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A resurvey of a Wood Turtle (*Glyptemys insculpta*) population in northern New Hampshire, USA, after 13 years

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Abstract
Populations of Wood Turtle (*Glyptemys insculpta*) have declined across the species' range. We surveyed a protected Wood Turtle population in northern New Hampshire in 2007 and again in 2020 to determine whether the size of the population had changed and the average annual survival rate between the two periods. We used closed-population loglinear models to estimate the adult population size in 2007 and 2020 and, for the subset of turtles captured in both years, to estimate the rate of survival. Based on these models, we found an adult population of 56 (95% CI 33–126) in 2007 and 46 (95% CI 31–85) in 2020; we did not detect a statistically significant difference between the two population estimates. In addition, we estimated a 96% average annual adult survival rate and determined this rate could be no lower than 92%. This information provides useful baseline data and will help inform future monitoring and threat mitigation work for this population.

Key words: Wood Turtle; *Glyptemys insculpta*; mark–recapture; population estimates; loglinear models; survival; New Hampshire

Introduction
Wood Turtle (*Glyptemys insculpta*) populations have undergone well-documented declines across the species' range (Garber and Burger 1995; Daigle and Jutras 2005; Saumure *et al.* 2007; Jones and Willey 2015; COSEWIC 2018; Jones *et al.* 2018; Lapin *et al.* 2019). Threats to their population persistence include habitat loss, degradation, and fragmentation; elevated mortality associated with automobiles and agricultural machinery; and poaching and collection (Saumure *et al.* 2007; Erb and Jones 2011; Jones *et al.* 2018). Severe flooding events may also negatively affect Wood Turtle populations, especially in mountainous areas (Jones and Sievert 2009).

Regular losses of even small numbers of adults from a population of this long-lived, slow-to-mature species with high natural mortality rates during early life stages can result in chronic population declines. Compton (1999) estimated that the annual removal of only three adult Wood Turtles from a population of 100 would result in the extirpation of that population in 50 years. We studied a Wood Turtle population in New Hampshire using comparable methods 13 years apart to evaluate the species' probability of persistence in this portion of its range.

Methods
Our study area consisted of a stream and adjacent shrubby wetlands, forested uplands, and light residential development in northern New Hampshire, USA, on primarily publicly owned land managed by the United States Forest Service. Information that would help determine the exact location of the study area has been purposely withheld. Although the habitat is protected from development, threats to this population are numerous: it is adjacent to a high-traffic roadway; the habitat is popular with recreationists; it is effectively isolated from other populations; and it experienced substantial flooding during Tropical Storm Irene in August 2011. As such, the population is threatened by many of the same factors impacting other Wood Turtle populations across the species' range.

In 2007, M.T.J. conducted weekly mark–recapture surveys from May through October. A total of approximately 63 person-hours was spread across 28 surveys

(Jones 2009). M.T.J. searched for turtles in herbaceous and scrub–shrub clearings along the stream and on islets in the stream and by walking upstream toward submerged structural features, such as stumps, logs, and coarse woody debris. Captured turtles were individually marked by filing the marginal scutes with a steel triangular file following the numbering scheme developed by Ernst *et al.* (1974). Turtle age was estimated by counting growth lines, and the sex of each adult turtle was determined by observing the concavity of the plastron and the location of the cloacal opening. A telemetry study was also conducted on a subset of 10 adults; these turtles were only counted as recaptures if they were captured incidentally during surveys. In 2020, we employed a similar survey protocol as outlined in Jones *et al.* (2018) and searched the same stream reach and marked and aged turtles in the same manner as in 2007. We conducted 36 surveys from April through November (excluding August) for a total of 68 person-hours. Telemetry was not a component of the 2020 effort.

We estimated the size of the population in 2007 and 2020 using closed-population loglinear models (Otis *et al*. 1978; Rivest and Lévesque 2001) and conducted all analyses in the "Rcapture" package version 1.4-3 (Baillargeon and Rivest 2007) in the programming language R version 4.2.1 (R Core Team 2020). We considered models that account for different capture probabilities between capture events (M_t), varying capture probabilities between individual turtles (M_h), and behavioural changes resulting from the initial capture (M_b), in addition to the simplest model that assumes an equal capture probability across capture events and individual turtles (M_0). Others have used these closed-population models to estimate the population size of Wood Turtles (Daigle and Jutras 2005; Walde *et al.* 2007; Jones 2009).

Because juvenile Wood Turtles are typically less detectable than adults during visual surveys, combining juvenile detections with adult detections in population calculations can bias results (Daigle and Jutras 2005; Jones 2009). Therefore, juveniles (defined here as turtles of indeterminant sex under nine years of age; see Jones 2009) were excluded from the analysis. To address the problem of serial autocorrelation that can result from observing the same individuals during consecutive survey visits, we grouped survey results into biweekly blocks.

We selected models based on AICc (Burnham and Anderson 2004). We looked closely at the M_t model because there was a two-week period in June 2020 when many more turtles were captured compared with other capture periods. We estimated the survival rate of adult Wood Turtles captured and marked in 2007 by building a separate 2020 population estimate only for those turtles. To develop an estimate for the average annual survival rate, we took the 13th root (to account for the 13 years between surveys) of the estimated survival rate between the two periods. We ultimately used Cormack's (1992) multinomial profile likelihood approach for our population estimates and CI for all three datasets. We compared CI from the 2007 and 2020 population estimates to determine whether there was a significant difference at an alpha level of 0.05 in the adult population between the two years.

Results

In 2007, M.T.J. made 32 captures (including recaptures) of 26 individual turtles (12 males, 10 females, and four juveniles of indeterminant sex). In 2020, we made 48 captures of 28 individual turtles (10 males, 15 females, and three juveniles). Our total catch per unit effort was 0.51 turtles/person-hour in 2007 and 0.71 turtles/person-hour in 2020.

The M_0 model proved to be the best fit in 2007 and in 2020 as well as for the separate dataset used to estimate survival (Table 1); therefore, we selected it for our population estimates. We estimated a population size of 56 adults (95% CI 33–126) in 2007 and 46 adults (95% CI 31–85) in 2020. The 2020 estimate is 17% lower than the 2007 estimate, although we did not detect a significant difference in abundance of the study population between the two sampling periods because of the large and overlapping CI for both estimates, particularly in 2007.

Of the 26 turtles captured in 2007, nine (35%) were recaptured in 2020. Based on this dataset, an estimated 16 turtles captured in 2007 remained in the population in 2020, giving an estimated 96% average annual survival rate and a minimal average annual survival rate (assuming all turtles not captured have died) of 92% (Table 2). Note that the upper bound 95% CI would not exclude 100% survival.

Discussion

We did not detect a statistically significant difference in the population size of adult Wood Turtles between 2007 and 2020. Although it is possible that the study population has declined between the two sampling periods, the large CI for the population estimates prevents us from drawing any conclusions about a population trend. In a similar study involving two surveys conducted seven years apart, Daigle and Jutras (2005) were able to demonstrate a statistically significant 50% decline of a Wood Turtle population in Quebec. They captured far more turtles per survey and had more recaptures, factors that minimized their SE. Although Daigle and Jutras' (2005) 50% population decline was a total rate of decline between 1995

TABLE 1. Comparison of AICc values and other model selection metrics of several closed-population loglinear models for three sets of data for Wood Turtle (*Glyptemys insculpta*) population estimates for two years of surveys, northern New Hampshire, USA.

Model	Estimated population*	AICc	ΔAICc	*w*	*K*
2007					
M_0	56	72.693	0.000	0.696	2
M_b	36	74.673	1.980	0.259	3
M_h†	60	78.129	5.436	0.046	4
M_t	54	93.566	20.873	<0.001	10
2020					
M_0	46	105.681	0.000	0.678	2
M_b	34	107.531	1.849	0.269	3
M_h†	46	111.136	5.455	0.044	4
M_t	42	114.361	8.679	0.009	11
2007 recaptures‡					
M_0	16	47.075	0.000	0.864	2
M_b	11	50.865	3.790	0.130	3
M_h†	22	56.855	9.780	0.006	4

*Estimates for M_0, M_h, and M_t are derived from Cormack's (1992) multinomial profile likelihood approach and calculated by the closedpCI function in Rcapture. Because this approach does not work for M_b, the estimate reported in the table for this model is from the closedp function.
†Estimates from the M_h model are derived from Chao's (1987) moment estimator.
‡The sample size for this dataset ($n = 9$) was too small for us to consider M_t ($K = 9$).

TABLE 2. Estimated survival rate of Wood Turtles (*Glyptemys insculpta*) captured in 2007 and recaptured in 2020, northern New Hampshire, USA.

	Estimated	Minimum
No. surviving turtles (of 26)	16	9
Survival rate, %	62	35
Average annual survival rate, %	96	92

and 2002, we extrapolated their estimated total survival rate between those seven years into annual rates (Table 3). With an average annual survival rate of just over 80% (Table 3), their population declined by 50% in seven years. A more intensive survey effort would likely be required to detect statistically significant changes in our study population.

Despite the lack of statistical significance, it is important to note the biological significance of a 17% decline in 13 years. Removing one or two adults annually from a small population can lead to extirpation of that population within a century (Compton 1999). If the population truly has declined by 17% between 2007 and 2020, it may disappear within a matter of decades.

Others have estimated average annual rates of adult Wood Turtle survival ranging from 83% to 97%,

TABLE 3. Estimated rates of adult survival in various Wood Turtle (*Glyptemys insculpta*) populations.

Estimated annual survival rate, %	Location	Period	Study
97	Michigan	1998–2015	Schneider *et al.* (2018)
96	New Hampshire	2007–2020	Current study
93	New Hampshire	2005–2013	B. Wicklow (unpubl. data)
93	Ontario	1991–2007	Mullin *et al.* (2020)
89	Ontario	1991–2007	Mullin *et al.* (2020)
89	Minnesota	2015–2016	Lapin *et al.* (2019)
87–90	Quebec*	1998–1999	Saumure *et al.* (2007)
87	Wisconsin	2014–2015	Lapin *et al.* (2019)
86	Iowa	2012–2015	Lapin *et al.* (2019)
83.4 or 84.6	Quebec*	1995–2002	Daigle and Jutras (2005)

*Same population.

compared with our 96% (Table 3). Schneider *et al.* (2018) determined a significant population increase over the course of their study with an estimated annual rate of survival of 97%, whereas Saumure *et al.* (2007) and Daigle and Jutras (2005) noted a significant decline when survival dropped below 90% annually. These determinations agree with Compton (1999), who estimated that an annual adult survival rate of 96% would result in a stable Wood Turtle population, but that populations would decline if survival dipped below 94% annually. Lapin *et al.* (2019) posited that a minimum annual survival rate of 95% is required to maintain stable numbers over time. Therefore, the estimated 96% annual adult survival rate of our study population may indicate a stable adult population between 2007 and 2020. In light of the large CIs associated with our estimates, a survival rate that points to a stable adult population may indicate that the population size has remained relatively constant across sampling periods. Alternatively, if future monitoring confirms that the population is in decline despite this high adult survival rate, it may suggest that recruitment of hatchlings or juveniles is low and would warrant investigation. Recruitment failure has been noted in other populations and can be attributed to a variety of factors, including increased recreational use, agricultural practices, and predation (Brooks *et al.* 1992; Garber and Burger 1995; Daigle and Jutras 2005). A small proportion of captured young turtles can be attributed to poor recruitment (Daigle and Jutras 2005). It can also be a result of juveniles simply being harder to find: only 10% of Wood Turtles captured by Schneider *et al.* (2018) were juveniles and yet that population increased significantly over the course of their study.

If the nine turtles that were captured in both years represent the only surviving individuals, the corresponding average annual survival rate (92%) would not be indicative of a stable population. If this was the case, the adult population would likely be declining and poor recruitment may or may not be playing a role in a long-term population decline. More intensive survey efforts are needed to determine how adult survival and survivorship during earlier life stages are influencing population trends.

Turtles may also be removed from a population through illegal collecting and by dispersal. Although we do not know if collection plays a role in the dynamics of our study population, the collection and removal of an individual from the wild has the same effect on the population as if that turtle died; therefore, there is no need to differentiate between the two fates. However, dispersal may play a role. Jones and Willey (2020) have documented cross-watershed, overland, and long-distance (greater than 16 km of straight-line distance) movements by Wood Turtles, although such events are rare. Other Wood Turtle populations exist within 16 km, although development and other factors may isolate our study population from others. No exchange of turtles between our population and others has been observed. For these reasons, we believe the effects of dispersal on the survivorship rates described above are negligible.

Although crucial to the conservation of rare turtles, protecting habitat may not always be enough to sustain populations (Howell *et al.* 2019). The key habitat features of our study population are on lands owned by the United States Forest Service and are, therefore, protected from development, but threats to turtles remain. Recreation likely poses the biggest challenge. The simple act of encouraging the public to visit occupied Wood Turtle habitat can lead to devastating impacts: Garber and Burger (1995) determined that two separate Wood Turtle populations were extirpated within 10 years after their protected habitat was opened to recreation. The proximity of a high-traffic roadway also threatens our study population, as Wood Turtles have been documented crossing this road, and even low levels of road mortality could result in significant population decline. More research is needed to determine the risk and severity of road mortality and where crossing structures could be constructed to allow for safe turtle passage. Flooding from intense storms is also a concern. Had Tropical Storm Irene arrived later in the season when Wood Turtles were concentrated in streams instead of uplands, it may have had a far greater impact on our population.

Given the potential severity of these threats, we recommend more intensive monitoring at five-year intervals and, with increased search effort, documenting any statistically significant changes to the population and taking necessary conservation action. We also recommend nesting surveys and nest monitoring to help determine whether recruitment is an issue. In the meantime, we are working on management actions to further protect this population, because protection of existing populations should be prioritized over recovery after declines have already occurred (Keevil *et al.* 2018).

Author Contributions

Writing – Original Draft: B.H.; Writing – Review & Editing: B.H. and M.T.J.; Conceptualization: B.H. and M.T.J.; Investigation: B.H. and M.T.J.; Methodology: B.H. and M.T.J.; Formal Analysis: B.H. and M.T.J.

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