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RESEARCH ARTICLE

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Freedivers harvest thousands of sea turtles a year in the Solomon Islands

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Abstract

1. Sea turtles are harvested in many small-scale fisheries (SSFs), but few nations have quantified the impacts that SSFs are having on their sea turtle stocks. This study provides the first assessment on the catch composition, national harvest rates, and long-term trends in sea turtle catches in the Solomon Islands SSFs.
2. Between October 2016 and May 2018, 10 community monitors located in eight of the nine provinces of the Solomon Islands were trained and employed to work alongside fishers in their respective communities to document, photograph, and georeference the reefs where sea turtles were harvested. Local ecological knowledge (LEK) surveys were then conducted with 32 experienced fishers to infer whether the harvest rates of sea turtles had changed in recent decades.
3. Community monitors recorded information on 1,132 sea turtles that were harvested on 529 fishing trips: 1,119 sea turtles were identified to species level, with harvests consisting of 73.3% ($n = 818$) green sea turtles (*Chelonia mydas*), 25.7% hawksbill sea turtles ($n = 291$) (*Eretmochelys imbricata*), and 0.9% ($n = 10$) olive ridley sea turtles (*Lepidochelys olivacea*).
4. The great majority (92.6%) of sea turtles were captured by night-time and daytime freedivers who use masks, snorkels, fins, hooks, spears, and underwater flashlights to target a wide range of fauna that inhabit coral reefs.

5. A methodology that accounts for spatial heterogeneity in sea turtle catch rates was used to estimate that the SSFs of the Solomon Islands harvested 11,184 sea turtles per year, with a 95% confidence interval of 5,862–23,717 sea turtles.
6. Experienced freedivers reported a 4.9-fold decline in sea turtle harvest rates over the past 30 years, indicating that the sea turtle stocks of the Solomon Islands are being overfished.
7. The results and recommendations from this study were integrated into the Solomon Islands National Plan of Action for Marine Turtles 2023–2027.

KEYWORDS

Chelonia mydas, community monitors, *Eretmochelys imbricata*, *Lepidochelys olivacea*, local ecological knowledge, national harvest rates, small-scale fisheries, western Pacific Ocean, wildlife traffickers

1 | INTRODUCTION

Historical fishing has driven global declines in sea turtles (Jackson, 1997), and contemporary fishing practices hinder the recovery of many endangered sea turtle populations (Wallace et al., 2013; Burgess et al., 2018). Hundreds of thousands of sea turtles may be unintentionally killed each year in commercial fisheries (Wallace et al., 2010; Lewison et al., 2014), and increasing public awareness about this by-catch problem has put commercial fisheries under a global spotlight (Gilman et al., 2006), motivating many commercial fisheries to adopt practices that reduce sea turtle by-catch (Mazaris et al., 2017). There is now an extensive body of research into quantifying and mitigating sea turtle by-catch in trawl, longline, purse seine, and net fisheries (e.g. Gilman et al., 2006; Wallace et al., 2013; Lewison et al., 2014; Brown et al., 2021).

Sea turtles are also deliberately taken in small-scale fisheries (SSFs) that operate in most tropical coastal waters (Wallace et al., 2013). Although the impacts of SSFs remain poorly understood (Wallace et al., 2010; Lewison et al., 2014), there is mounting evidence that when the footprints of SSFs overlap with high-use areas for sea turtles (such as coastal foraging grounds), sea turtle mortalities in SSFs can exceed those caused by commercial fleets fishing in adjacent oceanic waters (e.g. Peckham et al., 2007; Gilman et al., 2010; Casale, 2011). In SSFs, sea turtles are either deliberately fished (e.g. Bell et al., 2006) or are unintentionally taken as by-catch, and then subsequently discarded (e.g. Peckham et al., 2007) or retained for consumption (e.g. Gilman et al., 2010; Alfaro-Shigueto et al., 2011). Although legal sea turtle harvest rates were estimated to have declined over the past 50 years, a legal take of sea turtles is still permitted in over 40 countries (Humber, Godley & Broderick, 2014), and the illegal sale of sea turtles into domestic and global markets continues (Miller et al., 2019; Senko et al., 2022).

Fisheries managers and conservation practitioners have expressed concern that the number of sea turtles harvested in SSFs may be unsustainable. This is particularly true in locations where there is rapid human population growth, a high dependency on fishing, existing demand and links to illegal wildlife markets, and limited capacity or cultural willingness to enforce existing management policies pertaining to the management of sea turtles (Humber et al., 2011; Miller et al., 2019). In countries where sea turtles form a component of SSFs, obtaining data on harvest rates and trends is needed to assess the sustainability of sea turtle fisheries and evaluate the effectiveness of existing management measures (Wallace et al., 2013). Such information is also relevant for conservation planning, as it can identify mortality hotspots that warrant targeted management interventions (Senko et al., 2014), and it allows the impact of SSFs on sea turtles to be evaluated relative to other threats, such as large-scale commercial fisheries (Wallace et al., 2013).

The methodologies that have been used to estimate sea turtle harvest rates in SSFs come from the environmental and social sciences, and include documenting the local ecological knowledge (LEK) of fishers (Early-Capistrán et al., 2018; Williams et al., 2019), examining discarded sea turtle carapaces at middens, dump sites, and fishing ports (Senko et al., 2014; Barrios-Garrido et al., 2020), surveying sea turtle catches at key landing sites (Stringell et al., 2013), and training community monitors to collect demographic information on harvested sea turtles (Humber et al., 2011).

Although sea turtles are harvested in many areas of the globe (Lewison et al., 2014), much of the published research on this topic has been undertaken in the Atlantic and eastern Pacific oceans and in the Caribbean and Mediterranean seas, with a focus on SSFs that use nets, traps, and demersal or pelagic longlines (e.g. Peckham et al., 2007; Gilman et al., 2010; Casale, 2011; Senko et al., 2014; Barrios-Garrido et al., 2020). Research on the impacts of SSFs on sea turtle populations has also been conducted in Africa, Australia, and Peru (e.g. Kingston et al., 2004; Alfaro-Shigueto et al., 2011; Humber et al., 2011). Although the Pacific Islands have the highest rates of legally harvested sea turtles in the world (Humber, Godley & Broderick, 2014), there have been limited attempts to empirically quantify sea turtle catches across the Pacific Island region (Broderick, 1997; Adams, 2003).

Even in locations where studies on sea turtle harvesting do exist, it has proven difficult to establish the impacts that SSFs are having on sea turtle populations at various geographical scales. This relates to a combination of factors. First, most studies have been conducted at small spatial scales, limiting the ability to confidently calculate country-wide estimates of sea turtle mortalities (Wallace et al., 2013). Second, information on the abundance of foraging and nesting sea turtle stocks rarely exists (Humber et al., 2011), and third, typically there are no quantitative data on how the harvest rates of sea turtles have changed over time (Wallace et al., 2013; Ingram et al., 2022).

These data gaps are all present in the Solomon Islands, an island nation in the western Pacific Ocean where sea turtles form a culturally and nutritionally important component of multispecies SSFs (Vaughan, 1981; Hamilton et al., 2012). To help address several of these knowledge gaps, the following questions were investigated: (i) what is the species and size-frequency composition of the sea turtles captured in Solomon Islands SSFs; (ii) how are the sea turtles taken in Solomon Islands SSFs captured and utilized; (iii) how many sea turtles are harvested annually in Solomon Islands SSFs; and (iv) what are the current trends in sea turtle harvest rates in the Solomon Islands? The data collected on sea turtle harvest included size and species composition across 10 representative sites in the Solomon Islands. Then, a mathematical model that accounted for spatial heterogeneity in sea turtle harvest rates was developed and used to provide a statistically robust estimate of national sea turtle harvest rates. The LEK of experienced fishers was also documented to infer the recent trajectories of harvested sea turtle populations. This study provides the first comprehensive assessment of sea turtle harvesting in a Pacific Island country, and the methodologies detailed are likely to have relevance for quantifying the impacts of SSFs on sea turtles in other locations across the globe.

2 | METHODS

2.1 | Ethics

Research clearance, which included ethics clearance, was provided by the Solomon Islands Ministry of Fisheries and Marine Resources (MFMR) and the Ministry of Environment Climate Change Disaster Management & Meteorology (MECDM). Fishers gave their verbal consent to participate in the study and consent was noted in the community monitors' notebooks. If verbal consent was not given, the inspection of the catch and interviews did not proceed.

2.2 | Environmental setting

The inhabitants of the Solomon Islands live a predominantly subsistence-based lifestyle, with most of the nation's population residing in approximately 4,000 coastal communities. Sea turtles are a culturally and nutritionally important resource that have been harvested for centuries in the Solomon Islands (Vaughan, 1981; Hamilton et al., 2015), and the legal trade in shells of the hawksbill sea turtle (*Eretmochelys imbricata*) formed an important component of people's livelihoods from 1840 until the early 1990s, when it was banned (Bennett, 1987; Richards, Bell & Bell, 1994). Sea turtles are typically hooked, held by hand, or speared by freedivers, who use fins, mask, and snorkel. Often this occurs at night, when freedivers will use an underwater flashlight to search shallow reef slopes for resting reef fish and sea turtles (Broderick, 1997; Hamilton et al., 2012). Under Solomon Islands law, all sea turtle species (except for the leatherback sea turtle, *Dermochelys coriacea*) can be harvested for subsistence purposes; however, the sale of any sea turtle product (meat, eggs, or shell) is banned, as is the harvesting of sea turtle eggs or nesting sea turtles (MECDM & MFMR, 2023). As well as the legal subsistence harvest, some sea turtle products are illegally sold. For example, green sea turtle (*Chelonia mydas*) meat is sold in local markets (Richards, Bell & Bell, 1994; Vuto et al., 2019), whereas hawksbill sea turtle scutes are sold to indigenous carvers, who sell their products domestically, and to Asian exporters in the capital Honiara, who are involved in the illegal global trafficking network for hawksbill shell (Hamilton et al., 2015; Vuto et al., 2019).

2.3 | Study location

This study was conducted in 10 coastal communities located in eight of the nine provinces in the Solomon Islands (Figure 1). Seven sites were selected to represent locations where the frequency of sea turtle landings was believed to be typical for Solomon Islands SSFs, and three sites were selected to represent atypical locations where sea turtle landings were known to be much higher than is seen at typical sites. The classification of typical versus atypical landing sites was based on observations of SSF landings that the authors have made across all nine Solomon Islands provinces since the 1990s and a search of available studies (e.g. Broderick, 1997; Hamilton et al., 2012). In a typical coastal community in the Solomon Islands, sea turtle landings are a rare occurrence, with sea turtles making up a small component (<5% by weight) of the total landings made in multispecies SSFs. For example, Hamilton et al. (2012) documented the catches from 41 night spearfishing trips on the reefs around Munda in the Western Province of the Solomon Islands, and reported that a total of 1,931.5 kg of seafood was harvested. This consisted of reef fish (95.6%, 1,846.1 kg), crayfish (1.2%, 24.1 kg), two juvenile green sea turtles (2.1%, 40.6 kg), and a juvenile hawksbill sea turtle (1.1%, 20.7 kg). The three sea turtles were captured on three different trips, that is, on the reefs around Munda a sea turtle was only captured 7% of the time on a night spearfishing trip.

The typical coastal communities selected were Marau, Toa/Gela, Radefasu, and Kaonasugu, and the provincial headquarters of Munda, Taro, and Lata. There were six sites in the Solomon Islands where landings of sea turtles were known to be atypically high (Kariki, Wagina, Kia, Buala, Furona Island, and Pileni Island). At these atypical sites, sea turtle landings occur almost daily in the SSFs, or are intermittent but high, often exceeding 10 sea turtles per fishing trip (authors, personal observations; Broderick, 1997). Three of these sites (Buala, Kia, and Wagina) were included in this study. Some sites that had high sea turtle landings (e.g. Kia) are also known to have high landings of reef fish (Hamilton et al., 2016), which suggests that sea turtles still made up a relatively small component of the multispecies SSFs at these sites.

2.4 | Community monitoring programme

In 2016, four community monitors from Buala, Kia, Taro, and Wagina were trained in data collection methods and paid $250 (USD) per

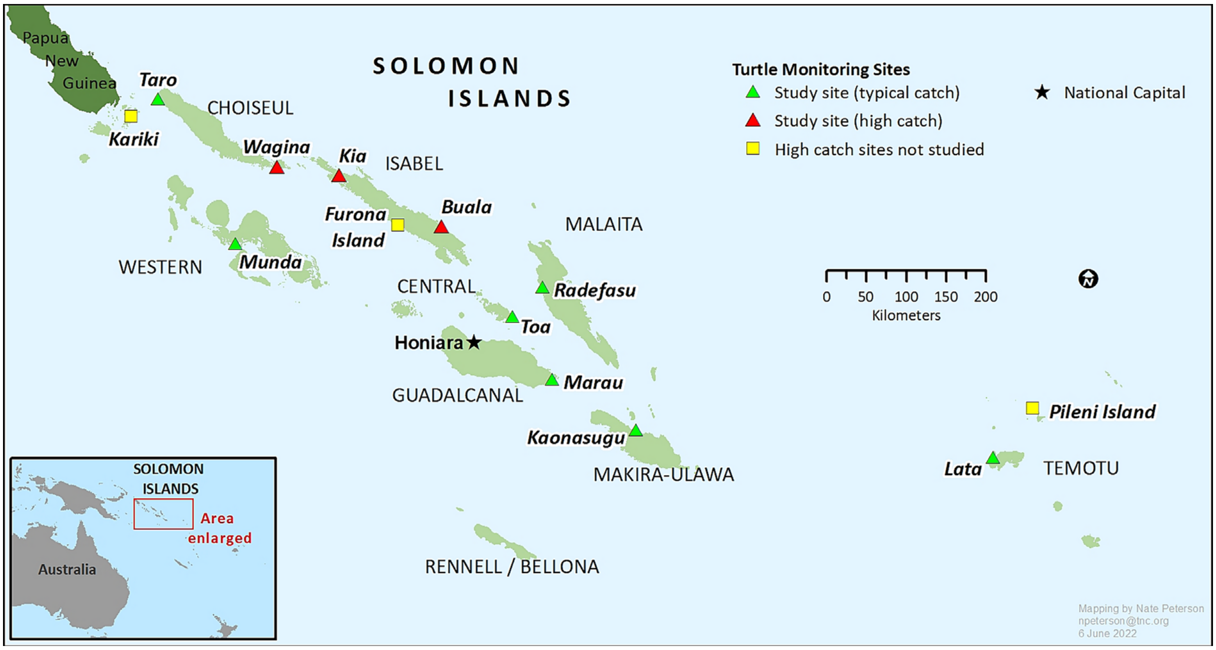


FIGURE 1 Locations of the 10 study sites and three other sites known to have high sea turtle catch rates but were not surveyed.

month from October 2016 to March 2017 to inspect and document information on sea turtles landed within their respective communities.

To expand the research to a national level, a community sea turtle monitoring workshop was held in April 2017 (Vuto, 2017). This workshop was attended by the four trained community members plus six additional community members from Kaonasugu, Lata, Marau, Munda, Radefasu, and Toa/Gela, and staff from MFMR. In the Solomon Islands, women rarely freedive on coral reefs (authors, personal observations), hence the decision was made to only select men as community monitors. Community monitors were selected based on the following criteria: they were well known among the freedivers in their communities, were contactable by phone, and were deemed reliable data collectors. Community monitors were recommended by respective provincial fisheries officers or were already known to the authors. Three of the community monitors were active freedivers.

During the sea turtle monitoring workshop, participants learned about sea turtle biology, sea turtle fisheries, and the purpose and protocols for this study. Participants were trained in demographic data collection on captured sea turtles and digital camera operation. Through role-playing exercises, they also practised explaining the purpose of the study and asking fishers for their consent to participate. Given the sensitive nature of the illegal sea turtle trade in the Solomon Islands, interviewees were assured that participation was voluntary, all information would be recorded anonymously, and participants could choose not to answer specific questions (Hancock et al., 2017). Community monitors were also provided with topographic maps of their community's fishing grounds, which had local reef names recorded on them so that the harvesting location of each sea turtle could be georeferenced (Vuto, 2017).

To assist community monitors in documenting information on both sea turtle landings and sea turtle use, community monitors were provided with multiple copies of two data forms that were designed to be used in instances where harvested sea turtles could be physically inspected. On Form A (Appendix S1), community monitors were asked to record the following information for each sea turtle observation: date inspected; name of recorder; village name; local reef name of where the sea turtle(s) were harvested; date and time of harvest; fishing method; type of boat used; and total number of sea turtles captured, curved carapace length (CCL), and species of each sea turtle recorded. Community monitors were also asked to record what the sea turtle catches would be used for (i.e. consumption, community feast, birthday celebration, or sale). When fishers reported that the sea turtles they had harvested would be sold, community monitors were asked to record further information on whether the whole sea turtle would be sold or just specific sea turtle products (i.e. shell, meat, and blood), and where it would be sold. Community monitors did not record information on the take of sea turtle eggs. To ensure confidentiality, the fishers names were not recorded.

Community monitors were also asked to complete an additional Form B (Appendix S2) for every sea turtle observed. On this shorter form the community monitors were asked to record the following information: date observed; name of recorder; local reef name of where the sea turtle was harvested; fishing method; date and time of harvest; and CCL and species. Once this information had been filled out, the community monitors were asked to place Form B on or near the corresponding harvested sea turtle and take a photo of that specific sea turtle and Form B. This photographic record served as an independent means of validating species identifications that were made in the field.

To account for variations in survey effort, each day community monitors recorded on a calendar whether they were present in the community and available to work. Community monitors were also asked to record and provide a reason for any days that they were not able to work. It was explained that if a community monitor was not available to work because of sickness or other commitments, this would not affect their monthly pay. To calculate the relative percentage of sea turtle harvesters that community monitors were able to engage with, each community monitor was also asked to record the total number of fishers in their community that were known to harvest sea turtles and how many of them were willing to participate in the study. At the end of the workshop, each community monitor was provided with monitoring kits that included, cameras, tape measures, pens, paper, phone credits, Form A and B data sheets, diaries, calendars, large topographic maps of their community fishing grounds, and a backpack.

2.5 | Data collection

Following the workshop, the 10 community monitors returned to their various communities, explained to the local fishers the purpose of this study, and sought their participation. The four original community monitors from Buala, Kia, Taro, and Wagina continued with their monitoring until May 2018 (representing a continuous 20-month period), and the six new monitors carried out continuous monitoring in their respective communities from April 2017 to May 2018 (representing a continuous 13-month period). All 10 community monitors were paid $250 for every month that they worked during this period. As most sea turtle harvesting in the Solomon Islands is performed at night, by freedivers, the community monitors walked or paddled a dugout canoe around their community every morning for approximately an hour, checking for captured sea turtles. Community monitors would also visit fishers at various times of the day or night if they learned of sea turtle harvests through word of mouth or via a phone text message. Community monitors were contacted via phone approximately monthly and were visited every 6 months by the authors to cross-check their data records, download photographs, and provide technical support. The cross-checking of local reef names against the Excel database and digitizing the local names of fishing grounds was also carried out with the support of community monitors and local fishers in the field.

2.6 | Estimating recent changes in sea turtle harvest rates

It is known that LEK is valuable for providing a historical perspective on the state of SSFs (Johannes, Freeman & Hamilton, 2000), and can be used to identify 'shifting baselines': long-term and usually negative changes that are often not immediately or readily apparent to new generations of fishers or scientists working in a data-poor area (Pauly, 1995). In the Solomon Islands, LEK on changes in the harvest rates of megafauna have been independently verified as accurate (Hamilton et al., 2019). To infer changes in the harvest rates of sea turtles over recent decades, LEK surveys were conducted in Kia, Wagina, Toa/Gela, Munda, and Taro between April and June 2019. Thirty-two experienced freedivers who were known to harvest sea turtles and had participated throughout the earlier part of this study were interviewed. The questions each fisher was asked were as follows: (i) what year did you start catching sea turtles; (ii) what was(were) the fishing method(s) you used when you started; (iii) what fishing grounds did you catch sea turtles on when you started catching sea turtles; (iv) when you first started catching sea turtles, what was the average number of sea turtles you would catch in a single fishing trip; (v) what is(are) the sea turtle fishing method(s) you have used in the past 2 years; (vi) what fishing grounds have you caught sea turtles from in the past 2 years; and (vii) what is the average number of sea turtles you have caught in a single fishing trip in the past 2 years?

2.7 | Statistical analysis

2.7.1 | Accuracy of species identification and catch demographics

To evaluate the ability of community monitors to correctly identify sea turtle species, two of the authors made species identifications from available photos and compared their assessments with the species identification made by the community monitors. In total, after accounting for sea turtles where no photos were available or where photos were of insufficient quality (i.e. taken at night in poor light), 786 comparisons were possible. Adult hawksbill sea turtles were defined as individuals with CCL > 75 cm, based on the minimum size of nesting females in the Solomon Islands (McKeown, 1977), and adult green sea turtles were defined as individuals with CCL > 90 cm, based on the regional minimum size of nesting females (Limpus & Chaloupka, 1997). The catch size and species composition were plotted across all sites pooled, as well as individually by site. Plots were created with the R program (R Core Team, 2021).

2.7.2 | Annual harvest estimates for the Solomon Islands

An annual harvest for the entire Solomon Islands, with associated uncertainty intervals, was estimated by scaling up the empirical data collected from the 10 surveyed communities. The scaling-up method involved correcting for differences in survey effort between the 10 communities, then estimating the spatial footprint of each community's fishing grounds from the records of catch locations. The first stage of the extrapolation considered harvest rates from the typical communities alone. The harvest per hectare was extrapolated to all regions of the Solomon Islands following a multiple step process that calculated the fishing grounds based on the location of all coastal communities in the Solomon Islands and the distances of reefs to those fishing grounds. The extrapolation considered uncertainty in the harvest rate of sea turtles per hectare of reef and uncertainty in the distance that fishers will travel from their communities (by bootstrapping over the estimates of these quantities from the typical communities). In the second stage, annual catch estimates for the six communities that had atypically high catch rates were added. A detailed description of this methodology is provided in Appendix S3, and the R code used is available on github.

2.7.3 | Estimating recent changes in sea turtle harvest rates

To investigate changes in sea turtle harvest rates, data from fishers who no longer caught sea turtles were excluded (three fishers), along with fishers who had changed fishing methods (one fisher who historically caught nesting sea turtles). Where a range of values were reported for either the year that the fisher began catching sea turtles or the average catch rates per trip, the midpoint of the range was used. From the remaining 28 freedivers, the mean and standard deviation of sea turtle catches per trip both when freedivers first began catching sea turtles and over the past 2 years were calculated. The mean and standard deviation of changes in harvest rates (total and annual) was also calculated. A generalized additive model was fitted to the historical catch, using year as a fixed effect and fisher identity as a random effect (Wood, 2017). A Poisson distribution for the data was used and midpoints were rounded to whole numbers. The models were fitted with the mgcv package in R (Wood, 2017).

3 | RESULTS

3.1 | Study participants

The 10 community monitors identified 278 fishers in their collective communities who were known to harvest sea turtles. All these fishers were males and 151 agreed and 127 declined to participate in this study. Between October 2016 and April 2018, the community monitors collected information on 1,132 sea turtles that were harvested on 529 fishing trips, with community monitors able to directly observe 1,105 of these sea turtles or their carapaces. The number of sea turtles landed in a fishing trip ranged from 1 to 21 (Appendix S4).

3.2 | Species identification

Overall, the community monitors correctly identified sea turtle species harvested 96.6% of the time. Incorrect species identifications were corrected in the database and these records were retained (Appendix S4). Community monitors who surveyed sites with high sea turtle catches made very few mistakes. Most incorrect species identifications were made by two community monitors: one community monitor misidentified olive ridley sea turtles (*Lepidochelys olivacea*) as green sea turtles, whereas another community monitor recorded hawksbill sea turtles as green sea turtles, and vice versa.

3.3 | Demographics of sea turtle catch

Across the Solomon Islands, the sea turtle catches were dominated by green sea turtles (72.3%, $n = 818$) and hawksbill sea turtles (25.7%, $n = 291$), with very few olive ridley sea turtles (0.9%, $n = 10$) (Appendix S4). The remaining sea turtles were unable to be identified (1.1%, $n = 13$), as they were butchered and the carapaces disposed of before being surveyed. The largest number of sea turtles harvested (80.2%, $n = 908$) were observed in Wagina, Kia, and Buala (30.5%, $n = 345$; 33.7%, $n = 381$; and 16.1%, $n = 182$; respectively; Appendix S4). Overall, the harvested sea turtles were dominated by juveniles (85.2%, $n = 942$ of the 1,105 sea turtles with both species and CCL recorded). Of the 807 green sea turtles with CCL recorded, 88.6% ($n = 715$) were smaller than the minimum CCL at maturity. Of the 288 hawksbill sea turtles with CCL recorded, 75.7% ($n = 218$) were smaller than the minimum CCL at maturity (Figure 2). Nine of the 10 olive ridley sea turtles observed in this survey were adults that were captured near or on a nesting beach in Makira, and these adults had a mean CCL of 66.9 cm. The only juvenile olive ridley sea turtle observed was an individual with a CCL of 51.5 cm that was captured in Wagina (Appendix S4). In this study, adult hawksbill sea turtles made up the highest proportion of catches at Wagina, which is located adjacent to the Arnavons Community Marine Park (ACMP).

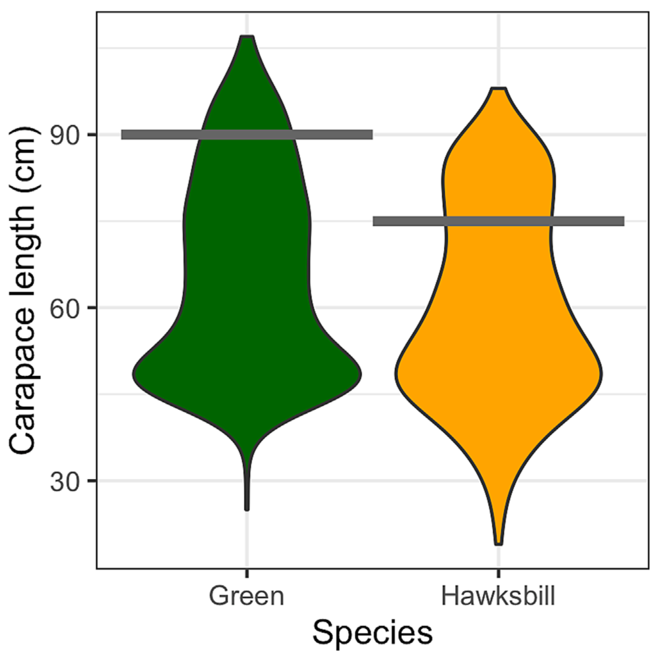


FIGURE 2 The size distributions of all green and hawksbill sea turtle catches. The grey bars represent the minimum curved carapace length at maturity (green sea turtle, >90 cm; hawksbill sea turtle, >75 cm).

The highest proportion of adult green sea turtles was captured at Edwards Bank, which lies 45 km north east off Buala (Figure 3).

3.4 | Harvesting techniques

The method of harvesting sea turtles was recorded for 1,101 sea turtles (Appendix S4). Of these sea turtles recorded, 92.6% (*n* = 1,020) were captured by freedivers, 3.2% (*n* = 35) were caught in gillnets, 2.5% (*n* = 28) were captured via 'rodeo' (where fishers leap from their boat onto a sea turtle that is near the surface), 1.4% (*n* = 15) were harvested while nesting, and 0.3% (*n* = 3) were captured on hook and line. The time of harvesting was recorded for 1,001 of the sea turtles captured by freedivers, with 74.3% (*n* = 744) harvested at night and 25.7% (*n* = 257) harvested during the day. The specific methods that freedivers used were recorded for 614 sea turtles; of these, 78.2% (*n* = 480) were harvested using large metal hooks that are tied to a 20–30 m long rope that is tethered to a float. This method involves swimming down and driving the metal hook into the sea turtle. The sea turtle is then hauled into a boat once the freediver resurfaces. Freedivers captured a further 13.7% (*n* = 84) of sea turtles by grabbing them underwater, with the remaining 8.1% (*n* = 50) of sea turtles speared using rubber powered spearguns or spears (Appendix S4).

3.5 | Sea turtle usage

Community monitors documented information on how fishers intended to utilize 763 green sea turtles and 277 hawksbill sea turtles (Appendix S4). Green and hawksbill sea turtles were predominantly retained for subsistence purposes by the fisher's family, either to supplement the family's daily nutrition or for feasts that marked important family events, such as birthdays, weddings, or funerals (Figure 4). Fishers also donated some sea turtles to community feasts that were held to celebrate events such as church festivals (Figure 4).

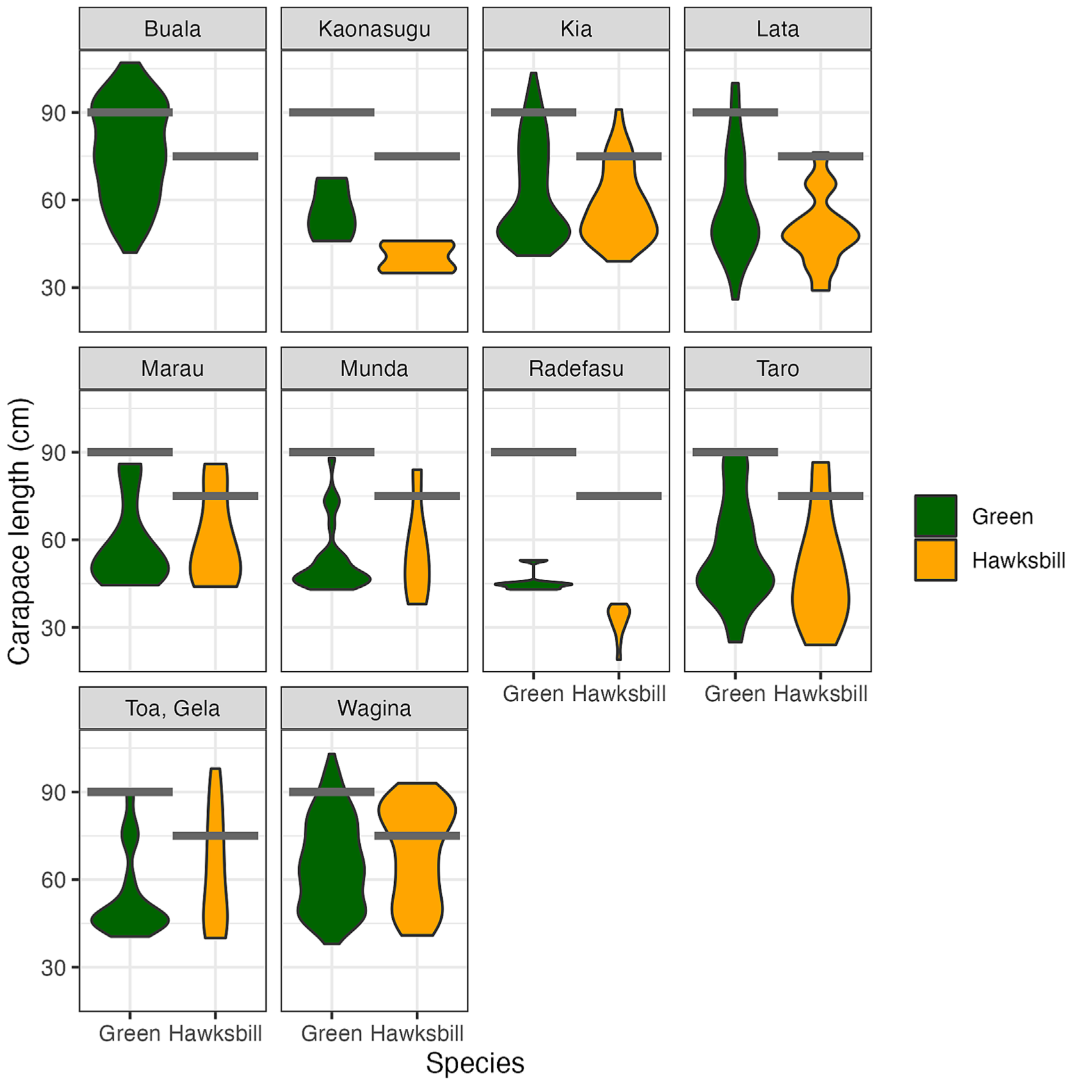


FIGURE 3 The size distributions of harvested green and hawksbill sea turtles, by community. The grey bars represent the minimum curved carapace length at maturity (green sea turtle, >90 cm; hawksbill sea turtle, >75 cm).

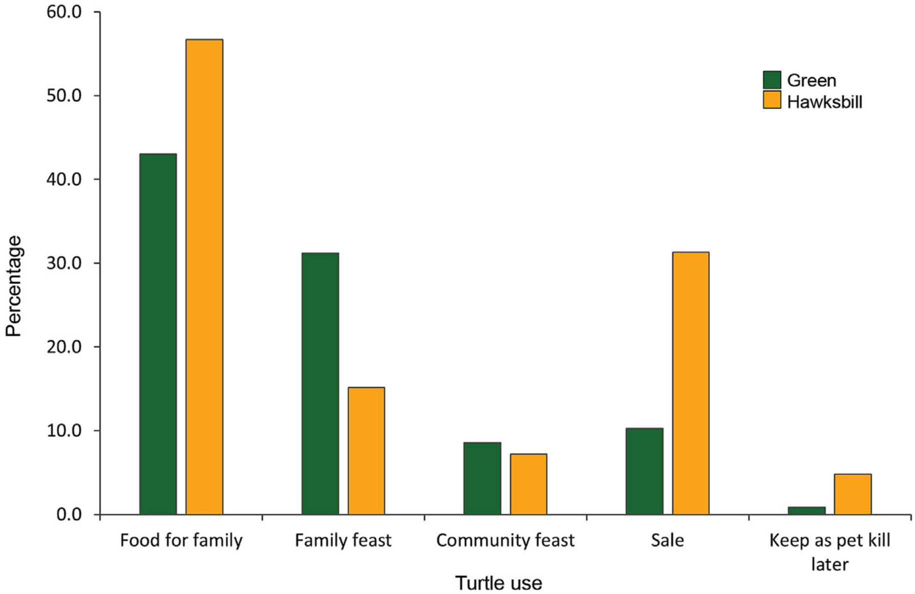


FIGURE 4 Uses of the 763 green sea turtles and 277 hawksbill sea turtles that were observed by the 10 community monitors between April 2017 and April 2018 and had at least one intended use documented (expressed as % of total catch for each species). Totals do not equal 100% as some sea turtles were used in multiple ways (i.e. hawkbill sea turtle meat was legally consumed for subsistence purposes but the shell was illegally sold).

The illegal sale of sea turtle products (meat, blood, and shell) was relatively minor compared with legal subsistence use (Figure 4), although the illegal sale of hawksbill shell was common in Wagina, with many Wagina fishers stating that hawksbill scutes would be sold to Asian buyers in Honiara for $60–75 (USD) per kilo. In Guadalcanal, several fishers stated that hawksbill scutes would be sold to indigenous carvers for $25–45 (USD) per kilo. A small percentage of sea turtles were neither eaten nor sold, but rather kept in captivity by local fishers who said that they intended to 'keep as a pet but kill later' when the sea turtle reached a larger size (Figure 4). All the sea turtles in this category were small juveniles (green sea turtles, 25–44 cm CCL; hawksbill sea turtles, 19–38 cm CCL; Appendix S4). Many of the small juvenile hawksbill sea turtles that fell into this use category were captured in Malaita Province and appear to have still been in their pelagic phase (Limpus et al., 2008), with fishers from Malaita describing that they opportunistically captured these 'floating' pelagic juvenile hawksbill sea turtles via rodeo when fishing for tuna in the open sea (author, personal communications).

3.6 | National annual estimates

The national sea turtle harvest was estimated to be 11,184 sea turtles per year (95% CI 5,862–23,717). The wide confidence interval reflects the variation in harvest per hectare among the communities surveyed; however, there is a high likelihood (>99%) that the annual harvest was greater than 5,800 sea turtles. Communities with atypically high catch rates accounted for 40.3% of the national harvest of sea turtles in the Solomon Islands (Appendix S4).

3.7 | Changes in turtle harvest rates

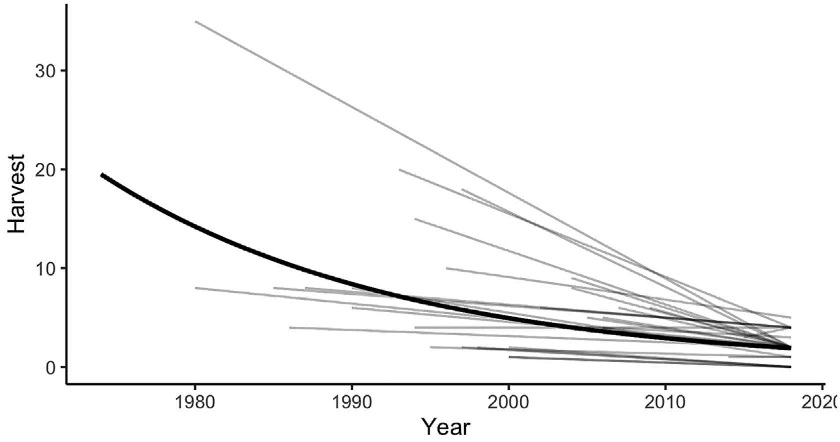
The freedivers interviewed reported first catching sea turtles from 3 to 33 years ago (19.1 ± 8.6 years ago, mean ± standard deviation). Midpoints of the initial harvest estimates ranged between 1 and 35 turtles (7.4 ± 7.3 turtles), and midpoints of current (over the past 2 years) harvest estimates ranged between 1 and 5 turtles (2.0 ± 1.3 turtles) (Figure 5). No free diver reported increased harvest rates of sea turtles (Figure 5). The decline predicted from the generalized additive model was 5.14% per year (95% CI 4.05%–6.22%) or a 4.9-fold decline over 30 years (Figure 5).

4 | DISCUSSION

The empirical data collected in this study and the subsequent modelling suggest that in the 2016–2018 period, approximately 11,000 sea turtles were captured per year in Solomon Islands SSFs, with an upper bound of the confidence interval of over 23,000 sea turtles. Over 92% of these sea turtles were captured by freedivers operating on shallow coral reefs, a fishing method that is popular throughout the Pacific Island region (Gillett & Moy, 2006). In comparison, an earlier global review of the legal harvest of sea turtles that was conducted through expert interviews and a literature review concluded that 1,843 sea turtles are harvested annually in the Solomon Islands (Humber, Godley & Broderick, 2014). The results of this study suggest that Humber, Godley & Broderick (2014) underestimated the sea turtle take in the Solomon Islands by at least 3.2 times and possibly up to 12.9 times. The observed differences highlight that the magnitude of deliberate sea turtle capture in SSFs may be far greater than previously thought.

The Solomon Islands national harvest estimate for sea turtles presented here should be considered conservative, for two reasons. First, the methods for estimating the confidence intervals for national turtle harvest accounted for all possible distances travelled by fishers and sea turtle harvests per hectare, hence accounting for spatial heterogeneity in the per hectare sea turtle harvest rates. Second, in some high harvesting areas, like Wagina, sea turtle landings were only surveyed at the largest of the three communities located around

FIGURE 5 Reported catch declines: light-grey lines show individual fishers, the black line shows the decline predicted from a generalized additive model.



Wagina Island. Although all Wagina communities are thought to harvest large numbers of sea turtles, to be conservative in the national extrapolation, the harvesting rates for Wagina communities that were not sampled were considered typical.

From a management perspective, it is crucial to gauge the impact of removing 11,000 sea turtles a year in the Solomon Islands. The best available proxies for evaluating this come from LEK and information on nesting populations. The LEK surveys that were conducted in this study provide compelling evidence that sea turtle populations in the Solomon Islands are being detrimentally impacted by SSFs, with 28 experienced freedivers from four provinces all reporting marked declines in their sea turtle harvest rates, compared with when they first began freediving, with the modelling predicting a 4.9-fold decline in sea turtle harvest rates over 30 years.

The available nesting data for the Solomon Islands provide a more complex and arguably positively skewed picture. Although there are over 50 known sea turtle nesting beaches in the Solomon Islands (MECDM & MFMR, 2023), long-term data on nesting sea turtle populations are only available from the ACMP. The ACMP supports the largest hawksbill sea turtle rookery in the South Pacific, and for the past 28 years has received continuous financial and technical support from The Nature Conservancy (TNC), which has enabled the permanent presence of community rangers in the park. Hence, although the ACMP continues to experience some poaching, nest numbers have increased following the establishment of protection in 1995 (Hamilton et al., 2015). The increase in nest numbers is attributable to both the efforts of the ACMP rangers and the ecology of the hawksbill sea turtles that nest here. Satellite tracking studies that were conducted in the ACMP have shown that, collectively, tracked female hawksbill sea turtles spent 98.5% of their nesting season within ACMP boundaries, with 56% of satellite-tagged ACMP nesters then migrating to distant and highly protected foraging grounds in Queensland, Australia (Hamilton et al., 2021).

Although quantitative data on other nesting beaches are lacking, anecdotal information suggests that nesting beaches that have not benefited from intense conservation efforts may be faring poorly. For example, the historically important hawksbill nesting beach on Haycock Island that is located near Wagina is now thought to be functionally extinct because of ongoing harvesting pressure near and on the nesting beach (Madden Hof et al., 2022). On balance, the existing lines of evidence indicate that sea turtle stocks in Solomon Island coastal waters are being overfished by SSFs, with 40% of the national annual harvest coming from only a handful of atypical sites, where some fishing parties preferentially target sea turtles over reef fish (Broderick, 1997; Vuto et al., 2019).

Improving the conservation trajectories for sea turtles in the Solomon Islands will require a range of different strategies, several of which are outlined below. First, where possible, government and environmental non-governmental organizations (NGOs) should increase their levels of support to communities who wish to protect and monitor their sea turtle nesting beaches. There are already several excellent examples of this in the country (MECDM & MFMR, 2023), although funding for this work can be sporadic as it is often linked to project funding cycles.

Second, greater efforts are needed to raise awareness on the cultural and ecological values of sea turtles and the importance of conserving sea turtle populations for future use. In 2022, TNC partnered with the Pacific Games Committee to raise national awareness on sea turtles. The 2023 Pacific Games are being held in Honiara in November 2023 and have a sea turtle as their mascot. In 2022, the Pacific Games Committee and TNC ran a national naming competition for the mascot with school children, with ‘Solo’ being chosen as the mascot's name. In December 2022, TNC scientists attached a satellite tag to a leatherback sea turtle that was nesting at a protected nesting beach in Isabel Province and named this sea turtle Solo, after the mascot. Throughout 2023, TNC provided information on sea turtle biology and updates on Solo's location through the Pacific Games Facebook page, which has over 25,000 followers.

Third, there is a need to improve the enforcement of existing regulations that ban the trade in sea turtle products, such as the shell of the critically endangered hawksbill sea turtle. Awareness campaigns and the enforcement of national laws could be targeted at atypical sites such as Wagina, where fishers are known to poach hawksbill sea turtles for their shells from within the nearby ACMP (Hamilton et al., 2021). At a national level, prosecuting individuals who stockpile and export hawksbill sea turtle scutes would reduce the domestic demand for this product, and greater efforts could also be made to limit the export of hawksbill jewellery. An obvious place to start would be curbing the sale of hawksbill sea turtle shell earrings and bangles from gift shops in the international departure lounge at Honiara airport (Hamilton et al., 2015).

Finally, provincial governments could consider managing important foraging sites such as Edwards Bank. Protecting Edwards Bank would require the Isabel Provincial government to work with stakeholders to have this area declared as a managed area, potentially with a ban on sea turtle harvest or the enforcement of quotas for feasts. As most of the sea turtles captured from Edwards Bank are landed in the provincial headquarters of Buala, it would be feasible to have the provincial fisheries officers that are stationed at Buala trained to enforce management measures specific to Edwards Bank.

In conclusion, this study demonstrates how sea turtles remain an important, and for the large part, legal component of the SSFs in Solomon Islands. As is the case in many tropical nations, the drivers of sea turtle consumption and sale would appear to include poverty, the limited enforcement of existing regulations, and the cultural significance of eating sea turtles (Humber et al., 2011). Sea turtles will remain an important component of the SSFs in the Solomon Islands and many other countries for the foreseeable future (Kinch, 2020; Ingram et al., 2022), but current harvest rates appear to be unsustainable and sea turtle stocks in the Solomon Islands would benefit from improved management. The management recommendations from this study were first shared with government stakeholders in 2019 (Vuto et al., 2019), and have now been integrated into the Solomon Islands National Plan of Action for Marine Turtles 2023–2027 (MECDM & MFMR, 2023).

AUTHOR CONTRIBUTIONS

Richard Hamilton: Conceptualization; funding acquisition; methodology; oversight and leadership; project administration; supervision; writing—original draft. **Simon Vuto**: Data curation; investigation; project administration; supervision; writing—review and editing. **Christopher Brown**: Formal analysis; methodology; software; validation; writing—original draft. **Peter Waldie**: Data curation; formal analysis; writing—review and editing. **John Pita**: Investigation; writing—review and editing. **Rose Babaua**: Project administration; writing—review and editing. **Rosalie Masu**: Project administration; writing—review and editing. **Nate Peterson**: Data curation; visualization; writing—review and editing. **Christine Madden Hof**: Methodology; writing—review and editing. **Col Limpus**: Methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The raw data, scripts, and code required to reproduce the results and figures in this article are available on the publicly accessible GitHub Repository: https://github.com/cbrown5/turtle-fishing-solomons.

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