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Impact of recreational power boating on two populations of northern map turtles (Graptemys geographica)

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ABSTRACT

1. Recreational power boating is growing in popularity in North America. This activity is known to have lethal and sub-lethal effects on aquatic wildlife and freshwater turtles may be particularly sensitive to this activity.
2. This study reports on patterns of traumatic injuries inflicted by powerboat propellers to northern map turtles (*Graptemys geographica*) from two sites differing in boat traffic intensity in Ontario, Canada.
3. The relative vulnerability of turtles was assessed, in light of seasonal patterns in boat traffic, as a function of sex- and age-specific movement patterns, habitat use, and basking behaviour obtained by radio-telemetry. Population viability analyses (PVA) were also conducted to evaluate the potential demographic consequences of mortality induced by powerboats.
4. The prevalence of propeller injuries was two to nine times higher in adult females than in adult males and juvenile females. Patterns of movement, habitat use, and aquatic basking indicated that adult females are more exposed to collisions with boats. PVA showed that boat-induced mortality in adult females could lead to rapid population extinction if the risk of mortality when hit by a boat is greater than 10%.
5. The results of this study showed that recreational power boating is a serious threat to northern map turtles, even under moderate boat traffic. The need to adopt measures restricting boat traffic in areas important to turtles is discussed.

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KEY WORDS: powerboat; propeller; traumatic injury; northern map turtle; population viability analysis; Ontario

INTRODUCTION

Recreational boating is a highly valued and popular activity in Canada and the USA. Many freshwater ecosystems are thus used extensively for recreational boating. In Canada, there are approximately 2.5 million recreational boats (Government of Canada, 1999) while there are over 12 million registered powerboats in the USA (National Marine Manufacturers Association: NMMA, 2008). Powerboats, which include outboards, inboards, and personal watercraft, are the most common type. In Canada and the USA, power boating is increasing at compound average annual rates of 2.6% (NMMA Canada, 2006) and 8% (NMMA, 2004), respectively. This growing use of motorized watercraft is likely to compromise the physical, chemical, and biological integrity of aquatic ecosystems (Mosisch and Arthington, 1998).

Indirect impacts of power boating on aquatic wildlife include disturbance during reproductive activities (Moore and Seigel, 2006), interference with intraspecific sound communication (Vasconcelos *et al.*, 2007), physiological disturbances such as increased cardiac output (Graham and Cooke, 2008), and altered auditory sensitivity (Scholik and Yan, 2002). Direct impacts have also been documented such as mutilations or mortality resulting from collisions with boat propellers (Killgore *et al.*, 2001; Gutreuter *et al.*, 2003). Most studies examining the direct effects of boating on animals have focused on marine mammals (Nowacek *et al.*, 2004; Laist and Shaw, 2006), birds (Mikola *et al.*, 1994; Burger, 1998; Knapton *et al.*, 2000), and fish (Scholick and Yan, 2002; Popper *et al.*, 2004; Graham and Cooke, 2008). Very few studies have examined the impact of power boating on freshwater turtles, even though many are species at risk. Studies assessing the vulnerability of freshwater turtles to such direct effects are essential for establishing regulatory guidelines that will minimize the negative impacts of boating activities.

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Eastern and central North America possesses an important diversity of freshwater turtles (Ernst *et al.*, 1994), but many species are declining (Gibbons *et al.*, 2000). Causes of population decline include road mortality of females during nesting migrations (Gibbs and Shriver, 2002), habitat destruction or alteration (Moore and Seigel, 2006), and bycatch in commercial fisheries (Dorcas *et al.*, 2007). The life histories of turtles are characterized by high adult survivorship and long reproductive lifespans that compensate for the low survivorship of early life stages (Congdon *et al.*, 1993, 1994). Slight increases in adult mortality can consequently lead to important population declines (Congdon *et al.*, 1993, 1994; Gibbs and Shriver, 2002). Identifying sources of adult mortality is therefore essential to establish guidelines for turtle conservation and recovery. Freshwater turtles may be especially susceptible to collision with powerboats because they regularly come to the surface to breathe and often bask while floating at the surface of the water. Nevertheless, little information is available regarding the vulnerability of turtles to this threat as well as its potential demographic consequences. Studies on spiny softshell turtles (*Apalone spinifera*) and diamondback terrapins (*Malaclemys terrapin*) have reported a high prevalence of traumatic injuries caused by boat propellers (Roosenburg, 1991; Galois and Ouellet, 2007) and boating activities were suggested to cause population declines in painted turtles (*Chrysemys picta*; Smith *et al.*, 2006).

This study reports on sex- and age-specific patterns of traumatic injuries inflicted by powerboat propellers in two populations of northern map turtles (*Graptemys geographica*) from Ontario, Canada. As many other species of turtles in North America (e.g. *Apalone* sp., *Graptemys* sp., *Malaclemys terrapin*, *Pseudemys* sp.), northern map turtles inhabit large water bodies. They occur in large lakes and rivers of eastern and central North America: from Arkansas to Minnesota and from Mississippi to Ontario and southern Québec. In Canada, the Northern map turtle is federally listed as a species of special concern (Roche, 2002) and the Canadian range is restricted to south-western Québec and south-eastern Ontario. Recreational power boating requires large water bodies, thus leading to potential negative effects on turtles. The Canadian distribution of most freshwater turtles, including the northern map turtle, corresponds to the most populated area of Canada. Thus, at least throughout their Canadian range, northern map turtles are exposed heavily to powerboats. To assess the relative vulnerability of northern map turtles as a function of age and sex at each site, patterns of propeller injuries were interpreted in light of seasonal patterns of boat traffic as well as detailed data on sex- and age-specific movement patterns, habitat use, and basking behaviour obtained by radio-telemetry in each population (Carrière, 2007; Bulté *et al.*, 2008a; Carrière *et al.*, in press).

Quantifying the mortality rate, and thus the demographic impact of boat-induced mortality, is very challenging because turtles killed by boats are rarely recovered. To gain insight into the potential impact of mortality caused by powerboats, a population viability analysis (PVA) was conducted. Life history and demographic information from the study populations (Carrière, 2007; Bulté *et al.*, 2008b; Bulté and Blouin-Demers, 2009) were used to simulate how the probability of population extinction varies as a function of the probability of death when hit by a propeller.

METHODS

Study sites and quantification of propeller injuries

Northern map turtles were studied in the St. Lawrence River and in Lake Opinicon in Ontario, Canada (Figure 1). The St. Lawrence River study site was located within

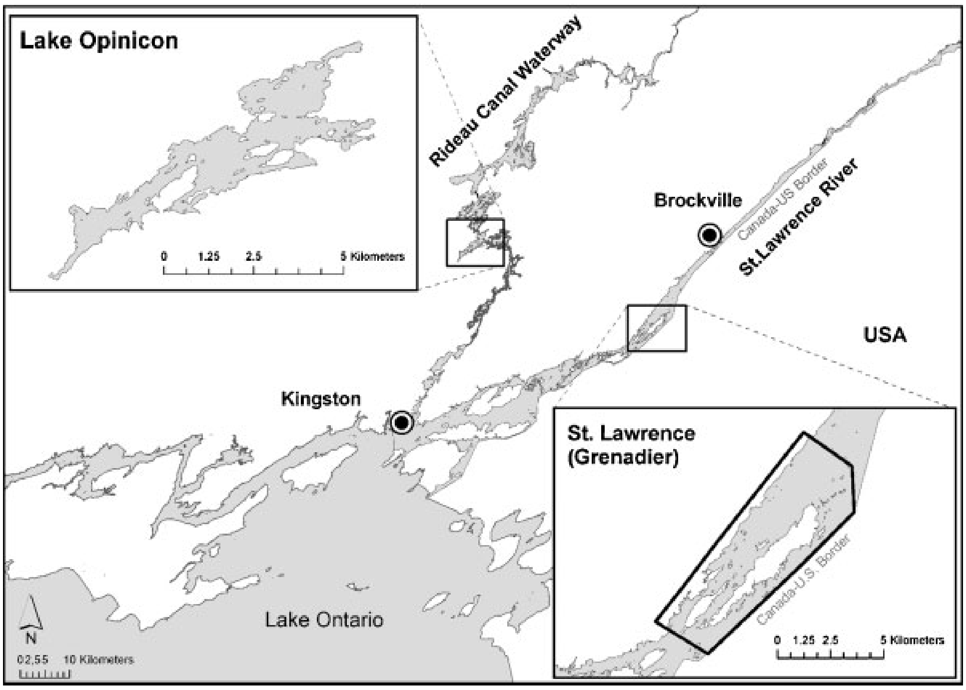

Figure 1. Study sites of northern map turtles in eastern Ontario, Canada.

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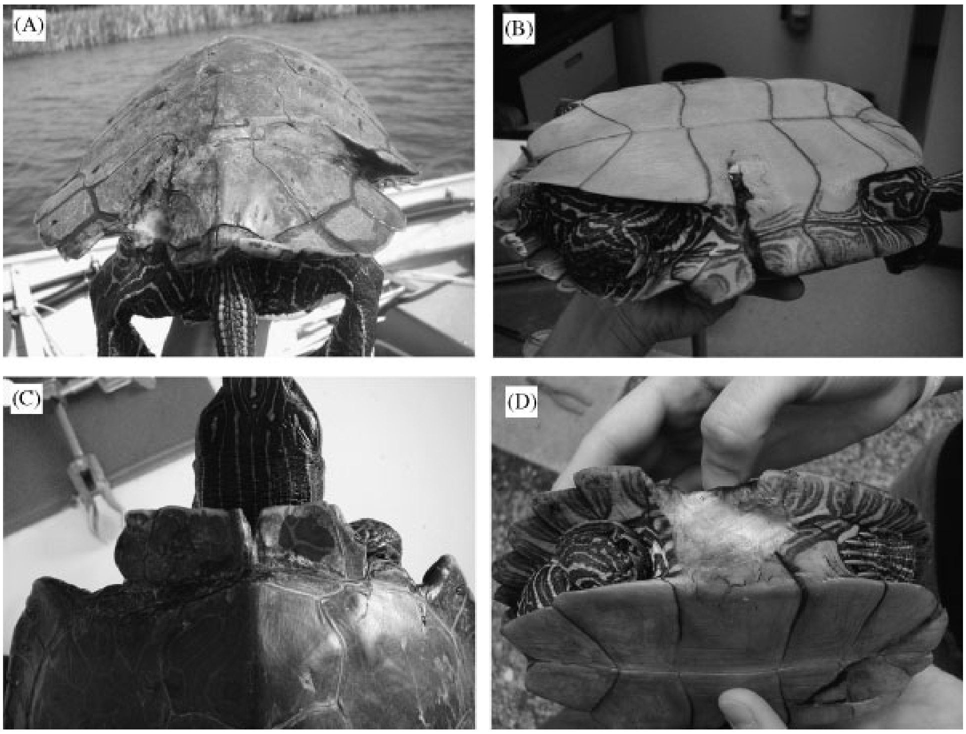

Figure 2. Examples of propeller injuries on northern map turtles from the St. Lawrence River (A&B) and Lake Opinicon (C&D), Ontario, Canada. (A) Adult female with a fresh propeller wound on the left side and a healed propeller scar on the right side. (B) Adult female with an extensive propeller wound on the abdominal scutes. (C) Mature female with a healed scar on the maginal scutes. (D) Immature female with a fresh wound on the left bridge and right intergular, gular, and pectoral scutes.

St. Lawrence Islands National Park (hereafter SLINP) in the Thousand Islands at the border of Ontario and New York State. The Thousand Islands region is one of the most important sites for recreational boating in Ontario. The Canadian Coast Guard estimates that 65% (780 000) of the recreational powerboats in Ontario are used on the Great Lakes and on the St. Lawrence River (Great Lakes Commission, 2000). The SLINP study site covers an aquatic area of 2890 ha located around Grenadier Island. Lake Opinicon is a small lake (788 ha) that is part of the Rideau Canal waterway linking the Ottawa River to Lake Ontario, 30 km to the north-west of SLINP. Although recreational boating in Lake Opinicon is not as intensive as in SLINP, the Rideau Canal is also an important area for nautical tourism in Ontario with, on average, 5003 boats using the canal per year between 2004 and 2006 (Parks Canada, unpublished data). At both sites, map turtles were captured by snorkeling and with basking traps. All turtles were marked individually by drilling small holes in their marginal scutes and were examined for traumatic injuries caused by boat propellers. Only individuals displaying unambiguous and extensive propeller-induced damage to the carapace or plastron (see Figure 2 for examples) were included in the analysis.

Spatial ecology, aquatic basking, and boat traffic

To understand better sex- and age-specific exposure to propeller injuries, findings on the prevalence of injuries were compared with patterns of habitat use, movements, and basking behaviour. In parallel studies, radio-telemetry was used to quantify movement patterns (Carrière *et al.*, in press) and habitat use (Carrière, 2007; Bulté *et al.*, 2008a) in both populations. In the current study, patterns of aquatic basking are also reported. Basking while floating at the surface of the water (aquatic basking) is a common thermoregulatory behaviour in emydid turtles. Aquatic basking may put turtles at risk of being hit by a boat. The seasonal variation in aquatic basking as well as sex- and age-specific differences in this behaviour was investigated. Observations of aquatic basking were collected from 53 radiotelemetered map turtles (17 adult females, 18 juvenile females, and 18 adult males) from Lake Opinicon between 2004 and 2006. Although turtle behaviour at the time of telemetry location was noted in SLINP, approaching floating turtles inconspicuously at this site was often difficult due to waves, boat traffic, and the geography of the river, making observing aquatic basking difficult. Seasonal patterns in movement and aquatic basking were compared with seasonal patterns in boat traffic. Data on the number of boats visiting SLINP (boat docking records) between 2000 and 2008 (Parks Canada, 2008) and on the number of boats passing through Lake Opinicon on the Rideau Canal between 2005 and 2007 (Parks Canada, unpublished data) were used as indirect measures of boat traffic.

Population viability analysis

The software Vortex 9.93 was used to explore the effects of different mortality rates on the probability of persistence of map turtles at each site. The input parameters for the simulations are summarized in Table 1. Data on clutch size were obtained from 61 females from Lake Opinicon as part of a previous study (Bulté *et al.*, 2008b). Mark–recapture was used to estimate population size at each site. For the Lake Opinicon population, more than 2000 captures over 6 years were used. For the SLINP population, 780 captures over 4 years were used. Population size at each site was estimated with the Jolly–Seber model using the software CAPTURE (Rexstad and Burham, 1991). Age at maturity and maximum reproductive age were estimated from a growth model of the Lake Opinicon population (Bulté and Blouin-Demers, 2009). Growth rates and maturation were assumed to be similar in the two populations. This assumption is realistic because the two populations are only separated by 30 km and are subject to the same climatic conditions.

Vortex requires estimates of survival rate at different ages. Six years of mark–recapture data from Lake Opinicon were used to obtain initial estimates of annual survival for juveniles (2–4 years old), adult males (>4 years old), sub-adult females (5–11 years old), and adult females (>11 years old). Mark–recapture data were fitted to the Cormack–Jolly–Seber model with the software MARK to obtain survival estimates based on model averaging. It was confirmed that the model with the most parameters among the candidate models fitted the data well with a bootstrap goodness-of-fit test of 1000 iterations and the lack of fit was corrected by adjusting the variance inflation factor (ĉ-hat) to its estimated value (Cooch and White, 1998). The survival estimates obtained from the mark–recapture study (Table 1) incorporated both natural and artificial sources of mortality, including mortality caused by boats. The annual survival estimates were adjusted to keep the population stable ($r = 0$) over 500 years with 1000 iterations (Table 2). Because of insufficient data to estimate annual survival rates for turtles between age 0 and age 1 and between age 1 and age 2, survival estimates for snapping turtles (Congdon *et al.*, 1994) were used.

The number of turtles killed every year (N_{kill}) is virtually impossible to quantify, but this number must be known to estimate the probability of population extinction (*PE*). Thus, instead of running simulations with a known value of N_{kill}, a series of simulations were run by varying N_{kill} within a biologically realistic range (two adult females per year to one adult female every 10 years). For the different levels of N_{kill}, *PE* over 500 years was estimated with 1000 iterations of the simulation. The harvest function in Vortex 9.93 was used to incorporate N_{kill} in the simulations. Taking into account population size and the prevalence of scars, N_{kill} was expressed as the probability of death when hit by a boat (P_{kill}), $P_{\text{kill}} = N_{\text{kill}}/N_{\text{hit}}$ where N_{hit} is the total number of turtles hit by boats every year and is given by $N_{\text{hit}} = N_{\text{surv}} + N_{\text{kill}}$ where N_{surv} is the annual number of turtles hit and surviving. N_{surv} was calculated as $N_{\text{surv}} = P^{*}_{\text{surv}}N$ where N is the population size and P_{surv} is the probability of surviving when hit. P_{surv} was calculated as $P_{\text{surv}} = F_{\text{scar}}/T_{\text{inj}}$ where F_{scar} is the proportion of turtles with scars in the population and T_{inj} is the age of turtles at the time of the injury. Because most turtles with scars were adults and because T_{inj} was unknown, injury was assumed to have happened in the first 22 years of life. This age was selected because it is the mid-point between birth and attainment of the asymptotic size, which is the best estimate of longevity for the population (Bulté and Blouin-Demers, 2009). Because females appeared to be more exposed to collision with boats, the simulations were conducted by varying only the number of females killed. This approach makes estimates of the probability of extinction more conservative.

Table 1. Life history parameters and population sizes for northern map turtles from the St. Lawrence River and Lake Opinicon, Ontario, Canada

Parameters	Value	Source
Mean clutch size (s.d.)	8.4 (3.3)	Bulté *et al.*, 2008b
Max clutch size	14	Bulté *et al.*, 2008b
Age at maturity (years)		Bulté and Blouin-Demers, 2009
Males	4	
Females	12	
Mortality rate		This study
2–4 years	35%	
4–11 years (females only)	26%	
Adults (males)	19%	
Adults (females)	6%	
Population size (95% C.I.)		This study
SLINP	629 (597–661)	
Lake Opinicon	1529 (1487–1662)	

RESULTS

Traumatic injuries

In total, 1317 map turtles were examined for propeller injuries. At SLINP, 8.3% (32/354) of the turtles examined exhibited unambiguous propeller scars compared with 3.8% (35/896) in Lake Opinicon. Turtles were divided into three classes according to sex and reproductive status (males, juvenile females, and adult females). Females were divided into two groups because immature females have different behaviours from adults (Carrière, 2007). A logistic regression was used to test for the effects of site and reproductive class on the probability of propeller injuries. The probability of propeller injuries differed between reproductive classes (Wald test: Wald chi-square = 24.28, df = 2, $P<0.0001$), but not between sites (Wald test: Wald chi-square = 0.43, df = 1, $P>0.51$). Overall, the prevalence of propeller injuries was much higher in adult females compared with males and juvenile females (Figure 3). Males and juvenile females did not exhibit appreciable differences in the prevalence of injuries.

Seasonal variation in boat traffic and aquatic basking

Boat traffic at each site was highly seasonal and exhibited the same trend (Figure 4). The number of boats peaked in July and August

Table 2. Annual mortality rate (%) used to simulate the probability of extinction of northern map turtle populations using Vortex 9.93

Age class	Female	Male
0 to 1	53	53
1 to 2	35	37
2 to 3	32	32
3 to 4	32	32
4 to 5	32	17
5 to 6	26	17
6 to 7	26	17
7 to 8	26	17
8 to 9	26	17
9 to 10	26	17
10 to 11	26	17
>11	5	17

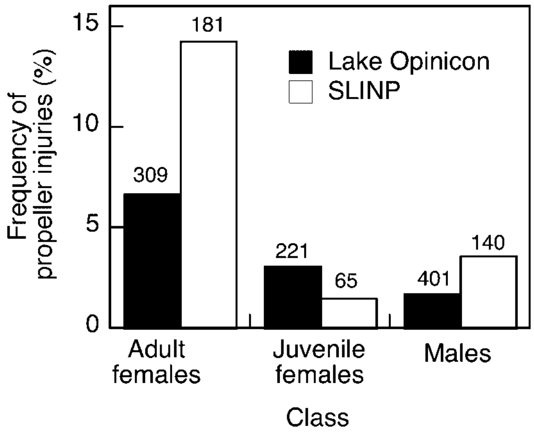

Figure 3. Frequency of propeller scars on northern map turtles in St. Lawrence Islands National Park (SLINP) and Lake Opinicon, Ontario, Canada. Numbers above the bars indicate the number of turtles examined.

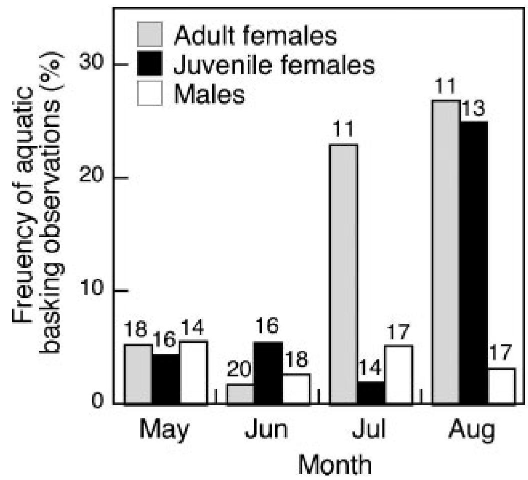

Figure 5. Frequency of aquatic basking based on 720 basking observations from 53 radio-tracked northern map turtles in Lake Opinicon, Ontario, Canada. Numbers on each column indicate sample size.

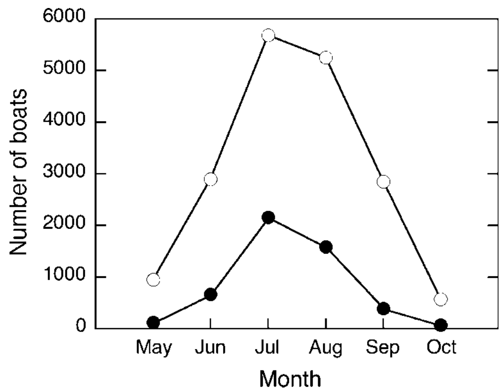

Figure 4. Monthly mean number of boats visiting St. Lawrence Islands National Park (open dots) between 2000 and 2008 and monthly mean number of boats passing through Lake Opinicon (solid dots) via the Rideau Canal, Ontario, Canada.

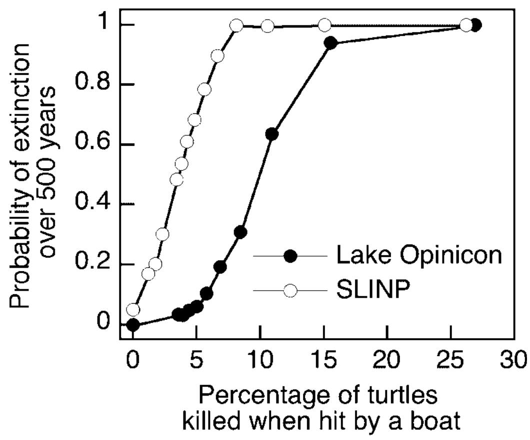

Figure 6. Probability of population extinction as a function of the proportion of females killed when hit by a boat given an annual probability of being hit of 0.75% at St. Lawrence Islands National Park (SLINP) and of 0.14% in Lake Opinicon, Ontario, Canada.

(Figure 4). A total of 3077 telemetry observations were collected on the 53 individuals tracked in Lake Opinicon between 2004 and 2006. Turtles were observed basking at the surface of the water 23% (720 observations) of the time. A logistic regression was used to test if the frequency of aquatic basking varied as a function of reproductive class (males, juvenile females, and adult females) and month (May to August). In Lake Opinicon, the frequency of aquatic basking was influenced both by reproductive class (Wald chi-square = 9.05, df = 2, $P = 0.01$) and by month (Wald chi-square = 11.6, df = 5, $P = 0.04$). The effect of season on the frequency of aquatic basking was more apparent in females than in males (Figure 5). Females basked more than males in late summer when boat traffic is most intense.

Population viability analysis

In Lake Opinicon, the annual probability of being hit by a boat and surviving was estimated to be 0.3% and 0.14% for males and females, respectively. In contrast, at SLINP this probability was 0.75% for females and 0.33% for males. Using these probabilities, it was estimated that 27 females and 9 males are hit and survive every 10 years in Lake Opinicon. In comparison, at SLINP 28 females and 8 males are hit and survive every 10 years. The PVA analyses indicated that even low mortality rates in females can lead to a high probability of extinction over 500 years, but the impact was more severe for the SLINP population (Figure 6). For instance, if the percentage of females killed when hit increases from 0 to 10%, the probability of extinction of the Lake Opinicon population increases from 0 to 63% while the probability of extinction of the SLINP population increases from 5% to 99% (Figure 6). A 10% mortality rate corresponds to one adult female being killed by a boat every 3 years.

DISCUSSION

Powerboats have the potential to injure and kill wildlife and there is growing evidence that freshwater turtles are not exempt from this threat (Roosenburg 1991; Smith *et al.*, 2006; Galois and Ouellet, 2007). This study provides further

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evidence of the seriousness of this menace for freshwater turtles.

A clear sex-specific prevalence of traumatic injuries was found. At both sites, the prevalence of injuries was much higher in females than in males. This bias is concordant with findings of previous studies of riverine turtles that are also highly sexually dimorphic in size (Roosenburg, 1991; Galois and Ouellet, 2007). Northern map turtles are extremely size dimorphic with mature females being more than twice the size of males (Bulté and Blouin-Demers, 2009). Sex- and size-specific behavioural and ecological differences are present in map turtles and these differences probably contribute to the bias in traumatic injuries.

Roosenberg (1991) suggested that adult female diamondback terrapins are unable to escape oncoming boats as fast as males and small females because of their larger body size. However, swimming speed is an unsatisfactory explanation for the bias in traumatic injuries because female northern map turtles swim faster than males (Pluto and Bellis, 1986). Alternatively, it was found that both adult and juvenile females bask more at the surface of the water than males (Figure 5). Turtles floating at the surface are likely to be at a higher risk of being hit by powerboats than turtles basking on land or sitting at the bottom. This risk may be especially high when turtles are basking in thick mats of floating macrophytes or filamentous algae, as they commonly do. In such mats, the diving ability of turtles appears to be greatly reduced because of the obstruction caused by the plants (G. Bulté, pers. observation). Moreover, the seasonal variation in the frequency of aquatic basking in females from Lake Opinicon was concordant with the seasonal variation in the intensity of boat traffic.

Many species of river turtles with pronounced sexual size dimorphism exhibit marked intersexual differences in spatial ecology (Pluto and Bellis, 1986; Jones, 1996; Bodie and Semlitsch, 2000; Lindeman, 2003; Carrière *et al.*, in press). Intersexual differences in spatial ecology are only present at the SLINP site (Carrière *et al.*, in press), but these differences may nonetheless explain, at least partly, the bias in propeller injuries.

At SLINP, adult females use habitats with more open water and further away from shore than males and immature females (Carrière, 2007). Boat traffic is higher and faster in these habitats, which would put adult females at higher risk of collision. In addition, mature females at SLINP move more frequently and greater distances than males and juvenile females in June, July, and August (Carrière *et al.*, in press). The movements of females in June and July are tied to nesting activities and females often travel long distances (up to 5 km: Carrière, 2007) to reach their nesting sites. Boat traffic is high during these months, and by travelling long distances females may be more likely to cross areas of high boat traffic and thus get hit.

In addition to the ecological and behavioural factors discussed above, an intersexual difference in mortality rate when hit by a boat may also contribute to the sexual bias in traumatic injuries. Indeed, everything else being equal, larger individuals (i.e. females) are more likely to survive a collision with a powerboat than smaller individuals (i.e. males and juvenile females) because injuries inflicted by a propeller will be relatively more severe for a small individual. Thus, if males are killed more often when they are hit, the prevalence of injuries is expected to be lower in males. There is evidence that males have slightly lower survival rates than females (Bulté and Blouin-Demers, 2009). Higher mortality rate in males could be due to collision with powerboats, but intersexual differences in longevity or predation rate may also be responsible for this bias in survival (Bulté and Blouin-Demers, 2009).

In animals with delayed maturity, the probability of population extinction is more sensitive to female than to male mortality (Row *et al.*, 2007). In map turtles, as in other river turtles (Roosenburg, 1991; Galois and Ouellet, 2007), ecological and behavioural differences between the sexes seem to put females at risk of collision with boats more than males. Although the probability of being killed when hit by a powerboat is unknown, the PVA indicated that even a low rate of mortality can compromise the persistence of both populations. For instance, a 10% risk of mortality when hit was sufficient to put both populations in jeopardy. Given the seriousness of the propeller-induced injuries, it seems quite reasonable that at least 10% of turtles hit by a powerboat would be killed as a result. In addition, even if the rate of mortality from boats is low, this mortality is added to other potential sources of mortality such as road mortality (Gibbs and Shriver, 2002), which is also biased toward females (Steen *et al.*, 2006). The PVA showed that the SLINP population was more prone to extinction than the Lake Opinicon population. At SLINP, the prevalence of propeller injuries in females was almost 8% higher than in Lake Opinicon, indicating that the SLINP females are more exposed to boats. In addition, the estimated population size at SLINP is much smaller than in Lake Opinicon (Table 1) and small populations are more prone to extinction (Melbourne and Hastings, 2008). The SLINP population, however, is more open (i.e. in a river) than the Lake Opinicon population (i.e. in a lake) and may thus be more likely to benefit from a rescue effect. Unfortunately, there is no information at present on the metapopulation structure at each site and on their connectivity.

The results of this study show that recreational boating activities have a direct impact on map turtles inhabiting water bodies with moderate and high recreational boat traffic. Circumstantial, but we feel convincing, evidence suggests that adult females are at higher risk of being hit by boats due to differences in habitat use, movement patterns, and basking behaviour. The higher vulnerability of females could lead to rapid population extinction if the risk of mortality when hit by a boat is $>10\%$, which seems plausible.

Conservation measures such as restricting speed or prohibiting powerboats in critical habitats could reduce injuries and mortality caused by boating and promote population persistence. Critical habitats especially sensitive to powerboats may include areas surrounding communal hibernation sites, nesting areas, and important basking sites. Restricting engine size or speed may also contribute to reduce collision with powerboats. Unfortunately, we are unaware of any study testing the efficacy of such conservation measures. Data on the efficacy of these measures are needed because putting restrictions on the use of pleasure craft is likely to generate resistance on the part of their users. Speed restrictions, however, are already in place in many lakes to limit shoreline erosion (i.e. 'no wake' zones). Thus, this particular conservation measure would not be novel. Adopting conservation measures will become increasingly important as the use of recreational powerboats is likely to increase in the future (NMMA Canada, 2006; NMMA, 2004). Conservation measures restricting the use of powerboats may also have beneficial impacts on other aquatic wildlife including game fish (Graham and Cooke, 2008).

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