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Twenty Years of Sea Turtle Strandings in New Caledonia

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In this study, we investigated cause-specific temporal and spatial trends in sea turtle strandings in New Caledonia. Five species of sea turtles were recorded in the 406 strandings documented between January 1999 and March 2021. Green turtles represented the majority of the stranded species (68%), reflecting the importance of the resident green turtle population in New Caledonian waters. Nearly half of the individuals stranded were juveniles (48%). The great majority of strandings were recorded in the South Province, the most populous province of New Caledonia (73%). The main causes of the strandings were classified as unknown (50%), followed by poaching (17%), by-catch (15%), collision (10%), natural (8%), plastic ingestion (0.5%) and other (0.5%). This study contains the first official record of the presence and relative importance of fibropapilloma in New Caledonia, but we could not determine if it was the cause of death for the stranded individuals. Two individuals, after necropsies, were found to have ingested plastic (one in 2011 and the other in 2020). This is the first record of plastic ingestion for sea turtles in New Caledonia. Three significant trends were also found during the study: an increase in the number of individuals reported in the study since 2004; a seasonal effect, with most strandings occurring in summer (November to January); and stranding hotspots. Rehabilitation allowed for 35% of individuals found alive to be released back into the wild. This study suggests that mitigation strategies such as “go slow” zones and a robust stranding network should be put in place in New Caledonia.

Key words: Megafauna, Bycatch, Anthropogenic impact, Rehabilitation, Management.

BACKGROUND

Sea turtles have been on the IUCN Red List since 1982 but have recently been facing new, more intense threats worldwide from environmental factors like climate change and pollution. Multiple studies have assessed the research priorities for these species (Eckert et al. 1999; Hamman et al. 2010; Rees et al. 2016) and indicated that one of the most important should be to study the threats to the different populations and find mitigation strategies. Different studies have suggested that the monitoring and analysis of strandings can supply the data necessary to identify trends and threats to the near-shore foraging populations of sea turtles (Epperly et al. 1996; Tomás et al. 2008). Strandings have been reported to occur due to a range of anthropogenic threats. These threats have been documented in multiple studies and range from vessel strikes to fishing by-catch and plastic ingestion (Clukey et al. 2017; Hazel and Gyuris 2006). Long-term monitoring has been essential to understanding sea turtle species around the world (Balazs and Chaloupka 2004; Hawkes et al. 2005;

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Troëng and Rankin 2005; Limpus 2009) and long-term monitoring of strandings has provided stakeholders with key information (Botterrell et al. 2020; Chaloupka et al. 2008; Tomás et al. 2008; Flint et al. 2015b).

New Caledonia is a French archipelago located in the South Pacific. It is divided into three provinces (South, North and Loyalty), each of which has its own laws regarding the environment (*i.e.*, jurisdictions). The waters outside the provinces' jurisdictions are under the Territory jurisdiction and constitute the major part of the exclusive economic zone (EEZ). Three species of sea turtles are seen on a regular basis foraging in New Caledonia—*Chelonia mydas*, *Caretta caretta* and *Eretmochelys imbricata*—but only the first two are known to nest in the country (Read 2015). All species of sea turtles are protected in New Caledonia. To this day, all monitoring of threats to sea turtle populations in New Caledonia has been done on nesting grounds (Read et al. 2013 2020a), but no study has been done on the threats to foraging populations, even though they were noted as a priority for future research (Read 2015). A previous study indicated that foraging individuals in the South Province spend 80% of their time at less than 5 m deep, which makes them vulnerable to human activities (Read 2015). The first study to document strandings in New Caledonia focused on fur seals, sea-lions and cetaceans (Rancurel 1973). Since then, multiple studies have been done in New Caledonia regarding strandings, but they have specifically targeted marine mammals (Borsa 2006; Clua et al. 2014; Garrigue and Greaves 2001; Garrigue et al. 2016). Ours is the first to investigate the cause-specific and spatial trends of marine turtle stranding from 1991 to 2021 in New Caledonia.

MATERIALS AND METHODS

Starting in January 1999, all reported sea turtle strandings in New Caledonia were recorded by the Aquarium des Lagons and, starting in 2007, data from onboard observers on long-line fishing campaigns were added to the database. For the purpose of this study, we considered strandings as dead or living individuals that were a) washed ashore, b) floating in coastal areas or 3) by-catched. Spatial data (precise location, area and province) and the exact date of the stranding were recorded. In order to study seasonality in the different strandings, the year was divided into four seasons: summer (December to February), autumn (March to May), winter (Jun to August) and spring (September to November). The following were collected when possible: biological data (species, sex, presence of fibropapilloma), external injuries described, the presence of tags was checked, status of the individual when found (dead or alive) and curved carapace length (CCL) (Limpus et al. 1994). Species was determined (by direct observation with recorders or by an expert when only photos were available) as one of five turtle species (green *Chelonia mydas*, loggerhead *Caretta caretta*, hawksbill *Eretmochelys imbricata*, olive ridley *Lepidochelys olivacea* or leatherback *Dermochelys coriacea*) based on dichotomous key characteristics.

Individuals were pooled into five CCL size classes used as a proxy for age (Limpus et al. 1994): (CCL) post-hatchlings (5< … < -35 cm), juveniles (35 < … < -65 cm), sub-adults (65 < … < -90 cm), adults (> 90 cm) and unknown. Age class is only an approximation of maturity and does not confirm reproductive development. The rehabilitation data (*e.g.*, number of days spent in rehabilitation, whether a necropsy occurred) were provided by the Aquarium des Lagons, which is where most sea turtles were brought when found alive. Causes of strandings were grouped into seven categories: unknown (no necropsies were done and no apparent cause of death by external examination), natural (necropsies were done and concluded that the turtle died by natural causes), poaching (individuals found with spear-fishing trauma or butchered), collision (blunt force trauma to carapace or skull), by-catch (individuals found dead or alive with or in fishing gear), plastic ingestion (presence of plastic within gut content) and other. All analyses were done using Statgraphics 19, and $p < 0.05$ was considered significant.

RESULTS

This study examined a total of 406 sea turtle strandings from May 1999 to March 2021 (Fig. 1). The number of strandings were significantly different among the four jurisdictions of New Caledonia (χ^2 test; $p < 0.001$). It was highest in the South Province (298), followed by the North (65), EEZ (24) and Loyalty Islands (5) (post hoc χ^2; $p < 0.01$).

Strandings changed over time (χ^2 test; $p < 0.001$). They were stable between 2010 and 2014 (χ^2 test; $p > 0.05$), then they increased from 2014 to 2020 (χ^2 test; $p < 0.001$; $r = 0.93$; $p < 0.01$) (Fig. 2a). A seasonal effect was also detected (χ^2 test; $p < 0.001$). Strandings were most frequent from November to January (post hoc χ^2; $p < 0.05$) (Fig. 2b).

There was a significant difference in the number of stranding per species (Krustal-Wallis test, $p < 0.001$). Green *Chelonia mydas* was found the most (278 turtles), followed by hawksbill *Eretmochelys imbricata* (76), loggerhead *Caretta caretta* (24), olive

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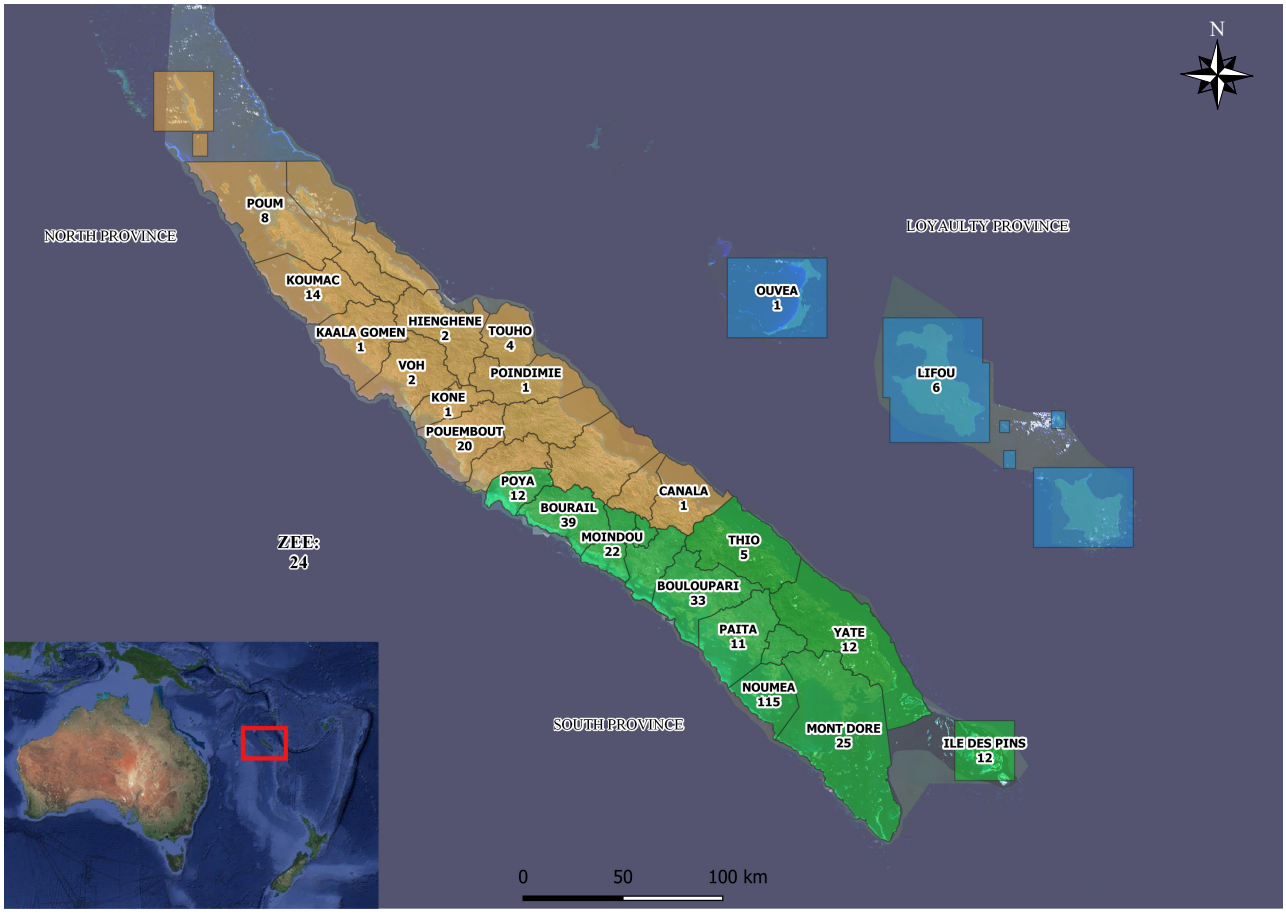

Fig. 1. Map of recorded sea turtle strandings per town of New Caledonia between 1999 and 2021. Blue area represents the Loyalty Province, the orange area represents the North Province and the green area represents the South Province.

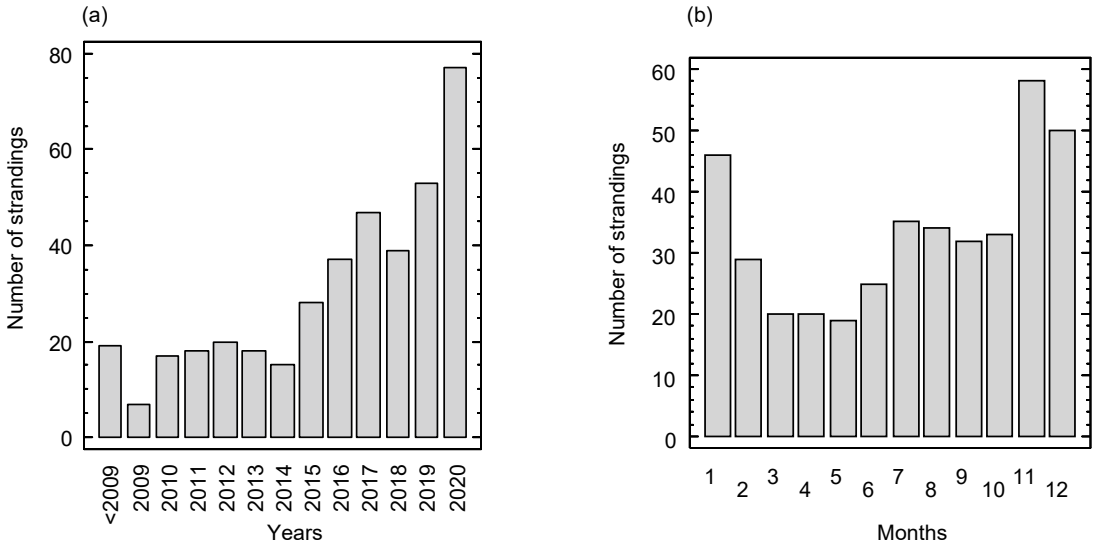

Fig. 2. Number of recorded sea turtle strandings in New Caledonia (a) per year, and (b) per month (1999 to 2021).

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ridley *Lepidochelys olivacea* (13), unknown (12) and leatherback *Dermochelys coriaca* (3) (Fig. 3a).

The size classes of the strandings were significantly different (χ^2 test, $p < 0.001$) (Fig. 3b and Fig. 4). Juveniles (35–65 cm CCL) were the most abundant size class (195 turtles), followed by sub-adults and adults (65–90 and > 90 cm CCL, respectively) (101) and, lastly, post-hatchlings (5–35 cm CCL) (14) (post-hoc χ^2, 5–35 < (65–90; +90) < 35–65 cm CCL). No size information was available for 96 individuals. A similar pattern was found within the stranded *Chelonia mydas* individuals (χ^2 test, $p < 0.001$), with the highest number of individuals belonging to the juvenile size class (133).

Half of the individuals (238 turtles) were recorded as stranded for an unknown reason. Poaching accounted for the second most strandings (68), followed by by-catch (coastal and off-shore) (60), collision (38), natural causes (31), plastic ingestion (2) and other (2). Of all the strandings, 116 individuals were found with external injuries (exact test $p < 0.001$).

When the cause of death could be established, the majority of strandings died from anthropogenic causes (170 turtles) instead of natural causes (31 turtles) (exact test, $p < 0.001$). Sex was only recorded for 38 of the individuals (all adults), and there were more females (27) detected than males (11) (exact test, $p < 0.05$). Eight individuals were found to have titanium tags when recovered. Five of the individuals were tagged and released into the area where they were found stranded.

A significant difference was found between the number of stranded individuals with or without external fibropapilloma lesions (exact test: $p < 0.001$). All 11 individuals with fibropapilloma were *Chelonia mydas*. No age class information was available for three of these individuals, but the others were juvenile (5), sub-adult (2) and adult (1).

There was no significant difference between the number of living (197) and dead (205) individuals (Exact test, $p > 0.05$). All individuals found alive were sent to be rehabilitated (either at the Aquarium des Lagons or different veterinarian clinics). Of the 197 living individuals, 50 died within the first day and 71 were released back into the wild. The mean time the stranded turtles spent in treatment was 70.423 ± 32.33 days (mean ± 95% confidence interval).

DISCUSSION

The majority of strandings were reported in the South Province. This may be due to the higher population density in that province (which houses 70% of New Caledonia's residents), as well as awareness campaigns carried out by the Aquarium des Lagons

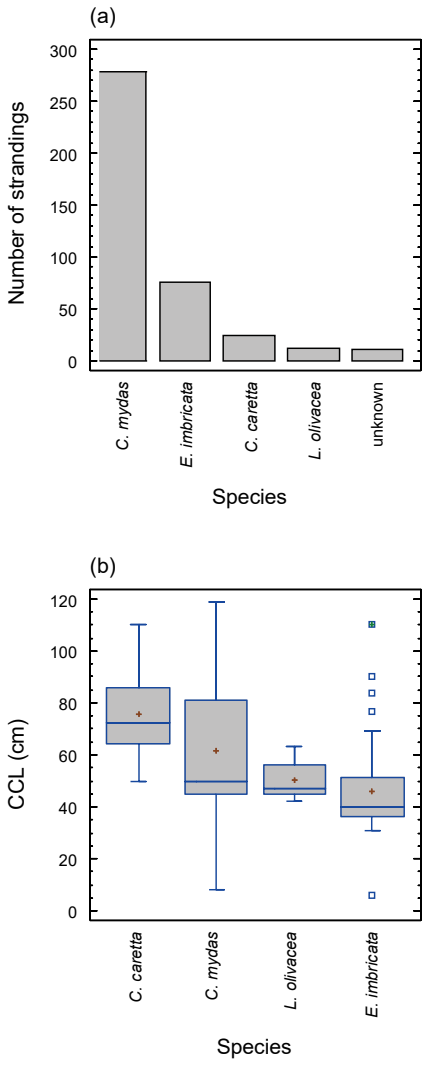

Fig. 3. Recorded sea turtle strandings in New Caledonia a. per species and b. per species and mean Curved Carapace Length (in cm) from 1999 to 2021 with 95% confidence intervals.

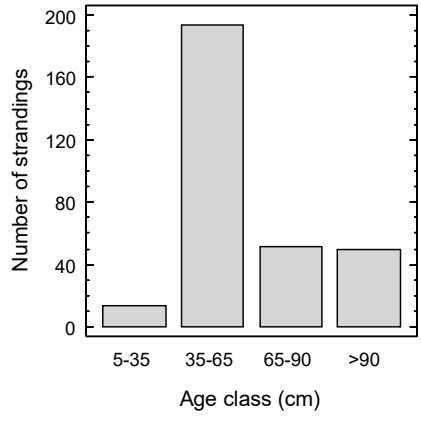

Fig. 4. Recorded strandings in New Caledonia per age class between 1999 and 2021.

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and the South Province. Only five stranded individuals were reported in the Loyalty Province. Some areas (like Nouméa, Boulouparis and Bourail) seemed to have a disproportionate number of strandings (Fig. 1). This could be explained by the oceanography of the area and the presence of passes in the barrier reef. One previous study also explained the influence of nearshore flow during the seasons when strandings were high: when an offshore flow of surface water appeared, the strandings were lower because the new current potentially directed the stranded individuals away from the coastline instead of onto the beach (Hart et al. 2006).

The increasing number of stranding reports since 2014 (Fig. 2) could be explained by the increase in the number of boat owners, from 24,732 in 2014 to 27,786 in 2020 (DAM). Another factor could be the multiples awareness campains since 2015 "Guide du Lagon". The coming years will show us if the increase in strandings is due to awareness tools or if the numbers are actually increasing.

The most strandings occurred from the end of autumn into the first part of summer (November to January; N = 126), peaking in November (N = 58). A study done in Queensland, Australia from 1996 to 2013 showed seasonal variation with peaks in October and troughs in March–June (Flint et al. 2015b). In that study, adult and large immature turtle strandings peaked in October while small immature turtle strandings peaked in August. This peak in small immature turtle strandings was later than in our study, which could be explained by the environmental factors that impact sea turtles (Flint et al. 2017). Rainfall seems to be the main factor impacting the sea grass foraging areas and indirectly impacting the number of strandings (Meager and Limpus 2014). Turtle strandings were reported to be cyclical over the years in Queensland, with two peaks a year (first peak in the months following winter and second peak during the months following summer), when the water starts to cool (Flint et al. 2015b). This pattern was also recorded in the Mediterranean Sea and the Pacific Ocean (Cheng et al. 2019; Corsini-Foka et al. 2013). Borsa's (2006) study of 72 stranding events of marine mammals in New Caledonia also revealed a seasonal pattern. Strandings were most frequent from August to December and peaked in November, which is similar to the present study.

Results show that 68% of individuals found stranded in New Caledonia were *Chelonia mydas* (Fig. 3). This concurs with multiple studies done in foraging areas across the country, which show that the main species found in New Caledonian waters is *Chelonia mydas* (Read et al. 2015; Read and Jean 2021). The second most abundant stranded species was *Eretmochelys imbricata* (76 turtles), followed by *Caretta caretta* (24). Similar results have been found in Queensland—with a majority of strandings being *Chelonia mydas* (69.6%) (Flint et al. 2015)—and other regions of the world (Alava et al. 2005; Cheng et al. 2019; Hama et al. 2019; Sönmez 2018). Strandings of two species not usually found in New Caledonia, *Lepidochelys olivacea* (13 turtles) and *Dermochelys coriaca* (3), were recorded. One report (Liardet 2003) recorded that *Dermochelys coriaca* was sighted occasionally, but no details could be found on where they were sighted. Bauer and Sadlier (2000) stated that *Lepidochelys olivacea* was probably present in New Caledonian waters, but did not actually record any sighting. The first record is in Etaix-Bonnin et al. (2011), which recorded a by-catch specimen in 2008 (data included in the current study). In this study, all *Dermochelys coriaca* were caught as by-catch by longliners in pelagic waters, but their CCLs were not recorded. However, even though the majority of the *Lepidochelys olivacea* were also caught as by-catch in pelagic waters, four individuals (all juveniles) were found stranded on beaches of Nouméa and brought to the Aquarium des Lagons for rehabilitation. Two of them were released alive.

The majority of the strandings belong to the juvenile size class (Fig. 3). Similarly to our study, Flint et al. (2015b) reported an increase in juvenile green turtle strandings in Queensland over a period of 18 year. This increase in Australia is likely linked to the increase of this age-class within the foraging population, but it could also be influenced by environmental stress factors such as the drastic change from pelagic to coastal areas (Flint et al. 2010a b 2015). The causes are likely similar in New Caledonia considering the high proportions of juveniles recorded there (Read et al. 2020b) and that Australian and New Caledonian individuals experience similar conditions in their pelagic to coastal phases.

Half of the strandings we analyzed had unknown causes. This is mainly due to a lack of resources and organized networks to conduct any proper analysis when an individual is found. The number of strandings has significantly increased over the years and necropsies are now being done more regularly. Identifying the causes of mortality should be a priority in the near future because it would help researchers better understand the health of the sea turtle populations in New Caledonia (Flint et al. 2009; Aguire and Lutz 2004). No necropsy was performed on the individuals with clear signs of shark attacks, so it is impossible to say if their death was linked to the attack or something else. Our results identify poaching as a major threat to foraging sea turtles in New Caledonia, both historically and currently. This is still a threat in many regions around the world (Gaillard et al. 2020; Hama et al.

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2019; Joseph et al. 2019). Larger individuals are mostly targeted during poaching, and this especially impacts the New Caledonian foraging populations because they have a low number of adults (Read et al. 2020b).

One of the leading causes of stranding for New Caledonian turtles is by-catch. The majority of the by-catch was done by coastal fishermen (N = 36) using crab pots, individual fishing nets or even handlines. The tuna-specific fisheries of New Caledonia declared that they found on average less than one turtle as by-catch per year from 2012–2019. It was argued that the impact of longline fishing remains minimal for the sea turtle population in New Caledonia (0.0001% of hooks catch sea turtles) (DAM 2017). It is important to point out that in half of the cases, the turtles are found alive and released. Crews are trained to handle turtles accidentally caught and found alive to maximize the animal's chances of surviving (DAM 2017). The results of our study regarding by-catch by fisheries are very encouraging, highlighting that this type of fishing method is rarely the cause of sea turtle strandings in New Caledonia compared to other countries (Lewison and Crowder 2007; Peckham et al. 2007; Putman et al. 2020). However, there should be awareness campaigns for coastal fishermen that use "homemade" or deteriorated fishing gear that trap and kill sea turtles. The campaigns should also include a phrase explaining the biology of sea turtles to decrease the misconceptions that more sea turtles decrease fish stocks (Panagopoulou et al. 2017).

Thirty-eight individuals had collisions of some kind. Over half of these specimens that did not survive were in Marine Protected Areas (mostly close to Noumea and thus with a higher density of recreational boaters). In Queensland between 1999 and 2002, 65 individuals were struck by boats per year (Hazel and Gyuris 2006). Boats striking sea turtles in marine protected areas is a global issue (Denkinger et al. 2013). The collision impact for three strandings in this study in 2019 were different to those previously recorded for sea turtles. The carapaces were not shattered but "sliced." This type of impact could be due to the new type of foil on kitesurfing and windsurfing gear that is becoming very popular in New Caledonia. More studies should be done on the individuals that are stranded with this new type of specific wound.

Only two individuals (both *Chelonia mydas*) in this study were found to have ingested plastic. An adult female (CCL: 97.5 cm) was found stranded on a beach in January 2011 and a juvenile (CCL: 43 cm) was found floating in a lagoon in August 2020. A recent study recorded a 50% chance of mortality once a sea turtle ingests 14 pieces of plastic (Wilcox et al. 2018). The juvenile found stranded in 2020 ruled by a veterinarian to have died by plastic ingestion had over 50 pieces of plastic in its gut. The cause of death was declared to be plastic ingestion because a hard piece of plastic punctured its gut. Most plastics found in the present study (18 pieces in total) were soft, but hard pieces were also present. In Brazil, a study found that over 70% of the studied individuals had ingested plastic (Santos et al. 2015). Countries close to New Caledonia like Japan (Moriya 2010) and Taiwan (Cheng et al. 2020) also provided data on plastic ingestion. In an Australian study, it was found that over 50% of pelagic turtles and 25% of foraging individuals had ingested plastic debris (Schuyler et al. 2012). In New Caledonia, a previous study of marine mammal strandings revealed plastic debris in a small number of individuals (Garrigue et al. 2016), but this was not determined to be the cause of death. Sea turtles, which have been identified as "sentinels" of ecosystem health (Aguire and Lutz 2004), can serve as indicators of environmental problems through the presence of plastic in their gut and subsequent deaths caused by plastic ingestion. In the present study, very few individuals were found to have ingested plastic, which could in turn suggest that plastics do not yet have a large impact on the marine ecosystems used by turtles in New Caledonia.

Two individuals' deaths were classified into the "other" category. One was found on Lifou Island (Loyalty Province) covered in tar, a couple of days after a container ship was wrecked in July 2017. This cause of mortality seems to be relatively rare (Casale et al. 2010). The second individual was a nesting female that died from sustained injuries from being attacked by two dogs while laying her eggs.

In a study done in Hawaii and the insular pacific, the most common causes of stranding were by-catch and collision (excluding fibropapillomatosis) (Work et al. 2015). In Turkey, by-catch and marine pollution were the main causes of strandings (Sönmez 2018). By-catch was also targeted as an important issue for sea turtles in Taiwan and Spain (Cheng et al. 2019; Tomàs et al. 2008). The causes of stranding appear to be similar around the world, but the top causes of stranding differ with region, thus demanding that actions be region-specific. These studies, including the present one, highlight the importance of anthropogenic impacts broadly on the sea turtle populations worldwide and how impacts differ with region.

Eight stranded individuals had titanium tags when found. All of them were originally tagged in New Caledonian waters. Four were tagged post-rehabilitation (second stranding occurred due to poaching and boat-strike for two of them, and unknown for the other two). One was tagged at the nesting site and was found stranded on the same nesting site. The last three

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individuals were tagged at the two most important nesting sites for *Chelonia mydas* (D'Entrecasteaux reefs N = 2 and Chesterfields reefs N = 1) and found stranded at different locations. The results from the last three tag recoveries are correlated with a previous study done in New Caledonia (Read et al. 2014) where individuals were found to be nesting in New Caledonian's largest nesting areas (D'Entrecasteaux reefs and Chesterfields atolls) and foraging on the coast of the main island of New Caledonia. These results were also narrowed with a genetic study (Read et al. 2015), suggesting that the majority of the sea turtles foraging in the south of New Caledonia were from the two main nesting areas (D'Entrecasteaux reefs and Chesterfields atolls).

The first ever stranded individual to be reported carrying external lesions of fibropapilloma in New Caledonia was in 2011. In 2013, a publication mentioned an individual stranded with fibropapilloma in New Caledonia, but no analysis was done at the time to confirm the virus (Work and Balazs 2013). In 2014, a sample of the external lesion was sent to the National Wildlife Health Center-Honolulu field station. Gross and microscopic pathology results were consistent with fibropapillomatosis. Molecular analyses confirmed the presence of chelonid herpesvirus 5 DNA for F-Sial and MO4 genes. In New Caledonia, less than 3% of the stranded individuals presented the lesions, whereas in Hawaii 28% of the strandings had fibropapilloma (Chaloupka et al. 2008). In this study, it could not be determined if the individuals were stranded because of their fibropapilloma lesions or another condition because no necropsies were done.

CONCLUSIONS

This study highlights that over 40% of the recorded stranding in New Caledonia over the past 20 years are due to anthropogenic impacts. The most impacted individuals are the juvenile *Chelonia mydas*. Two peculiar causes of strandings have been recorded in this study (fibropapilloma and plastic ingestion) and need to be closely monitored in the future, even if they are currently not deemed a threat to the New Caledonian sea turtle population. The success of rehabilitation has been analyzed in multiple studies and the 35% success rate in New Caledonia is similar to or higher than the results found elsewhere (Baker et al. 2015; Baron 2014). However, a stranding network with a single phone number, active volunteers and shared protocols should be put in place in New Caledonia to collect standardized data which would be beneficial, as monitoring strandings is a proven, efficient management tool. The use of a web-based application would also ensure that the data are not lost over the years and that all the project partners enter the same data. In Flint et al. (2015a), management actions such as "go slow" zones, Turtle Excluder Devices, protection areas, and net attendance rules proved to be successful mitigation strategies. These rules do not currently exist in New Caledonia, except in the marine protected areas. These could be put in place to reduce the number of mortalities within New Caledonian waters, but should take into account the specifics of each area (Shimada et al. 2017).

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Competing interests: The authors declare that they have no competing interests.

Availability of data and materials: Stranding records of each turtle species per year in New Caledonia is in supplementary materials. Additional data are available upon request.

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Supplementary materials

Appendix 1. Stranding records of each turtle species per year in New Caledonia. (download)

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