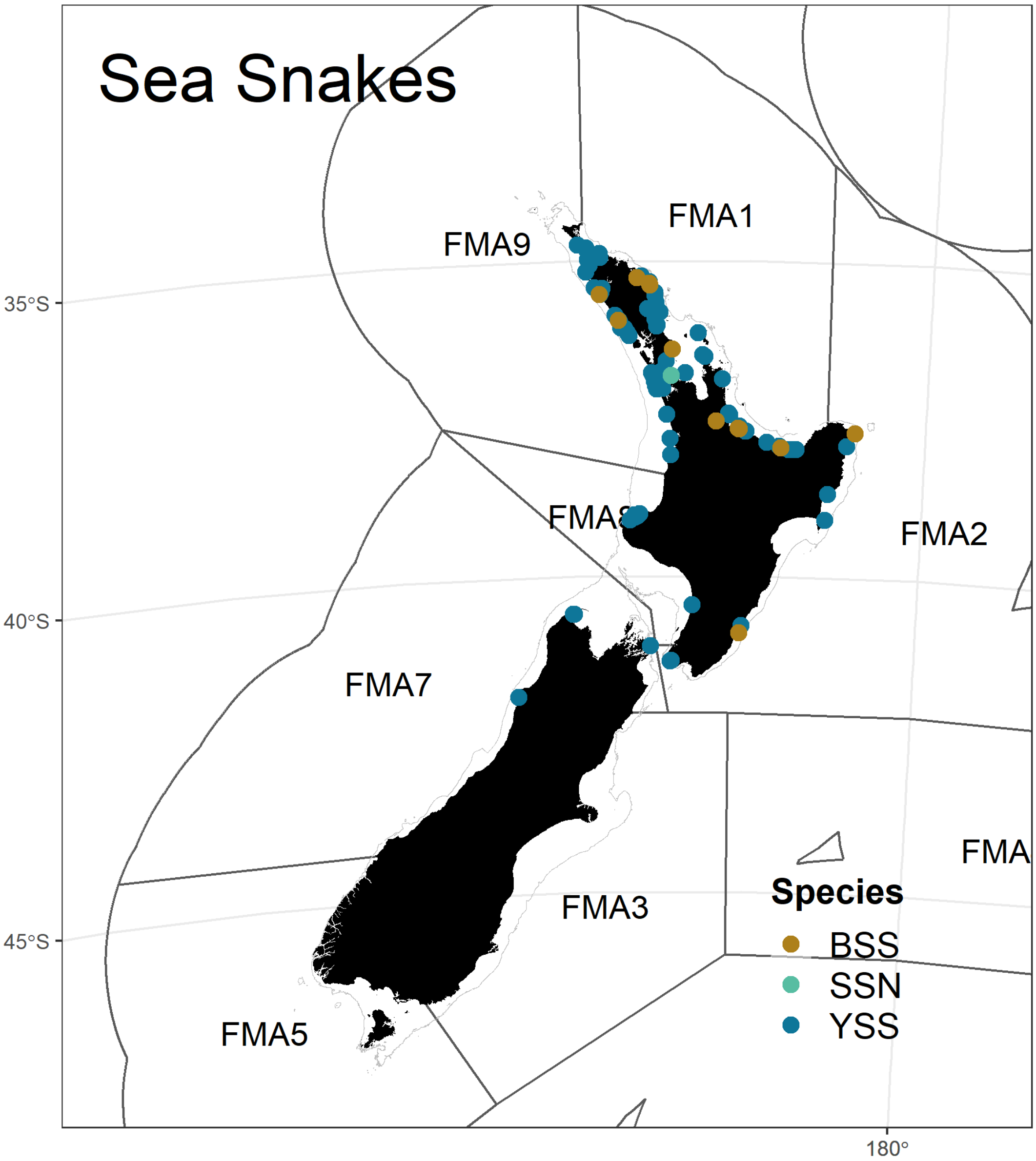

Figure B2: Distribution of all sea snake records in the Amphibian and Reptile Distribution Scheme (ARDS) database from 1837–2020. BSS: banded sea krait (n = 12); SSN: blue-lipped sea krait (n = 1); YSS: yellow-bellied sea snake (n = 87).

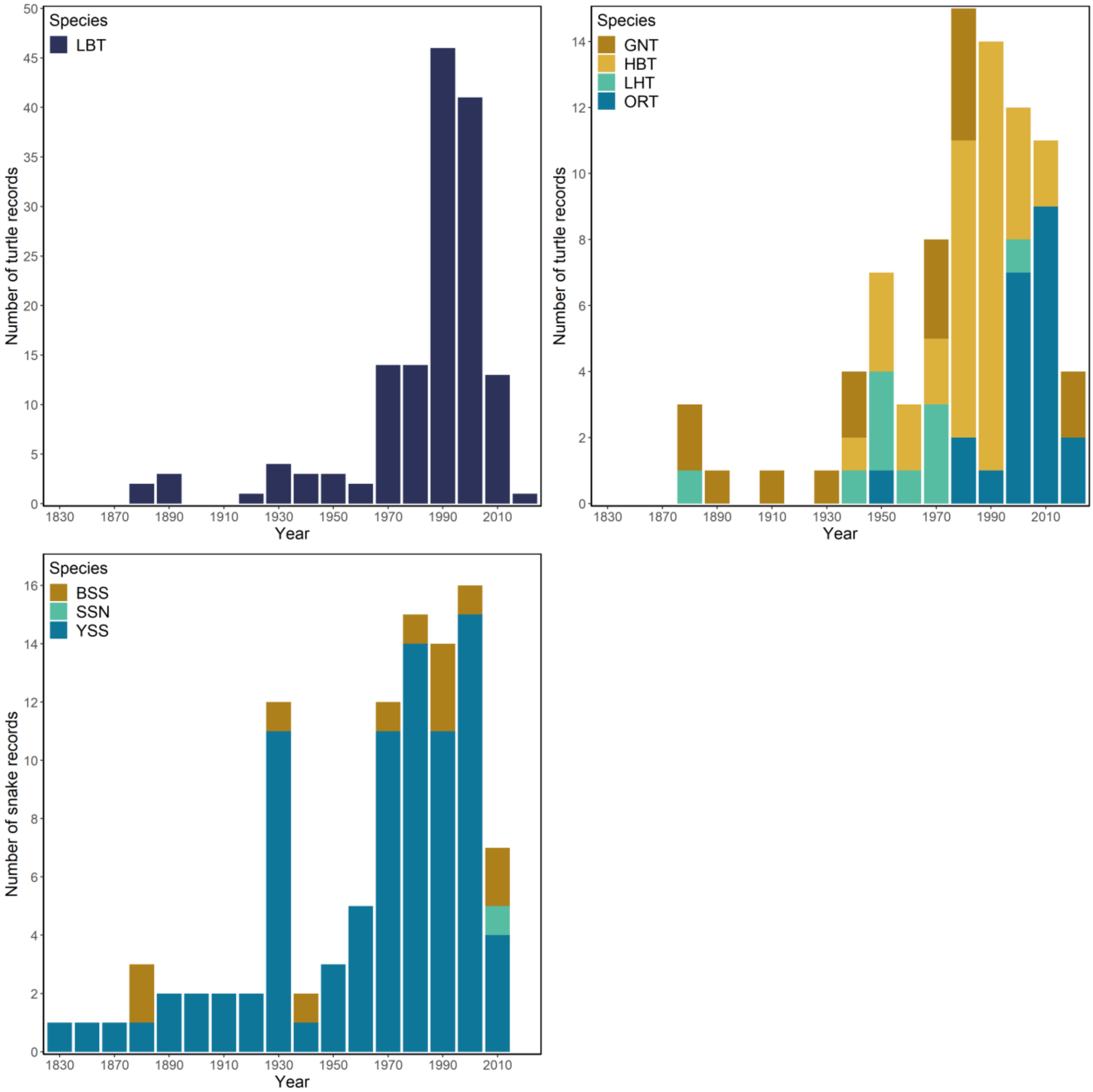

Figure B3: Frequency of Amphibian and Reptile Distribution Scheme (ARDS) database records by decade for (top left) leatherback turtle (LBT); (top right) green turtle (GNT), hawksbill turtle (HBT), loggerhead turtle (LHT), olive ridley turtle (ORT); and (bottom left) banded sea krait (BSS), blue-lipped sea krait (SSN), and yellow-bellied sea snake (YSS).

Table B1: Annual Amphibian and Reptile Distribution Scheme (ARDS) database records by species from 1837–2020. GNT: green turtle (n = 101); HBT: hawksbill turtle (n = 36); LHT: loggerhead turtle (n = 48); ORT: olive ridley turtle (n = 22); BSS: banded sea krait (n = 12); SSN: blue-lipped sea krait (n = 1); YSS: yellow-bellied sea snake (n = 87).

	Sea turtles					Sea snakes		
	GNT	HBT	LBT	LHT	ORT	BSS	SSN	YSS
1837	0	0	0	0	0	0	0	1
1868	0	0	0	0	0	0	0	1
1878	0	0	0	0	0	0	0	1
1880	1	0	0	0	0	1	0	0
1882	0	0	2	0	0	0	0	0
1883	0	0	0	0	0	0	0	1
1885	1	0	0	1	0	0	0	0
1889	0	0	0	0	0	1	0	0
1892	0	0	1	0	0	0	0	0
1894	0	0	1	0	0	0	0	0
1895	0	0	1	0	0	0	0	1
1896	1	0	0	0	0	0	0	0
1898	0	0	0	0	0	0	0	1
1903	0	0	0	0	0	0	0	1
1905	0	0	0	0	0	0	0	1
1911	1	0	0	0	0	0	0	0
1916	0	0	0	0	0	0	0	2
1922	0	0	0	0	0	0	0	1
1924	0	0	1	0	0	0	0	0
1926	0	0	0	0	0	0	0	1
1930	0	0	2	0	0	1	0	0
1931	0	0	0	0	0	0	0	1
1933	0	0	0	0	0	0	0	6
1936	1	0	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	1
1938	0	0	0	0	0	0	0	2
1939	0	0	2	0	0	0	0	1
1945	0	0	1	0	0	1	0	0
1946	0	0	0	0	0	0	0	1
1947	0	0	1	0	0	0	0	0
1948	1	0	1	0	0	0	0	0
1949	1	1	0	1	0	0	0	0
1951	0	0	0	0	0	0	0	1
1952	0	0	0	2	0	0	0	0
1953	0	0	1	0	0	0	0	0
1954	0	0	1	0	0	0	0	0
1955	0	0	0	0	0	0	0	1
1956	0	2	0	1	1	0	0	0
1957	0	0	0	0	0	0	0	1
1959	0	1	1	0	0	0	0	0
1960	0	1	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	2
1965	0	0	0	0	0	0	0	1
1966	0	1	0	1	0	0	0	0
1967	0	0	1	0	0	0	0	0
1968	0	0	0	0	0	0	0	2
1969	0	0	1	0	0	0	0	0
1970	0	0	1	0	0	0	0	1
1971	1	0	0	0	0	0	0	3
1972	0	1	1	0	0	0	0	2
1973	0	1	2	2	0	0	0	2
1974	0	0	0	0	0	0	0	2
1975	1	0	2	1	0	0	0	1
1976	0	0	2	0	0	0	0	0
1977	0	0	4	0	0	1	0	0
1978	1	0	0	0	0	0	0	0
1979	0	0	2	0	0	0	0	0
1982	0	1	2	0	0	0	0	1
1983	1	0	2	2	0	0	0	0
1984	2	2	1	1	0	0	0	1
1985	1	1	2	3	2	0	0	1

1986	0	0	2	4	0	0	0	3
1987	0	1	0	1	0	0	0	1
1988	0	1	2	2	0	0	0	1
1989	0	3	3	3	0	1	0	6
1990	1	0	4	5	0	2	0	0
1991	2	1	6	0	0	1	0	2
1992	2	1	2	1	0	0	0	0
1993	0	0	9	1	0	0	0	2
1994	0	1	1	3	0	0	0	0
1995	2	0	1	2	0	0	0	0
1996	6	6	13	10	1	0	0	3
1997	5	1	10	0	0	0	0	0
1998	2	1	0	0	0	0	0	3
1999	2	2	0	0	0	0	0	1
2000	4	2	0	0	0	1	0	4
2001	4	0	8	0	2	0	0	0
2002	9	1	1	1	0	0	0	4
2003	7	0	10	0	0	0	0	2
2004	8	1	3	0	2	0	0	0
2005	3	0	5	0	0	0	0	0
2006	8	0	6	0	0	0	0	1
2007	5	0	5	0	2	0	0	0
2008	3	0	2	0	0	0	0	2
2009	1	0	1	0	1	0	0	2
2011	0	2	2	0	1	0	1	2
2012	2	0	2	0	1	0	0	1
2013	0	0	1	0	0	0	0	0
2014	2	0	0	0	0	0	0	1
2015	2	0	3	0	1	0	0	0
2018	1	0	0	0	1	1	0	0
2019	4	0	5	0	5	1	0	0
2020	2	0	1	0	2	0	0	0

Appendix C Miscellaneous marine reptile records

Table C1. Miscellaneous sea turtle records found in the Ministry for Primary Industries *rec_data* database, and records from the recently established DOC Protected Species Catch app

Date	Species	Location	Verification	Source
17/03/2001	TLE	Whangarei Harbour	Unverified	*rec* database (survey NOR01)
23/04/2017	TLE	Whangarei Harbour	Unverified	*rec* database (survey NOR17)
4/07/2021	GNT	174.404 E, 35.786 S	Verified	DOC*
24/12/2021	GNT	174.769 E, 36.835 S	Verified	DOC*
21/02/2022	GNT	176.041 E,37.619 S	Unverified	DOC*

* https://docnewzealand.shinyapps.io/protectedspeciescatch/

Table C2. Miscellaneous marine reptile records from New Zealand sources, including published records, unpublished data, museum collections, data held at the Department of Conservation and not on the ARDS database, and public sightings, including those reported on iNaturalist. GNT: green turtle (n = 44); HBT: hawksbill turtle (n = 8); LBT: leatherback turtle (n = 48); LHT: loggerhead turtle (n = 6); ORT: olive ridley turtle (n = 19); TLE: unidentified turtles(n = 17); BSS: banded sea krait (n = 1); YSS: yellow-bellied sea snake (n = 16).

Date	Location	Species	n	Sighting Type	ID Reliability	Latitude	Longitude	Curved carapace length (mm)	Total length (mm)	Source
c. 1900	Te Kaha	LBT	1	Dead	Verified	-37.74	177.67	NA	>1500	Auckland War Memorial Museum
1908-05-01	Raoul Island	GNT	1	Live	Verified	-29.26	177.95	NA	NA	Oliver (1911), Gill (1997)
1975/76	Waitangi, Chatham Islands	LBT	1	Dead	Verified	-43.95	176.55	NA	c. 1500	Unpublished data
1977-03-27	Kaikoura	LBT	1	Dead	Unverified	NA	NA	NA	NA	Fordyce & Clark (1977)
1977-03-27	Adderley Head, Bank's Peninsula	LBT	1	Live	Unverified	NA	NA	NA	NA	Fordyce & Clark (1977)
1977-04-03	South Bay, Kaikoura	LBT	1	Live	Unverified	NA	NA	NA	NA	Fordyce & Clark (1977)
c. 1979	Off Owenga, Chatham Islands	LBT	1	Dead	Verified	-44.02	176.34	NA	>1500	Unpublished data
1982-12-01	Kaka Point, Southland	ORT	1	Dead	Verified	-46.39	169.78	NA	NA	iNaturalist
1983-02-01	Castlepoint	LBT	1	Dead	Unverified	-40.89	176.23	NA	NA	MONZ Te Papa Tongarewa
1984-05-24	Conway River	LBT	1	Live	Unverified	-42.62	173.47	NA	NA	Edward Percival Field Station
1985-10-27	Egeria Rock, Raoul Island	HBT	1	Live	Verified	-29.25	177.90	NA	NA	Gill (1997)
1987-03-09	Wairau River	LBT	1	Live	Unverified	-41.49	174.06	NA	NA	Edward Percival Field Station
1987-03-13	Kaikoura	LBT	1	Dead	Unverified	-42.42	173.64	NA	NA	Edward Percival Field Station
1989-02-18	Okiwi Bay, Croisilles Harbour	LBT	1	Dead	Verified	NA	NA	NA	NA	Public sighting
1990-04-14	East Bay, Queen Charlotte Sound	LBT	1	Live	Unverified	-41.15	174.34	NA	1500-1800	Duffy & Brown (1994)
1992-05-01	Denham Bay, Raoul Island	GNT	1	Live	Verified	-29.28	177.95	NA	NA	Gill (1997)
1997-03-06	28 km northwest of North Cape, on transit between Northeast Island, Three Kings Islands, and North Cape	LBT	1	Live	Unverified	-34.31	172.78	NA	NA	Public sighting
1997-12-11	Ohope Beach	LBT	1	Dead	Verified	NA	NA	NA	NA	Department of Conservation
1999-11-07	Thornton, Matata Beach	HBT	1	Live	Unknown	-37.91	176.88	NA	NA	Department of Conservation

2001-01-03	3 miles east of Whale Island	LBT	1	Live	Unverified	NA	NA	NA	2000	Department of Conservation
2002-01-26	North side of White Island	TLE	1	Live	Unverified	-37.51	177.18	NA	NA	Department of Conservation
2002-01-26	15 nm northeast of Whakatane	TLE	1	Live	Unverified	-37.74	177.20	NA	NA	Department of Conservation
2002-01-26	10 nm north of Whale Island	LBT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2002-02-07	Off Murphy's Holiday Camp, Matata	TLE	1	Live	Unverified	-37.85	176.73	NA	NA	Department of Conservation
2002-02-17	North side of White Island	TLE	1	Live	Unverified	-37.51	177.18	NA	NA	Department of Conservation
2002-10-01	1 nm west of Whale Island	TLE	1	Live	Unverified	-37.85	176.94	NA	NA	Department of Conservation
2003-01-18	South of Volkner Rocks	LBT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2003-01-29	Off Lyttelton	LBT	1	Live	Unverified	NA	NA	NA	NA	Department of Conservation
2003-03-11	Homestead Reef, White Island	GNT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2003-11-18	3 nm north of Kohi Point	LBT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2003-12-01	Mercury Islands	GNT	1	Live	Verified	-36.62	175.85	NA	NA	iNaturalist
2004-01-08	15 nm north of Kohi Point	ORT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2004-02-01	Papamoa Beach	LBT	1	Dead	Verified	NA	NA	NA	NA	Department of Conservation
2005-01-04	Off Whanarua Bay	TLE	1	Live	Unverified	-37.66	177.78	NA	NA	Department of Conservation
2005-03-31	12.1 km ne of Tawhiti Rahi Island, Poor Knights Islands	LBT	1	Live	Unverified	-35.43	174.87	NA	NA	Public sighting
2005-05-21	Manukau Harbour	LBT	1	Dead	Verified	-37.04	174.72	NA	2000	Public sighting
2006-01-01	Challenger Scallop Company spat catching site off Tarakohe Harbour, Golden Bay	LBT	1	Dead	Verified	NA	NA	NA	NA	Public sighting
2006-02-02	9 nm north of Whale Island	TLE	1	Live	Unverified	-37.70	176.98	NA	NA	Department of Conservation
2007-01-24	Mayor Island	LBT	1	Live	Verified	-37.29	176.30	NA	>1800	Public sighting
2007-08-15	Karamea	TLE	1	Sign	Verified	-41.27	172.09	NA	NA	Public sighting
2008-01-02	Between Whale Island and Rurima Island	LBT	1	Live	Unknown	NA	NA	NA	NA	Department of Conservation
2009-01-07	7.5 nm northeast of Whale Island	LBT	1	Live	Unknown	-37.75	177.06	NA	NA	Department of Conservation
2009-01-20	12.5 nm north of Kohi Point	LBT	1	Live	Unknown	-37.73	177.02	NA	NA	Department of Conservation
2009-03-02	Muriwai Beach	LBT	1	Dead	Verified	-36.70	174.34	NA	2500	Public sighting
2009-04-27	Bryan's Beach	ORT	1	Dead	Verified	-37.99	177.17	NA	NA	Department of Conservation
2009-10-11	Whatipu	GNT	1	Live	Verified	-37.03	174.48	NA	NA	Public sighting
2010-11-28	18 nm north of Kohi Point	LBT	1	Live	Unknown	-37.64	177.02	NA	NA	Department of Conservation

2010-12-26	Meyer Islets, Kermadec Islands	GNT	1	Live	Verified	-29.24	-177.88	NA	NA	Department of Conservation
2012-03-01	Raukokore beach, Bay of Plenty	ORT (tenative ID)	1	Dead	Verified	-37.64	177.88	NA	NA	Public sighting
2012-08-14	Off Raoul Island airstrip	TLE	1	Live	Unverified	-29.36	177.99	NA	NA	Public sighting
2012-10-28	Waiomu	LBT	1	Live	Unverified	NA	NA	NA	1000-1500	Public sighting
2013-01-24	Bay of Plenty	LBT	1	Live	Verified	NA	NA	NA	NA	Public sighting
2013-06-01	Black Rocks, Mercury Islands	GNT	1	Live	Verified	-36.70	175.86	NA	NA	iNaturalist
2014-01-01	Waipapakauri-Tom Bowling Bay, Northland	TLE	1	Live	Verified	-34.42	172.96	NA	NA	iNaturalist
2015-01-07	Parengarenga Harbour	LBT	1	Live	Verified	-34.52	172.96	NA	NA	Public sighting
2015-02-08	6 nm north of Poor Knights	LBT	1	Live	Verified	NA	NA	NA	1500-1800	Public sighting
2015-03-02	Off Whananaki, just north and inside of the Poor Knights Islands	LBT	1	Dead	Verified	-35.44	174.66	NA	1500	Public sighting
2015-04-25	Te Kopi, Wilson's Bay, Pelorus Sound	LBT	1	Dead	Verified	-41.07	173.91	NA	2300	Public sighting
2015-07-09	Taranaki	ORT	1	Live	Verified	NA	NA	NA	NA	Department of Conservation
2015-11-01	Waipapa Beach Southland	ORT	1	Dead	Verified	-46.66	168.87	NA	NA	iNaturalist
2015-12-28	Off Fisherman's Island, Tasman Bay	LBT	1	Live	Verified	NA	NA	NA	NA	Public sighting
2016-01-21	East of Northland	LBT	1	Live	Verified	-35.36	174.62	NA	NA	Public sighting
2016-10-06	Kawakawa River, Bay of Islands	GNT	1	Live	Verified	-35.33	174.12	NA	NA	Department of Conservation
2016-11-09	Muriwai Beach	ORT	1	Live	Verified	-36.83	174.43	NA	NA	Department of Conservation
2016-12-08	Off Mangawhai Heads, Hauraki Gulf	LBT	1	Live	Verified	-36.08	174.61	NA	NA	Public sighting
2017-01-01	Bay of Plenty	LBT	3	Live	Verified	-37.38	176.24	NA	NA	Public sighting
2017-09-01	Palliser Bay	ORT	1	Dead	Verified	-41.38	175.10	NA	NA	iNaturalist
2017-12-01	Ninety Mile Beach	ORT	1	Live	Verified	-35.11	173.17	NA	NA	iNaturalist
2018-03-06	East side of Meyer Islets, Kermadec Islands	HBT	1	Live	Verified	-29.25	177.88	NA	NA	iNaturalist
2018-06-01	NE Great Barrier Island	GNT	1	Live	Verified	-36.10	175.44	NA	NA	Public sighting
2018-12-03	Te Arai, just north of Pacific Rd	LHT	1	Dead	Verified	-36.14	174.63	NA	NA	Department of Conservation
2019-01-12	2 nm off Adele Island, Tasman Bay	LBT	1	Live	Verified	NA	NA	NA	>2000	Department of Conservation

2019-01-13	South of Cape Brett and north of the Poor Knights Islands, around 250m depth	LBT	1	Live	Unverified	-35.31	174.56	NA	1500-1800	Public sighting
2019-02-04	Wynyard Wharf, Waitemata Harbour	GNT	1	Dead	Verified	NA	NA	NA	NA	Department of Conservation
2019-02-06	Between Bird Rock and Cape Brett/ Motu Kōkako (Piercy Island)	LBT	1	Live	Unverified	-35.41	174.34	NA	NA	Public sighting
2019-05-18	Poor Knights Islands	GNT	1	Live	Verified	-35.46	174.73	NA	NA	iNaturalist
2019-08-01	Northern end of Oreti Beach	ORT	1	Dead	Verified	NA	NA	NA	NA	iNaturalist
2019-10-01	Cape Egmont	ORT	1	Dead	Verified	-39.28	173.75	NA	NA	iNaturalist
2019-10-02	Otaki Beach	ORT	1	Dead	Verified	-40.73	175.12	NA	NA	Department of Conservation
2019-10-04	Port Waikato	ORT	1	Dead	Verified	NA	NA	NA	NA	Department of Conservation
2020-02-15	Kapiti Island	TLE	1	Live	Verified	-40.85	174.94	NA	1000	Public sighting
2020-02-25	Mahia Beach	LBT	1	Dead	Verified	-39.08	177.87	NA	NA	Department of Conservation
2020-05-27	Takapuna Beach	GNT	1	Live	Verified	NA	NA	NA	NA	Public sighting
2020-09-16	Plimmerton Beach	ORT	1	Dead	Verified	-41.09	174.87	NA	NA	Public sighting
2020-09-26	Parua Bay, Whangarei Harbour	TLE	1	Dead	Verified	-35.78	174.47	NA	NA	Public sighting
2020-10-01	Entrance to Houhora harbour	GNT	1	Live	Verified	-34.83	173.16	NA	NA	iNaturalist
2020-10-01	Poor Knights Islands	GNT	1	Live	Verified	-35.48	174.74	NA	NA	iNaturalist
2020-10-22	Poor Knights Islands	GNT	1	Live	Verified	-35.48	174.74	NA	NA	iNaturalist
2020-11-01	Port Waikato	ORT	1	Dead	Verified	-37.38	174.71	NA	NA	Department of Conservation
2020-12-01	One Tree Point, Whangarei	GNT	1	Dead	Verified	-35.82	174.46	NA	NA	Department of Conservation
2020-12-01	Great Exhibition Bay	GNT	1	Live	Verified	-34.64	173.02	NA	NA	iNaturalist
2021-01-15	Whangaparaoa	GNT	1	Dead	Verified	-36.59	174.83	NA	NA	Public sighting
2021-01-15	Waihi Beach, Bay of Plenty	LBT	1	Dead	Verified	NA	NA	NA	NA	Public sighting
2021-02-01	Great Exhibition Bay	GNT	1	Dead	Verified	-34.66	173.03	NA	NA	iNaturalist
2021-02-25	Tewerahi Beach, Northland	GNT	1	Live	Verified	NA	NA	NA	NA	Department of Conservation
2021-03-28	Off Fisherman's Point, Whangarei Harbour	GNT	1	Live	Verified	-35.79	174.42	NA	NA	Public sighting
2021-04-01	Poor Knights Islands	GNT	1	Live	Verified	-35.48	174.74	NA	NA	iNaturalist
2021-04-06	Raglan	TLE	1	Dead	Verified	-37.81	174.83	NA	NA	Department of Conservation
2021-04-21	Rangitoto Channel	GNT	1	Dead	Verified	-36.80	174.83	NA	NA	Department of Conservation
2021-05-16	Tauranga Harbour	GNT	1	Dead	Verified	-37.66	176.16	NA	NA	Department of Conservation

2021-05-26	Waitangi West Beach, Chatham Islands	ORT	1	Dead	Verified	-43.77	176.81	NA	NA	Department of Conservation
2021-08-09	Muriwai Beach	ORT	1	Dead	Verified	-36.81	174.42	NA	NA	Department of Conservation
2021-09-01	Muriwai Beach	GNT	1	Live	Unverified	-36.82	174.42	NA	NA	iNaturalist
2021-09-09	Long Bay, Auckland	GNT	1	Dead	Verified	-36.68	174.75	NA	NA	Public sighting
2021-10-01	Glinks Gully	GNT	1	Live	Verified	-36.08	173.86	NA	NA	iNaturalist
2021-10-02	Colville Bay, Coromandel Peninsula	GNT	1	Live	Verified	-36.63	175.47	NA	NA	Public sighting
2022-02-01	Hen & Chickens Islands	GNT	1	Live	Verified	-35.90	174.75	NA	NA	iNaturalist
2022-03-01	Wahine Bay, Hen Island, Northland	TLE	1	Live	Verified	-35.97	174.72	NA	NA	iNaturalist
2022-03-12	Motuhoa Island, Tauranga Harbour	GNT	1	Live	Verified	-37.63	176.07	NA	NA	Department of Conservation