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Frequency of Propeller Damage in a Turtle Community in a Northern Indiana, USA, Lake: a Long-term Study

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Abstract**.—Recreational boating can have significant impacts on freshwater turtle individuals and populations through a variety of mechanisms, including direct injuries due to propeller strikes. We monitored the incidence of propeller wounds in four species of freshwater turtles in Dewart Lake in northern Indiana, USA, nearly annually from 1979-2014. Overall, *Chrysemys picta* (18.4%) had the highest frequency of propeller wounds, followed by *Graptemys geographica* (10.7%), and *Trachemys scripta elegans* (5.3%), and *Chelydra serpentina* (4.4%). We found little evidence for any changes in the proportion of turtles with propeller wounds over the entire study period for any of the species we examined. However, previous analyses showed an increase in propeller wounds in *C. picta* from 1993–2003, and our new analyses show that this was followed by a strong decrease in the proportion of *C. picta* with propeller injuries between the years 2002–2010 (i.e., the years after the terrorist attacks in the U.S. in 2001 and the global recession of 2008). In conclusion, our observations suggest that the frequency of propeller injuries can vary among species, with species-specific behaviors (e.g., basking, water column use) potentially driving the differences and vary over time, perhaps with economic factors that influence recreational use of lakes.**

Key Words.—Chelydra serpentina; *Chrysemys picta*; *Graptemys geographica*; injury rates; recreational boating; *Trachemys scripta*

Introduction

It is becoming increasingly clear that freshwater turtle populations and communities are under growing pressures from human activities and associated alterations of the environment (e.g., Garber and Burger 1995; Marchand and Litvaitis 2004; Steen and Gibbs 2004; Selman et al. 2013; but see Bowen and Janzen 2008; Laverty et al. 2016). In aquatic ecosystems, one human activity known to have negative impacts on wildlife populations is recreational boating (Boyle and Samson 1985; Burgin and Hardiman 2011). In particular, freshwater turtles can be significantly impacted by recreational boating. For example, basking and other behaviors in turtles can be disrupted by approaching humans and boats (Moore and Seigel 2006; Jain-Schlaepfer et al. 2017; Pittfield and Burger 2017) and fishing can result in potentially harmful consequences, such as increased mortality due to bycatch (Midwood et al. 2015) and injury from ingested fish hooks (Steen et al. 2014; Steen and Robinson 2017; Hamer et al. 2018).

Another concern associated with recreational boating is the injuries produced by collisions between boats and turtles or damage due to propeller strikes on turtles (see Burger and Garber 1995), and mortality arising from boat collisions with freshwater turtles has been observed (Selman et al. 2013; Mitchell 2014). Bulté et al. (2010) ran population viability analyses and concluded that populations of Northern Map Turtles (*Graptemys geographica*) could be endangered if mortality rates associated with boat-related injuries were greater than 10% per year. Injured Diamondback Terrapins (*Malaclemys terrapin*) exhibited lower body condition in males, and lower survivorship if the injury was rated as severe (Cecala et al. 2009).

The proportion of turtles in a population suffering from or showing evidence of propeller wounds or boat collision-induced injuries varies considerably among species (see Table 1). There is also evidence that such injury rates are increasing for some populations of freshwater turtles (Burger and Garber 1995; Smith et al. 2006; Cecala et al. 2009; Lester et al. 2013). For some of these populations, the increase in injury rate appears to parallel increases in recreational boating activity (Smith et al. 2006; Cecala et al. 2009).

As part of a long-term study of the turtle community in Dewart Lake in northern Indiana, USA, we monitored the incidence of injuries in several species of freshwater turtles nearly annually for 35 y (1979–2014). In a previous analysis covering our observations from 1992 to 2003, we found the proportion of Painted Turtles (*Chrysemys picta*) with propeller damage increased over the study period but Northern Map Turtles and Red-eared Sliders (*Trachemys scripta elegans*) showed no increase (Smith et al. 2006). During this same period, the number of *C. picta* in the community declined as did their adult survivorship, whereas the numbers of the other turtle species stayed relatively constant (Smith

Table 1. Review of previously published frequencies of propeller- or boat-collision related wounds in freshwater turtles. The frequency of wounds for *Apalone spinefera* was reported only as boat-collision related injuries.

Species	Frequency of wounds	Citation
Apalone spinifera	8.0% in females, 0% in males; 5.5% total	Galois and Ouellet (2007)
Chrysemys picta	12–30% in a given year	Smith et al. (2006)
Graptemys geographica	3.8% and 8.3% (two populations)	Bulté et al. (2010)
G. geographica	Female: 28.6%; Male 12.8%	Bennett and Litzgus (2014)
G. geographica	0-17% in a given year	Smith et al. (2006)
G. gibbonsi	24.5%	Selman and Lindeman (2015)
Malaclemys terrapin	8-17%	Burger (1989); Seigel and Gibbons (1995); Cecala et al. (2009); Lester et al. (2013)
Pseudemys concinna suwanniensis	10% in less protected site; 4% in more protected site[1]	Heinrich et al. (2012)
Sternotherus odoratus	3.6%	Bennett and Litzgus (2014)
Trachemys scripta	0–30% in a given year	Smith et al. (2006)

et al. 2006). We attributed the increase in injury rates and the decline in *C. picta* to increased boating and recreational use of the lake including the increase in residential development and construction of seawalls (Smith et al. 2006). Here we report on the incidence of propeller wounds in the turtle community from 1979 to 2014. This analysis extends the previous analysis (Smith et al. 2006) temporally, and also expands it to include the Common Snapping Turtle (*Chelydra serpentina*).

Materials and Methods

Study area.—We studied the freshwater turtle community located at the southeast end of Station Bay (area = 4.5 ha) in the southeast part of Dewart Lake near Syracuse, Kosciosko County, Indiana, USA. Turtle populations have been studied in Dewart Lake for over 50 y (see Wade and Gifford 1965), with relatively regular study from 1979–2015 (see Iverson 1988; Smith and Iverson 2002, 2004; Smith et al. 2006, 2016). Substantial residential development of the Dewart Lake shoreline began by 1965 and reached near saturation with new construction in the late 1970s and early 1980s (JFNew and Associates, unpubl. report). The Dewart Lake shoreline is now almost completely lined with concrete seawalls. Non-resident boat access to Dewart Lake probably increased with the construction of a public access boat launch by the Indiana Department of Natural Resources in 1985, and further increased when the boat launch was paved in the early 2000s (JFNew and Associates, Walkerton, IN, unpubl. report). However, an apparent peak in boat use in the late-1990s was followed by a perceived reduction in boating on the lake extending into the very early 2010s (pers. obs.).

Sampling methods.—We surveyed the turtle community in Station Bay nearly annually (in late July to early August) since 1979 using a variety of trapping and capture methods. Prior to 1992, we used aquatic wire funnel traps (n = 5–15; see Iverson 1979 for design). Starting in 1992, we used 2.5 cm mesh fyke nets (n = 2–12) deployed with 15 m (50 ft) leads between a pair of 90 cm (3 ft) hoop diameter funnel traps. We checked traps every 2–3 h from sunrise to 1–2 h post-sunset. No turtles entered the traps during the night (Smith and Iverson 2004). We measured carapace and plastron lengths, weighed, determined sex, and individually marked turtles, which we retained and subsequently released at the end of the sampling period (2–5 d). We examined each captured individual turtle for signs of propeller wounds and recorded the nature of any such wounds. We considered a turtle to have a propeller wound if there was at least a distinct nick or slice on the carapace and/or plastron. For smaller potential injuries on the marginal scutes or edge of the plastron, we specifically looked for matching damage on the plastron or carapace, respectively, which would indicate the damage was due to a propeller strike rather than some other cause. We did not consider any damage that could possibly resemble erosion or gnawing by a mammal as a propeller wound.

Statistical methods and analyses.—We tallied the proportion of *C. serpentina*, *C. picta*, *G. geographica*, and *T. s. elegans* captured each year that showed signs of propeller damage (see Smith et al. 2006). Overall mean annual sample size for *C. serpentina* was 12.4 (range, 1–31), for *C. picta* was 94.2 (range, 13–261), for *G. geographica* was 14.3 (range, 1–46), and for *T. s. elegans* was 11.1 (range, 1–21; Table 2). Turtles are long-lived and accumulate propeller scars as they age; therefore, the proportion of turtles with propeller scars might increase over time. This is particularly true as several individuals were captured in multiple years.

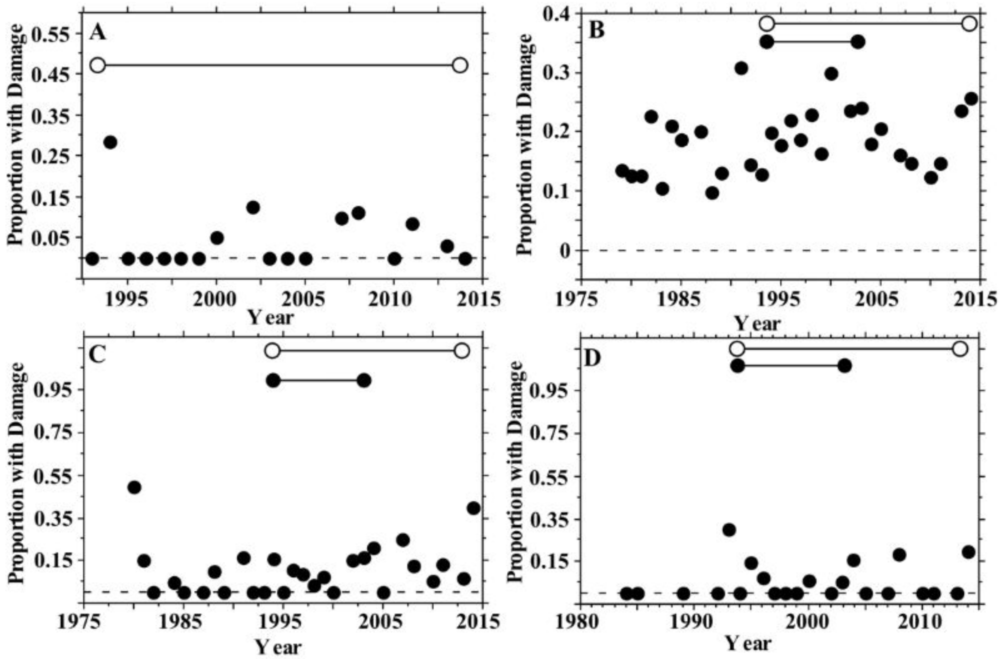

Figure 1. Proportion of captured (A) *Chelydra serpentina*, (B) *Chrysemys picta*, (C) *Graptemys geographica*, and (D) *Trachemys scripta elegans* from Dewart Lake, northern Indiana, USA, with propeller wounds from 1979–2014 (black dots). Horizontal lines connecting open circles indicate the span of fyke net years. Horizontal lines connecting closed circles indicate the span of years analyzed in Smith et al. (2006). Dashed lines indicate proportion = 0.

However, young or unmarked turtles are constantly added to the population and older or marked turtles disappear. We assume that a sample in one year is relatively independent of samples in other years because there was at least a year between each survey and there would be a chance an uninjured, marked turtle could become injured, and that marked turtles could be captured or not in any given year. However, this approach does violate, at least partially, the assumption of independence, and so our comparisons among species should be treated with caution. We do not believe the accumulation of propeller scars as turtles grow older or that repeatedly capturing turtles should bias our results or interpretations (see Smith et al. 2006).

We compared the mean proportion of turtles with propeller wounds among species using a Kruskal-Wallis test, followed by a Mann-Whitney post hoc test for all years and for Fyke net years, if applicable. We adjusted *P*-values from the multiple Mann-Whitney post hoc tests using the method outlined in Legendre and Legendre (1998). We performed the same comparisons for pre-Fyke net years only using Mann-Whitney tests because only two species were captured in those years. Because of violations of the assumption of normality, we used non-parametric correlations (Kendall τ) to assess the relationship between the proportion of each species with propeller wounds and the year of capture. We ran analyses on all years, just years in which fyke nets were used (1993–2014), just years when fyke nets were not used (1979–1992), and just years (2004–2014) after our initial analyses (Smith et al. 2006). For all tests, α was 0.05. We report means ± 1 standard error (SE). We used JMP Pro 13.0 (SAS Institute Inc., Cary, North Carolina, USA) for all statistical analyses.

Results

For all years, the four species differed in the frequency of propeller wounds (Table 3; $H = 38.57$, df = 3, $P < 0.001$), with *C. picta* having the significantly highest frequency, followed by *G. geographica*, *C. serpentina*, and *T. s. elegans*, which did not differ significantly from each other (Table 4). Results were similar when using only data from years with fyke nets only (Tables 3, 4; $H = 30.12$, df = 3, $P < 0.001$). For years before fyke nets, *C. picta* had significantly higher frequencies of propeller wounds than *G. geographica* (Table 3; $U = 4.79$, df = 1, $P = 0.029$).

Chelydra serpentina.—We found that *C. serpentina* rarely exhibited propeller wounds (Fig. 1A; Table 3). There was no significant relationship between year and proportion of *C. serpentina* with propeller wounds (n = 18 y: Kendall $\tau = 0.114$, $P = 0.544$). There also was no significant relationship between year and proportion of *C. serpentina* with propeller wounds for the years after our initial analysis (2004–2014; n = 8 y; Kendall $\tau < 0.001$, $P > 0.999$).

Table 2. Numbers of turtles of each species examined for propeller wounds during the years of our study of the turtle community from Station Bay in Dewart Lake, northern Indiana, USA. We also indicate the subsets of years used in our analyses.

Year	Pre-fyke years	Fyke net years	Post Smith et al. (2006) years	Post U.S. attack and recession years	*Chelydra serpentina*	*Chrysemys picta*	*Graptemys geographica*	*Trachemys scripta*
1979	X					67		
1980	X					104	2	
1981	X					16	13	
1982	X					31	1	
1983	X					19		
1984	X					133	22	1
1985	X					75	13	4
1986	X							
1987	X					60	17	
1988	X					61	10	
1989	X					23	16	2
1990	X							
1991	X					13	6	
1992	X					165	8	3
1993		X			4	118	7	10
1994		X			7	226	19	16
1995		X			23	261	22	21
1996		X			14	224	19	14
1997		X			7	160	46	9
1998		X			1	70	30	4
1999		X			3	86	13	12
2000		X			19	104	6	16
2001		X						
2002		X		X	8	51	13	6
2003		X		X	11	87	6	19
2004		X	X	X	5	89	24	19
2005		X	X	X	12	88	3	9
2006		X	X	X				
2007		X	X	X	10	118	24	6
2008		X	X	X	18	144	8	16
2009		X	X	X				
2010		X	X	X	9	65	18	18
2011		X	X		23	75	15	16
2012		X	X					
2013		X	X		31	55	15	13
2014		X	X		18	39	5	10

Chrysemys picta.—We found that *C. picta* exhibited high rates of propeller wounds, ranging between 10 and 30% in a year (Fig. 1B; Table 3). When all years were included, there was no significant relationship between year and proportion of all turtles with propeller wounds (n = 30 y; Kendall $\tau = 0.216$, $P = 0.094$). When considering only years before Fyke nets, there also was no relationship between year and proportion of turtles with propeller wounds (n = 11; Kendall $\tau = 0.110$, $P = 0.639$), nor when we only included Fyke net years (n = 19; Kendall $\tau = 0.111$, $P = 0.506$). When we only considered data from 2004 to 2014 (i.e., after our

Table 3. Mean proportion of four species of turtles from Dewart Lake, northern Indiana, USA, with propeller wounds for different subsets of the study period. Means are given ± 1 SE (sample size in parentheses). Means sharing the same letter for a time interval are not significantly different (see Table 4 for results of post-hoc tests).

Species	All years	Fyke net years only	Pre-fyke net years
Chelydra serpentina	0.044 ± 0.018 (18)[c]	0.044 ± 0.018 (18)[c]	—
Chrysemys picta	0.184 ± 0.010 (30)[a]	0.193 ± 0.011 (19)[a]	0.168 ± 0.01 (11)[a]
Graptemys geographica	0.107 ± 0.023 (28)[b]	0.106 ± 0.024 (20)[b]	0.107 ± 0.05 (9)[b]
Trachemys scripta	0.053 ± 0.018 (22)[c]	0.062 ± 0.021 (19)[c]	—

previous study), there was no significant relationship between year and proportion of turtles with wounds for all turtles (n = 8 y; Kendall τ = 0.143, *P* = 0.621).

Graptemys geographica.—The population of *G. geographica* had intermediate frequencies of propeller wounds, ranging between 0 and 50% in a year (Fig. 1 C; Table 3). Over the entire duration of the study, the proportion of *G. geographica* with propeller wounds did not change when all turtles were considered (n = 28 y; Kendall τ = 0.201, *P* = 0.147). During the pre-fyke net years, there was no significant relationship between year and proportion of turtles with propeller wounds (n = 9; Kendall τ = -0.183, *P* = 0.511). For fyke net years, there was a significant increase in the proportion of *G. geographica* with evidence of propeller wounds with year (n = 19 y; Kendall τ = 0.332, *P* = 0.052). When we restricted our analysis to years after our original study (i.e., 2004–2014), we found no significant relationship between the proportion of turtles showing propeller damage and year (n = 8 y; Kendall τ = 0.143, *P* = 0.621).

Trachemys scripta elegans.—Like *C. serpentina*, *T. s. elegans* (Fig. 1D) had low propeller injury rates in most years (Table 3). Captures of *T. s. elegans* during non-Fyke net years were uncommon. There was no significant relationship between the proportion of turtles with propeller wounds and year for all turtles (n = 22 y; Kendall τ = 0.111, *P* = 0.511), when only years in which Fyke nets were used (n = 19; Kendall τ = -0.028, *P* = 0.876) or for the years 2004 to 2014 (n = 8; Kendall τ = 0.089, *P* = 0.774).

Discussion

In our previous analysis, there was a clear increase in the proportion of *C. picta* with propeller wounds from 1992–2003 in Dewart Lake (Smith et al. 2006). At the same time there was no significant change in the incidence of propeller wounds in *T. s. elegans* or *G. geographica* (Smith et al. 2006). In our current, expanded analysis, we found little evidence for a long-term systematic change (i.e., 1979–2014) in the proportion of turtles with propeller wounds for any of the species we examined.

One possible explanation for the discrepancy in the trends in the frequency of propeller wounds in *C. picta* over the entire course of our study compared to the 1992–2003 analysis may be changes in boat use on Dewart Lake, perhaps associated with changes in the economy and fuel prices. As noted in Smith et al. (2006), from 1980 to the early 2000s, there was residential development and a precipitous increase in the use of personal watercraft (motor boats and waverunners; JFNew and Associates, unpubl. report). However, during the mid- to late-2000s to the early 2010s, we noticed an obvious decline in the use of power boats on the lake. This decline in the use of power boats, and in the general use of the lake, coincided with the economic downturn after the terrorist attack on the U.S. in 2001 and the global economic recession that started in 2008.

We do not have access to direct quantitative data on the recreational use of Dewart Lake; however, several studies have indicated that the recessions and economic downturns in the 2000s led to decreased visitation to national parks (Poudyal et al. 2013) and

Table 4. Results of pair-wise Mann-Whitney post-hoc comparisons with *P*-values adjusted for multiple comparisons for all years and for fyke net years only (df = 1 for all cases).

	All years		Fyke net years only	
Pairwise comparison	*W*	Adj. *P*	*W*	Adj. *P*
Chrysemys picta – Graptemys geographica	3.742	0.0008	3.150	0.0064
Chelydra serpentina – Trachemys scripta elegans	0.119	0.905	0.160	0.873
T. s. elegans – G. geographica	-2.150	0.063	-2.334	0.039
C. serpentina – G. geographica	-2.269	0.070	-2.480	0.039
T. s. elegans – C. picta	-5.024	< 0.0005	-4.039	< 0.0005
C. serpentina – C. picta	-4.871	< 0.0006	-4.606	< 0.0006

travel (Carden 2005; Ritchie et al. 2010; Latinopoulos 2014). In addition, increased gas prices in the 2000s led to decreased visitation at state (Oh and Hamitt 2011) and national parks (Poudyal et al. 2013), as well as decreased driving in the U.S. (Manville et al. 2017). Thus, it may be that the economic downturn of the first part of the 21st Century may have contributed to our observation of reduced boat traffic on Dewart Lake, which may explain the patterns of injury rates we observed after our previous study (i.e., reduced injury rates in *C. picta*). Indeed, between the years 2002–2010 (i.e., including the years post-terrorist attack and the recession), there was a negative relationship between the proportion of *C. picta* with propeller injuries and year ($n = 7$ y, Kendall $\tau = -0.81$, $P = 0.011$).

Overall, *C. picta* had the highest frequency of turtles with propeller wounds, with almost twice the rate of the next highest species, *G. geographica*. Whereas *Chelydra serpentina* and *T. scripta elegans* had the lowest frequencies of propeller wounds. The low injury rate for *C. serpentina* is consistent with its bottom-dwelling habit in relatively shallow waters (Obbard and Brooks 1981; Brown et al. 1990; Brown and Brooks 1991). *Trachemys scripta elegans* also tends to use shallower areas of lakes more than deeper waters (Lindeman 2000). Thus, these two species may be less likely to encounter power boats. In contrast, in the summer, *C. picta* often bask at the surface of the water because the water is often warm enough to support thermoregulation, and hence they do not aerially bask as much in the summer (Lefevre and Brooks 1995; Grayson and Dorcas 2004; Rowe et al. 2017). This frequency of surface-water basking also may be exacerbated by the lack of basking structures in our study area. In addition, *C. picta* generally uses open water a great deal of the time (Rowe and Dalgarn 2010). Thus, *C. picta* may be more susceptible to power boats since they can be found near the surface in open water where recreational boating occurs. Similarly, larger *G. geographica* tend to be farther from the shore and in deeper water than smaller individuals (Pluto and Bellis 1986), which might explain their elevated levels of propeller wounds compared to *T. s. elegans* and *C. serpentina*.

Another possible explanation for among-species variation in injury rates is that species can have different lifespans. Individuals in species with longer life spans have more time to accumulate injuries than species with shorter life spans. Thus, one might expect differences in injury rates due to differences in life spans. In our case, it is highly unlikely that this explains the patterns of injury rates among the species that we observed. *Chelydra serpentina* has a life span of 56–90+ y (Galbraith and Brooks 1987; Congdon et al. 1994); that of *C. picta* is 25–61 y (Gibbons 1968; Zweifel 1989; Frazer et al. 1991; Congdon et al. 2003); that of *G. geographica* is at least 20 y (Nagle and Congdon 2016); and that of *T. s. elegans* is 22–40 y (Frazer et al. 1990; Parker 1996; Tucker and Moll 1999). Given that *C. picta* had the highest injury rate and *C. serpentina* had the lowest injury rate, it appears that the estimated life spans of each species in our study would not account for differences in injury rates.

Our observations of the frequency of propeller wounds in a community of turtles in a temperate lake suggest that the frequency of wounds can vary over time, perhaps with economic or other factors that influence recreational use of lakes, and the frequency of propeller wounds varies among species, with species-specific behaviors (e.g., microhabitat preference, basking frequency, water column use) likely driving the differences. We only observed injury rates. Presumably, these injury rates serve as an index of the potential relative mortality rates of each species due to turtle-boat interactions (i.e., the higher the injury rate, the higher the mortality rate). This assumes that all species have similar mortality rates from propeller injuries. We have no reason to believe that there are likely to be differences among species, especially the three emydids (*C. picta*, *G. geographica*, and *T. s. elegans*) in their ability to survive the same severity of injury (i.e., a mortal wound is likely a mortal wound regardless of the species).

Given that all species of turtles in our study showed at least a 4% injury rate, our observations suggest that boats could be a substantial source of mortality in this turtle community (see Smith et al. 2006 for circumstantial evidence for increased mortality in *C. picta* with increased incidence of propeller wounds). Indeed, modeling studies show that even small increases in adult mortality rates in freshwater turtle populations can have significant impacts on population viability. For example, Bulté et al. (2010) ran population viability analyses and concluded that populations of *G. geographica* could become endangered if mortality rates associated with boat-related injuries were greater than 10%. In addition, increases in adult mortality rates due to anthropogenic causes, even relatively small increases on the order of 2%, can have a significant effect on the population growth rates of freshwater turtles (e.g., Crawford et al. 2014; Spencer et al. 2017).

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lines established by the American Society of Ichthyologists and Herpetologists.

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