The effects of sea turtle and other marine megafauna consumption in northeastern Madagascar

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ABSTRACT
Sea turtles are essential to the health of marine ecosystems, yet nearly 90% are threatened with extinction. The unsustainable consumption of sea turtles contributes to their global decline. Because sea turtle meat is also high in heavy metals, the monitoring of sea turtle consumption is a priority for both marine conservation and public health. Despite this, sea turtle consumption was understudied along Madagascar’s eastern coastline. We used structured interviews (collected over nine years) in northeastern Madagascar to study the rural consumption of sea turtles and other marine megafauna (including dolphins, whales, and dugongs). Sea turtle consumption is increasing in the southwest Indian Ocean. Over 80% of households ate a mean of 1.47 kg of sea turtle meat per year over the prior decade. The vast majority of sea turtle meat was purchased. Households which were more financially and nutritionally secure ate significantly more sea turtle meat. Sea turtle meat did not provide a significant source of nutrients to insecure households. Thus, its elimination from the diet would be unlikely to economically or nutritionally harm consumers. In fact, sea turtle meat contributed significantly to heavy metal burdens within communities and reducing consumption is a key step toward ensuring both adequate public and environmental health. Social marketing campaigns on the content and effects of heavy metals in sea turtle meat paired with increased heavy metal testing of children and pregnant women, may benefit both local communities and marine conservation.

INTRODUCTION
Sea turtles and other marine megafauna, have long captivated biologists and the public alike (Godley et al. 2020). They are essential to the functioning of the world’s vast ecosystems, acting as key marine predators, nutrient suppliers, parasitic hosts, and habitat landscapers, possibly even helping to engineer the ecosystems themselves (Bjorndal and Jackson 2002; Bjorndal and Bolten 2003; Verissimo et al. 2012). Yet, the world’s sea turtle populations are declining: 85.7% of sea turtles are threatened with extinction (Crouse et al. 2002; Seminoff 2004; IUCN 2020). Our species familiarity with sea turtles is, in part, because they are more accessible than many other species of marine megafauna. They predictably nest on sandy beaches, allowing for people and other predators to easily harvest their eggs (National Research Council 1990). At sea, they are easily caught and are often appreciated for their taste in addition to their ecosystem roles (Mack et al. 1982; Spotila 2004). The continued unsustainable consumption of sea turtles has led to decreasing populations of threatened turtles, and the subsequent degradation in ecological integrity in the marine environments they once inhabited (Verissimo et al. 2012).

Eating sea turtles affects more than marine ecosystems, it also has complex effects on human health and nutrition (Roos et al. 2003). Malnutrition is one of the largest drivers of global disease, contributing to nearly half of global child mortality annually (Black et al. 2013). Deficiencies in key animal-sourced micronutrients including vitamin A and zinc, can result in both cognitive and physical growth delays, as well as an increased risk of infection, and early death (Ezzati et al. 2002; Black et al. 2013). Marine resources are an essential part of coastal food security and nutrition (Alva et al. 2016). Sea turtle meat may add essential micro- and macro-nutrients to coastal diets (Olmedo and Farnés 2004; Hoffman and Cawthorn 2012; USDA 2019). Sea turtle meat has similar protein content to many species of marine fish. However, it is often higher in micro-nutrients which are both key for proper physiological functioning and often limited in rural diets, including iron, zinc, calcium, and vitamin A (USDA 2019).

Eating the meat of sea turtles can, however, lead to many adverse health effects (Aguirre et al. 2006). Sea turtle meat is high in heavy metals such as cadmium, mercury, and lead, which cause developmental delays, neurotoxicity, and reduce cardiovascular and...
immune system function (Aguirre et al. 2006; Diez et al. 2008; Morais et al. 2012). Zoonotic diseases can also spill over from marine species; several potential and actual zoonotic bacterial and parasitic pathogens have been identified in sea turtle meat, including Salmonella, Mycobacterium, Vibrio, Escherichia coli, Chlamydophila, Leptospira, Entamoeba, Cryptosporidium, and Spirochidae (Aguirre et al. 1994a; Kinne 1985, 1994b, 1998, 2006; Mader 1996; Gordon et al. 1998; O’Grady and Krause 1999; Cordero-Tapia 2005). In addition, the condition ‘chelonintoxicism’ is used to classify people of all ages who fall ill from eating sea turtles; symptoms include gastrointestinal and neurological issues, renal failure, and flu like symptoms which can lead to death (Fussy et al. 2007; Rasamimanana et al. 2017). Despite these clear health concerns, food safety controls are often lacking because the vast majority of sea turtle meat is eaten illegally.

The Indian Ocean is a priority for sea turtle and marine megafauna conservation; its subtropical and tropical latitudes support high levels of biodiversity, including coral reef ecosystems (Bovin et al. 2013). The Indian Ocean contains 30% of the world’s coral reefs and the world’s largest estuaries (Wafar et al. 2011). The western Indian Ocean is particularly important for global sea turtle conservation (Bullock et al. 2021). The southwest Indian Ocean (SWIO) holds a significant proportion of the genetic diversity of the global sea turtle population including unique haplotypes to the region as well as those from the Atlantic, East Indian, and Pacific Oceans (Wallace et al. 2011; Jensen et al. 2020). Within the Indian Ocean, the nation of Madagascar is well known for its forest biodiversity; however, the protection of its biodiverse marine environment has been comparatively slow (Harris 2011).

Madagascar is home to five species of sea turtle (Hughes 1974; Bourjou 2015). The capture of sea turtles has been regulated in Madagascar since the early 1920s when laws first restricted the capture of nesting green and hawksbill turtles, or turtles with a plastron diameter less than 50 cm (Decree of 23 May 1923). Sixty-years later, the nation banned the harvest of all marine turtles (Decree 1988–243), and today marine turtles are further protected from exploitation by national regulations which prohibit the hunting and trade of any threatened marine species (Decree 2005–018). In spite of these regulations, rapid assessments revealed that the consumption of sea turtles was common along the western coasts of Madagascar a decade ago (Rakotonirina and Cooke 1994; Metcalf et al. 2007; Whitty et al. 2010; Humber et al. 2015). The northern regions of Madagascar are a significant source of juvenile sea turtles within the southwest Indian Ocean (Jensen et al. 2020). Two of the only foraging patches of seagrass for sea turtles in northeastern Madagascar border the Masoala Peninsula (Doukakis et al. 2008; Dalleau et al. 2019). Despite its conservation priority, there have been no long-term studies of sea turtle or marine megafauna consumption in this region.

To quantify the rates of consumption, and to understand whether and how they affect marine conservation and human nutrition and health in rural communities, we collected six years of data over nine years on the consumption of marine megafauna on the Masoala Peninsula. The region is home to humpback whales, (Megaptera novaeangliae; Least Concerned; Cooke 2018), dugongs (Dugong dugon; Vulnerable; Marsh and Sobtzick 2019), sub-Antarctic fur seals (Arctocephalus tropicalis; Least Concerned; Hofmeyr 2015), and all three species of eaten marine turtle: the hawksbill sea turtle (Eretmochelys imbricata; Critically Endangered; Mortimer & Donnelly 2008), the green sea turtle (Chelonia mydas; Endangered; Seminoff 2004), and the olive ridley sea turtle (Lepidochelys olivacea; Vulnerable; Abreu-Grobois & Plotkin 2008). Such data is key to ensuring the long-term survival of threatened marine species and the safety of the human communities that depend on this important marine eco-region.

**Methods**

**Study site**

This study took place over nine years (2012–2020), including six years of data collection (2012, 2015, 2017–2020) in collaboration with eight coastal communities on the Masoala Peninsula of northeast Madagascar. The peninsula contains the largest national park in Madagascar, including three marine protected areas. Masoala National Park occupies most of the peninsula’s interior, its coast is lined with small communities of 50–2,000 households (mean of 4.44 individuals per household). Because there are few roads in the region, travel between these communities is primarily completed by foot, motorcycle (on the eastern coast), or boat (on the western bay). The livelihoods of these coastal residents depend on agriculture and the harvest of both marine and terrestrial resources.

**Measurements of sea turtle consumption**

We interviewed either the male or female head of, and the individual responsible for food preparation in, 863 households in eight communities semi-annually, and asked households about the consumption of eight different species of marine megafauna,
including three species of sea turtle, one sirenian, and four pinnipeds and cetaceans. Of the eight species, four are threatened with extinction: Chelonia mydas, Eretmochelys imbricata, Lepidochelys olivacea, and Dugong dugon (Table 1). All interviews were completed in the local dialect of Betsimisaraka Malagasy and lasted between one and two hours. In small communities we surveyed all households. In communities with more than 50 households, we randomly selected study households by using a grid system in each village, assigned a number to each household in each grid, and selected a subset of households in all quadrants using a zigzag survey method. Because diet and income can vary seasonally (Borgerson et al. 2016; Golden et al. 2019), all surveys included annual recalls, which while prone to underestimation, provided more accurate estimates than by extrapolating monthly recalls, because of the high seasonality and saliency of rare events (Golden et al. 2014).

When purchased, some households could not identify the species of sea turtle they ate. To estimate the total number of species eaten, we applied the proportion of known sea turtle species consumption across all six years to these unknown turtles. This likely underestimates the true number of commonly eaten species (green and hawksbill) and overestimates the rarely eaten species (olive ridley) because of the effect of saliency on sea turtle recall.

To determine if data collection included a robust enough percentage of coastal households to extrapolate the total number of these species eaten across the entire peninsula, we used 1 km² gridded high-resolution satellite images of roofs from WorldPop (Lloyd 2016; Lloyd et al. 2017) to calculate population size within 2 km of the shore, and calibrated this data using both the mean number of roofs and people per household (4.44) within the Masoala region (Borgerson et al. 2019).

Measurements of human wellbeing

To determine if income affected the consumption of marine megafauna, we used annual recalls of all 29 cash generating activities present within the communities. All prices were reported in Malagasy Ariary (MGA) and were converted to the United States Dollar (USD) using the rate at the time of data collection.

We determined food security using a Coping Strategies Index (CSI) (“Cordero” and “Crouse”: CARE 2008) to measure changes in feelings, perceptions, and behaviors during the prior week in response to insufficient access to food (coping strategies). Temporal variance in data collection may not accurately depict malnutrition in relevance to the season in which sea turtles are eaten (austral summer). We weighted CSI values based on the qualitative perception of the severity of each coping strategy in each community (categorically ranked on a scale of 1–4). A CSI score of 0 reflects a household which perceives itself as food secure and higher CSI scores reflect greater perceived food insecurity. We defined a food insecure household as any household that could not access adequate food to feed their family one or more days during the prior week. We also recorded the age, gender, height, weight, and hemoglobin level (using photometry) of all available household members (a mean of 1,750 individuals aged two weeks to 91 years old, per year) and used WHO guidelines to determine whether individuals were stunted, underweight, wasted, anemic, and/or had severely low BMIs (Body Mass Indices) or mid-upper-arm circumferences (MUAC) (WHO 2003, 2011).

To determine the role of sea turtle meat in the diet, meat consumption overall, and to examine the effects of sea turtle consumption on adequate nutrition and over-exposure to heavy metals, we also calculated total dietary nutrient intake and individual malnutrition using 24-hour recall surveys. We asked households to recall the amount of 160 items of food eaten during the prior day. All foods were reported in culturally appropriate units, and each unit was weighed ten times for each food type, to estimate the grams of each food item served. The nutritional content of each food was determined using data from the Food and Agriculture Organization of the United Nations (FAO, 2003, 2012) and GENuS (Smith et al. 2016). We converted all household members into their adult-male-equivalent (AME) score using FAO guidelines (FAO 2004; Weisell and Dop 2012), and divided the total amount consumed by that household’s total AME.

The nutritional and heavy metal content of sea turtle meat was calculated using data from the United States Department of Agriculture (USDA 2019) and Ross et al. (2017). To determine whether these nutrients and heavy metals met or exceeded recommended daily allowances, (RDA) we used cutoffs from the Joint FAO/WHO Expert Committee on Food Additives (JECFA 2013). FAO/WHO/EFSAS/USEPA max levels included: 0.1 μ g/kg per week for organic mercury, 8.0 μ g/kg for arsenic per week, and 0.3 (children 1–4) 1.2 (adults) μ g/kg per day for lead.

Ethics statement

We obtained oral informed consent and/or assent from all participants. All research was approved by Human Subjects Institutional Review Boards (Protocols #2010-0595 University of Massachusetts Amherst, #15-2230 Harvard T. H. Chan School of Public Health, and #18-19-1349 Montclair State University), the Republic of Madagascar, and Madagascar National Parks (Permits 111/13, 325/14, 111/15, 228/15, 270/15, 230/16, 105/17, 85/18, 104/19, /MEEF/SG/DGF/DCB.SAPP/SCB or MESupReS/
Results

Sea turtle consumption

Sea turtle consumption was both common and high on the peninsula. In 2020 alone, 88.4% of households reported eating sea turtle meat during the prior year (Table 1). Over the prior decade, households each ate an average of 1.47 ± SD0.99 kg of sea turtle meat, or 0.35 ± SD0.27 kg of green sea turtle meat, 0.09 ± SD0.05 kg of hawksbill sea turtle meat, and 0.13 ± SD0.10 kg of olive ridley sea turtle meat (Table 1). Currently, green sea turtles (Chelonia mydas) are the most eaten sea turtle species (57.3%) during most recent prior year), hawksbill (Eretmochelys imbricata) are the second most (24.7%), and olive ridley (Lepidochelys olivacea) are the least (17.8%). While sea turtle consumption levels fluctuated annually, they are increasing overall on the peninsula, with current rates (3.42 kg per household per year) over ten times higher than that of a decade ago (Table 1). In contrast to sea turtle meat, none of our households reported eating the meat of seals or whales, and the overall consumption of pinnipeds and sirenians was extremely low (Table 1). Approximately 24,372 households live within two kilometers of the coast on the Masoala Peninsula. Because we interviewed 3.54% of these coastal households, we chose to not extrapolate consumption regionally.

The vast majority of sea turtle meat was purchased in local communities, and not caught by the family who ate it (Table 2). A kilogram of sea turtle meat cost 3,000 MGA ($0.79 USD). Sea turtle hunters were primarily men who caught turtles using spears and/or spearguns while snorkeling (Table 3). Less than 2% of sea turtles caught across all years were caught in nets. Sea turtles were actively targeted September until February, when seas were at their calmest and warmest. Bycatch was uncommon.

The interactions between human wellbeing and sea turtle consumption

Mean annual household income was 6,488,559 MGA ($1,987 USD) with a median of 4,800,250 MGA ($1,470 USD). Income primarily relied on salary and sales (35.9% of all income earned regionally) and was supplemented by cash crops and forest products. Fishing provided 32.9% of regional total cash income (Supplementary Materials, Table SM1). Overall, most people derived some of their income from the sale of goods and services (74.4% of

SG/DGRP/PBZT/DIR). Further, we designed the study collaboratively with communities and we shared all results with participant communities during town forums before publication.
households) and 11.8% of households earned some annual cash income from fishing (SM1). The cost of sea turtle meat per kilogram was comparable to other marine fish, and less expensive than that of livestock (Table 4).

Those who ate sea turtle meat were significantly wealthier than those who did not (T = 2.85 (772.24), p > 0.0045, 1,771,731 ± 3,391,084 MGA vs. 1,073,673 ± 3,492,022 MGA annual income). Households that ate sea turtle meat also had significantly more members who were predictably salaried than those who did not (T = 7.14 (690.06), p < 0.0001, 0.99 ± 1.01 vs. 0.52 ± 0.83 salaried household members). While households that earned a greater percentage of their income from the ocean were less likely to purchase aquatic meat overall (R²(1) = 0.002, χ² = 7.85, p = 0.005), they were more likely to eat sea turtle meat (R²(1) = 0.01, χ² = 7.09, p = 0.004; T = 2.63 (701.52), p = 0.0087, 17.53 ± 30.11 vs. 12.28 ± 25.22%).

Just over half (58%) of coastal households were food insecure. On average, people were food insecure 1.8 days during the prior week. However over the study period, food insecurity has improved significantly (R²(792) = 0.09, F = 74.08, p < 0.0001). We found high levels of stunting, underweight, wasting, and a moderate to high prevalence of anemia throughout all sub-populations measured on the coastal Masoala Peninsula. There was notable variation between communities, however, 23% of all children under five were stunted, 27% were underweight, 7% were wasted, and 27% were anemic. On average, stunting, underweight, wasting, and anemia in children under five was classified as medium severity for stunting, high for children who were underweight, and medium or poor for wasting. While households were food insecure, 82.0% of household members were able to eat the minimum number of recommended calories per day. However, several micronutrients were insufficient in the diet; on average, people ate only 15.0% of the recommended daily allowance of iron.

Marine resources were an important part of the diet; of all meat eaten during the prior week, 80.9% of weight (grams), 72.4% of calories (kilocalories), and 7.3% of protein, came from fresh and/or salt-water animals. In the past 24 hours 67.2% of households reported eating some type of meat, of that 64.0% of households ate aquatic meat, while less than 8.6% ate meat from a terrestrial source. While overall meat consumption decreased slightly during the study period (R²

### Table 2. The methods used by consumers to obtain sea turtle meat in eight coastal communities on the Masoala Peninsula of Madagascar (2015–2020).

| METHOD       | 2015  | 2017  | 2018  | 2019  | 2020  |
|--------------|-------|-------|-------|-------|-------|
| Snorkel      | 12.61%| 16.98%| 5.43% | 15.02%| 27.95%|
| Net          | 0.56% | 0.00% | 0.00% | 1.41% | 0.00% |
| Bought       | 84.59%| 76.10%| 83.71%| 73.71%| 56.21%|
| Gift         | 2.24% | 6.92% | 10.86%| 9.86% | 15.84%|

### Table 3. Marine and freshwater resource collection and use by both coastal and interior towns (14) on the Masoala Peninsula of Madagascar.

| METHOD       | Adult | Female | Male | Child |
|--------------|-------|--------|------|-------|
| Snorkeling   | 3.98% | 7.14%  | 6.44%| 11.01%|
| Sifting      | 7.14% | 7.14%  | 7.14%| 7.14% |
| Fishing      | 7.14% | 7.14%  | 7.14%| 7.14% |
| Hunting      | 7.14% | 7.14%  | 7.14%| 7.14% |
| Collecting   | 7.14% | 7.14%  | 7.14%| 7.14% |

Total: Adult 7.14% Female 7.14% Male 7.14% Child 7.14%
Sea turtle meat did not improve the food security of households. In fact, because sea turtle meat was purchased, members of households that ate sea turtle meat were already far more likely to be food secure (T = −6.31 (663.35), p < 0.0001; mean of 4.49 ± 7.63 vs. 9.72 ± 15.08 Weighted CSI) and to have eaten a diet with the recommended daily amount (per AME) of calories (χ² = 8.57, N = 207(1), R² = 0.03, p = 0.0034; 73.1% vs. 51.0%), protein (χ² = 4.21, N = 207(1), R² = 0.02, p = 0.03; 61.5% vs. 54.9%), and zinc (χ² = 7.09, N = 207(1), R² = 0.03, p = 0.0055; 37.8% vs. 17.6%) than those who did not eat sea turtles. Houses which had served sea turtle meat were less likely to contain a member who was stunted, underweight, wasted, or had a low BMI (χ² = 9.30, N = 205(1), R² = 0.03, p = 0.0023), or a child under five with a low MUAC (T = −3.10 (30.87), p = 0.0041; mean of 0.38 ± 0.61 vs. 0.81 ± 0.59 children with low MUAC). During our most recent year of data collection, sea turtle meat provided each person (AME) only a mean of 908.91 milligrams of calcium, 685.54 kilocalories, 152.51 grams of protein, 10.78 milligrams of iron, and 7.02 milligrams of zinc. Despite its high nutritional value, this represents less than 1% of the annual animal-sourced kilocalories, protein, and iron in the local diet. While sea turtle meat did not provide a significant source of nutrients to insecure households, sea turtle meat did contribute significantly to the heavy metal burdens within the community, compared to other purchased meats (Table 4). Each person ate an estimated 23.10 μg g of organic mercury, 4,043.91 μg g of arsenic, and 61.62 μg g of lead during the prior year from sea turtle meat. These values well exceeded the recommended maximum allowance of 0.1 μg/kg per week for organic mercury, 8.0 μg/kg for arsenic per week, and 0.3 μg/kg (children 1–4) or 1.2 μg/kg (adults) per day for lead (USEPA 2007; EFSA 2009; JECFA 2011c). If we conservatively assume that only the minimum purchasable amount of sea turtle was consumed that day (1 kilogram) by a mean of 4.44 household members, then at least once per year each person ate 225.23 grams of sea turtle meat or 6.76 μg g of organic mercury, 1,182.43 μg g of arsenic, and 18.02 μg g of lead during a 24-hour period.

### Discussion

Sea turtles are commonly eaten on the northeastern coast of Madagascar; most households (88.4%) reported eating sea turtle meat during the prior year. Endangered green sea turtles are the most commonly eaten marine turtle in northeastern Madagascar, followed by Critically Endangered hawksbill sea turtles. While these species are also targeted in western Madagascar, our relative rates of consumption of hawksbill and olive ridley sea turtles are significantly higher than those previously reported elsewhere in Madagascar (Humber et al. 2011). In contrast to the high levels of sea turtle consumption, people rarely ate other marine megafauna, including dugongs, dolphins, and whales.

While sea turtle consumption had declined in southwestern Madagascar (Walker and Roberts 2005), rates of sea turtle consumption are currently increasing across the northeast. Households, on average, ate one- and one-half kilos of sea turtle meat per year over the prior decade. Yet, current rates of consumption exceed three- and one-half kilos per household per year, more than ten times the amount eaten a decade ago. This increase may reflect improving population sizes in the southwestern Indian Ocean. However, the current population size of many species of sea turtle in the region is unknown. Turtles in the northeast were caught for their meat and purchased by financially secure households to increase the diversity and quality of diet. Thus, an increase in consumption may also reflect increasing income and the ability to purchase meat that is unmet by current meat supply; as sea turtle meat consumption increased, other meat consumption declined.

Sea turtles were primarily targeted on the Masoala during the austral summer, due to the calmer and warmer seas which free divers preferred. While the sea turtle hunting season reported in southwestern Madagascar (Humber et al. 2011), is similar to that in the northeast, sea conditions in the southwest are roughest during this time. This consistent seasonal increase in sea turtle catch during the austral summer thus may also be due in part to an increase in the availability, or accessibility, of turtles during seasonal nesting activity when they are closer to shore (Metcalf et al. 2007). Therefore, efforts targeting sea turtle
conservation during the austral summer may be most effective, regardless of region.

In contrast to the consistency in seasonal increases in sea turtle hunting across Madagascar, we note key differences in the reasons and methods used for catching sea turtles within the nation. While sea turtle carapace was sold and used for ornamental products in other regions of Madagascar (Rakotonirina and Cooke 1994; Humber et al. 2011; Rakotonirina 2011), all shells were discarded on the Masoala Peninsula. Further, while 73% of turtles in southwestern Madagascar were caught in nets (Humber et al. 2011), turtles were very rarely caught in nets in the northeast and were instead targeted by free divers. Thus, conservation efforts which target improving the livelihoods of free divers and addressing consumer incentives for meat during the austral summer may be more effective in the northeast, whereas efforts which target net fishers, reducing incidental catch, and addressing both food and ornamental trade may be more effective in the southwest.

Sea turtle consumption on the Masoala Peninsula was not driven by food security, nor did it affect nutrition. This contrasts with the consumption of forest mammals in the region, which were rarely purchased and driven by high food insecurity and malnutrition (Borgerson et al. 2016, 2019; Golden et al. 2019). Whereas terrestrial conservation efforts must ensure that they do not further drive food insecurity and malnutrition, reducing sea turtle consumption may improve human health and welfare. Wealthy, food secure households purchased sea turtle meat as a luxury good. Thus, efforts to increase food security with sustainable meat may not work to reduce consumption unless they also address consumers’ needs for sustainable luxury meats.

Sea turtle meat can be high in heavy metals such as lead, arsenic, mercury, and cadmium (Ross et al. 2017). Madagascar has a high per capita mercury footprint compared to other nations (UNEP 2011), and heavy metal concentrations of lead and cadmium are high in coastal sediments in Madagascar (Hervé et al. 2010). Therefore, herbivorous grazers like green sea turtles may be consuming higher amounts of heavy metals which are then consumed by our communities, posing serious risks to human health. On the west coast of Madagascar, even small fish can have lead, arsenic, and mercury levels which exceed WHO/FAO maximum recommended values for human consumption (Kojadinovic et al. 2007; Rasoazanany et al. 2018). The heavy metal content of sea turtles has not been directly measured in Madagascar, and values may in fact be higher than those estimated here. When eaten in quantities such as those seen on the Masoala, heavy metals can cause neurological and cardiovascular damage, and increase the risk of lung cancer and developmental delays (Smith et al. 2006; JECFA, 2011a, 2011b; Sagiv et al. 2012). Public health advisory efforts that increase knowledge on the content and effects of heavy metals in sea turtle meat may be a mutually beneficial implementation for both community safety and marine conservation.

Eating sea turtle meat on the Masoala likely poses significant risks to both sea turtle conservation and the health of local people. Yet, knowing a meat causes health issues, does not alone prevent its consumption (Friant et al. 2015). Frequent heavy metal testing of children under five and pregnant women in rural coastal communities may increase public awareness of heavy metal burdens in the region. Because those who eat sea turtle meat are wealthier and more food secure, they have the capital and desire to change their diets to reduce heavy metal exposure. Such integrated public health and conservation efforts may be mutually beneficial for both sea turtles and the rural coastal communities of northeastern Madagascar.

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Author contributions

CB and BJRR collected the data and designed the study. ER and CB completed data analysis, interpreted the data, and wrote this manuscript. All authors approved the final manuscript.

Disclosure statement

The authors declare that there are no known conflicts of interest.

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