

THE RESPONSE OF BRUMATING WOOD TURTLES (*GLYPTEMYS INSCULPTA*) TO A SEVERE FLOOD EVENT IN NEW HAMPSHIRE, USA

BRETT HILLMAN¹ AND ANNE LISE WALING

U.S. Forest Service, 71 White Mountain Drive, Campton, New Hampshire 03223, USA

¹Corresponding author; e-mail: brett.hillman@usda.gov

Abstract.—The threat that extreme floods can pose to Wood Turtle (*Glyptemys insculpta*) populations, particularly during the winter when individuals are most susceptible to downstream displacement, has not been well studied. The hydrology of occupied Wood Turtle sites undoubtedly plays a major role in how seriously turtles are impacted by floods. We investigated the response of Wood Turtles at a known site in New Hampshire to a major flood in December 2023 and compared our results to a population in Massachusetts that was subjected to floods in the past. The Massachusetts study represents the only other published work providing an in-depth look at the impact of severe flooding on Wood Turtles. We found that turtles at our study site were transported significantly shorter distances downstream compared to the Massachusetts population in a flood of comparable peak discharge. We suggest that our study population may be relatively protected from severe floods due to the broad floodplain of our study stream, and this may contribute to the relative health and stability of the population. Our study builds on the limited body of knowledge addressing the threat of floods to Wood Turtles while demonstrating the need for land managers and conservationists to consider the flood resilience of Wood Turtle populations when making management decisions. With climate scientists predicting more intense rain events during the winter across the range of this species, flood resilience may become an increasingly important attribute to consider in the management of Wood Turtles.

Key Words.—climate change; hibernating; precipitation; reptile; streamflow; telemetry; winter storm

INTRODUCTION

Freshwater turtles are among the most imperiled taxa on the planet (Lovich et al. 2018; Rhodin et al. 2018). One of the many species of high conservation concern is the Wood Turtle (*Glyptemys insculpta*), a species that has declined across its range primarily because of anthropogenic pressures (van Dijk and Harding 2011), and urban and agricultural development have eliminated, degraded, and fragmented Wood Turtle habitat (Willoughby et al. 2013; Willey et al. 2022). Human encroachment into occupied Wood Turtle sites has introduced numerous additional threats, including interactions with vehicles and agricultural machinery (Gibbs and Shriver 2002; Saumure et al. 2007), subsidized predators (Moldowan 2023), and illegal collection (Hollowell 2011). Additionally, rising temperatures associated with climate change may threaten the continued existence of the species (Mothes et al. 2020).

Because Wood Turtles are tied to fluvial systems, severe floods can pose a threat to individuals and populations. While seasonal flooding is very important in the maintenance and creation of Wood Turtle habitat (Michael Jones et al., unpubl. report),

severe floods can have deleterious effects. With more extreme precipitation events forecast for the future throughout much of the range of the Wood Turtle range due to climate change (Easterling et al. 2017; Whitehead et al. 2023), it is important to gain a better understanding of how severe flooding may impact Wood Turtle populations.

During the cold winter months, Wood Turtles brumate in streams. It is at this time, when turtles are sluggish and the entirety of a given population is present within aquatic environments, that populations may be most impacted by flooding. Therefore, the timing of the extreme precipitation forecasted by climate scientists could have serious consequences for the species. The combination of increased precipitation during the winter, higher winter temperatures, and more frequent rain-on-snow events will result in more runoff into streams when turtles are brumating (Huntington et al. 2009; Thibeault and Seth 2014; Bjerklie et al. 2015; Demaria et al. 2016; Janowiak et al. 2018), thus increasing the potential for high flow events to impact Wood Turtle populations in the future.

Jones and Sievert (2009) is the only published study focused on the displacement of Wood Turtles during



FIGURE 1. Adult Wood Turtle (*Glyptemys insculpta*) from our study site in New Hampshire, USA, with transmitter affixed to the posterior end of its carapace. (Photographed by Brett Hillman).

flooding events. The authors noted seven floods over 4 y at a site in Massachusetts that were severe enough to displace turtles downstream. They determined that flows 14.5-times higher than the average flow were capable of displacing Wood Turtles. According to their estimates, flooding displaced 40% of the population at least 1.4 km downstream each year. Several other authors also noted displacement and/or mortality of turtles because of flooding (Latham 1971; Sweeten 2008; Parren 2013; Lapin et al. 2019). While the downstream movement of turtles during floods may be an important factor maintaining population connectivity (Sweeten 2008; Jones and Sievert 2009), it may also act as a significant stressor at the individual and population levels. Here, we present a case study on the displacement of brumating Wood Turtles at a site in New Hampshire, USA, during a major flood event in December 2023. We compare our results to those of Jones and Sievert (2009) and discuss the conservation implications given the anticipated effects of climate change.

MATERIALS AND METHODS

Study site.—We studied a Wood Turtle population that occupies a stream system on publicly owned land in New Hampshire, USA. The stream reach occupied by Wood Turtles is braided and very complex, consisting of several channels, small tributaries, beaver-influenced wetlands, alder swales, and an extensive floodplain. Prior to our study, intensive Wood Turtle surveys were conducted on this population in 2007 and 2020 (Jones 2009; Hillman and Jones 2022). To protect this population from the threat of illegal collection, we have withheld further

location details.

Overwintering Wood Turtles primarily occupied three discrete channels within the braided reach of the study stream: Channels A, B, and C. Prior to the December storm, Channel A was disconnected from the main channel (Channel C) by an upstream log jam that had collected sediment and formed a natural dam. All flow into Channel A was from a small tributary downstream of the natural dam. The channel was dry between the dam and tributary and therefore did not support brumating Wood Turtles. Channel B, located downstream of Channel A, had high complexity, characterized by large amounts of coarse, woody debris, substantial sandy point bars, and an accessible floodplain. Channels A and B converged before feeding back into Channel C, which bears more streamflow and is wider than the other channels. It had a moderate amount of woody debris and floodplain access, though proportionally it may have had less than Channel B. Channel C was artificially straightened upstream of the area occupied by Wood Turtles and thus was quite scoured, reducing potential floodplain access and channel complexity upstream and likely limiting the distribution of turtles. Channel gradients were < 1% at the occupied reaches of all three channels as there was minimal elevational change.

Turtle surveys and radiotelemetry.—We conducted mark-recapture surveys for Wood Turtles during the pre-brumation period in 2023 (mid-September through mid-November) using the protocol outlined by Michael Jones et al. (unpubl. report). We filed a unique notch code into the marginal scutes and photographed the carapaces and plastrons of all captured turtles so that individuals could be identified and inspected for recent injuries upon recapture (Ernst et al. 1974). We estimated the age of each turtle by counting annuli (Germano and Bury 1998) and relied on annulus counts from the 2007 survey effort to estimate the ages of older recaptured turtles with worn carapaces.

We attached radio transmitters (Model R1680, 3.6 g, Advanced Telemetry Systems, Isanti, Minnesota, USA) to 24 turtles (10 males, 10 females, and four juveniles) using two types of adhesives: WaterWeld Epoxy Putty (J-B Weld, Sulphur Springs, Texas, USA) and Loctite Marine Epoxy (Henkel Corporation, Rocky Hill, Connecticut, USA; Fig.1). We used a scanning receiver (Model R410, Advanced Telemetry Systems) and a three-element Yagi antenna to locate radiotagged turtles where they were brumating prior

to and following the flooding event (on 12 December 2023 and 4 January 2024, respectively). Over the rest of the brumation period, we tracked turtles every four weeks to record any additional movement. Once turtles became active in the spring, we captured them to check for injuries and then tracked them once per week until September 2024 to determine post-flood survivorship. We recorded coordinates using a handheld GPS unit (GPSMAP 64s, Garmin, Olathe, Kansas, USA).

Streamflow analysis.—On 18–19 December 2023, up to 20 cm of rain fell across northern New Hampshire and temperatures rose above 10° C (<https://www.weather.gov/wrh/climate?wfo=gyx>). Much of the existing snowpack melted quickly and streams with headwaters at high elevations rapidly reached flood stage. The study stream did not have a discharge gage, so we estimated discharge using U.S. Geological Survey (USGS) monitoring stations within the same watershed (<http://waterdata.usgs.gov/nwis>). We scaled the discharges of nearby streams to reflect the watershed area of the study stream. This is an appropriate method of estimating discharge as watershed area ratio describes 93% of variance in daily flow among nested catchments (Gianfagna et al. 2015). For the purposes of this study, we deem this approximation as suitable as we aimed to compare the relative size of the December flood to other high flow events and to the long-term average discharge, not the precise peak flow values.

To decide which gauge to scale our discharge to, we looked at nearby gauges in systems with similar geomorphology and sizes. We also compared the estimated high flows on December 18–19 to a rating curve derived from stage data at a downstream regulatory feature (Justin Bristol, unpubl. data), a method used by USGS to estimate discharge at stream gages (Olson and Norris 2005; Turnipseed and Sauer 2010). By estimating the discharge based on this rating curve, we selected a gage downstream of our study site to estimate streamflow since this gage best reflected the rating curve discharge at the given stage. It should be noted that this method likely underestimates the maximum discharge of our study stream during the flood as the pressure transducer measuring stage at the regulatory feature was likely unable to record maximum discharge (Justin Bristol, pers. comm.). In addition, the headwaters of the study stream received more rain than other sites within the watershed where the National Oceanic and Atmospheric Administration measures precipitation.

Thus, our best estimate of streamflow is conservative, and actual streamflow was likely higher than what we present below.

We compared the average daily flow during the flood event to the average annual daily flow using 15-min instantaneous data following Jones and Sievert (2009). To calculate the average daily flow during the flood, we chose the 24-h period when the flow was the highest (from 1130 on 18 December to 1045 on 19 December). We calculated the average annual flow from water years 1992 through 2023, an interval reflecting all complete water years available for 15-min instantaneous data. We use the water year for this analysis (1 October–30 September), which captures streamflow inputs associated with snowmelt. The oldest known turtles at our study site hatched no later than 1985; thus, this interval is a good approximation of the streamflow conditions that the oldest turtles currently occupying this site have experienced over the course of their lives.

Analysis of turtle displacement.—While Wood Turtles are known to move short distances during the winter, these movements generally do not exceed 15 m measured over the course of the entire brumation season (Greaves and Litzgus 2007; Parren 2013; Curtis and Vila 2015). Therefore, we suggest downstream movements greater than 15 m between the tracking events immediately prior to and following the December 2023 storm to be the result of the storm and do not represent normal movements of brumating Wood Turtles. To measure the distance turtles were displaced during the high flow event, we overlaid coordinates on an aerial photography basemap in ArcGIS Pro (Version 3.2, Esri, Redlands, California, USA) and followed the meanders of the stream course with the measuring tool to determine stream distance between points. To compare displacement distances between turtles at our study site with the distances observed by Jones and Sievert (2009), we conducted a Welch's *t*-test for two samples of unequal variances in the program R, version 4.4.1 (R Core Team 2024). We considered the difference to be significant if $P \leq 0.05$. Because most turtles were not visible where they brumated, we waited until they were active in the spring to determine if their transmitters were still attached, if they survived their displacement, and if they suffered any externally identifiable injuries.

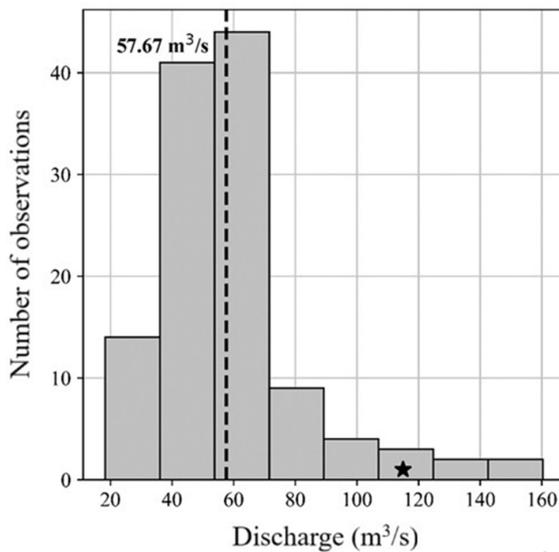


FIGURE 2. Histogram of annual peak flow data from 1904 to 2023 at our study stream in New Hampshire, USA. Graph displays the frequency of observations of annual peak flow for a given range of discharge values. December 2023 storm, with a discharge of $114.97 \text{ m}^3/\text{s}$, is shown at the star symbol. Average peak flow is shown at dotted vertical line with a discharge of $57.67 \text{ m}^3/\text{s}$.

RESULTS

Severity of December flood.—We determined that the December 2023 storm likely produced the highest peak streamflow since 1 April 1987 and the seventh highest peak discharge on record (Fig. 2). The average annual peak discharge was $57.7 \text{ m}^3/\text{s}$ whereas the December flood produced a peak discharge of at least $115 \text{ m}^3/\text{s}$. Based on peak discharge, this flooding event was more severe than other high-profile destructive floods in recent memory, including those associated with Tropical Storm Irene in August 2011 and the remnants of Tropical Storm Philippe in October 2017. The average streamflow over a 24-h period during the flood was $83.2 \text{ m}^3/\text{s}$, which was 21.8 times higher than the long-term average discharge calculated from 15-min instantaneous data dating back to water year 1992. A key geomorphological change caused by this event was a breach of the natural dam that had restricted flow into Channel A. This channel does not exhibit much complexity or floodplain access, suggesting much of the storm flow went through this small channel and did not have an opportunity to disperse its energy.

Impacts on Wood Turtles.—Nine of the 24 radiotagged turtles (38%) were displaced during the flooding event. Eight of these remained in their

channels and were transported downstream of their pre-flood locations by an average distance of $135.5 \pm 89.34 \text{ m}$ (mean \pm standard deviation), with a range of values of 60–340 m. One turtle was transported out of Channel A and into a forested backwater 134 m (straight line distance) from its initial location. The rest of the radio-tagged turtles remained in their pre-flood locations.

All transmitters remained attached during the brumation period. By 9 May 2024, all 24 radiotagged turtles had emerged from their respective overwintering locations. We recorded no additional movements of greater than 15 m after the displacing flood event while turtles were still brumating. All turtles survived until September 2024, and we did not note any obvious physical injuries since their initial capture.

Prior to the storm, Channels A, B, and C held nine, nine, and five radio-tagged turtles, respectively (Fig. 3). One additional turtle overwintered in a small tributary away from the braided stream reach. Channel A had the highest turtle displacement rate (67%; six of nine turtles displaced). The displacement rate was 22% for Channel B (two of nine) and 20% for Channel C (one of five). The turtle that overwintered in the small tributary remained in place.

DISCUSSION

Jones and Sievert (2009) observed 14 instances of turtles displaced by floods in a 4-y period at their study site in Massachusetts. The researchers found that floods displaced turtles by a mean downstream distance of $4,281.9 \pm 4,925.09 \text{ m}$ with a range of values of 311–16,841 m. The turtles at our study site were displaced significantly shorter distances than those at the Massachusetts site ($t = -3.15$, $df = 13$, $P = 0.008$).

The average flow during the December flood was at least 21.8 times higher than the long-term average instantaneous flow at our study site, greater than the minimum relative magnitude of a flooding event capable of displacing turtles at least 1.4 km downstream at the study site of Jones and Sievert (2009), where flows just 14.5 times the average flow were capable of displacing turtles at least that far. Despite this, the Wood Turtles at our study site were transported significantly shorter distances. This suggests that while our study site does experience severe flooding, turtles are less likely to be displaced large distances compared to the Massachusetts site.

Geomorphology likely plays a major role in how

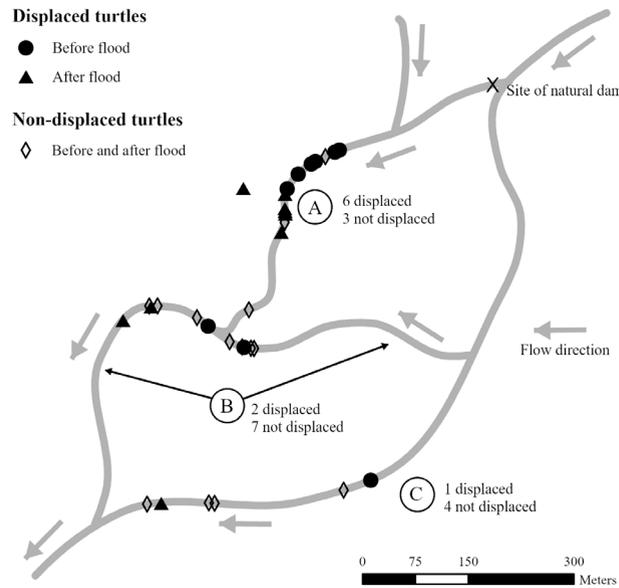


FIGURE 3. Map of study area in New Hampshire, USA, showing the different channels and locations of brumating Wood Turtles (*Glyptemys insculpta*). To mask the location of this site, aerial imagery and identifiable landmarks are not included in the map. (Map created in ArcGIS Pro with U.S. Forest Service data).

Wood Turtles responded to flooding at these sites: the Massachusetts site was characterized by steeper gradients and a straighter, less braided stream channel than our study site. This reflects known habitat preferences of the species. Wood Turtles are most frequently found in stream reaches with gradients below one percent where their chances of being displaced by flooding are low (Jones and Sievert 2009).

At a study site in Virginia, USA, three of 15 radio-tagged Wood Turtles (20%) were displaced 1–9 km downstream during a mid-November high flow event (Sweeten 2008). This is the only other study that reports flood displacement distances of Wood Turtles. Although the displacement distance was not reported with precision, Lapin et al. (2019) noted the death of a Wood Turtle at a site in Iowa that was displaced several kilometers during a major flood in May 2013. These displacement distances are also much greater than the distances we observed.

The percentage of turtles displaced in Channel A was higher than for the other channels. This is likely because the intense streamflow breached the natural dam that had previously disconnected this side channel from the main channel. High streamflow can rapidly breach natural dams and lead to sharp increases in flow downstream (Jiang et al. 2018). Because the main channel was contributing no flow to Channel A before the flood, the increase in streamflow through Channel A during the event must

have been proportionally higher than in the other channels, potentially increasing the likelihood of a turtle being displaced.

Wood Turtles typically brumate in sites that offer protection from stronger flows (Parren 2013; Tamplin et al. 2024). At our study stream, such sites include recesses in streambanks, calm, deep pools, and among logs, roots, and other accumulations of woody material that provide shelter. Given the dynamic nature of stream habitat, brumation sites rarely persist indefinitely and individual Wood Turtles, many of which brumate in the same sites year after year, are often forced to find new overwintering sites (Parren 2013). One log in Channel A harbored five brumating turtles, four of which were displaced after the flood scoured the organic material and sediment from around the log. This site, and others across all three channels, may no longer serve as brumation habitat in the future. If severe floods become more common, Wood Turtles may be forced to find new brumation sites more frequently.

While many turtles initially survive even long-distance displacements, their survival rates plummet afterward due to injuries sustained during the flood, or from threats they face while attempting to return to their home stream reaches and/or find new suitable habitat (Jones and Sievert 2009). Despite the severity of the flood, displaced turtles at our study site did not travel far. Likely as a result, they all survived, acquired no obvious physical injuries, and did not

have to navigate long distances to find suitable habitat in the spring. The turtle that was displaced the farthest (340 m) did return close to its chosen brumation site as soon as it became active in the spring. Otherwise, there was no obvious detriment to turtles resulting from their displacement.

Based on the recapture rate of turtles first captured at the study site in 2007 and then again in 2020, Hillman and Jones (2022) estimated a 96% annual adult survival rate with a minimum rate of 92%. We have since found three additional 2007 captures that were not captured in 2020, which would raise the minimum annual adult survival rate to 94% between 2007 and 2020. This level of adult survivorship is indicative of a stable population (Compton 1999; Lapin et al. 2019). One factor contributing to the stability of this population may be its apparent resilience to extreme flooding events.

Similar to the study site of Jones and Sievert (2009), our site was bounded by a dam that may have served to limit downstream movement of displaced Wood Turtles. Only one of the displaced turtles in our study traveled as far as the impounded reach of the stream, however, while Jones and Sievert (2009) noted five instances of turtles being transported over a dam. It is likely that the complexity of the braided stream reach occupied by the turtles with its multiple beaver dams and large, forested floodplain helped dissipate stream energy and limited impacts to turtles at our study site. The dam likely plays a role in the hydrology at this site, so the effects of dam removal or changes to dam operations on upstream turtle populations should be considered when such activities are proposed (Jones and Sievert 2009).

While our study population faced many of the anthropogenic threats known to impact the species and is likely isolated from other populations, it exists primarily on conserved land within a heavily forested watershed and appears to be stable. Our research indicates this population may be resilient to flooding, which will become increasingly important to its long-term persistence given projected climate change. The hydrology of occupied Wood Turtle sites plays a major role in the resilience of a population to flooding and can help inform conservation efforts by allowing managers to focus on sites most likely to harbor resilient populations into the future. Our study site and other nearby streams support Wood Turtle populations that are among the largest and densest in New England, USA (Jones 2009). Considering that New Hampshire and other northeastern U.S. states may serve as climate refugia for Wood Turtles in

the future (Mothes et al. 2020), conservation of this population is paramount.

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BRETT HILLMAN is a Wildlife Biologist with the U.S. Forest Service on the White Mountain National Forest, Campton, New Hampshire, USA. Brett earned his M.S. in Conservation Biology from Antioch University New England, Keene, New Hampshire, USA, in 2013. His primary interests involve the study and conservation of nongame species that are often overlooked. His current research focuses on the conservation of Wood Turtles and the odonate communities that occupy high-elevation wetlands. (Photographed by Erica Roberts).



ANNELISE WALING is a Hydrologist with the U.S. Forest Service on the White Mountain National Forest, New Hampshire, USA. She earned her M.S. in Hydrology from the University of New Hampshire, Durham, USA, in 2021. Her primary research interests include flooding, stream geomorphology, and floodplain restoration. (Photographed by Erica Roberts).