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Assessing Injury Rates in Northern Map Turtles (*Graptemys geographica*) From Motorboats Using iNaturalist Canada

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Abstract.—**Many freshwater turtles live in waterways where motorboats are common. Propeller strikes from boats can injure or kill turtles. Injury rates can be high in some areas, but few studies have examined the threat across a broad area. We made use of community science data from iNaturalist Canada to assess carapace injuries in Northern Map Turtles (*Graptemys geographica*) across the Canadian range of the species. The injury rate varied from 2.1–7.0% across regions, and overall, 4.0% of Northern Map Turtles had injuries consistent with propeller strikes. Injured turtles occurred across the Canadian range of the species and the median distance from an uninjured turtle to an injured one was only 5.3 km (range, 0–114.8 km). Injured Northern Map Turtles were observed within eight of 16 protected areas with observations of the species. Females were more apt to be injured than males and injuries were significantly more frequent on the posterior half of the carapace than the anterior half, suggesting either that turtles are less likely to survive a propeller strike on the anterior portion of the carapace because of potential head trauma, or that turtles diving to avoid a boat are struck on the posterior half of the carapace. Our results suggest that boat strikes are a widespread threat to Northern Map Turtles and that community science is an effective tool for assessing injury rates in turtles that commonly bask.**

Key Words.—anthropogenic threats; community science; *Graptemys geographica*; motorboats; propeller strikes

Introduction

Turtles are one of the most endangered groups of vertebrates in the world (Lovich et al. 2018; Stanford et al. 2020). Many populations are declining as a result of various threats including habitat loss and degradation (Gibbons et al. 2000; Klemens 2000; Paterson et al. 2021), overexploitation for food and the commercial pet trade (Thorbjarnarson et al. 2000; Luiselli et al. 2016), and road mortality (Gibbs and Shriver 2002; Steen and Gibbs 2004; Howell and Seigel 2019). Many turtles are long-lived with associated co-evolved traits such as multiple reproductive events over many years, high rates of egg mortality, and high rates of adult survival (Congdon et al. 1993, 1994). Even small increases in adult mortality rates can lead to population declines (Congdon et al. 1994; Cunnington and Brooks 1996; Heppell 1998) and turtle populations are slow to recover after declines (Keevil et al. 2018; Mullin et al. 2020).

In addition to the threats noted above, another source of mortality for species of freshwater turtles that frequent navigable waterbodies is propeller strikes from motorboats when individuals come to the surface of the water to breathe or when basking while floating at the surface (Bulté et al. 2010). Injuries consistent with propeller strikes have been observed in species from all four freshwater turtle families found in North America (Galois and Ouellet 2007; Bennett and Litzgus 2014; Hollender et al. 2018; Smith et al. 2018). It is estimated that there are more than six million motorboats in Canada (National Marine Manufacturers Association Canada 2021), so turtles occupying larger waterbodies such as lakes and some rivers may commonly interact with boats. Propeller-related injury rates in turtles are likely increasing over time with increases in boat traffic (Burger and Garber 1995; Cecala et al. 2009; Heinrich et al. 2012; Hollender et al. 2018), as supported by a decline in boat strikes during a major recession, which was likely associated with reduced boat use (Smith et al. 2018). While injured turtles have been frequently reported, evidence of mortality from propeller strikes is more limited as turtles killed by boats are rarely found. An adult female Spiny Softshell (*Apalone spinifera*) was found dead with deep lacerations from a propeller strike on a shoreline in Québec, Canada (Galois and Ouellet 2007). An adult female Suwannee Cooter (*Pseudemys concinna suwanniensis*) was found dead with multiple cuts from a propeller strike in Florida, USA (Heinrich et al. 2012). Almost half (46%) of River Cooter (*Pseudemys concinna*) and 25% of Eastern Musk Turtle (*Sternotherus odoratus*) deaths of determined cause were a result of boat propeller strikes in Florida (Bancroft et al. 1983). Those turtles that do survive boat strikes may have lower survivorship (Cecala et al. 2009). A population of Painted Turtles (*Chrysemys picta*) with high rates of propeller injury has declined over the past three decades at a lake in Indiana, USA (Smith et al. 2006, 2018), suggesting that boat strikes are at least partially responsible for the decline. If only 10% of boat strikes lead to a fatality, then a population faces a high risk of extinction (Bulté et al. 2010).

Injury rates from propeller strikes vary greatly among species at a given site and across sites. Only 4.4% of Snapping Turtles (*Chelydra serpentina*) but 18.4% of Painted Turtles had injuries consistent with propeller strikes at a lake in Indiana (Smith et al. 2018). For Northern Map Turtles (*Graptemys geographica*), the propeller injury rate was 3.8% and 8.3% at two sites in Ontario, Canada (Bulté et al. 2010), 10.7% at a lake in Indiana (Smith et al. 2018), and 20% at a location in Ontario (Bennett and Litzgus 2014). Most previous studies on the effects of boat strikes on Northern Map Turtles have been limited to one or a few study sites (Bulté et al. 2010; Bennett and Litzgus 2014; Hollender et al. 2018; Smith et al. 2018) because of the logistical difficulties of sampling many sites. While it is clear that Northern Map Turtles in many areas are injured by boats, it remains unclear how widespread this threat is and whether it is limited to only certain areas with high numbers of motorboats. To examine the geographic pattern of boat injuries in Northern Map Turtles, we made use of public observations collected throughout the Canadian range of the species on iNaturalist Canada (https://inaturalist.ca), a community science platform for reporting all native and exotic species.

We focused on the Canadian range of the Northern Map Turtle for a number of reasons. The Northern Map Turtle is listed as a species at risk in Canada, designated Special Concern, by the Government of Canada (https://species-registry.canada.ca/index-en.html#/species/712-76). An examination of the magnitude of boat injuries in Northern Map Turtles and the geographic scope of such injuries will be valuable for future re-assessment of the status of the species in Canada. The species is also at its northern limit in Canada and has different demographic and life-history characteristics than more southerly populations. For example, the shorter growing season results in sexual maturity being reached at an older age than in more southern populations (Vogt et al. 2018) and hence individuals must avoid the threat of propeller injuries for longer before being able to breed. In addition, while the boating season is likely shorter in Canada than more southerly locations, the intensity may be higher because of this shorter season.

Community science (also called citizen science), which involves scientists partnering with members of the public, has been used to make meaningful contributions to ecology. Platforms such as eBird (https://ebird.org/) and iNaturalist (https://www.inaturalist.org/) collate millions of observations on thousands of species from around the world. Observations from iNaturalist have been used to answer questions regarding patterns in urban biodiversity (Callaghan et al. 2020), plant phenology (Li et al. 2021), responses of species to wildfires (Rowley et al. 2020; Kirchhoff et al. 2021), the distribution of exotic species (Werenkraut et al. 2020; Martel et al. 2022; Mo and Mo 2022), and even responses of wildlife to human behavioral changes during the COVID-19 pandemic (Vardi et al. 2021). In addition to examining geographic or temporal patterns in species, photographs attached to community science observations have been used to analyze variation in wing phenotypes in damselflies (Drury et al. 2019), color variation in birds and plants (Laitly et al. 2021), color and pattern variation in subspecies of snakes (Fritz and Ihlow 2022), predation risk and parasitism across an urban gradient (Putman et al. 2021), hunting behavior in rattlesnakes (Urquidi and Putman 2021), and estimate the number of Blanding's Turtles (*Emydoidea blandingii*) in a population (Cross et al. 2021).

iNaturalist Canada has become the largest community science platform in Canada for reporting native and exotic species, with more than ten million observations of more than 35,000 species by more than 170,000 observers as of 1 May 2023. (https://inaturalist.ca/observations). There are more than 60,000 observations of turtles on iNaturalist Canada, making this a large database with many research possibilities. The Northern Map Turtle is the fourth most commonly reported turtle on iNaturalist Canada, with only the Painted Turtle, Snapping Turtle, and the Blanding's Turtle having more observations. We examined Northern Map Turtle observations on iNaturalist Canada with the following goals: (1) to determine the injury rate in Northern Map Turtles across the Canadian range; (2) to compare the spatial distribution of injured and non-injured turtles to determine whether boat injuries were geographically widespread or clustered in a few areas; (3) to examine regional variation in injury rates; (4) to determine if the injury rate in the largest lakes and rivers was greater than in other water bodies; (5) to determine the occurrence rate of injured Northern Map Turtles in protected areas; (6) to examine whether there was any pattern to the location of the injuries on the carapace of the turtles (e.g., left vs right side, or anterior vs posterior half of the carapace); and (7) determine if there was a sex bias to the injury data.

Materials and Methods

We examined the digital photographs associated with 1,953 observations of Northern Map Turtles in Canada, collected by 886 observers on iNaturalist Canada.

The observations were made from December 1979 to October 2021. From these observations, we identified 1,526 turtles from July 1987 to October 2021 where the carapace could be clearly examined. We included observations where all or only half of the carapace was visible. We excluded observations when the photograph was blurry, less than half of the carapace was visible, the carapace was largely covered with algae, or the turtle was clearly a juvenile. We also excluded obvious juvenile turtles as these individuals are less likely to be prone to boat strikes (Bulté et al. 2010). For observations in which multiple Northern Map Turtles could be seen in a single photograph, we included all turtles that were clearly visible.

We followed the methodology of previous researchers in determining what injuries should be considered the result of a propeller strike, by considering turtles with "long, deep cuts on the carapace, small, V-shaped cuts in the marginals, and large V-shaped cuts out of the shell to be the likely result of boat propeller strikes" (Bennett and Litzgus 2014). We excluded minor nicks to marginal scutes, shallow scratches along the carapace, and any other ambiguous injuries or abnormalities to produce a conservative estimate of propeller injury rate. The two senior authors reviewed all observations with potential injuries from a propeller strike and we only included these observations in the final dataset if both agreed the injury was likely from a propeller strike. In a few cases, we found multiple observations of a turtle with a similar injury in the same geographic location. We considered these as duplicate records, and we only included the earliest observation. Removal of these observations and observations from the USA from iNaturalist Canada users reduced the final dataset to 1,513 observations of Northern Map Turtles.

iNaturalist Canada obscures the actual locations of all Northern Map Turtle observations on their website by placing a random point in a grid cell 0.2 × 0.2 degrees (roughly 20 × 20 km, depending upon the latitude of the observation). We obtained the actual locations of the obscured Northern Map Turtle observations from iNaturalist Canada and used those locations for all analyses, but for mapping purposes we shifted all points 5–10 km in various directions and the map lacks high resolution of geographic features to maintain the data confidentiality of locations required by iNaturalist Canada. We compared the spatial distribution of injured and uninjured turtles using the Distance Matrix tool in QGIS 3.4 (https://qgis.org/). We first calculated the maximum distance between any two points within each dataset (injured and uninjured turtles), which we defined as the range length. We then calculated the distance from each uninjured turtle to the nearest injured turtle. These results are slightly inaccurate, as two injured turtle observations were marked private by users in iNaturalist and hence had a spatial accuracy of approximately 20 km. Given the spatial extent of the uninjured turtles was greater than 850 km, we consider that this measurement error is minor.

We determined various regions by using natural gaps in the distribution of the Northern Map Turtle observations across its Canadian range, and then we calculated the percentage of injured turtles for each region. To compare the injury rate in large lakes (> 100,000 m^2) and the two major river systems (the St. Lawrence River and the Ottawa River) versus smaller waterbodies, we used the Ontario Hydro Network waterbody shapefile, available through Ontario GeoHub (https://geohub.lio.gov.on.ca/) and we visually determined from air photographic interpretation for Québec due to very few observations. We buffered lakes and the two major rivers by 200 m to determine the number of observations of injured and uninjured turtles in or near each lake. We considered all remaining observations to be in smaller lakes or rivers.

Protected areas included provincial and national parks as well as provincial nature reserves and national wildlife areas. We excluded city parks, conservation areas, and other small public spaces as these were not always included in GIS data layers. A protected area had to have at least one observation of a Northern Map Turtle within its boundary for us to count it as occupied, but for abundance measurements, we included observations from within 5 km of the protected area. Northern Map Turtles can move more than 12 km (Flaherty 1982), but we selected a 5-km buffer around protected areas as a more conservative measure of turtles likely to make use of the protected area.

For comparing injury locations on the carapace, we excluded observations where injuries were on both the left and right side (e.g., the middle of the rear margin of the carapace) or when injuries were on both the anterior and posterior half of the turtle (e.g., the middle of one side of the carapace). We included all injured turtles in spatial and regional analyses. We used Chi-square tests to compare the injury rate on the left vs right side of the carapace, the anterior and posterior half of the carapace, and the number of observations of turtles with all or half of the carapace visible. The injury rate on major lakes and rivers was compared with other waterbodies using a Chi-square 2 × 2 Contingency Table test. We considered results significant for either test if $P \leq 0.05$.

We used the relative size of individuals in photographs to determine the sex of injured Northern Map Turtles. We could not determine the sex of a few turtles with any confidence (unknown sex), and a number of individuals were likely, but not conclusively, females (probable females). Given that the data were biased towards females, to be conservative in our assessment, we assumed all turtles of unknown sex were males and excluded all probable females from the Chi-square analysis.

Table 1. Distribution of injured (n = 60) and uninjured (n = 1,453) Northern Map Turtles (*Graptemys geographica*) by region based on data obtained from iNaturalist Canada.

Region	Major waterway	Number injured	Number uninjured	Percentage injured
Southwest Ontario	Lake Erie	21	279	7.0
Toronto area	Lake Ontario	4	147	2.6
Georgian Bay area	Georgian Bay	10	173	5.5
Kingston area	Lake Ontario/St. Lawrence River	17	490	3.4
Ottawa area	Ottawa River	7	326	2.1
Montreal area	St. Lawrence River	1	38	2.6
Total		60	1,453	4.0

Results

We found that the injury rate in Northern Map Turtles varied from 2.1% in the Ottawa area to 7.0% in southwestern Ontario/Lake Erie area (Table 1). Overall, 4.0% (60 of 1,513 observations) of Northern Map Turtles had injuries consistent with propeller strikes (Fig. 1). The injury rate was 3.1% (26 of 833 observations) on major lakes and the two major rivers and 5.0% (34 of 646 observations) on smaller lakes and rivers, and this difference was significant ($\chi^2 = 3.94$, df = 1, $P = 0.047$).

The proportion of injured turtles with only half (n = 33) or all (n = 27) of the carapace visible in the observation photograph did not differ significantly ($\chi^2 = 0.60$, df = 1, $P = 0.439$). The proportion of uninjured turtles with only half the carapace showing (n = 1,284) was significantly greater than those with all of the carapace showing (n = 169; $\chi^2 = 855.6$, df = 1, $P < 0.001$). Observations of both injured and uninjured Northern Map Turtles were biased towards the recent past, with a median observation year of 2020 and only 10 injured turtles that were observed before 2018.

Both injured and uninjured Northern Map Turtles occurred across the Canadian range of the species from southwestern Ontario to southwestern Québec (Fig. 2). The range length of all injured turtles (813.9 km) was only slightly less than the range length of all uninjured turtles (867.7 km). The median distance from an uninjured turtle to an injured turtle was only 5.3 km (range, 0–114.8 km) and 80.5% of uninjured turtles

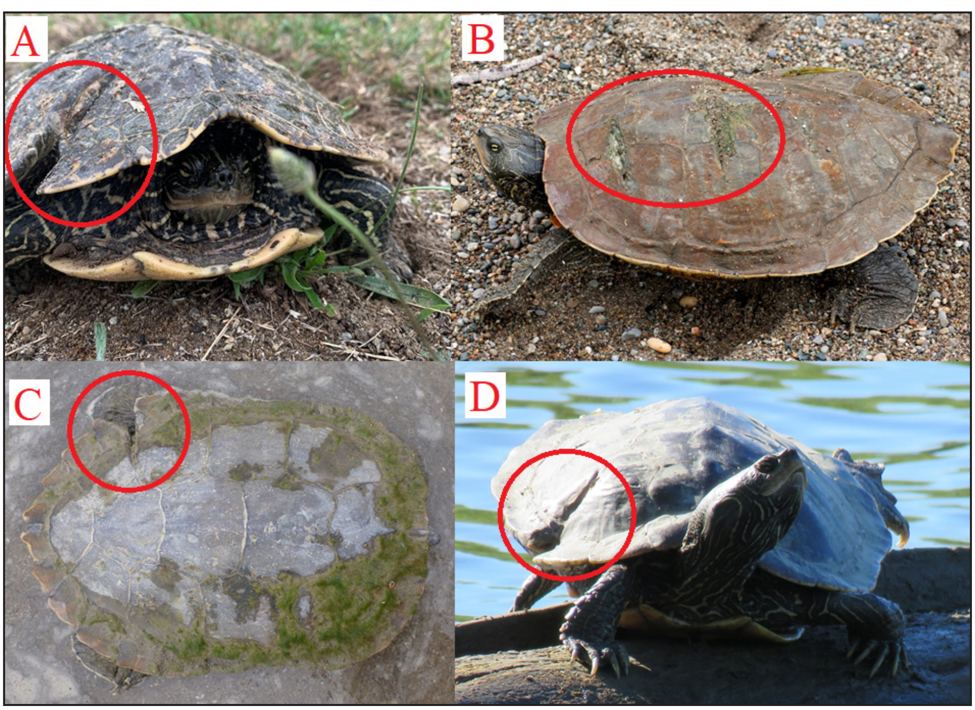

Figure 1. Examples from iNaturalist Canada of Northern Map Turtles (*Graptemys geographica*) with injuries consistent with propeller strikes. (Photographed by Peter Stranberg, A; Josh Vandermeulen, B; Pauline Catling, C; and Mike Leveille, D).

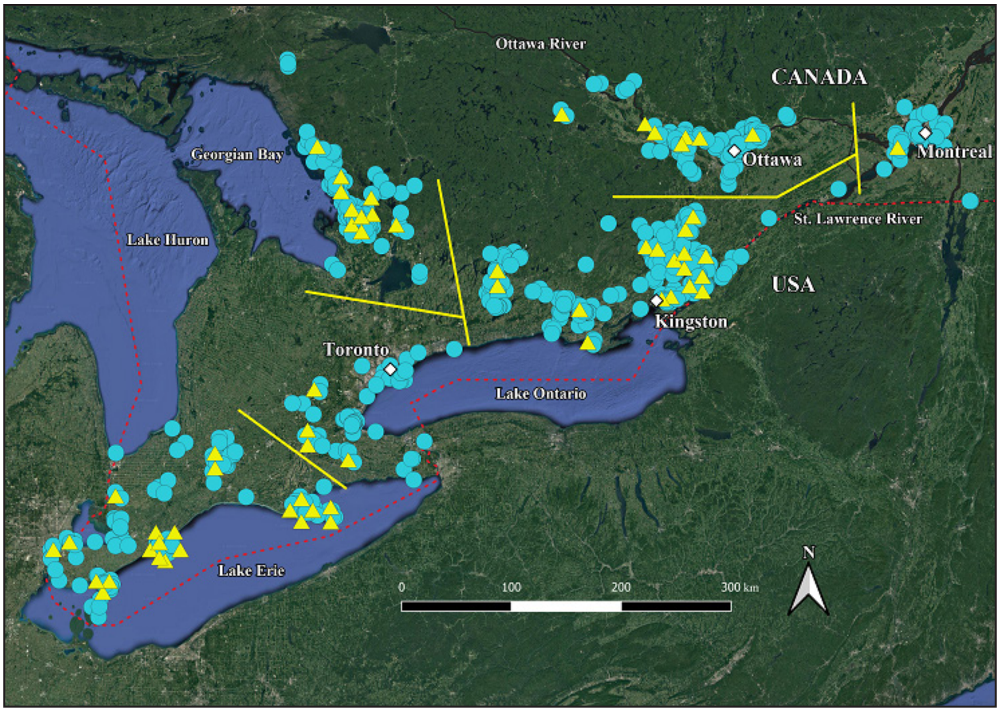

Figure 2. Distribution of injured and uninjured Northern Map Turtles (*Graptemys geographica*) observations in Canada from iNaturalist Canada. Blue circles indicate uninjured turtles and yellow triangles indicate injured turtles. All points were shifted 5–10 km in various directions to maintain the level of data confidentiality required by iNaturalist Canada. The six regions as defined in Table 1 are demarcated by yellow lines.

were within 20 km of an injured turtle. Nine of the 10 uninjured turtles farthest from injured turtles were in the Greater Toronto Area.

Injured Northern Map Turtles were observed within eight of 16 (50%) protected areas with observations of the species. Four of the protected areas only had one observation of a Northern Map Turtle. Injury rates were notably high in two protected areas: 14% (seven of 52 turtles) in Rondeau Provincial Park and 14% (six of 45 turtles) in the combined Long Point Provincial Park and Long Point National Wildlife Area. Both of these areas are along the Lake Erie shoreline in the region with the highest injury rate (Table 1).

Northern Map Turtles had significantly more injuries on the posterior half of the carapace (n = 32) than the anterior half (n = 16; χ^2 = 5.33, df = 1, P = 0.021). There was no significant difference in the proportion of injuries on the left (n = 24) and right sides (n = 24) of the carapace (χ^2 = 0.00, df = 1, P = 1.00). The proportion of injured females (n = 32) was significantly greater than the proportion of injured males and turtles of unknown sex (n = 7; χ^2 = 16.03, df = 1, P < 0.001).

Discussion

There can be various biases and limitations to data obtained from community science projects. Data biases include an over-representation of large-bodied and common species, with more cryptic or hard to find species being under-represented (Seburn and Mallon 2017; Callaghan et al. 2021). Such biases are of limited concern in our study, as the Northern Map Turtle is one of the largest species of freshwater turtles in Canada and commonly basks communally (Ernst and Lovich 2009), making it conspicuous to iNaturalist observers. Data on iNaturalist are biased towards the recent past, as the number of users and observations has been growing exponentially over the past decade (Di Cecco et al. 2021). This was also true for the Northern Map Turtle data where the majority of observations of both injured and uninjured turtles were from 2020 and 2021. A bias towards more recent data is advantageous when assessing the current effects of a threat on a particular species; however, turtles observed in the recent past may have been injured several years earlier. iNaturalist data are also biased towards more developed areas (Di Cecco et al. 2021), likely because more people live in urban areas. Such a bias can mean that Northern Map Turtle observations are biased towards areas with more people and possibly more motorboats. While this bias may exist, Northern Map Turtle data were widely dispersed across the known Canadian range of the species, although this area also corresponds with one of the most populated areas of the country. Although the data may be biased towards more developed areas, Northern Map Turtles are associated with large waterbodies, which have high development pressure and high amounts of recreational boating. Misidentification of species can be an issue with iNaturalist data (Barbato et al. 2021) but this problem is usually more of an issue for smaller and harder to identify species. There are only eight species of native freshwater turtles in Canada and there are no other native species of *Graptemys*. We examined all photographs to confirm the species of turtle was a Northern Map Turtle. In one instance, an observation was of a False Map Turtle (*Graptemys pseudogeographica*), an exotic species in Canada, and we excluded it from the data. Overall, our results support the idea that iNaturalist data and the associated photographs recorded opportunistically, without the direction of a scientist or coordinator, can be a powerful tool for examining injury trends across a broad geographic area and we encourage other researchers to make use of these valuable resources. The number of observers, observations, and species identifiers in iNaturalist provides a vast dataset for use across a wide breadth of wildlife research questions.

Most studies of boat-induced injuries in freshwater turtles have focused on one or a few study sites (Bulté et al. 2010; Bennett and Litzgus 2014; Hollender et al. 2018; Smith et al. 2018); however, museum specimens were used to examine the injury rate across Florida in the Suwannee Cooter (Heinrich et al. 2012). Our estimate of 4.0% of the observations having injuries consistent with a propeller strike is likely a major underestimate of the actual injury rate for several reasons. First, over 85% of uninjured turtles only had photographs of half of the carapace. As a result, injuries on the other half of the carapace would remain out of sight and not counted. Most of these turtles were observed basking out of the water and only one side of the carapace was visible. In addition, it is likely that we counted some uninjured turtles multiple times as several areas have prominent basking sites where multiple turtles will routinely bask and are easily photographed. This counting of individual Northern Map Turtles multiple times would decrease the apparent injury rate. We did not attempt to identify unique uninjured turtles; however, an injured turtle could more easily be matched based on the injury location(s). As an example, we had five observations of the same injured turtle in one public area. We also used a conservative assessment technique for identifying turtles with propeller injuries, which also reduced the apparent injury rate. In addition, most of our observations came from 2020 and 2021, which corresponds to the peak of the COVID-19 pandemic. Stay-at-home restrictions could have reduced boating activity and hence reduced the number of boat strikes in those years. Lastly, we could not include turtles that were hit and killed by boat strikes because we did not find any dead turtles with injuries in the iNaturalist observations. Other researchers have noted that turtles killed by propeller strikes are rarely found (Bulté et al. 2010; Bennett and Litzgus 2014).

Our injury rate of 4.0% is substantially less than the 8–20% reported in Northern Map Turtles at some sites (Bulté et al. 2010; Bennett and Litzgus 2014; Smith et al. 2018) but similar to the 3.8% found in one large lake in eastern Ontario (Bulté et al. 2010). Other researchers have found that injury rates may be positively correlated with boat traffic and boat speed (Bulté et al. 2010; Hollender et al. 2018). The spatial extent of injured and uninjured turtles was quite similar, suggesting that boat injuries are widespread across the Canadian range of the Northern Map Turtle. This finding suggests that boat strikes are a threat across the range, not just in localized areas, although the injury rate likely varies across sites. One area with fewer injured turtles than expected is the Greater Toronto Area, the largest urban center in Canada. The lack of injured turtles in the western end of Lake Ontario is particularly surprising given the presence of busy marinas, although there were few observations of any Northern Map Turtles along the lakeshore.

We found that the injury rate on large lakes and rivers was slightly less than the injury rate on smaller waterbodies, although this difference may not be meaningful. Injury rates on the St. Lawrence River were also higher than in a nearby large lake, but this was based on a sample of only one river and lake, with the river having abundant boater traffic (Bulté et al. 2010). The Canadian Coast Guard estimates that approximately 65% of the recreational motorboats in Ontario are operated on the Great Lakes and the St. Lawrence River (Great Lakes Commission 2000), so injury rates may be higher on these waterbodies, although there may also be more Northern Map Turtles on these larger waterbodies. Our observed injury rates in various regions or types of waterbodies may reflect actual differences in injury rates in the turtles or be influenced by various observer biases in the data and any comparisons should be made with caution.

The presence of injured Northern Map Turtles in almost half of the protected areas where the species has been observed is suggestive that turtles are at risk of propeller strikes even in these areas. Given that Northern Map Turtles can have a home range length > 12 km (Flaherty 1982), it is also possible that observed injuries may have been sustained outside protected areas. Other studies have also found turtles with injuries consistent with propeller strikes in protected areas (Bulté et al. 2010; Heinrich et al. 2012). We found that most injured turtles had injuries to the posterior half of the carapace, which is similar to results in multiple species of freshwater turtles at sites in Oklahoma, USA

(Hollender et al. 2018). More injuries to the posterior half of the carapace in living turtles could be because turtles are less likely to survive injuries to the anterior portion of the carapace, as such strikes could include head trauma. It is also possible that more injuries to the posterior half of the carapace are suggestive of turtles being hit as they dive to avoid an oncoming boat. Diamond-backed Terrapins (*Malaclemys terrapin*) did not change behavior when exposed to the sounds of motorboats (Lester et al. 2013), suggesting turtles may not engage in avoidance behavior until boats are nearby, increasing the risk of being hit. Turtles basking on mats of floating macrophytes may also be at greater risk of being hit by a motorboat as diving behavior is slowed by the vegetation (Bulté et al. 2010).

Female Northern Map Turtles were substantially more likely to have injuries than males, consistent with other research (Bulté et al. 2010, Bennett and Litzgus 2014) and likely due to the larger size of females and possibly because they may bask more at the surface of the water to help develop their eggs. Females may also make more use of open-water habitat of boat channels (Bulté et al. 2010). Also, it is possible that large females are more apt to survive a boat strike than smaller males.

It is likely that boat injuries are increasing over time (e.g., Smith et al. 2006), given that the number of motorboats is increasing (Bulté et al. 2010). We could not examine any temporal trend to the injury data, as most of our data are skewed toward the recent past. All injured turtles were observed after 2005 and only 10 injured turtles were observed before 2018.

A number of mitigation measures could be implemented that would reduce the incidence of propeller injuries to Northern Map Turtles. Increasing the number of motorboat-free areas where Northern Map Turtles congregate could reduce the injury rate in these populations. Lower injury rates in Suwannee Cooters in Florida were found in a state park where there was limited motorboat activity as compared to other areas of the state (Heinrich et al. 2012). To be truly effective, motorboat-free areas should be larger than the home ranges of Northern Map Turtles. Where complete closures to motorboats are not possible, we concur with Heinrich et al. (2012) that restricting boats to electric motors would also likely reduce the number of injuries. Another approach would be to reduce the speed limit of motorboats in areas with populations of Northern Map Turtles. Green Sea Turtles (*Chelonia mydas*) were much more likely to avoid slow-moving boats (4 km/h) than fast-moving boats (19 km/h; Hazel et al. 2007). Spectacled Caimans (*Caiman crocodilus*) had no propeller injuries in a waterway with enforced speed reductions, while on unregulated waterways, 37% of caimans had injuries consistent with propeller strikes (Grant and Lewis 2010).

Speed reductions may decrease injuries in Northern Map Turtles; however, they may not eliminate all propeller injuries. Diamond-backed Terrapins only dived approximately 30 cm when a motorboat approached (Harrison 2010) and this depth may not be enough to avoid being hit by a propeller. A solution that could reduce propeller injuries is the installation of propeller guards, which are widely recommended to reduce both human and wildlife related propeller injuries (Van Waerebeek et al. 2007; Heinrich et al. 2012; Olson et al. 2021; Ehrhardt et al. 2022). To date, there have been limited tests on the effectiveness of propeller guards in reducing injuries to turtles. In tests with artificial Loggerhead Sea Turtles (*Caretta caretta*), propeller guards reduced slicing wounds but there was more blunt force damage (Work et al. 2010). Whether propeller guards would reduce injuries in live freshwater turtles, which are much smaller than sea turtles, is unknown. Jet outboard motors could also potentially reduce injury rates compared with outboard motors with propellers. Tests on artificial Loggerhead Sea Turtles resulted in no major injuries at low or high speeds from boats with jet outboard motors (Work et al. 2010).

Population modeling suggests that if only 10% of boat strikes lead to a fatality, then a population of Northern Map Turtles faces a high risk of being extirpated (Bulté et al. 2010). Given the risk to population persistence and the widespread nature of boat strikes, actions to reduce injury rates are urgently required. Additional research on boat-related mortality rates and the effectiveness of propeller guards in reducing injuries to freshwater turtles is needed. Motorboat-free zones, boat speed restrictions, propeller guards, or the use of jet outboard motors should all be considered in areas where Northern Map Turtles are known to congregate.

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