Status *and* Conservation *of the* Wood Turtle *in the* Northeastern United States

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COVER IMAGES: Wood turtle habitat in Aroostook County, Maine (top) and Morgan County, West Virginia (bottom); male and hatchling wood turtles from New England.

Status and Conservation of the Wood Turtle in the Northeastern United States

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Status and Conservation of the Wood Turtle in the Northeastern United States

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Table of Contents

Executive Summary

In 2009, state and federal agencies, researchers, and land managers began coordinating conservation efforts for the wood turtle (*Glyptemys insculpta*) in the northeastern United States. *Status and Conservation of the Wood Turtle in the Northeastern United States* is the first product of this multi-state cooperation, which was funded in 2011 by the Regional Conservation Needs (RCN) program. In this document we summarize relevant Wood Turtle ecological studies; compile, corroborate, and analyze available wood turtle occurrence data; assess detection and monitoring protocols; initiate the first regional monitoring effort with standardized protocols and centralized reporting/analysis; quantify the landscape status at multiple scales to prioritize conservation action; outline a multiscale conservation strategy and offer Best Management Practices.

Wood turtles (*Glyptemys insculpta*) occur in the northeastern United States and southeastern Canada. The northeastern United States encompasses the largest portion of the wood turtle's current range. In this area, wood turtles have been identified as both a species of regional conservation concern, regional conservation responsibility, and as a high-value focal species for landscape-scale conservation in the northern forest. Wood turtles are riverine and riparian obligates, overwintering and mating in clear, cold, primarily sand-, gravel-, and rock-bottomed streams and foraging in riparian zones, fields and upland forests during the late spring and summer.

Abundant evidence strongly indicates that the wood turtle has undergone widespread population declines. The wood turtle occurs primarily in small, isolated, declining populations. This appears to be due in part to the fragmentation and degradation of its preferred riverine, instream, riparian, and upland habitats, but is exacerbated by heavy adult mortality from agricultural machinery, cars, and collection for pet markets. This is compounded by the wood turtle's late maturity (15–18 years), low reproductive potential (one clutch of approximately eight eggs every one to two years), and high nest and hatchling depredation rates, but is typically offset by multi-decade reproductive periods. Correspondingly, major declines leading to population collapse are essentially irreversible without expensive and intensive long-term management. To avoid further declines, conservation actions will prioritize remaining, functional populations in high-quality riparian contexts throughout the historical range of the turtle through targeted land acquisition, riparian restoration, and landscape-scale management activities, while simultaneously responding to riparian restoration and population management opportunities on protected lands elsewhere in the range.

Key Findings

Based on Species Distribution Models (SDMs) constructed from stream geomorphology and recent climate data, approximately 127,000 stream kilometers in the Northeastern United States provide potential stream habitat for wood turtles (being similar to the 85th percentile of segments known to support wood turtles).

Large portions of the Northeast region and numerous HUC4 basins (Maine Coastal, St. Francois, Lake Erie, and Southwestern Lake Ontario, and Monongahela) and Level III ecoregions (Atlantic Coastal Pine Barrens, the Western Allegheny Plateau, and the Central Appalachians) are data deficient and may also be ecologically significant.

Occurrences in the Allegheny and Monongahela River watersheds of western Pennsylvania and Maryland are noteworthy as the only occurrences in the Ohio watershed, and the only Mississippi watershed occurrences south of the Great Lakes.

Massachusetts had the highest density of corroborated wood turtle occurrences, while Maine has the lowest density of known occurrences.

Wood turtles occur in stream segments that are lower gradient, higher flow, and more sinuous than what is generally available on the landscape, though the squared terms of these variables were often important.

Approximately 27% of the habitat surrounding all corroborated occurrences is protected (compared to 19% of the region at large) and approximately 25% of occurrences are at least 50% protected.

Approximately 15% of habitat surrounding suitable stream segments is protected (compared to 19% of the region at large) and 14% of suitable stream segments are more than 50% protected.

Surveys for wood turtles have higher detection rates in the spring, but fall surveys are generally effective at detecting turtles. In the spring, surveys earlier in the day produced significantly more turtles than those occurring later, and warmer fall surveys, earlier in the season generally produced larger counts, but this was not significant. Surveys conducted at air temperatures less than 12˚C were rarely productive. Observer effect on survey success is potentially large.

At long-term sites (not random sites on the landscape), estimates of adult and subadult population size ranged from 6.4 to 198.4 turtles/segment.

It appears that over 50% of suitable stream habitat in the Northeast Region may have been impaired by urbanization and deforestation to a level that negatively influences wood turtle abundance. Further studies are strongly encouraged to validate this model. Further, our results strongly suggest that wood turtle abundance is influenced by urbanization and deforestation at relatively large scales, larger than the annual home ranges of wood turtles.

New Jersey and Maryland are the most potentially impaired states in the Northeast Region, with over 80% of SDM stream habitat having similar urbanization and deforestation characteristics as survey sites with negative results.

Maine, West Virginia, and New Hampshire have the largest proportion of non-impaired habitats.

Of 145 potentially significant populations in the Northeast region that have ≥5 turtles in optimal landscape context or ≥20 turtles, 90 occur in potentially optimal landscape conditions.

Historic occurrences last observed before 1983 have higher site impairment values based on urbanization and deforestation.

The level of regulatory protections provided to wood turtles and wood turtle habitat, especially upland areas, in the Northeast are surprisingly minimal, and do not appear to correspond to the high level of regional concern for wood turtle conservation.

Project Summary

Part 1. Wood turtles (*Glyptemys insculpta*) occur in the northeastern United States and southeastern Canada. Populations are found throughout three distinct jurisdictional regions: portions of Nova Scotia and New Brunswick, Québec, and Ontario (Canada), New England, New York, New Jersey, Pennsylvania, Maryland, West Virginia, and Virginia (northeastern United States), and portions of Michigan, Wisconsin, Minnesota, and Iowa (Midwest/Great Lakes). The northeastern United States encompasses the largest portion of the wood turtle's current range, and they have been identified as both a species of high regional conservation responsibility and concern and a high-value focal species for landscape-scale conservation in the northern forest. Wood turtles are riverine and riparian obligates, overwintering and mating in clear, cold, primarily sand-, gravel-, and rock-bottomed streams and foraging in riparian zones, fields and upland forests during the late spring and summer.

Similar to the bog turtle (*Glyptemys muhlenbergii*), Blanding's turtle (*Emydoidea blandingii*), spotted turtle (*Clemmys guttata*), and the American box turtles (*Terrapene* spp.), to which the wood turtle is related at the subfamily level (Emydinae), the wood turtle has evidently undergone widespread population declines and occurs primarily in small, isolated, declining populations. This is clearly due in part to the fragmentation and degradation of its preferred riverine, instream, riparian, and upland habitats, but is exacerbated by heavy adult mortality from agricultural machinery, cars, and collection for pet markets. The wood turtle's life history is well known, and corresponds to that of most other emydine turtles. Adults mature between the ages of 11 and 20 years (15–18), lay one clutch of approximately eight eggs every 1–2 years, sustain high nest and hatchling depredation rates, and likely reproduce well into their 50s. Correspondingly, the generation time is approximately 45 years, and major declines leading to population collapse are essentially irreversible without expensive and intensive management. To avoid further declines, conservation actions will prioritize remaining, functional populations in high-quality riparian contexts throughout the historical range of the turtle through targeted land acquisition, riparian restoration, and landscape-scale management activities, while simultaneously responding to riparian restoration and population management opportunities on protected lands elsewhere in the range. To accomplish this most effectively, the thirteen Northeastern states (and District of Columbia) will need to coordinate tracking, monitoring, research, and conservation efforts.

In 2009, state and federal agencies, researchers, and land managers began coordinating conservation efforts as a Northeast Wood Turtle Working Group (NEWTWG) through the Northeast chapter of Partners in Amphibian and Reptile Conservation (NEPARC). In 2011, the NEWTWG began compiling a status assessment and conservation strategy for the Northeast Region with the support of the Northeast Association of Fish and Wildlife Agencies' Regional Conservation Needs Program. *Status and Conservation of Wood Turtles in the Northeastern United States* is the first product of this multi-state cooperation. This document is intended to summarize relevant wood turtle ecological studies, compile, corroborate, and analyze available wood turtle occurrence data, assess detection and monitoring protocols, initiate the first regional monitoring effort with standardized protocols and centralized reporting/analysis, and quantify the landscape status at multiple scales to prioritize conservation action.

The level of regulatory protections provided to wood turtles and wood turtle habitat, especially upland areas, in the Northeast are surprisingly minimal, and do not appear to correspond to the high level of regional concern for wood turtle conservation.

Part 2. We analyzed the historic (1850–present) distribution of wood turtles (*Glyptemys insculpta*) in the northeastern United States using corroborated occurrences associated with streams and logistic regression. We built species distribution models (SDMs) for states, watersheds (USGS HUC4), and EPA Level III ecoregions, and summed these to obtain a regional SDM. We combined a wide variety of available datasets from natural heritage programs, museum databases, published literature, technical reports, reptile and amphibian atlas programs, expert interviews, private datasets, and standardized regional surveys. The quality, density, and consistency of occurrence data varied substantially throughout the Northeast Region. To improve consistency across states, watersheds, and ecoregions, we developed a database of "corroborated" occurrences within the Northeast Region. We used the standardized dataset of occurrences, along with stream variables including stream gradient, flow accumulation, sinuosity and a principal component of broad landscape-scale climatic variables to assess stream characteristics of segments known to support wood turtles and to build stream-based SDMs for wood turtle.

At the regional scale, wood turtles occur in stream segments that are lower gradient, higher flow, and more sinuous than what is generally available on the landscape, though the squared terms of these variables were often important. This suggests that the likelihood of wood turtle occurrence responds unimodally (increasing and then decreasing) rather than monotonically (steadily increasing) to some habitat variables. Stream segments where wood turtles occur vary climatically across the region, and SDMs were locally fit and applied to account for this non-stationarity. The final SDM produced in this section allows us to assess broadscale patterns of data deficiency, unique and isolated populations, and provides the basis of subsequent analyses of habitat quality and degradation.

According to the final SDM, 127,000 stream kilometers in the Northeast are similar to the 85th percentile of segments known to support wood turtles. The number of suitable stream kilometers is further summarized by state, watershed, and ecoregion. Massachusetts had the highest density of corroborated occurrences, with one corroborated occurrence/155 km of stream within the species range, while Maine was the least sampled, with one corroborated occurrence/1020 km of stream. Because of Maine's potential to harbor regionally significant populations, it is considered a priority region for standardized surveys. Large areas of western New York and western Pennsylvania near the species' range limit have low densities of corroborated occurrences and long-term or intensive studies and are considered priorities for standardized surveys and monitoring. Historic occurrences on the coastal plain of New Jersey are noteworthy in a regional context because of the general lack of occurrences in other coastal plain areas from Massachusetts to Virginia. Several Level III ecoregions had relatively few occurrences, and these may represent meaningful or significant ecological lineages. For example, the Atlantic Coastal Pine Barrens, the Western Allegheny Plateau, and the Central Appalachians ecoregions may be considered data deficient and ecologically significant. At the watershed (HUC4) scale, the Maine Coastal, St. Francois, Lake Erie, and Southwestern Lake Ontario, and Monongahela all have four or fewer corroborated occurrences. Occurrences in the Allegheny and Monongahela River watersheds of western Pennsylvania and Maryland are noteworthy as the only occurrences in the Ohio watershed, and the only Mississippi watershed occurrences south of the Great Lakes. Last, approximately 27% of the habitat surrounding all corroborated occurrences is protected (compared to 19% of the region at large) and approximately 25% of occurrences are at least 50% protected. Approximately 15% of habitat surrounding suitable stream segments is protected (compared to 19% of the region at large) and 14% of suitable stream segments are more than 50% protected.

Part 3. We summarize and analyze monitoring protocols and survey results for the 2012–2013 field seasons, and discuss considerations for future sampling. We developed a flexible survey protocol designed to: 1) work in a variety of stream and field conditions; 2) fit easily within existing research programs; and 3) use nested sampling periods for multiple levels of population assessment. The standard spatial sampling unit is one kilometer of meandering stream and adjacent riparian habitats, measured along the stream centerline. The segment is surveyed by one or more experienced observers in one hour. A lead observer is designated for each survey regardless of total number of observers. Three surveys were undertaken in a single season when detection probabilities are highest and wood turtles are present in the immediate vicinity of the stream corridor (e.g., spring and autumn). Survey start and end times, and start/end locations, were recorded (the start and end locations are fixed across all surveys), and time spent not surveying was subtracted. Air and water temperature and weather observations were recorded (˚C) at the beginning and end of the survey. Surveys were conducted at a network of survey sites across the Northeast Region, and sites were designated either Long-Term Reference (LTR) and Rapid Assessment (RA) sites. LTR sites were sampled in both the spring and fall seasons over the course of multiple years (i.e., 3 surveys in each season, e.g., 3 in spring 2012, 3 in fall 2012, 3 in spring 2013, etc.). All sites that were sampled three times in both a spring and fall season in at least one year were considered LTR sites. RA sites were sampled three times in one single season only (spring or fall). We added a random site selection component by surveying sites in New Hampshire, Massachusetts, New Jersey, and Virginia that were selected from a Classification and Regression Trees (CART) model of suitable stream habitat, empirically trained with confirmed occurrence data from Maine to Virginia. Further, we overlaid the LTR sampling protocol onto five wood turtle sites studied in previous decades, from the 1970s to the 2000s. Data collected through the coordinated effort are maintained in a centralized, web-based, encrypted data repository at the University of Massachusetts.

During the 2012 and 2013 field seasons, 825 surveys (383 in the spring, 71 during nesting, and 371 in the fall) were conducted on 196 stream segments. Each stream segment was surveyed between 1 and 15 times (mean=4.2), and a total of 1,567 wood turtle sightings occurred on 73 of 96 streams (with segments on the same stream pooled). Fewer than half of the surveys (43.9%) yielded no turtles, and the average survey yielded 1.9 turtles (sd=3.17), 1.33 (sd=2.03) of those were seen by the lead observer. Using zero inflated poisson mixture models, the individual probability of detection (or detection rate) was estimated to be 0.06 when evaluating all sites with three or more surveys and 0.07 when evaluating only spring surveys, and site abundance decreased significantly with impervious surface cover at 3 km around the site. The total abundance across all 78 sites sampled at least three times in the spring was estimated to be 1461 (95% CI=1003–2074), though this may be an underestimate of the total number of turtles present in a given year, based on total captures and results from capture-mark-recapture models.

Total survey success improved with number of observers, as expected. Survey success varied by observer, and surveys conducted by experienced surveyors yielded significantly more turtles. Survey success was significantly higher when air temperature increased rapidly from the starting temperature during a survey (i.e., cool starting temperature and warm ending temperature). Longer surveys produced significantly more turtles than shorter surveys, and spring surveys produced significantly more turtles (about twice the detection rate) than fall surveys, though fall surveys were still effective at detecting turtles. In the spring, surveys earlier in the day produced significantly more turtles than those occurring later, and warmer fall surveys, earlier in the season generally produced larger counts, but this was not significant.

We used classification trees to tease apart the complex interactions between geographic location, time of year, time of day, and air temperature and their correlation with survey success in the spring. Surveys conducted at air temperatures less than 12˚C were rarely productive. The interaction terms between the growing degrees at the site location and Julian day, as well as the interaction between Julian day and air temperature also proved important predictors of survey success, in addition to air temperature and the air/water temperature differential.

We were able to estimate population size using Capture-Mark-Recapture (CMR) models at 17 sites using open population models and 24 using closed population models. Estimates of adult and subadult population size ranged from 6.4 to 198.4 turtles / segment (mean=66 turtles for open population models and 63 for closed population models). Average survey results were significantly correlated with population estimates and explained 66% of the variation, suggesting that for sites with at least nine surveys, average survey returns are a good indicator population size. This model also suggested that detection rate per survey for individual turtles averages 0.03, less than that estimated with the mixture models, suggesting regional population sizes for the mixture models may be an underestimate.

Part 4. There is compelling evidence that wood turtles have sustained widespread declines in most regions, and further evidence to suggest that declines are ongoing. Almost all long-term or repeat-interval studies have demonstrated quantifiable declines. Nearly all reviewers who closely examined certain geographic areas have concluded that wood turtles have experienced a range contraction or substantial reduction in numbers, especially in the vicinity of Boston, Worcester, New York, Havre de Grace, Baltimore, and Washington. Historical data suggest an eastward contraction away from the Great Lakes and Ohio-Pennsylvania border. A strong anecdotal link has been established between the decline of wood turtles associated with urbanization and loss of riparian and upland habitats or impaired stream quality. Preliminary analyses in Part 3 of this report indicated a strong negative relationship between impervious surface cover at the 3 km scale and the abundance of wood turtles at standardized survey plots. It is certainly the conclusion (and presumption) of most wood turtle researchers that the species has declined substantially and is continuing to decline—so it is essential that we be overly critical of our own methods to explore this phenomenon. In this section, we investigate the relationships between wood turtle abundance and land cover (broadly expressed as forested or urbanized) at multiple scales. We then extrapolate the modeled relationship to the stream-based Species Distribution Model (SDM) developed in Part 2. We quantify the extent of severe habitat alteration at multiple scales. Based on our analysis, it appears that over 50% of suitable stream habitat in the Northeast Region may have been impaired by urbanization and deforestation to a level that influences wood turtle abundance. Further, our results strongly suggest that wood turtle abundance is influenced by urbanization and deforestation at relatively large scales, larger than the annual home ranges of wood turtles. We also used results from surveys with 75th percentile results to identify landscape contexts that are potentially optimal. We used the modeled outputs of potentially optimal habitat, combined with corroborated occurrence data, to identify 145 potentially significant populations in the Northeast region, 90 or which occur in potentially optimal landscape conditions.

Part 5. Based on the review of available information provided in Part 1 and the original analyses presented in Parts 2–4, as well as a Delphi poll of wood turtle experts in the northeastern United States, we present a summary overview of Recommended Conservation Measures for the wood turtle in the Northeast Region. These recommendations are preliminary, and will be updated in 2015–2016 through a Competitive State Wildlife Grant. These fall broadly into eight programs or categories: 1) Landscape-Scale Habitat Protection and Management; 2) Effective Regulation of Priority Sites; 3) Improved Regional Data Collection and Analysis; 4) Coordinated Monitoring; 5) Regionwide Genetic Analysis; 6) Reduce Trade of Wild-Caught Adults; 7) Coordinated Educational Campaign; and 8.) Wood Turtle Council. Recommendations are provided at the state or watershed level, where appropriate, but most recommendations are proposed as coordinated regional actions to improve effectiveness and efficiency. A range of proactive and applied measures are proposed. We place heavy emphasis on site prioritization (greater protections for the "best" sites in a given region) as a technique to facilitate greater regulatory protection and allocate scarce resources. We anticipate that if these actions are achieved in the near-term and sustained, the ongoing decline of wood turtles may be slowed or mitigated.

Part 6. This document provides an overview of recommended Best Management Practices (BMPs) for wood turtles (*Glyptemys insculpta*) in the northeastern United States, based on literature, technical reports, and unpublished data of the Northeast Wood Turtle Working Group. The primary goal of this document is to seek a convergence in the recommended management guidelines from across the Northeast Region, and to outline BMPs for a number of representative land-management scenarios. Last but importantly, we propose that more stringent management standards should be applied at higher-priority populations, which requires an adequate and flexible method of assessing and ranking populations. Prioritization and triage of populations is a central theme.

The biological parameters of the wood turtle area well established (see Part 1). The wood turtle occurs primarily in clear, clean, cold streams in both forested and agricultural areas from Maine to Virginia. Remaining populations range in density of adults and subadults from 1 to nearly 200 turtles per kilometer of stream. In order to meet minimum probabilities of viability, populations should be unfragmented by roads, consist of a wide range of age classes, and be situated in suitable landuse mosaics, which are generally large, isolated tracts of forest with minimal urbanization and impervious surface area. Wood turtle populations in urbanized or heavily agricultural landscapes may require intensive management to persist. Resources should be allocated to these populations to maintain the historic extent of occurrence, maintain populations in ecologically significant areas, and in areas where there are populations in highly functional contexts have been protected and adequately managed.

All age classes use a variety of riparian and upland habitats during the warm season, which may range from March to October in the southern states and low elevations from May to September in the northern states and high elevations. During the annual terrestrial period, wood turtles are exposed to increased risk of mortality caused primarily by machinery associated with agriculture, forestry, and land development. Although the primary risk associated with these activities is the direct mortality of adult turtles due to crushing injuries from cars and machines such as mowers, tractors, plows, and trucks, improper land-use practices may indirectly harm wood turtle populations in a number of other ways. Inappropriately placed recreational access areas may place stress on the population over long periods by facilitating incidental and commercial collection. Roads constructed for timber operations may subsequently facilitate residential development or elevate roadkill rates. Improper sediment control systems in logging and agricultural areas may increase sedimentation of rivers, degrading stream quality. Undersized bridges or culverts may exacerbate downstream erosion and reduce the permeability of roadways to turtles. Certain landuse practices may provide corridors for the colonization of invasive plant species such as Japanese knotweed (*Fallopia japonica*), which may compromise nesting areas.

Thus, Best Management Practices (BMPs) should be flexible but restrictive, and geared toward supporting populations or sites for which intensive management is feasible, as on some federal and state wildlife refuges. Application of BMPs should be determined by the relative significance and viability of the wood turtle population at the regional and state scale, which may be assessed either from: 1) standardized survey data; 2) population estimates from long-term monitoring data; and 3) aerial photo interpretation, GIS analysis, or habitat assessment combined with 1) and 2). If no population data are available, effort should be made to assess the site on the ground before requiring stringent restrictions. We present a synthesis of recommended protections for wood turtles and propose that the most stringent and restrictive protections be reserved for sites with a higher probability of persistence without intensive management unless the resources necessary for intensive management have been pledged by a managing authority and actions are being taken to mitigate sources of mortality or causes of population decline, in which case a range of efforts to increase recruitment may be necessary.

Two different protection scales are proposed for terrestrial habitat zones adjacent to streams, based on movement data from the literature and unpublished sources: 90 m (general protection) and 300 (maximum protection for significant populations). Agricultural activities should be constrained beyond the 300 m boundary from significant wood turtle streams. Forestry activities should occur primarily in the winter, and should not result in new road construction within 300 m of significant overwintering streams. Further, forestry activities should capitalize on opportunities to create open canopy **nesting areas** and early successional clearings between 30–90 m from the stream *if these features are lacking*. Residential development should be minimized, and sometimes prohibited, within 300 m of significant streams and key features such as communal nesting areas, and within 90 m of low-quality streams. Further, our analyses indicate that it is valuable to maintain an unfragmented, forested landscape at much larger scales of up to several kilometers from significant streams although this goal appears unattainable in most areas.

Part 1. Biology and Ecology of the Wood Turtle

Introduction

This document summarizes the major components of an initial effort by the states of the Northeast Region to evaluate the current status of Wood Turtles (*Glyptemys insculpta*) by: 1) gathering, synthesizing and analyzing the published and technical literature; 2) gathering, synthesizing and analyzing available occurrence information; 3) developing and testing standardized monitoring and survey protocols and initiating a regional monitoring program; 4) identifying and implementing long-term conservation objectives; and 5) developing Best Management Practices. A complete bibliography is provided.

The North American wood turtle (*Glyptemys insculpta* LeConte 1830[1829]) is a semi-terrestrial riverine and riparian species. Its current distribution includes large portions of the eastern forest from Cape Breton Island and mainland Nova Scotia, throughout New Brunswick, southern Québec, New York, and New England to the mountains and Piedmont of Pennsylvania, New Jersey, Maryland, West Virginia and Virginia. To the west, wood turtles are associated with the forested regions of the northern Great Lakes from Ontario, New York, and Michigan to the Upper Mississippi basins of Minnesota, Wisconsin, and Iowa. Wood turtles are known to occur naturally in twelve of the thirteen northeastern United States, from Maine to West Virginia and Virginia; as such, the Northeast Region comprises the largest contiguous portion of the wood turtle's current range.

The wood turtle has been identified as an extremely high-value focal species for landscape scale conservation in the northern forest (Beazley and Cardinal 2004).[1] At present, the wood turtle is of conservation concern throughout a majority of its natural range, considered "Endangered" by the IUCN and "Vulnerable" by NatureServe (van Dijk and Harding 2011). The wood turtle is listed on the Wildlife Action Plan (WAP) of all thirteen northeastern States (NEPARC 2010), and is considered "secure"(S4) in only two states (Maine and Maryland) and as a result is considered a G3 "Vulnerable" species by NatureServe. Biologists have expressed concern for over thirty years that the wood turtle appears to be declining throughout its range, and no less so in the northeastern States. Quantifiable evidence of decline has grown substantially since the 1990s but is still lacking, or is insufficiently broadscale to conclusively demonstrate regional collapse.

In a 1995 response to a listing petition the previous year (RESTORE: The North Woods et al. 1994), the U.S. Fish and Wildlife Service (Amaral 1995) rejected a Threatened status listing because of "...the inadequacy of existing data to support the contention that the wood turtle has undergone rangewide decline or that the threats identified in the petition are affecting wood turtle populations across all or a significant portion of its range to the extent that the species is likely to become an endangered species in the foreseeable future." The USFWS is currently considering a proposal by the Center for Biological Diversity (2012) to list the wood turtle as Threatened as part of a proposal to list 53 amphibians and reptiles.

In this review, we assess the status of wood turtles in six parts. In short, these are as follows:

1. Provide an review of published and technical literature, including a detailed summary of population declines and threats to population persistence;

1 Beazley and Cardinal used a delphi poll to assess 62 mammals, 17 reptiles, 18 amphibians, 92 birds, and 51 freshwater fishes native to Maine. Species were scored based on 19 criteria organized in six categories reflecting types of important species: 1) keystone/functionally important; 2) umbrella; 3) flagship; 4) habitat quality indicator; 5) vulnerable; and 6) information availability.

2. Conduct the first analysis of region-wide, corroborated occurrence and distribution data gathered from researchers, state agencies, natural heritage programs, reptile and amphibian atlases, museums and build predictive stream habitat models using logistic regression;
3. Report the results of original analyses of a two-year, pilot, coordinated monitoring program in eleven states and the District of Columbia;
4. Assess the level of impairment of known and modeled wood turtle streams and make conservative estimates of range contraction;
5. Articulate regional conservation actions, research needs, and a regional monitoring strategy;
6. Develop best management practices for wood turtle habitat covering roads, agriculture, development, forestry, dams, and invasive plant species.

General Reviews and Major Studies

Excellent summary accounts of the wood turtle have been provided by Pope (1939), McCauley (1945); Carr (1952), Ernst (1972), Harding and Bloomer 1979; Ernst et al. (1994); Ernst and Lovich (2009), and others (Compton 1999; Akre and Ernst 2006; COSEWIC 2007).

Intensive, multi-site, or long-term studies of wood turtle ecology in the Northeast Region have been undertaken in Maine (Compton 1999; Compton et al. 2002), New Hampshire (Carroll 1991, 1999; Tuttle and Carroll 2003; 2005; Jones 2009), Vermont (Parren 2013), Massachusetts (Jones 2009); Connecticut (Klemens 1993; Garber and Burger 1995), New York (Carroll and Ehrenfeld 1978), New Jersey (Harding and Bloomer 1978; Farrell and Graham 1991; Castellano 2008), Pennsylvania (Kaufmann 1992; Kaufmann 1995; Ernst 2001), Virginia (Akre 2002; Akre and Ernst 2006; Sweeten 2008); and West Virginia (Niederberger 1993; Niederberger and Seidel 1999; Breisch 2006). Major published studies and studies underway are shown in Figure 1.

Biological Information

Species Description

The wood turtle is medium-sized turtle with a broad, flat, ovate, lightly to strongly keeled carapace (Surface 1908, p. 158; Logier 1939; Ernst and Lovich 2009, p. 251; Figure 2), serrated posteriorly. The scutes of the carapace may be lightly pyramidal and typically number 39 as follows (Storer 1840, p. 210): twelve marginal and four pleural scutes on both sides; five vertebral scutes; a single, narrow nuchal scute. The color of the carapace may be brown, reddish brown, tan, grey, or black in adults (Surface 1908, p. 158), with or without radiating or reticulated yellow-gold and blackish markings, and with or without "concentric and radiating striae (Storer 1840, p. 210)". The scutes of the carapace accumulate growth rings in the outer layers of keratin; these may contribute to a sculptured or pyramidal appearance in young adult turtles. The posterior margins of the carapace are serrated (Vogt 1981, p. 94), and sometimes strongly flared (Surface 1908, p. 158), especially in males. The plastron is notched posteriorly, yellowish-cream or horn-colored with prominent blackish pigmentation located posteriolaterally on each plastral scute (Surface 1908, p. 158–159; Vogt 1981, p. 94), except in tannin- or iron oxide-stained animals, which may be obscured by reddish brown coloration. Similar black blotches are found on the ventral surface of the marginal scutes (Babcock 1919, p. 403). Like the carapace, the plastron accumulates growth rings visible in the outer layers of keratin. These are added along the medial and cranial edges of each plastral scute. New growth is often evident as lighter-colored annuli along the plastral midline.

The head, outer surfaces of the forelimbs, and tail of wood turtles are typically black. The neck, forelimbs, and hind feet are often bright orange to red in both males and females (Ernst 1972, p. 125.1), but may be dull yellowish in some individuals. Color may vary in intensity seasonally or geographically (Harding and Bloomer 1979) or by sex (Ernst and Lovich 2009, p. 251). Wood turtles from the Great Lakes region are often said to have have light yellow or yellow-orange limbs and neck, with more reddish-orange tones seen in the Appalachian region (Harding and Bloomer 1979; Ernst and Lovich 2009, p. 251). The nape of the neck and throat may be dark gray, and the throat may be adorned with yellow in young individuals. The upper jaw is strongly hooked, and notched at the tip, and the lower jaw is similarly hooked upward. Mottled lines of black, white, blue, and yellow may be present on keratinized surfaces of the beak. Some adults possess a prominent golden ring in the iris; the function of which is unknown (Figure 2L and 3C).

Male wood turtles are larger than females. Lovich et al. (1990) reported that males are approximately 1.07 to 1.1 times larger than females. Our data from Maine, New Hampshire, and Massachusetts correspond with this estimate (1.1, 1.08, and 1.06, respectively; M. Jones and L. Willey, unpublished data). Additional morphometric data for adult wood turtles are presented in Table 1.

Adult males have long, thick tails with the cloacal vent equal to or posterior to the carapace rim, a strongly concave plastron, and heavy scales on the forelimbs (Figure 2). Males have heads that are absolutely and relatively larger than those of adult females (Akre 2002). Ernst and Lovich (2009, p. 251) report that some older males have carapace indentations at the bridge. Jones and Compton (2010, p. 71) report an unusually large male wood turtle (SCLmax=251 mm) from northwestern Maine.

Ernst (1972, p. 125.1) provides additional references for technical descriptions of the skull, shell, seam contacts, cervical vertebrae, nasal choanae, arterial canals of the ear, and penis (Romer 1956; Parker 1901 and Zangerl 1939; Tinkle 1962; Williams 1950; Parson 1960 and 1968; McDowell 1961; Zug 1966). Hatchlings may appear to be uniform gray-brown, with a mottled grayish plastron and no carapace keel (Vogt 1981, p. 96). Adult coloration is usually evident by the third year in the wild (Figure 3). Of 500 hatchlings measured by Dragon (unpubl. data) in northwestern Virginia in 2012–2013, the average shell dimensions were as follows: SCL: 35.4 (30.4–39.5) mm; SPL: 29.70 (24.4–34.2) mm; carapace width: 35.0 (25.7–41.0) mm; mass: 9.7 (6.4–12.3) g. These measures appear consistent with those reported throughout the range (Ernst and Lovich 2009).

Key descriptive features of the wood turtle are as follow:

- females are typically 170–200 SCLmin; males up to 11% larger; maximum reported SCLmax is 251 mm;
- carapace with low keel, brown to black, solid color or with radiating or reticulated yellow marks or spots, with or without "sculptured" appearance;
- plastron cream to white with twelve black pigment blotches located on each plastral scute (the plastron may be stained brown with tannins or iron oxide in some areas);
- solid (unstriped) red, orange, or yellow coloration on neck, forelimbs, and hind feet;
- head, outer surfaces of forelimbs, and tail are black.

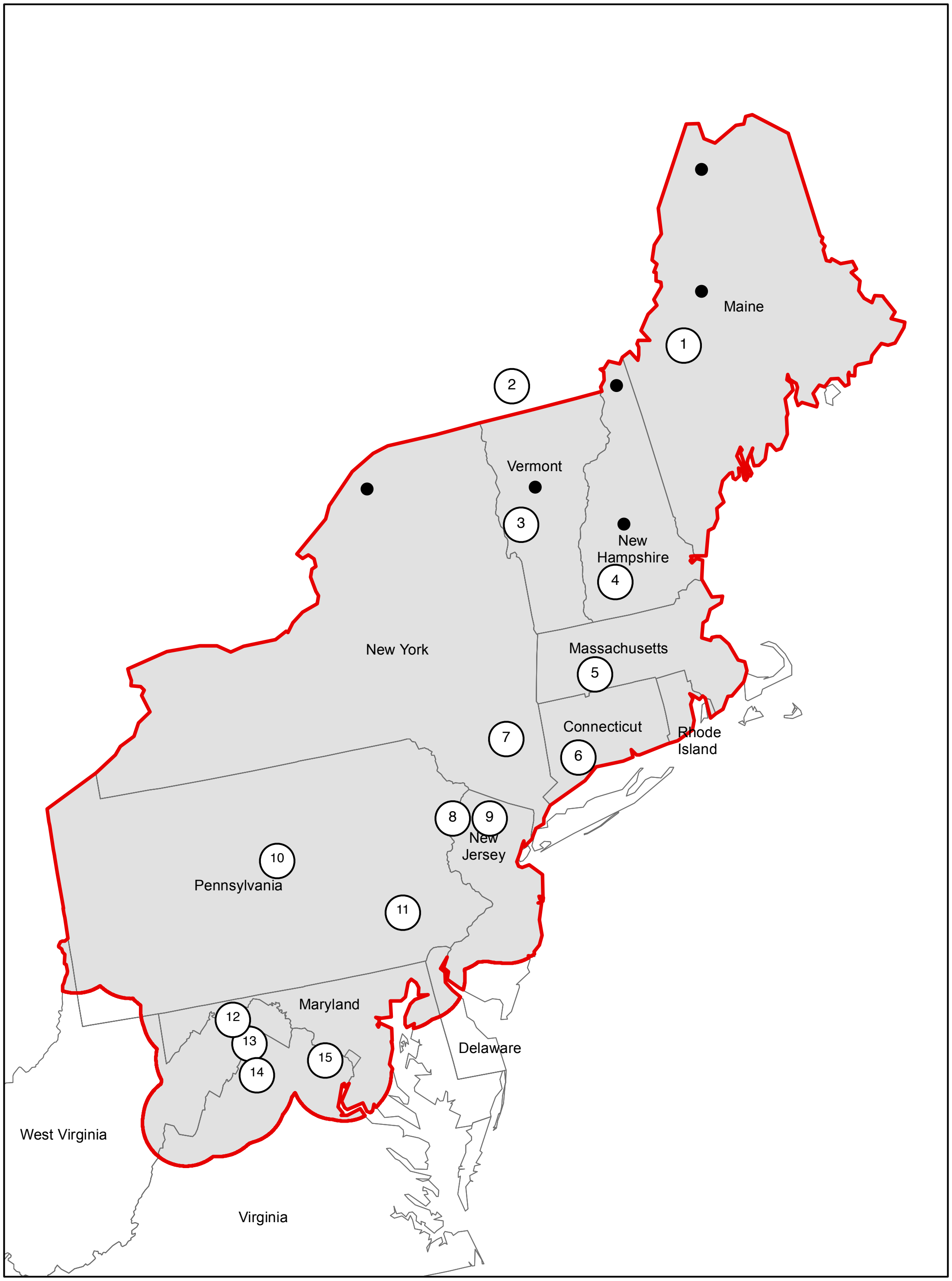

Figure 1. Intensive, long-term, or multi-site studies of wood turtle ecology in the Northeast Region: [1] Maine (Compton 1999; Compton et al. 2002), [2] southern Québec (Saumure 2004; Daigle and Jutras 2005; Saumure et al. 2007); [3] Vermont (Parren 2013); [4] New Hampshire (Carroll 1991, 1999; Tuttle and Carroll 2003; 2005; Jones 2009), [5] Massachusetts (Jones 2009); [6] Connecticut (Klemens 1993; Garber and Burger 1995), [7] New York (Carroll and Ehrenfeld 1978), [8,9] New Jersey (Harding and Bloomer 1978; Farrell and Graham 1991; Castellano 2008; Buhlmann and Osborn 2011), [10,11] Pennsylvania (Kaufmann 1992; Kaufmann 1995; Ernst 2001), [12] West Virginia (Niederberger 1993; Niederberger and Seidel 1999; Breisch 2006; Spradling et al. 2010); [13, 14, 15] Virginia (Akre 2002; Akre and Ernst 2006; Sweeten 2008). Black dots indicate intensive, multi-site, unpublished studies underway. Locations are generalized.

Table 1. Summarized morphometric data from throughout the wood turtle range. In each case, the number in parentheses indicates the number of turtles weighed.

		Females			Males			
State/ Prov.	Site	SCLmin (mm)	Mass (g)	*n*	SCLmin (mm)	Mass (g)	*n*	Source
QC	Mauricie	201.1±10.9	1083±168	83	214.5±4.2	1173±252	55	Walde et al. (2003)
QC	Brome Co.	181.0±5.51	881.7±92.91	12	193.9±9.0	1008±147	15	Saumure & Bider (1998)
QC	Pontiac Co.	200.5±11.6	1061±127	10	215.6±22.3	1219±361	9	Saumure & Bider (1998)
ON	Sudbury Dist.	195±5	1099±127	21(18)	205±19	1152±238	15(13)	Greaves & Litzgus (2009)
MI	Upper Pen.	182	-	105	200	-	86	Harding & Bloomer (1979)
ME	Aroostook Co.	189.1±8.5	1060±145	69	207.2±10.6	1231±156	60	Jones & Willey (2013b)
ME	Somerset Co.	181.1±7.5	1006±100	102	196.2±8.1	1114±119.2	51	Jones & Willey (2013b)
ME	Somerset Co.	193.7±10.3	1121±174	23(29)	201±13.2	1210±179	9(11)	B.W. Compton (unpubl. data)
NH	Coos Co.	184.3±8.6	973±126	37	200.4±10.1	1116±150	28	Jones & Willey (2013a)
NH	Grafton Co.	174.8±9.9	865.9±111	66	189.3±8.9	973±133	54	Jones & Willey (2013a)
MA	Conn. R.	171.8±7.67	875±121	83(12)	182±7.57	872±121	83(15)	Jones et al., unpubl. data
MA	Deerfield R.	170.9±7.0	830±37	37(14)	184.4±7.5	889±102	42(16)	Jones et al., unpubl. data
MA	Berkshire Co.	176.8±10.4	911±160	9(8)	185.4±6.27	939±91	18(16)	Jones et al., unpubl. data
MA	Westfield R.	172±7.6	854±96	64(19)	186±9.6	887±120	49(2)	Jones et al., unpubl. data
NJ	Passaic Co.	165	-	464	178	-	311	Harding & Bloomer (1979)
NJ	Sussex Co.	170.9±9.3	NA	49	177.0±8.9	NA	69	Farrell & Graham (1991)
VA	Fairfax Co.	185±9.5	NA	78	195±12.5	NA	43	Akre (2002)
WV	E. Panhandle	179±9.6	846.7±174	15	190.6±12.2	932±178	16	Breisch (2006)

Taxonomy and Nomenclature

The Wood Turtle is placed within the genus *Glyptemys* with a single congener, the Bog Turtle (*G. muhlenbergii*) of the central and southern Appalachian Mountains. The genus *Glyptemys* is placed within the subfamily Emydinae, which encompasses at least 11 species in the genera *Actinemys*, *Clemmys*, *Emydoidea*, *Emys*, and *Terrapene* of North America and Europe (Figure 4). The wood turtle was classified in the genus *Clemmys* (Ritgen 1828) for most of the 20th century (Strauch 1862, p. 104; Babcock 1919, p. 403). In the sense of McDowell (1964), *Clemmys* encompassed three North American species in addition to the wood turtle: the spotted turtle (*C. guttata*), bog turtle (*C. muhlenbergii*), and western (or Pacific) pond turtle (*C. marmorata*). Holman and Fritz (2001, p. 323) note that McDowell's arrangement of *Clemmys* was based on plesiomorphic (basal) rather than synapomorphic (derived) traits, including the

Figure 2. Appearance of the wood turtle. The carapace of the wood turtle is gray to brown to black when dry (A). Yellow radiating lines, vermiculate markings, or spots may be evident when the shell is wet (B–D). Turtles from iron-rich seeps are occasionally stained from iron oxide (E and J) and tannins may also discolor turtles. The wood turtle plastron is typically horn, cream, yellow, or white with bluish black pigment spots posteriolaterally on each plastral scute (F–H). Young turtles <15–20 years exhibit new growth as light-colored annuli near the plastral midline (H). Old adults may become completely worn and depigmented (I). The limbs and neck are orange, reddish, or yellow, and the head and outer forelimbs and tail are black (K and L). Some adults, especially males, exhibit a golden iris (L). Photos © Michael T. Jones

Figure 3. Male and female wood turtles are strongly dimorphic. Males are approximately 1.1 times larger in shell dimensions and approximately 1.2 more massive. A comparison of a female (L) and male (R) is provided in photo (A). Males have concave plastra (A and B) and large tails with the cloaca posterior to the margin of the carapace (B). Mature males have heads that are proportionally larger than females, and heavy scales on the forelimbs (C). Females have narrower heads and smaller scales on the forelimbs (D). Photos © Michael T. Jones

Figure 4. Hatchling wood turtles are gray or brown with a rough carapace, serrated posterior marginals, and relatively long tail (A). The plastron is mottled bluish-black, black, gray, yellow, or brown (B and E). Adult coloration of the limbs is evident within the first or second year of growth, as pictured in this two- year-old from Maine (C). A profile image of a submerged hatchling is presented in (D). A single clutch of Massachusetts hatchlings is shown in (E). Photos © Michael T. Jones

unhinged, buttressed plastron with bony bridges, and the lack of a scapular suspensorium as described by Bramble (1974). Beginning in the late 1980s, several authors critically explored the relationships within *Clemmys* (Gaffney and Meylan 1988; Lovich et al. 1991) and several authors subsequently provided evidence that the traditional genus *Clemmys* was made paraphyletic by not including the sister genera *Emys* and *Emydoidea* (which are more closely related to *Actinemys* [=*Clemmys*] *marmorata* than to either *G. insculpta* or *G. muhlenbergii*) and possibly also *Terrapene*; (Bickham et al. 1996; Burke et al. 1996; Lenk et al. 1999; Holman and Fritz 2001; Ernst 2001a; Feldman and Parham 2002; Seidel and Wood 2002; Stephens and Wiens 2003; Wiens et al. 2010; Fritz et al. 2011; see Crother 2012, p. 75). Burke et al. (1996) speculated on possible reconfigurations of the emydine taxa to reflect the clear paraphyly of *Clemmys*, including combining most species (except *G. insculpta* and *G. muhlenbergii*) into *Emys*, although this would have obscured clearly monophyletic lineages and distinct genera groups. Holman and Fritz (2001) and Feldman and Parham (2002) reassigned the wood turtle from *Clemmys* to *Glyptemys* (Agassiz 1857) and *Calemys* (Agassiz 1857), respectively. *Glyptemys* and *Calemys* occur on the same page in the original publication by Agassiz (1857, Vol. 1, p. 443), but because the former was selected by Holman and Fritz (2001), it was determined to be the correct genus for both species. Although the final taxonomic schemes reflecting the relationships within the Emydinae are contentious, concerns pertain primarily to the genera *Actinemys*, *Emydoidea*, and *Emys*, and all authors agree that the wood and bog turtles form a living monophyletic clade (Bickham et al. 1996; Burke et al. 1996; Lenk et al. 1999; Holman and Fritz 2001; Feldman and Parham 2002). For further discussion, see Crother (2012, p. 75). The genus *Glyptemys* is described by Holman and Fritz (2001, p. 324; combined from Ernst 1972; Ernst and Bury 1977; Ward 1980; Ernst et al. 1994 and unpublished data of Holman and Fritz) as follows:

> "*Glyptemys* Agassiz, 1857. Small to medium-sized turtles (shell length 8.0–22.5 cm), with an elongated, keeled carapace which may be serrated posteriorly. Premaxillary notch with adjacent tomiodonts. Foramen carotico-pharyngeale located anteriorly of articular condyles. Alveolar shelf with lateral ridge. Horney seams between submarginals and pectoral and abdominal scutes located on the hyo- and hypoplastron. Entoplastron elongated to bell-shaped. Xiphiplastral notch moderate to well-developed."

The type locality for *G. insculpta* is the northern United States, restricted to New York City vicinity by Schmidt (1953, p. 92). Synonyms follow (adapted and revised from Jones 1865, p. 118; Fowler 1906; Babcock 1919, p. 403; Ernst 1972, p. 125.1; Vogt 1981, p. 94; Bowen and Gillingham 2004, p. 5; Saumure 2013):

Emys pulchella	Sweigger 1814, p. 34
Emys scabra	Say 1825*, 210
Testudo insculpta	LeConte 1830, p. 112
Terrapene scabra	Bonaparte 1830, p. 157
Emys speciosa	Gray 1831, p. 26
Emys speciosa var. *levigata*	Gray 1831, p. 26
Emys inscripta	Gray 1831, p. 26
Emys insculpta	Harlan 1835, p. 152
Clemmys insculpta	Fitzinger 1835, p. 124
Clemmys insculpta	Strauch 1862
Geoclemys pulchella	Gray 1856, p. 18
Glyptemys insculpta	Agassiz 1857, p. 443
Glyptemys pulchella	Gray 1869, p. 196

Figure 5. Living representatives of the subfamily Emydinae include the "sculpted turtles" (Ernst and Lovich 2009): wood turtle, *Glyptemys insculpta* (A); and bog turtle, *Glyptemys muhlenbergii* (B); the pond turtles: Blanding's turtle (*Emydoidea blandingii*[C]), western pond turtle (*Actinemys marmorata* [D]), European pond turtle (*Emys orbicularis* [E]); the spotted turtle (*Clemmys guttata* [F]), and box turtles (*Terrapene* spp.) including the eastern box turtles (*Terrapene carolina* complex [G]); the western box turtles (*Terrapene ornata* [H]). All of the emydine species are of conservation concern because of perceived range contraction and population decline. Photos © Michael T. Jones

Chelopus insculptus	Cope 1875, p. 53
Clemmys insculpta	McDowell 1964
Glyptemys insculpta	Holman and Fritz 2001

* Storer (1840, p. 210) and Ernst (1972) report that Say's (1825) *E. scabra* synonymy is erroneous (misidentified and placed with *Testudo scabra* L.)

Habitat

Some of the earliest reports on the suitable habitats of wood turtles include those of LeConte (1829; p. 113). Holbrook (1838; p. 19) repeated LeConte's observation that the species resides in ponds and rivers, but frequently leaves the water. Storer (1840, p. 209) also claimed that the species "not uncommon in the ponds" of Massachusetts but that "this species wanders a great distance from, and remains a long time out of the water, and being oftentimes found in *woods* and *pastures*, has received the common name of *wood tortoise*." Thoreau (2009; many entries between 1855–1860)[2] provided some of the most detailed 19th century observations of wood turtle ecology, and was probably the first to notice wood turtles' localized preference for copious amounts of sand. By the mid- to late-19th century, many authors recognized the basic amphibious nature of wood turtle life history, including Thoreau (2009) in Massachusetts; Jones (1865; p. 118) in Nova Scotia (who reported *G. insculpta* as terrestrial but sometimes ventures into lakes); Allen (1868; p. 175) in Massachusetts; Huse (1901, p. 49) in New Hampshire, and Fowler (1906, p. 243) in New Jersey; although Surface (1908, p. 161) in Pennsylvania, reported that the species "is liable to be found in any habitat or haunt throughout its range where the conditions are suitable, or where there are damp leaves in rather secluded woods" and went on to report instances of turtles hibernating in "comparatively dry woods in Centre County." A complete summary of aquatic, upland, and nesting habitats (which together meet the essential requirements of overwintering, foraging, and reproductive habitat) follows.

General Landscape Considerations

The habitat requirements of wood turtles are complex but constant throughout the northeastern range. The range of habitats in which wood turtles are found from Maine to Virginia all meet the basic requirements for individual persistence, plus some degree of population development. Minor behavioral differences and differences in microhabitat selection may be noted by sex and age as well as geographic location, stream size, season, and upland habitat composition. But in all circumstances, in order to persist without long-term intensive management (which itself is clearly necessary at some locations), wood turtle populations must have access to stable overwintering locations in streams (see Overwintering, below), upland nesting areas (see Nesting Habitat Requirements, later), and varied upland habitats (including natural or anthropogenic early-successional clearings) for foraging and thermoregulation.

Streams in an intact and unfragmented mosaic of high-integrity riparian habitats including instream nesting areas, stream- or beaver-influenced early successional habitats, and temporary wetlands, juxtaposed with mixed-age floodplain and upland forest appear offer an ideal long-term management context. Because of the compound expenses of intensive management, unfragmented sites with necessary habitat components and minimal human use are most likely to provide cost-effective conservation outcomes. Further, wood turtle populations appear to respond to landscape alterations at multiple scales (see Part 4), suggesting that significant populations should be managed as part of much larger landscapes of low-intensity development.

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2 The Journals of Henry David Thoreau have been published in edited and unedited volumes. We have used the New York Review of Books' edition (Thoreau 2009), citing the entry date when appropriate.

It should be noted that the ideal habitat configuration outlined above is relatively rare on the Northeastern landscape, and to maintain the historic range of the wood turtle will clearly require targeted management actions to improve or replace key features that are missing from the landscape, or to artificially boost recruitment where threats to adult persistence and nest/juvenile survival have been addressed (see Part VI for a more in-depth discussion of management scenarios and landscape considerations).

Wetland and Stream Habitat Requirements

Almost all recent studies of known wood turtle populations report strong associations with slow-moving sections of clear, cold, woodland streams that otherwise have moderate to fast current, especially with sand, gravel, or rock substrate (Finneran 1948; Vogt 1981, p. 95; Quinn and Tate 1991, p. 219; Kaufmann 1992b; Holman and Clouthier 1995, p. 214; Akre 2002, pp. 3 and 13; Arvisais et al. 2004, p. 392; Ernst and Lovich 2009, p. 253; Table 2; Figure 6). Streams appear to be central to the persistence of most known wood turtle populations as they provide essential overwintering habitat (Vogt 1981, p. 95; White et al. 2010; White 2013; *see* Overwintering, later.). In northern areas, wood turtles are associated with rivers that have well-developed riparian zones encompassing alder swales, marshes, sedge meadows, emergent and forested wetlands (Quinn and Tate 1991, p. 217; Compton et al. 2002, p. 834; Walde et al. 2003, p. 378), but riparian swales and wetlands are critical throughout the region (Akre and Ernst 2006). In Wisconsin, wood turtles occur in forested areas along fast-moving streams (Vogt 1981, p. 95). Buhlmann and Osborn (2011, p. 317) report wood turtles from a typical stream in New Jersey: "flowing current, gravel bottom, deep pools, and undercut banks with overhanging trees," the latter of which provide stable overwintering sites. In Virginia, wood turtles are associated with clear brooks and streams (Ernst and McBreen 1991).

Stream size.—Although wood turtles appear to tolerate a wide range of streamflow conditions, they are most often associated with mid-sized streams between about 3 and 20 m wide (Brooks and Brown 1992 *in* Foscarini and Brooks 1997; Foscarini and Brooks 1997; Arvisais et al. 2004, Breisch 2006, p. 24; Akre and Ernst 2006; White 2013; *but see* detailed discussion in Part 3 and Table 2; illustrated in Figure 4). There are many published and anecdotal reports from smaller streams (Wright 1918, p. 55; Akre and Ernst 2006; Jones 2009; Dragon et al. 2012) and much larger streams (Niederberger 1999), and the extent to which wood turtles reside in both may be as much a function of the availability of key structural features (pools, logjams, cutbanks, riparian clearings; see Habitat Requirements, later) as past landuse history in the watershed. In a number of cases, wood turtles have been reported in associated with very large rivers (≥50 m wide), including major rivers in Ontario (Brown 1940), Québec (Denman and Lapper 1964, p. 20); Maine (Maine Department of Inland Fisheries and Wildlife, unpublished occurrence data 2011; J. Mays, ME IF&W, pers. comm.); central New Hampshire (New Hampshire Fish and Game Department, unpublished occurrence data 2011); Pennsylvania and New Jersey (New Jersey Fish and Wildlife, unpublished occurrence data, 2012; Pennsylvania Natural Heritage Program, unpublished data, 2012), Maryland (Cooper 1949; MacCauley 1955, p. 155; E. Thompson, MD DNR, pers. comm.; B. Cukla pers. comm. to S. Smith, MD DNR), Virginia (Henshaw 1907; Brady 1937; Akre and Ernst 2006; Akre, pers. comm.), and West Virginia (K. O'Malley, WV DNR, pers. comm.; T. Akre, pers. comm.). In many cases, wood turtles in large rivers appear to be associated with braided channels, sidearms, or tributary streams. Isolated occurrences have been documented in association with beaches of very large rivers in central Massachusetts, possibly representing nesting animals, although these may have originated from any of several smaller streams nearby (Massachusetts Natural Heritage and Endangered Species Program rare species database, 2012; Jones, unpublished data). A quantitative analysis of stream watershed area is presented in Part 3.

Stream substrate.—White (2013) reported wood turtles in Nova Scotia in association with primarily cobble stream substrate. Akre (2002, p. 13–14) reported that conditions along the same third-order tributary of the Potomac watershed in Fairfax County, Virginia varied from "clear, moderate-current" with "sand-gravel substrate" to "slow-flowing with suspended sediments and clay-gravel substrate." This stream flowed through the Piedmonth escarpment/fall line into the Potomac river floodplain, and the upper half, outside of the river floodplain, was clear and gravelly while the lower half was clay and often murky. The flow was often slowed down by the Potomac River volume backing up into the tributary (Akre, pers. comm.). Breisch (2006, p. 24) reports wood turtles in West Virginia in association with sand- and rocky substrates. However, Parren (2013, p. 183) points out that the population he studied was associated with calcareous bedrock and silt, and cautions that wood turtles likely tolerate a wide range of stream conditions. Jones and Willey (unpublished data) observed Massachusetts, New Hampshire, and Maine wood turtle stream locations (n=5125) dominated by wide range of stream substrates including organics and muck (3.1%), clay (0.3%), silt (3.6%), silty sand (14%), sand (40.5%), gravel (14.3%), cobble (17.2%), boulders (6.4%), and bedrock (0.3%).

Use of tidal wetlands and estuarine creeks.— Wood turtles have not been reported from brackish habitats, but there is evidence that individual wood turtles occasionally occur in freshwater tidal wetlands. For example, an unusual metapopulation may occur along both banks of the fresh-tidal Hudson River in New York near Dutchess, Greene, and Columbia counties, where a dozen individual turtles were observed in tidal marshes and islands in the Hudson River by researchers during long-term monitoring in the 1980s and 1990s (Kiviat and Barbour 1996). The animals reported here may represent flood-displaced individuals from farther up the Hudson River or the smaller tributaries nearby, or they may represent functional populations. It is possible that a similar arrangement exists, or existed, in tributaries of the Parker River estuary of Essex County, Massachusetts (P. Huckery, Massachusetts Division of Fisheries and Wildlife, pers. comm. to L. Willey; D. Taylor pers. comm. to T. French, Massachusetts Division of Fisheries and Wildlife, *in* Kiviat and Barbour 1996). In New Jersey, there is at least one wood turtle record from Beverly, Burlington County, in the lower watershed of the Delaware River (Street 1914), and there are two historic records from 1933 and 1951 from the vicinity of Rancocas Creek, in the records of the New Jersey Endangered Species Program (New Jersey Division of Fish and Wildlife 2012). Records from the mouth of the Susquehanna River in Harford County, Maryland (Cooper 1949) may represent individuals from populations associated with tidally-influenced streams or smaller side streams, and several of the streams on Elk Neck, Cecil County, Maryland, where wood turtles were documented between the 1950s and 1970s, are in close juxtaposition with tidal estuaries and wood turtles likely had access to tidal systems in recent decades. It is possible that wood turtles once occurred in the lower Potomac River in Maryland and Virginia nearly as far as the tidal mouth (Akre, pers. comm.; Akre and Ernst 2006), and in northeastern Virginia historic occurrences in coastal creeks may have encompassed tidal stream reaches (Akre, pers. comm.).

Springs, vernal pools, seeps, and temporary wetlands.—Many authors have observed the tendency of wood turtles to exploit the seasonal availability of vernal pools and ephemeral wetlands (Mitchell et al. 2008, in Calhoun and deMaynadier 2008, p. 172). In Maryland, wood turtles have been reported from a mountain spring in the Catoctin Mountains (Reed 1956, p. 80), and Abbott (1884, p. 254) provides an account of three wood turtles congregating at a forest spring near Trenton, Mercer County, New Jersey. Breckenridge (1958, p. 169) reports wood turtles in "spring holes" and "woods ponds," as well as wooded streams, in Minnesota. Surface (1908, p. 161) recounts an individual wood turtle in Centre County, Pennsylvania hibernating on a wooded hillside "with a temporary pool only a few yards away". Akre and Ernst (2006) report consistent use of seepage areas in deciduous forest in Virginia and report that small wetlands may

Figure 6. Wood turtles overwinter primarily in clear, cold, sand-, gravel-, or rock-bottomed streams. Stream habitats depicted in spruce-fir forest in northern Maine (A); red maple-white pine upland forest in central New Hampshire (B); abandoned agricultural land in central Vermont (C); spruce-fir forest in western Massachusetts (D), deciduous floodplain forest in northern New Jersey (E); river birch-sycamore-American elm floodplain forest in northern West Virginia (F); and mixed pine-oak upland forest in northern West Virginia (G). Photos © Michael T. Jones

be attractors on the landscape. Occasional use of vernal pool habitats was reported from Northampton County, Pennsylvania, and Westchester County, New York by S. Angus (unpublished data). In Massachusetts and New Hampshire, 80 of 7348 active season radiolocations (1.1%) were within vernal pool habitat, and 117 (1.6%) were within 5 m of vernal pool habitat (M. Jones, L. Willey, and P. Sievert, UMass, unpublished data). Springs, seeps, and vernal pools appear to be complementary landscape features that do not support overwintering populations.

Use of channelized rivers and canals.—Multiple individuals have been recorded from an 1890s canal system in Hampshire County, Massachusetts (Massachusetts Division of Fisheries and Wildlife, Natural Heritage and Endangered Species Program, unpublished occurrence data, 2012), and wood turtles may be associated with portions of the Chesapeake and Ohio Canal system in Maryland (T. Akre, pers. comm.).

Use of lakes, ponds, and reservoirs.—Although many early authors reported the wood turtle to frequent or reside in lakes or "ponds," this statement appears to be suppositional or erroneous (see Logier 1939). For example, Jones (1865, p. 118) reported use of lakes in Nova Scotia. As frequently reported, the wood turtle appears to be a stream obligate species in the winter months. However, there are several instances in which wood turtles have been found in association with lakes and ponds. There are wood turtle element occurrences associated with several large lakes in Québec (Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs, unpublished data), and Quinn and Tate (1991, p. 218) presented evidence by at least one individual of seasonal lake use in Ontario (although they stated that most aquatic habitats were streams). There are other numerous records primarily of single animals on roads near lakes in Maine and New Hampshire (Maine Department of Inland Fisheries and Wildlife, unpublished data; New Hampshire Department of Fish and Game and New Hampshire Natural Heritage Bureau, unpublished data; M.T. Jones, unpublished data). In Monroe County, Pennsylvania, two wood turtles (one of them dead) were observed in the fall near the outlet of a small reservoir, and the living one was recaptured in March of the following year (S. Angus, pers. comm.), suggesting that the animal had overwintered in the muck-bottomed reservoir. One of the clearest examples of a wood turtle population overwintering in a lake or reservoir environment is from Huntingdon County, Pennsylvania, where a population of wood turtles, including juvenile and young adults, overwinters in a cove of a large reservoir created in the 1970s (R. Nagle, Juniata College, pers. comm.). Whether the cove is spring-influenced or hydrologically distinct from surrounding areas of lakeshore is unknown. A head-started wood turtle overwintered in a manmade pond at Great Swamp NWR in 2012–2013 (C. Osborn, pers. comm.). In Bergen County, New Jersey, one very old female was found nest-searching near the edge of the Monksville Reservoir (and other wood turtles were observed in the area; R. Farrell, Herpetological Associates, pers. comm.). In Franklin County, Massachusetts, Jones and Sievert (2009) and Jones (2009) reported that a subpopulation of wood turtles resided in the catchment area behind an 1890s power dam that had largely silted in, although radiotracked turtles primarily used riverine and riparian features within the old reservoir area.

pH.—Most authors do not report stream pH associated with wood turtle sites (but see Parren 2013), and it is not known the extent to which stream pH influences the distribution or abundance of wood turtles.

Table 2. Summarized characteristics of streams with known wood turtle populations.

Stream Characteristics						
State	**Site**	**Width (m)**	**Depth**	**Substrate**	**Other features**	**Source**
QC	Mauricie	5–10	up to 2 m	sandy to rocky		Arvisais et al. (2002)
NS	Cape Breton	~8	~0.2–2.0	clay, gravel	Gravel bar	Gilhen & Grantmyre (1973)
WI	Wisconsin R.	3–5	0.3–1.5	sandy		Ross et al. (1991)
ME	Aroostook Co.	24–34	-	sand, gravel, cobble		Jones & Willey (2013b)
ME	Somerset Co.	20–27	>2 m	clay, silt, sand, gravel		Jones & Willey (2013b)
NH	Coos Co.	13–15	>1.5 m	silt, sand, and gravel		Jones & Willey (2013a)
NH	Coos Co.	12–15	>1.5 m	sand and gravel		Jones & Willey (2013a)
NH	Grafton Co.	7–10	>1.5 m	sand and gravel		Jones & Willey (2013a)
NH	Grafton Co.	11	>2.5 m	silt, sand, gravel		Jones & Willey (2013a)
VT	Addison Co.	4.5–12	-	silt, gravel, cobble, rock, boulder	≤1% gradient	Parren (2013)
CT	New Haven Co.	4–5	1–1.5			Garber & Burger (1995)
NJ	Morris Co.	4–6	-	gravel	Pools; undercut banks, large trees	Buhlmann & Osborn 2011; Buhlmann, pers. comm.
PA	Centre Co.	5–10	up to 1.5	-		Kaufmann (1995)
VA	Frederick Co.–Shenandoah Co.	3–13	0.1–2.5	silt, sand, gravel, cobble, bedrock	Fairly straight stream with wide floodplain	Akre & Ernst (2006)
VA	Frederick Co.	1–5	0.05–2.0	silt, sand, gravel, cobble, boulders	Narrow floodplain and steep slopes	Akre & Ernst (2006)
VA	Loudoun Co.	5–20	0.1–3.0	silt, sand, gravel, cobble	Variable floodplain width	Akre & Ernst (2006)
VA	Fairfax Co.	2–4	0.1–2.0	clay, silt, sand, gravel	third order	Akre 2002; Akre, pers. comm.

Terrestrial Habitat Requirements

Upland and floodplain habitats used by wood turtles varies by geographic region, season, and spatial scale (Harding and Bloomer 1979; Strang 1983, p. 43; Quinn and Tate 1991; Compton 1999; Compton et al. 2002; Walde et al. 2003; Arvisais et al. 2004; Jones 2009). It is clear from corroborating studies that wood turtles are often found using upland mosaics of forested and nonforested habitats. Compton et al. (2002) suggested that forest edges may provide opportunities to balance thermoregulation and food requirements.

Forest tree species composition.— Across their range in the Northeast region wood turtles are found in a broad range of forest ecoregions and canopy associations (Table 3). Forest associations range from spruce-fir (*Picea glauca, P. rubens, P. mariana*, and *Abies balsamea*) forests and northern hardwood (*Betula* spp., *Acer saccharum, Fagus grandifolia*) associations of northern New England, the Berkshires, and the Adirondacks, to extensive pine and northern hardwood forests of Ontario and the Great Lakes, to Appalachian forests in Virginia, West Virginia, and Maryland in which sycamore (*Platanus occidentalis*), river birch (*Betula nigra*), tulip poplar (*Liriodendron tulipifera*) are abundant in floodplains and oaks (*Quercus* spp.), hickories (*Carya* spp.) and pines (*Pinus* spp.) dominate on adjacent hillsides. Local topography can drive forest composition, including the degree to which floodplain tree species such as silver maple (*Acer saccharinum*), sycamore, and river birch dominate over upland species such as oaks, hickories, and pines. The most common tree genera reported from floodplains and adjacent upland forests near streams with wood turtles are presented in Table 3.

At broad spatial scales, wood turtles are associated with a range of early and late-successional habitats of the eastern deciduous and mixed forests of the southern boreal zone. Quinn and Tate (1991, p. 217) reported that wood turtles in Ontario occur in mixed woods associations of white and red pine (*Pinus strobus* and *Pinus resinosa*), poplar (*Populus* spp.), white birch (*Betula papyrifera*), red maple (*Acer rubrum*), and red oak (*Quercus rubra*), but at finer scales were found frequently in speckled alder (*Alnus rugosa*) swales (30% of terrestrial observations), mixed forest (28%), and grassy openings (12%). In the Mauricie region of Québec, Walde et al. (2003, p. 378) reported wood turtles from the boundary of the boreal/Great Lakes St Lawrence lowland forest (Farrar 1995), where forests are dominated by white spruce (*Picea glauca*), white birch (*Betula papyrifera*), and aspen (*Populus tremuloides*) and floodplains are dominated by speckled alder. Arvisais et al. (2004, p. 392) reported a largely forested mosaic of balsam fir (*Abies balsamea*), poplar, birch, and spruce, with alder near watercourses, in which wood turtles were strongly associated with alder stands and young (16 years) forest. In an agricultural area of southern Québec (Brome County), Saumure and Bider (1998) reported extensive hay fields and cattle pastures juxtaposed with forest dominated by box elder (*Acer negundo*), American elm (*Ulmus americana*) with willows and speckled alder prevalent. At a largely forested site in southern Québec (Pontiac Co.), Saumure and Bider (1998) report undisturbed floodplain forest dominated by balsam fir, white spruce, aspen, and alder. In Nova Scotia, White (2013) describes a mixed agricultural and forested landscape, with forests dominated by northern hardwood species such as yellow birch (*Betula alleghaniensis*), red maple, white birch, red oak, and black cherry (*Prunus serotina*) with some white pine, balsam fir, and hemlock (*Tsuga canadensis*), and open riparian areas dominated by alder, cherry, elder (*Sambucus* sp.), hawthorn (*Crataegus* sp.), serviceberry (*Amelanchier* sp.), and raspberries (*Rubus* spp.). On Cape Breton Island, Gilhen and Grantmyre (1973) report a mosaic of hayfields, alder, and meadows.

Compton (1999, p. 33) and Compton et al. (2002, p. 834) reported a population in western Maine associated with mixed and coniferous industrial forest. In western Vermont, Parren (2013) reported that his study site was divided amongst the Mesic Clayplain Forest (in floodplain areas) and northern hardwood forest (upland areas). Jones (2009, p. 59–60; unpublished data) reported on populations in central New England occurring in both agricultural landscapes (including dairy farms, hayfields, and row crops) and forested landscapes dominated by upland spruce-fir, northern hardwoods (*Betula alleghaniensis, Acer saccharum,* and *Fagus grandifolia*) and transition hardwoods, and extensive floodplain forests (associated with larger rivers) dominated by silver maple (*Acer saccharinum*). Wood turtles in New Haven County, Connecticut, were associated with streams in central hardwoods forest (Garber and Burger 1995). In Sussex County, New Jersey, Farrell and Graham (1991, p. 1) reported on a population of wood turtles occurring in a mosaic of agricultural land, wet meadows, open pasture, and deciduous fores, and in Morris

County, New Jersey, Buhlmann and Osborn (2011, p. 317) reported wood turtles from a stream bordered by “riparian hardwood forest” and abandoned pastures with blackberry (*Rubus* sp.) and invasive multiflora rose (*Rosa multiflora*). In Warren County, New Jersey, Castellano et al. (2008) reported wood turtles from a deciduous forested landscape interspersed with row crop agricultural fields. In Cumberland County, Pennsylvania, Strang (1983, p. 43) reported wood turtles in lowland areas dominated by oaks (*Quercus* spp.), black birch (*Betula lenta*), and red maple, and in Centre County, Pennsylvania, Kaufmann (1992a) reported little use of deciduous forest. In eastern Virginia, Akre (2002) reported wood turtles from a third order stream near the Potomac River in floodplain forests dominated by red maple, tulip polar (*Liriodendron tulipifera*), ironwood (*Carpinus caroliniana*), pawpaw (*Asimina triloba*), river birch (*Betula nigra*), and sycamore; and red maple, sycamore, box elder (*Acer negundo*), slippery elm (*Ulmus rubra*), and ashes (*Fraxinus* spp.). At a site in Loudoun County, Virginia, Akre and Ernst (2006) report typical assemblages of southern floodplain hardwoods (Table 3) but also note the present of a relatively rare co-occurrence of wood turtles with the Piedmont Hardpan Forest, which includes Virginia pine (*Pinus virginiana*), eastern redcedar (*Juniperus virginiana*), small oaks, hickories, redbud (*Cercis canadensis*), and sweetgum (*Liquidambar styraciflua*). At a complex of sites in Shenandoah and Frederick counties, Virginia, Akre and Ernst (2006) report that sycamore, red maple, and tulip poplar are common in the floodplain, while oaks and hickories occur on undisturbed floodplain sites and adjacent slopes, where they occur with Virginia pine and pitch pine. White pine is present throughout the site complex. In northern West Virginia, Breisch (2006, p. 24) reported wood turtles from a forested stream with floodplain canopy consisting of sycamore, red maple, river birch, and rhododendron (*Rhododendron* sp.) Elsewhere in West Virginia, Niederberger (1993) describes a similar floodplain forest of sycamore, tulip poplar, and red maple, with red maple, black walnut (*Juglans nigra*) and hickory (*Carya* spp.) increasing at the “outer edge” of the riparian area. The floodplain forest gives way in places to open, savanna-like pastures with black walnut canopy and understory dominated by orchard grass (*Dactylis glomerata*) and other herbs.

The American chestnut (*Castanea dentata*) once reached great densities in the Appalachian forests from Maine to Virginia and undoubtedly was a prominent feature in wood turtle community ecology before its collapse from the chestnut blight in the early 20th century.

Nesting Habitat Requirements

The wood turtle requires open, well-drained, elevated, exposed areas of sand and/or gravel for nesting (Akre and Ernst 2006; Ernst and Lovich 2009; Jones 2009; Akre 2010), although appropriate nesting areas vary by geographic region (Figure 7–9). Over much of their range, wood turtles preferentially select nesting sites in coarse alluvium, poorly graded sand, or fine to medium gravel (Akre and Ernst 2006; Walde et al. 2007, p. 50) and sandy loam associated with a very wide range of natural and anthropogenic sites.

Common natural features include sandy point bars on the inside bends of rivers (Buech et al. 1997; J. Harding, Michigan State University, pers. comm.; Saumure and Bider 1998, p. 38; Jones 2010; Parren 2013, p. 180), cutbanks on the outer bend of rivers (Buech et al. 1997); sand and gravel bars deposits in the stream channel associated with stream obstructions, constrictions, or directional changes in flow (Gilhen and Grantmyre 1973; Vogt 1981, p. 96; Compton 1999; Akre 2002; Akre and Ernst 2006; Jones 2009; Parren 2013), and areas of overwashed sand in open floodplains (M.T. Jones and L.L. Willey 2013a) and dry stream beds (Graf et al. 2003; Jones 2008).

Anthropogenic sites include: abandoned, stable, or infrequently disturbed portions of sand and gravel pits (Compton 1999, p. 75; Tuttle and Carroll 2005; Walde et al. 2007, p. 50); gravel boat ramps (Compton 1999; Compton, pers. comm.); powerlines (Jones 2009; Akre 2010); roadsides and roadcuts (Saumure and Bider 1998, p. 38; Akre 2010; Akre et al. 2012); farm roads near streams (Jones 2009; Parren 2013),

Table 3. Canopy tree genera associated with forested habitats near Wood Turtle overwintering streams.

State	Site	*Abie*	*Pice*	*Pinus*	*Tsuga*	*Acer*	*Plantanus*	*Liriodendro*	*Betula*	*Populu*	*Quercus*	*Ulmaceae*	*Prunus*	*Caryacea*	*Fraxinus*	Source
		s	*a*					*n*		*s*				*e*		
QC	Mauricie		x		x				x	x						Walde et al. 2003
QC	Mauricie	x	x						x	x						Arvisais et al. 2002; 2004
QC	Brome Co.					x						x				Saumure and Bider 1998
QC	Pontiac Co.	x	x							x						Saumure and Bider 1998
ON	Algonquin			x		x			x	x	x					Quinn & Tate 1991
NS	Cape Breton											x	x			Graf et al. (2003)
NS	Mainland	x		x	x	x			x		x		x			White (2013)
ME	Aroostook Co.	x	x			x			x	x		x			x	Jones and Willey (2013b)
ME	Somerset Co.	x	x			x			x			x				Jones and Willey (2013b)
NH	Coos Co.	x	x			x			x			x				Jones and Willey (2013a)
VT	Addison Co.				x										x	Strang (1983)
MA	Western MA	x	x	x	x	x	x		x		x	x	x	x	x	Jones (2009)
CT	New Haven Co.					x					x			x		Strang (1983)
NJ	Warren Co.					x					x			x		Castellano et al. (2008)
PA	Cumberland Co.					x			x		x					Strang (1983)
PA	Monroe County				x						x					Angus (unpubl. data)
VA	Sites A–C			x	x	x	x	x	x	x	x		x	x	x	Akre and Ernst (2006)
VA	Loudon Co.					x	x	x			x	x		x	x	Akre and Ernst (2006)
VA	Fairfax Co.					x	x	x	x			x			x	Akre (2002)
WV	E. Panhandle					x	x		x							Breisch (2006)
WV	Cacapon R.					x	x	x					x			Niederberger (1993)

abandoned railroad beds (Vogt 1981, p. 95; Farrell and Graham 1991, p. 4), active rail beds (J. Foley, pers. comm.), gravel and cobble piles (Akre and Ernst 2006); sandy pastures (Jones 2009); junkyards and outdoor storage areas with sand piles (Jones 2009); golf course sand traps (Jones 2009), cornfields (Castellano et al 2008; Jones 2009). Of 52 nests primarily detected by radiotelemetry in Massachusetts and New Hampshire (Jones 2009, p. 156), 35% were deposited on beaches along the stream in which the turtle over-wintered, 27% were deposited in gravel pits, 19% were deposited on sand piles or along dirt roads in pastures, 4% were deposited under powerlines, and 2% each were deposited along dirt roads and in a corn field.

Wood turtles also use nesting areas anthropogenically created specifically for turtle nesting. At a site in Morris County, New Jersey, Buhlmann and Osborn (2011) created an artificial nesting mound 18 m long x 8 m wide x 1.5 m tall, 50 m from an occupied wood turtle stream and 100 m from a confirmed nesting site threatened by development. In Sussex Co., New Jersey, a >50 year old gravel extraction area was purposefully managed to improve suitability for nesting wood turtles (T. Duchak and R. Burke, Hofstra University, pers. comm.). Akre et al. (2012) and Dragon et al. (2012) proposed that roadcut banks may function as ecological traps on the George Washington National Forest in northwestern Virginia, where wood turtles occur in small, forested stream systems with limited natural nesting areas. Here, wood turtles nesting on well-drained substrates with some elevation above the surrounding landscape, in areas with good solar exposure and strong southern aspect (Akre 2010). Compton (1999, p. 76) also questioned whether anthropogenic nesting areas in Maine may function as ecological traps.

Paterson et al. (2012) reported that the selected, open upland habitats of hatchling wood turtles in Algonquin Park, Ontario, were encompassed by the larger-scale nesting areas of adults.

Of 52 nests reported by Jones (2009, p. 156) in Massachusetts, 64% were deposited in sand, 29% were deposited in mixed sand and gravel; 6% were deposited in organic materials or mixed organics and sand, and 2% were deposited in gravel.

Vascular plants associated with wood turtle nesting areas in New Hampshire include sweetfern (*Comptonia peregrina*), field hawkweed (*Hieracium pratense*), little bluestem (*Schizachyrium scoparium*), and goldenrods (*Solidago* spp.; Tuttle and Carroll 2005).

Associated Turtle Species

Although the wood turtle often co-occurs with the painted turtle (*Chrysemys picta*) at the watershed scale throughout the range of the former, the two species are usually found using different aquatic habitats within a given watershed (Harding and Bloomer 1979). Still, because of its widespread abundance, the painted turtle is probably the turtle species most often found in association with wood turtle populations in the northeastern States. The snapping turtle (*Chelydra serpentina*), because of its wide range of habitat tolerances, is perhaps the second most likely to co-occur with wood turtles in the Northeast. In fact, across most of northern New England and eastern Canada the wood turtle is likely to co-occur only with the painted turtle and the snapping turtle, and in northern Coos County, New Hampshire, and northwestern Maine, the wood turtle is sometimes the only turtle species present in a given stream system. In central New Hampshire, Carroll (1991; 1999; pers. comm.) reports that wood turtles co-occur in a diverse wetland mosaic with spotted, Blanding's, painted, and snapping turtles; elsewhere in central New Hampshire wood turtles occur frequently with painted and snapping turtles (Jones 2008; unpubl. data). Historically in the deltas of certain large rivers of northern Lake Champlain, wood turtles likely co-occurred with common map turtles (*Graptemys geographica*) and spiny softshells (*Trionyx spiniferus*). Similarly in parts of central and southwestern Wisconsin, wood turtles co-occur with spiny softshells as well as map turtles (*Graptemys* spp.) and Blanding's turtles (*Emydoidea blandingii*). In Massachusetts, the wood turtle occurs frequently

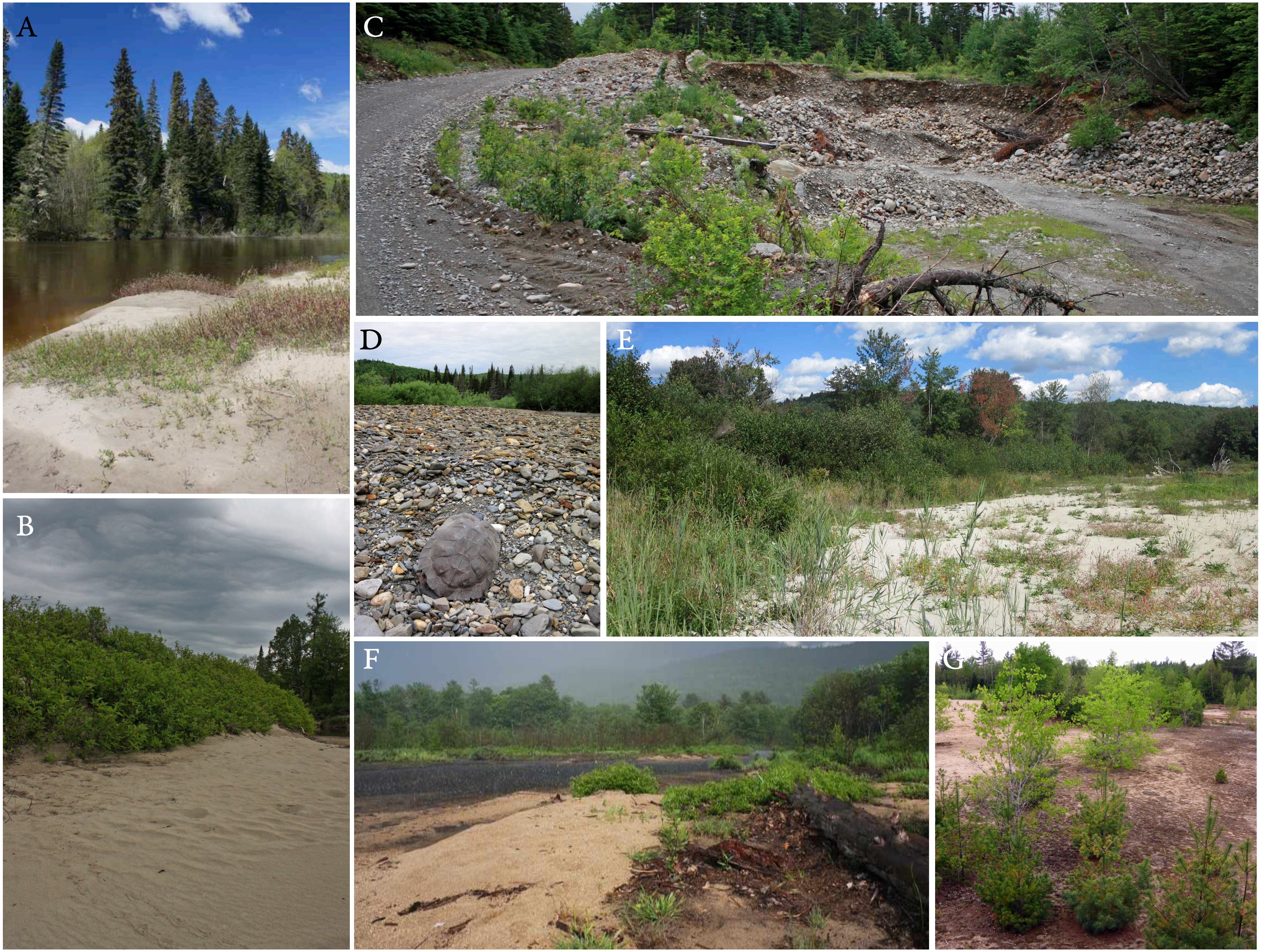

Figure 7. Wood turtle nesting areas in the northern Appalachians. Wood turtles nest primarily in poorly graded sand and gravel, as pictured here on natural river point bars in northern ME (A and B); an abandoned gravel pit in western ME at Compton's (1999) study site (C); a gravel and cobble bar in northern NH (D); a 0.2 ha area of overwashed flood-deposited sand in central NH (E); a sandy delta beach above a hydroelectric reservoir in central NH (F); an abandoned, sand and gravel quarry in central NH (G). Photos © Michael T. Jones and Lisabeth L. Willey

Figure 8. Wood turtle nesting areas in Massachusetts (Jones 2009). Sand pile in farm junkyard (A); powerline near river (B); sand traps in golf course (C); abandoned gravel pit rapidly becoming unsuitable as a result of gray birch and alder colonization (D); overwashed sand associated with major floods in sycamore-dominated floodplain (E); motorbike jumps in horse pasture (F). Photos © Michael T. Jones and Lisabeth L. Willey

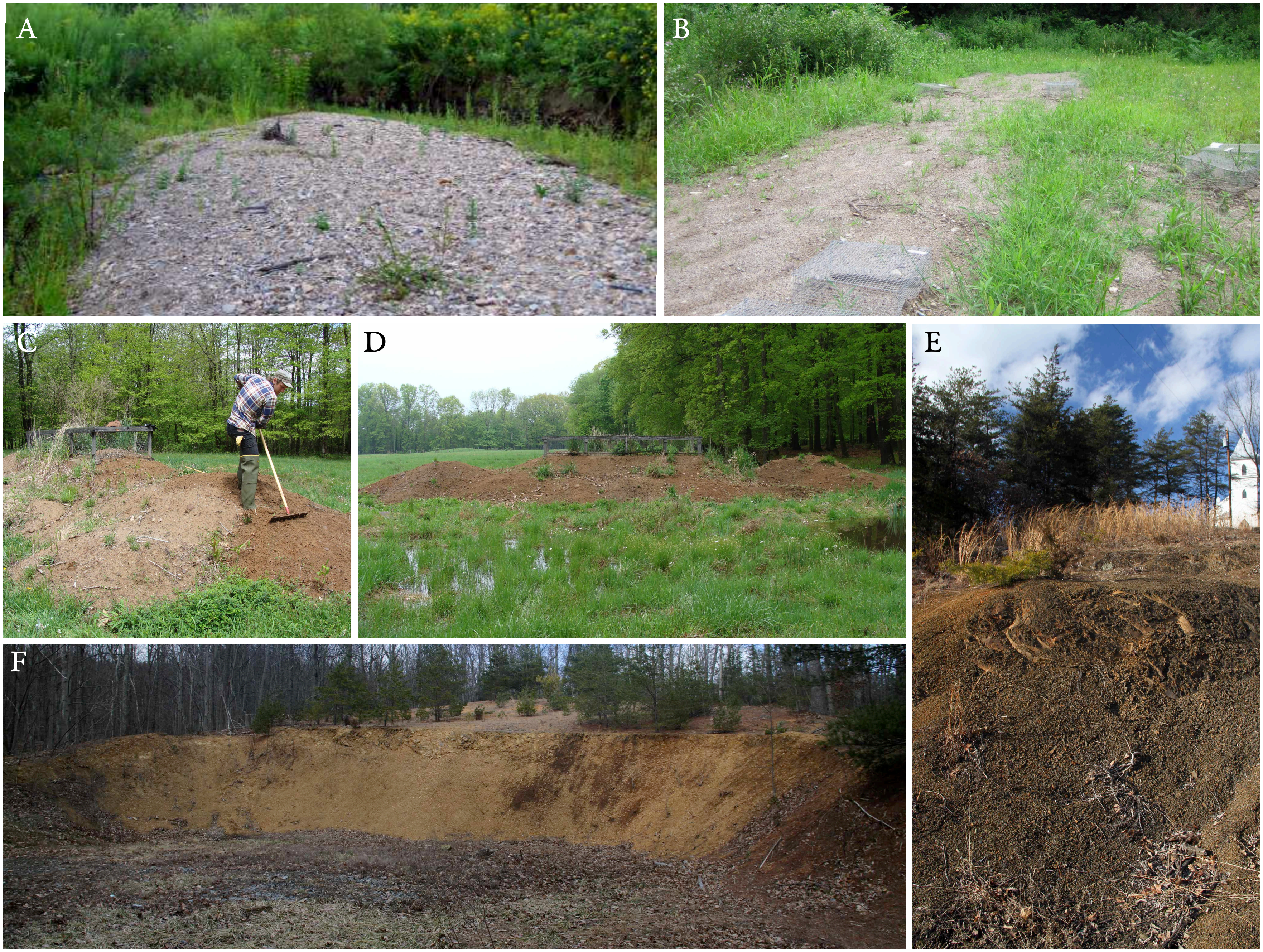

Figure 9. Nesting habitat for the wood turtle in southern New England and the Mid-Atlantic. Nesting habitat in Connecticut, an instream gravel bar (A; Photo by John Foley). A number of sites have been successfully managed to encourage nesting by wood turtles in New Jersey, including a former sand and gravel extraction site that was cleared and has become the primary nesting site at the study site of R. Burke and T. Duchak (B) and a 18 m x 8 m x 1.5 m tall nesting mound was constructed by the U.S. Fish and Wildlife Service in Morris County, New Jersey (C and D; Buhlmann and Osborn 2011; Photos by Colin Osborn). Adjacent to the George Washington National Forest of Virginia, wood turtles nest in powerline cuts (E). On the GMNF, wood turtles nest in roadcuts and borrow pits (F; Akre 2010; Akre et al. 2012). Photos © John Foley (CT), Colin Osborn (NJ), and Michael Jones

with painted and snapping turtles, often sharing nesting sites, and less often in the same wetland complexes as spotted (*Clemmys guttata*), bog (*Glyptemys muhlenbergii*; A. Whitlock, USFWS, pers. comm.), eastern or woodland box (*Terrapene carolina*), and Blanding's turtles (Jones and Willey, unpublished data). In Morris County, New Jersey, the wood turtle uses the same nesting areas as the snapping turtle, musk turtle (*Sternotherus odoratus*), painted turtle, and eastern box turtle (Buhlmann and Osborn 2011). In Sussex County, New Jersey, wood turtles co-occur with these species as well as bog and spotted turtles (R. Farrell, Herpetological Associates). Wood turtles seasonally inhabit calcareous fens with bog and spotted turtles in Sussex and Warren counties, New Jersey; southern Orange, Dutchess, and Putnam counties, New York; and Northampton and Monroe counties in Pennsylvania (S. Angus, pers. comm.). In eastern Pennsylvania, wood turtles co-occur in stream systems with spotted, bog, box, and snapping turtles (K. Gipe, PFBC, pers. comm.), and occasionally musk turtles in Berks County (J. Drasher, Aqua-Terra Environmental Ltd.). In northern West Virginia, Wood Turtles co-occur with Eastern Box Turtle (K. O'Malley, WV DNR, pers. comm.). In western Maryland, the Wood Turtle co-occurs with Eastern Box Turtle and in Virginia, the Wood Turtle co-occurs with the eastern box turtle as well as common musk turtle (*Sternotherus odoratus*; T. Akre, Smithsonian Conservation Biology Institute, pers. comm.; J. Dragon, George Mason University, pers. comm.).

Movements

Home Range Sizes

Comparing reported home range values is complicated by the wide variety of home range metrics reported, including both area and linear measurements, and by variable telemetry effort. Meta-analysis of home range data is further complicated by strong annual effects and the tendency to report mean rather than median values, which are more sensitive to individual effects (Saumure 2004; Jones 2009, B.W. Compton, pers. comm.). Meta-analyses of the influence of landscape on home range size is now complicated by the ingrained practice of withholding site location information (Litzgus and Brooks 1996). Arvisais et al. (2002, p. 406) and Smith (2000) noted that home range size in northern populations appeared to be larger than in southern populations; this observation was supported by data collected in western Maine (B.W. Compton, unpubl. data). Saumure (2004) observed that wood turtles at his disturbed, agri-forested site in southern Québec moved less than those observed by Arvisais et al. (2002) in a more intact forested landscape in the Mauricie region of Québec. Both observations have roughly been supported by subsequent studies (e.g., Jones 2009), and both phenomena have conservation implications. Certainly, it is ideal to obtain empirical data on the movements of individual turtles at key conservation sites.

Saumure (2004, Chapter 3) proposed standardized home range metrics into three categories: integral (100% minimum convex polygon [MCP]); statistical (95% MCP [locations most distant from harmonic mean are removed]), and linear (straight-line distance between the two most widely separated capture locations). In the following summary, we analyze the area and linear space of wood turtles representative studies throughout the range, using "statistical" range as an estimate of the total area required in a given year, and "linear" range to estimate the linear space requirements. While these measures capture the differences between sites and individuals and shed light on the influence of landscape on movement patterns, they do little to provide regulators with distance data necessary for adequate habitat mapping. The distance traveled along stream corridors has regulatory and biological significance, as does the distance traveled from streams (Jones 2009).

Statistical Range.—Statistical ranges (MCP 95%) of males are typically larger, although the difference is typically not reported to be significant. The mean value of thirteen averaged statistical ranges for males is 18.2 ha (0.3–32.2 ha). The mean value for females from the same studies is 11.6 ha (0.5–29.4 ha; Table 4).

Linear Range.—The linear range, or greatest distance between recorded locations in one year, of males is typically larger than that of females, driven in part by their tendency to use larger lengths of stream. The mean value of averaged linear home ranges from seven studies is 1028 m (481–1531 m) for males and 647 m (435–866 m) for females (Table 4).

Stream Range.—Males spend more time than females in streams during the active season (Akre 2002), and correspondingly have longer stream ranges. Several authors have reported that male wood turtles use greater stream lengths than females. Parren (2013) reported that females have a stream range of 659±563 m (range=130–1602 m; *n*=5), slightly less than males (760±445 m; range=287–1521 m; *n*=6), but the difference was not significant. From a sample of 123 adult turtles in Massachusetts and New Hampshire, Jones (2009; unpublished data) reported that males have a stream home range of 1422±1295 m (range=221–6304 m; *n*=56) and females exhibited stream ranges of 757±814 m (range=62–5537 m; *n*=67).

Distance from River.—Generally, females move greater distances away from their overwintering streams (Akre and Ernst 2006; Jones 2009; Wicklow, unpubl. data). Arvisais et al. (2002) reported that all locations were within 300 m in the Mauricie Region of Québec. In Massachusetts and New Hampshire, Jones (2009) reported the mean value of maximum distances traveled by male wood turtles away from the river to be 117±146 m (range=4–>1000 m; *n*=56), and females 209±175 m (range=29–933 m; *n*=67). Parren (2013) implied that most radiolocations were within 90 m of the overwintering stream, but forays beyond this distance ranged up to 54 days and extended 425 m from the river. In a sample of five females and six males, the mean maximum distance traveled from the river was 276±86 m (range=209–425 m) and 108±36 m (range=72–151 m), respectively.

Nesting Movements

In Massachusetts and New Hampshire, the median distance of confirmed nests (n=60) from the nearest river was 25.6 m (range = 0.2–600.0 m; Jones, unpublished data; Steen et al. 2012). Jones (2008) documented that most New Hampshire females nested on beaches within the stream corridor, but one moved 600 m from the stream to nest in a residential area. Jones (2009) reported that 35% of females in Massachusetts and New Hampshire nested within the stream channel on beaches and instream bars.

At Great Swamp NWR, New Jersey, three different female wood turtles made nesting movements over 1 km from their typical home ranges to deposit eggs (C. Osborn, pers. comm.).

In northwestern Virginia, Dragon and Akre (unpubl. data) report that nests in 2012 and 2013 were an average of 159.2 m (range=54.3–264.2 m) from the stream.

Nest Site Fidelity

Walde (1998) reported that 64% of females nested in the same gravel pit in 1996 and 1997, and that in some cases females nested in the same 1m^2 area in both years. In New Hampshire, B. Wicklow (unpublished data) observed 15 to 20 females returning to the same nesting area each spring for a period of ten years. At a nesting site purposefully created for wood turtles in Morris County, New Jersey, Buhlmann and Osborn (2011, p. 315) reported that one female turtle (of nine) returned to the nesting mound in three subsequent years.

Table 4. Summarized characteristics of wood turtle home ranges, following Saumure (2004).

State	Site	Sex	Year	Integral	Statistical (MCP 95% [ha])	Linear	Stream	Mean Max Distance	*n*	Source
MA	Connecticut Valley	F	2004	-	5.8±5.6	565±303	514±430	216±194	23	Jones (2009)
MA	Connecticut Valley	F	2005	-	14.8±30.9	823±742	895±1165	218±220	29	Jones (2009)
MA	Connecticut Valley	F	2006	-	13.8±25.0	866±614	1033±902	222±120	26	Jones (2009)
MA	Connecticut Valley	F	2007	-	3.9±3.7	449±137	546±276	135±105	12	Jones (2009)
NH	Merrimack Valley	F	2007	-	7.7±9.5	502±323	611±427	163±195	8	Jones (2009)
ON	Huron Co.	F	1991	6.4±3.7	-	-	-	-	4	Foscarini (1994)
QC	Brome Co.	F	1998	11.6±16.4	9.6±7.2	741±251	-	-	9	Saumure (2004)
QC	Brome Co.	F	1999	16.4±13.3	13.0±10.0	797±397	-	-	11	Saumure (2004)
QC	Mauricie	F	1996	-	25.9±32.9	-	-	-	14	Arvisais et al. (2002)
QC	Mauricie	F	1997	-	29.4±37.8	-	-	-	14	Arvisais et al. (2002)
PA	Centre	F	1988	3.3±0.5	2.6±0.5	435±74	-	-	4	Kaufmann (1995)
VA	Rockingham Site 1	F	2006–07	7.9±6.5	-	-	-	-	6	Sweeten (2008)
VA	Rockingham Site 1	F	2006–07	16.8±27.8	-	-	-	-	14	Sweeten (2008)
WI		F		-	0.5±0.3	-	-	-	-	Ross et al. (1991)

State	Site	Sex	Year	Integral	Statistical (MCP 95% [ha])	Linear	Stream	Mean Max Distance	*n*	Source
MA	Connecticut Valley	M	2004	-	17.8±25.0	1138±938	1670±1498	114±90	18	Jones (2009)
MA	Connecticut Valley	M	2005	-	16.0±17.0	1109±778	1478±1100	97±89	22	Jones (2009)
MA	Connecticut Valley	M	2006	-	20.3±44.8	976±954	1343±1341	97±63	25	Jones (2009)
MA	Connecticut Valley	M	2007	-	24.3±33.8	1014±594	1436±955	85±59	9	Jones (2009)
NH	Merrimack Valley	M	2007	-	6.6±5.5	673±485	921±653	66±59	8	Jones (2009)
ON	Huron Co.	M	1991	5.0±2.9	-	-	-	-	6	Foscarini (1994)
QC	Brome Co.	M	1998	19.4±13.1	16.7±11.3	1301±564	-	-	5	Saumure (2004)
QC	Brome Co.	M	1999	36.0±51.9	32.2±50.0	1531±1412	-	-	9	Saumure (2004)
QC	Mauricie	M	1996	-	32.1±38.7	-	-	-	4	Arvisais et al. (2002)
QC	Mauricie	M	1997	-	29.1±20.0	-	-	-	6	Arvisais et al. (2002)
PA	Centre	M	1988	5.0±1.5	3.8±1.4	481±75	-	-	6	Kaufmann (1995)
VA	Rockingham Site 1	M	2006–07	33.0±34.8	-	-	-	-	8	Sweeten (2008)
VA	Rockingham Site 1	M	2006–07	19.3±34.9	-	-	-	-	15	Sweeten (2008)
WI		M		-	0.3±0.2	-	-	-	-	Ross et al. (1991)

Hatchling Orientation and Movements

The movement, behavior, ecology, and survivorship of hatchling wood turtles was studied by Wicklow (unpublished data); Tuttle and Carroll (2005); Castellano et al. (2008); Dragon et al. (2012); and Patterson et al. (2012). Recently, researchers have used radiotelemetry to document fine-scale movements (e.g., Castellano et al. 2008; Dragon et al. 2012; Patterson et al. 2012). In Algonquin Park, Ontario, Patterson et al. (2008) observed that hatchling wood turtles moved toward brooks, selecting cooler sites with less leaf litter than generally available, and apparently overwintered near the shore. In central New Hampshire, Tuttle and Carroll (2005) reported total nest-to-river movements of 131.7±119.7 m (27–445 m) over 6.2±6.3 days (range=1–24 days) and suggested that hatchlings navigate to streams using "olfaction, vision, positive geotaxis, and auditory cues." One hatchling (of twelve to arrive at a stream) moved overland to arrive in a different brook than the one used by the parent female. The authors report that hatchlings left the nest site in a multidirectional dispersal pattern and headed for the nearest cover. Compton (1999, p. 75) also reported that hatchlings appeared to use geotaxis (downslope movements) to navigate, and suggested that deep gravel pits with no low-elevation exit may function as traps. Subsequent studies seem indicate that hatchlings are, in fact, willing to move over large obstacles. In an agricultural landscape in Warren County, New Jersey, Castellano et al. (2008) reported that radioequipped hatchlings remained in upland agricultural fields for several days or weeks following emergence, foraging and growing. Further, while in upland habitats, hatchlings moved less often and occupied sites with lower air and substrate temperatures than adult turtles. The authors noted that agricultural harvest could be detrimental to hatchlings that are still in the fields. In northwestern Virginia, Dragon (unpublished data) reported that hatchling wood turtles emerged from their nests and followed the topography of the landscape by moving down in elevation while taking the shortest route from the nest to the stream. Hatchlings from the same nest "patch" displayed similar patterns in direction and movements. Hatchlings took an average of 9.0 days (range=1–28) to reach the stream. Hatchlings that emerged from nest patches with a nearby seep complex (characterized by mucky soils and herbaceous growth) took longer (10.6–11.9 days) to reach the stream than those that emerged in nest patches without a nearby seep (4.6–8.8 days). The presence of a seep dictated the amount of days taken to reach the stream more than the distance of the nest from the stream, suggesting certain habitat features may act as a "nursery" and provide shelter for the journey from nest to stream. Hatchlings in Dragon's study moved an average of 253.8 m from emergence to hibernation, with a max movement of 1112 m. In New Hampshire, Wicklow (unpublished data) demonstrated through field and lab experiments that hatchlings exhibit phototaxis (navigating toward light). In the field, hatchlings appeared to navigate toward lighter (more open) areas. In the lab, hatchlings navigated toward full-spectrum light sources regardless of compass direction.

Dispersal

Dispersal in wood turtles is poorly understood and poorly documented. It is clear that individual wood turtles are capable of long-distance overland movements (to 17 km straight-line; Jones 2009, p. 73; Sweeten 2008), and that adult wood turtles are capable of short-range homing movements (Carroll and Ehrenfeld 1978; Barzilay 1980). It is also clear that turtles are occasionally swept downstream by floods and survive the initial displacement, and in some cases may subsequently either contribute to the genetic pool at the downstream location or at sites encountered while seeking suitable habitat in the years following the flood (Jones and Sievert 2009). Tuttle and Carroll (2005) reported an instance of a New Hampshire hatchling moving to a neighboring stream system upon emergence from the nest, and Jones (2009) observed two female wood turtles in Massachusetts and New Hampshire nesting near a watershed divide more than 600 m from her overwintering stream, suggesting that some small-scale dispersal may occur at very early life stages.

Reproduction

Maturity

Age at maturity has been reported to vary from 11 to 20 depending on sex and geographic area (about 12 years, Akre and Ernst 2006; 12 to 19 years, Harding and Bloomer 1979; 14 years, Farrell and Graham 1991; 14 to 20 years, Ross et al. 1991, p. 363; 17–18 years, Brooks et al. 1992; 12 years, Garber and Burger 1995; 14 to 18 years, Akre 2002, p. 3; 15 years (age of youngest mating male), Parren 2013, p. 179–180; see discussion in Compton 1999, p. 66–67). Documenting the age of onset of reproductive behaviors (mounting, courting) and secondary sex characteristics (plastral concavity, enlarged tail, etc.) is apparently easier and less time-intensive for males, so significant differences in age at maturity between sexes may be masked.

Lifespan and Survivorship

Determining the exact age of adult wood turtles is often problematic, but there is now abundant evidence that wild wood turtle often survive into their 50s. Continued long-term monitoring will likely indicate much greater lifespans, as have now been demonstrated for related taxa. Most authors agree that counting annular growth rings on the plastron or carapace is appropriate only for immature or recently mature, growing turtles (younger than 15–20 years; Harding and Bloomer 1979; Kaufmann 1992a; Ernst, pers. obs., *in* Ernst and Lovich 2009, p. 259; Parren 2013). Ernst (2001a) reports wild turtles over 40 years old in

Pennsylvania. In captivity, Oliver (1955) reported a maximum age of 58 years and Brooks (*in* COSEWIC 2007, p. 13) reports an adult of approximately >50 years. Recaptures of John Kaufmann's (1992a) study animals by Kathy Gipe (PFBC, unpublished data) in 2012–2013 as part of the this regional effort (described in Part 3) provides additional evidence of lifespans exceeding 50 years. Ray Farrell's (unpublished data) recent (2012–2013) recaptures of animals he marked in the 1970s (Farrell and Graham 1991) indicate ages in excess of 55 years. In Virginia, Dragon and Akre (pers. comm.) recaptured two wood turtles marked by Buhlmann (pers. comm.) in 1988 as mature adults, indicating minimum ages of 45 years. Jones (2009) estimated from time-lapse (interval) photographs of the carapace of 75 individual wood turtles in New England that complete wear of all carapace scutes may require approximately 80 years. A similar analysis of the depigmentation of the characteristic black blotches of the plastron indicated that they were reduced by >50% after approximately 70 years. Because turtles in these wear-class categories are frequently found in that region, the results may indicate natural lifespans exceeding 70 years.

Akre (2002, p. 5) notes that the wood turtle appears to exhibit a typical Type III survivorship curve with survivorship positively related to age, and this observation is supported by many reviews and published studies. Compton (1999) reported annual adult survivorship rates of 0.96–1.0 in Somerset County, Maine, but noted these may be as low as 0.92–0.96 if radioed turtles of unknown fate had actually died. In Hillsborough County, New Hampshire, Wicklow (unpubl. data) observed annual adult survivorship rate of 0.93 between 2005–2013. Jones (2009) provided supporting evidence indicating that young adult wood turtles sustained mortality rates twice as high as relatively old adults. In northwestern Virginia (Shenandoah and Frederick counties), Akre and Ernst (2006) reported annual survivorship (for adults and juveniles) of 0.92, 0.92, and 0.80 between 1999–2002.

Hatchling survivorship in the first year appears to be extremely low. Wicklow (unpublished data) reported survivorship data for postemergent hatchlings in southern New Hampshire, and of eight hatchlings with transmitters, only one survived to reach the overwintering stream. Of the remainder four were eaten by chipmunks (*Tamias striatus*), one eaten by a short-tailed shrew (*Blarina brevicaudata*), one was eaten by a striped skunk (*Mephitis mephitis*), and two were unaccounted for. Dragon (unpubl. data) reported survivorship data for postemergent hatchling wood turtles in northwestern Virginia. Of the total 68 hatchlings monitored, only 13 survived to overwinter (0.19), and the majority (86%) of deaths occurred within 20 m of the stream. The average lifespan of radiotracked hatchlings between emergence and hibernation was 27 days. Survival varied greatly between the two years studied. Of the 41 hatchlings sampled in 2012, 3 survived to overwinter (0.07). In 2013 a total of 27 hatchlings were sampled and 10 survived to overwinter (0.37). In Ontario, Paterson et al. (2012) reported extremely high post emergent mortality of hatchling wood turtles; only 11% survived from emergence to their first winter dormancy period. The authors inferred that most hatchlings had been eaten by small mammals. The mortality rate sustained by *G. insculpta* was much lower than observed in a similar sample of Blanding's turtle hatchings in Paterson's (2012) study.

Generations

Generation time or length is the average age of parent turtles of the current cohort (in this case, hatchlings of the current year present in the population). As generation time varies by region and from population to population it reflects the approximate turnover rate of breeding adults. Consequently, the generation length in long-lived, iteroparous species, such as the wood turtle, is older than the age at maturity and younger than the maximum lifespan of turtles in the population. The IUCN (2013) further specifies that when the generation length is depressed by anthropogenic sources, "the more natural, i.e. pre-disturbance, generation length should be used." According to Pianka (1974) generation length is the age to maturity plus one half the reproductive longevity. According to COSEWIC (2007), the IUCN formula for generation time (gt) is as follows, where (m)=average age at maturity and (am)=adult mortality rate: gt=(m)+(1/am). The generation time provided by COSEWIC (2007, p. 13) is 35 years, and van Dijk and Harding (2011), citing James Harding, suggested that it likely mirrors that of Blanding's turtle (*Emydoidea blandingii*) at approximately 36–47 years. Using an average age at maturity of 15 years, and the range of survivorship estimates of 0.96–1.0 provided by Compton (1999, p. 66–67) for a remote population in Maine, the generation time is >40 years (but may be as low as 32 years if three missing, radioed turtles actually had died). Adult annual survival estimates of 0.88 for 185 adult wood turtles of all adult age classes in agri-forested landscapes of Massachusetts and New Hampshire provided by Jones (2009) suggest generation times of 23 years. If these figures are indicative of other regions, generation time may vary from approximately 20 years at sites with high adult annual mortality rates (>0.2) to about 45 years at sites without anthropogenic sources of mortality. Based on these available data, we propose that 45 years is likely an adequate representation of generation time in undisturbed contexts. However, it should be noted that nest success and juvenile survival are probably as important in determining generation time as adult survival.

Courtship and Mating

Copulation almost always occurs in water, along the banks of streams, and in pools along the stream course (see review by Ernst and Lovich 2009). The wood turtle exhibits a number of noteworthy courtship rituals. Liu et al. (2013) summarize instances of head-bobbing courtship rituals and "shell clapping," in which the male thumps his plastron against the carapace of the female. Tronzo (1993) and Mitchell and Mueller (1996) report instances of plastron-to-plastron mating, although Kaufmann (1992) reports primarily plastron-to-carapace mating. Several instances of plastron-to-plastron mating were observed during the course of this study in the Fall of 2013 in Aroostook County, Maine (Jones and Willey 2013b); Coos County, New Hampshire (Jones and Willey 2013a); and Monroe County, Pennsylvania (Angus, unpublished data).

Fifty-three of 57 (93%) breeding attempts observed by Parren (2013, p. 180) in Vermont were in the water. Three instances of clasping/mounting were observed on the bank from 1–8 m from the river. Jones (2009, p. 158) observed courting behavior (clasping, mounting) or copulation on 110 occasions, of which 97% were in the water.

Nesting Frequency

All populations studied produce one or fewer clutches of eggs per year (M. Ewert, Indiana University, pers. comm. to T. Akre, *in* Akre 2002, p. 3). Farrell and Graham (1991, p. 4) reported that females did not appear to deposit more than one clutch per year. In Algonquin Provincial Park, Ontario, Brooks (unpublished data provided to T. Akre) found that 75% of females nest in a given year. Remarkably, in one of the most isolated populations of southern Ontario, Foscarini (1994) estimated that 33% of females nest annually. Walde et al. (2007) found that larger females in Québec are more likely to nest in consecutive years than smaller females. Jones (2009) reported that the proportion of adult females nesting in a given year between 2004–2007 ranged from 0.5 to 0.9 (mean=0.7) in Massachusetts and New Hampshire. Of twenty-five Massachusetts female wood turtles tracked for multiple years, the proportion of years in which turtles became gravid ranged from 0 to 1 and averaged 0.7. Akre (2002, p. 4) emphasized Kuchling's (1999) point that if females do not nest annually, it may be because they fail to ovulate despite a typical vitellogenic cycle.

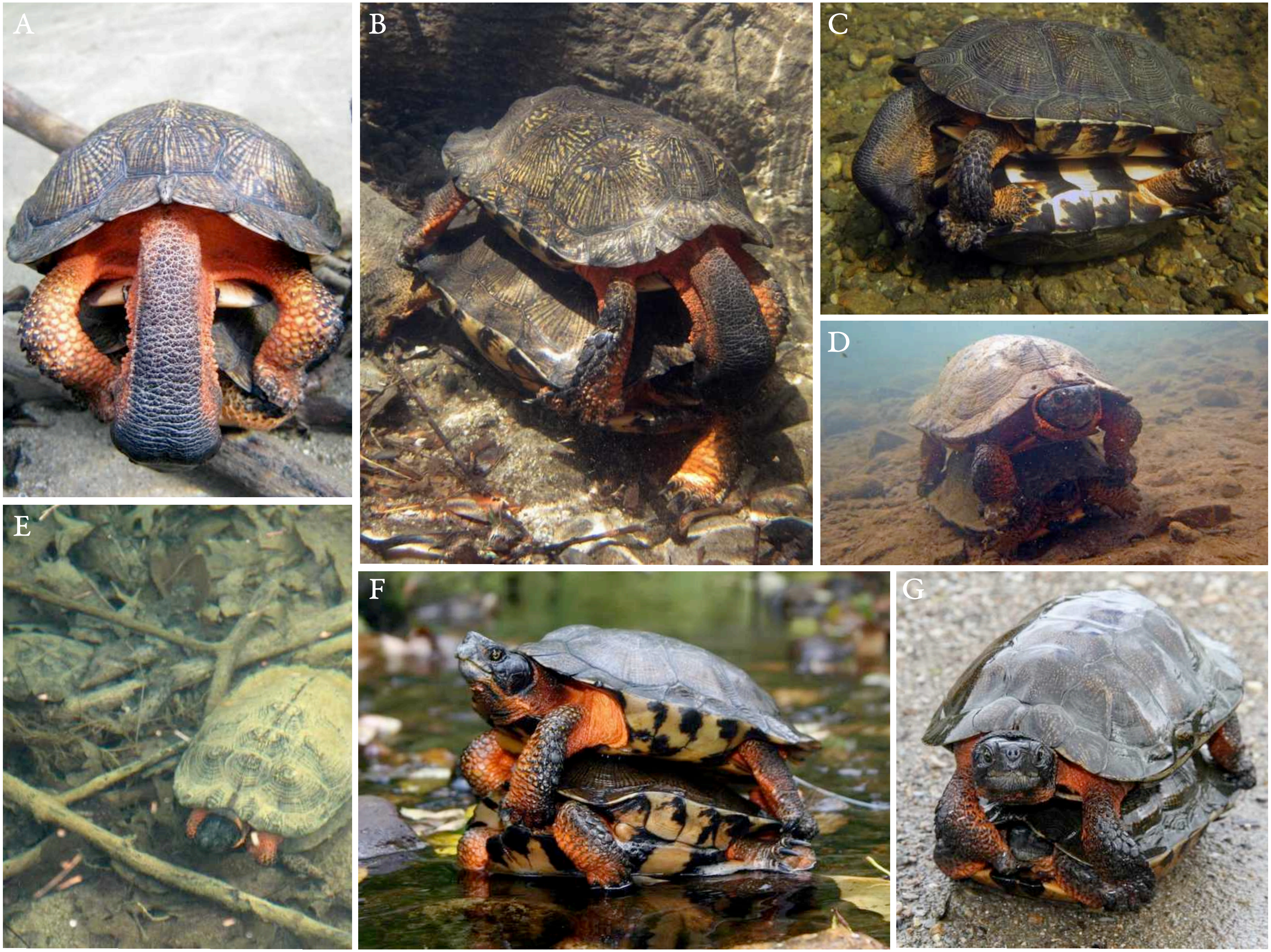

Figure 10. Wood turtles primarily court and mate underwater in quiet sections of streams (A–E), but the pair may be dragged from the water by the female as pictured here in New Hampshire and Maine (F–G). Males exhibit a range of head bobbing, throat pulsations, and biting behavior (A–C). Copulation takes place plastron-to-carapace but plastron-to-plastron also occurs, as pictured here in northern New Hampshire (C). Often mating occurs on the bottom of quiet pools, as pictured here in NW Virginia (D). Mating occurs often in proximity to overwintering sites, as pictured here in western Maryland (note quiescent turtle at left; E). Photos © Michael Jones

Clutch Sizes

Range wide, average clutch sizes contain approximately 7–11 eggs (Table 5). In Ontario, average clutch size range from 8.0 to 10.7 (range=3–15; Brooks et al. 1992; Foscarini 1994; Smith 2002; *in* COSEWIC 2007, p. 1). In the Sudbury District of Ontario, Greaves and Litzgus (2009, p. 302) reported clutch sizes of 8.8±2.2, 9.4±2.3 in 2005 (*n*=5) and 2006 *(n*=11). In the Mauricie region of Québec, clutch size averaged 10.1 (range 5–20; n=58; Walde 1998). Nova Scotia females examined by Powell (1967) had clutch sizes of 8.2 (range=4–11; n=20). Harding (1991) reported clutch sizes to range from 5 to 18 and average 10.5 in Michigan. Wisconsin wood turtles studied by Ross et al. (1991) had average clutches of 11 eggs.

In the Northeast, Tuttle and Carroll (1997) reported average clutch size of 7.8±1 (range=6–9; n=9) in New Hampshire. Jones (2009, p. 157) reported a range of 1–14 eggs per clutch and a mean of 7.3 (n=76) in Massachusetts and New Hampshire. Kaufmann (1992a) reported mean clutch size of 8.9 (range=5–12) in Centre County, Pennsylvania, and in Sussex County, New Jersey Harding and Bloomer (1979) reported similar mean and range of 8 and 5–11, respectively. Nearby at another site in Sussex County, Farrell and Graham (1991) reported a mean clutch size of 8.5±1.7 (range 5–11, n=21).

Several studies have report that clutch size is correlated to straight-line carapace length (Brooks et al. 1992; Walde et al. 2007; Jones 2009, p. 157).

Although a strong correlation has been found between female body size and clutch size in wood turtles, as noted by Akre (2002), other studies of Emydids and Kinosternids indicate a pronounced influence of environmental parameters. Gibbons et al.'s (1991, 1992) findings demonstrated that environmental conditions influence clutch size more than age class or genetics in populations of slider (*Trachemys scripta*), eastern mud turtle (*Kinosternon subrubrum*), and chicken turtle (*Deirochelys reticularia*). Iverson (1991) and Iverson and Smith (1993) similarly found that yellow mud turtle (*Kinosternon flavescens*) and western painted turtle (*Chrysemys picta bellii*) responded to variable environmental conditions with varied reproductive output.

Table 5. Summarized clutch size data from across the wood turtle's range.

Clutch characteristics						
State	**Site**	**No. eggs**	**Range**	**Year**	***n***	**Source**
QC	Mauricie	10.1	5–20	-	58	Walde (1998)
ON	Sudbury District	8.8±2.2	-	2005	5	Greaves & Litzgus (2009)
ON	Sudbury District	9.4±2.3	-	2006	11	Greaves & Litzgus (2009)
MI	-	10.5	5–18	-	-	Harding (1991)
NS	-	8.2	4–11	-	20	Powell (1967)
NH	Merrimack Co.	7.8±1.0	6–9	-	9	Tuttle & Carroll (1997)
MA	Western MA	7.3	1–14		76	Jones (2009)
NJ	Sussex Co.	8.5±1.7	5–11		21	Farrell & Graham (1991)
NJ	Morris Co.	-	7–16	2007–2010	23	Buhlmann & Osborn (2011)
PA	Centre Co.	8.9	5–12	-	-	Kaufmann (1992)

Egg Viability and Nest Predation

Nest viability rates appear to be variable. In Massachusetts and New Hampshire, Jones (2009) found that emergence rate, or nest success (excluding depredation by mammals) ranged from 0 to 1.0 and averaged 0.41. When emergence rate, or nest success, was regressed separately on a shell-wear index and straight-carapace length, no significant model was produced ($P=0.72$; $P=0.56$).

Nest depredation rates also appear to be variable, although skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), and numerous other midsize carnivores appear to be major factors in some areas (see Significant Threats to Population Stability, later in Part 1). Raccoon, skunk, and possibly turkey are predators of nests in New Jersey (S. Angus, pers. comm.). Buhlmann and Osborn (2011) noted that raccoons and red fox were significant nest predators in New Jersey.

Incubation

Compton's (1999) degree-day models using field-hatched (n=4) and lab-hatched (n=7) nests from Maine and other reported studies (Ewert 1979; M. Ewert, Indiana University, unpublished data; Vogt 1981; Herman 1991; J. Harding, Michigan State University, unpublished data) predict that a wood turtle egg will hatch when it has received 788 (se=10.1) degree-days above a threshold of 12.5˚C. Incubation time of the Maine nests ranged from 67 (at a mean temperature of 24.5˚C) to 113 days (with a mean temperature of 19.5˚C) with a median (n=11) of 89 days. Maine eggs incubated at the same rate as eggs from other localities, although he left open the question of whether incubation rates vary geographically based on low power and lack of replicates from a wide range of latitudes. Based on a soil temperature model built from historical weather data, Compton (1999, p. 20) inferred that there is a broad area in the northern half of the wood turtles' range in which nest failure is likely to occur in some years because of low summer temperatures.

In Warren County, New Jersey, Castellano et al. (2008) reported a mean incubation period of 72.2±3.0 days (range=69–76; *n*=10). In southern New Hampshire, Tuttle and Carroll (2005) reported both synchronous (all hatchlings emerged at the same time; *n*=5) and asynchronous (*n*=2) emergence from 13–29 August between 0820–1805 h.

Most nests emerge in August, but emergence ranges from July to October. Castellano et al. (2008) reported a range of emergence dates from 13 August to 20 August 2002 in Warren County, New Jersey. In Morris County, New Jersey, Buhlmann and Osborn (2011) reported a range of emergence dates from 29 July to 14 September, but noted that most hatchlings emerged in mid- to late-August (K. Buhlmann, pers. comm.). In northern Virginia, Akre (2010) reported emergence dates ranging from 3 August to 22 September 2010 with most hatchlings emerging before 19 August. Parren and Rice (2004) speculated that some wood turtle nests may overwinter on land in Vermont, but this has not been reported in other studies (Walde et al. 2007), although Wright (1918, p. 55) observed a turtle of "newly hatched form" in April 1913.

Demographics

A complete understanding of demographics in wood turtle populations requires either an intensive sampling effort directed at all age classes, or a long-term sampling effort. Most studies have reported female-biased or equal sex ratios and highly variable juvenile ratios, which range from 0% to 48.0% of captures (Greaves and Litzgus 2009, p. 303; Table 6). In Québec, Walde et al. (2003) reported a female-skewed sex ratio of 1 : 1.51 (males to females), which differed significantly from 1 : 1, but felt the result was biased because of their research emphasis on nesting females. Compton (1999; unpublished data) reported a female-based sex ratio of 1 : 2.7 in western Maine; this also may reflect intensive sampling for nesting females, or increased detectability of females. Jones and Willey (2013b) reported equal sex ratios in Aroostook County, Maine, and female-skewed sex ratios in Somerset County, Maine.

Caution should be used when interpreting absolute juvenile captures because they are detected at lower rates than adults and detection is probably variable across sites and habitats. Walde et al. (2003) reported that immature turtles accounted for 31% of the animals captured in the Mauricie region of Québec, by contrast, Compton (1999; unpublished data) detected only four turtles aged 14 or younger.

Saumure and Bider (1998) detected differences in the demographic structure of two populations in Québec, noting that juveniles were less common at the agricultural site. Jones (2008, p. 11) detected significant differences in age class structure between two populations in the White Mountains, New Hampshire, and Akre and Ernst (2006) report differences in demographic structure across five populations in northern Virginia.

Table 6. Summarized demographic data from selected sites throughout the range of the wood turtle.

State	Site	Males	Females	Juveniles	Ratio (M:F)	% Juvenile	Source
QC	Mauricie	55	83	50	1 : 1.51	0.27	Walde et al. 2003
QC	Brome Co.	18	24	10	1 : 1.33	0.19	Daigle (1997)
QC	Brome Co.	16	13	4	1 : 0.07	0.12	Saumure & Bider (1998, p. 39)
QC	Pontiac Co.	10	10	11	1 : 1.0	0.36	Saumure & Bider (1998, p. 39)
ON	Algonquin Park	21	56	13	1 : 2.57	0.14	Brooks et al. (1992)
ON	Sudbury Dist.	15	21	19	1 : 1.40	0.35	Greaves & Litzgus (2009)
ON	Huron Co.	83	136	51	1 : 1.60	0.19	Foscarini (1994)
NS	Mainland	14	20	10	1 : 1.43	0.23	White (2013)
MI	Upper Pen.	86	105	63	1 : 1.22	0.25	Harding & Bloomer 1979
WI	Black R.	20	37	1	1 : 1.85	0.02	Ross et al. (1991)
WI	Wisconsin R.	8	15	0	1 : 1.88	0	Ross et al. (1991)
ME	Aroostook Co.	60	69	37	1 : 1.15	0.22	Jones & Willey 2013b
ME	Somerset Co.	48	102	77	1 : 2.13	0.34	Jones & Willey 2013b
ME	Somerset Co.	10	27	4	1 : 2.7	0.1	Compton, unpubl. data
NH	Coos Co.	28	44	37	1 : 1.57	0.34	Jones & Willey 2013a
NH	Grafton Co.	54	66	112	1 : 1.22	0.48	Jones & Willey 2013a
NH	Merrimack Co.	17	29	36	1 : 1.8	0.44	Tuttle (1996)
MA	Connecticut R.	83	83	27	1 : 1.0	0.14	Jones et al., unpubl. data
MA	Deerfield R.	42	37	16	1 : 0.88	0.17	Jones et al., unpubl. data
MA	Berkshire Co.	18	9	9	1 : 0.5	0.25	Jones et al., unpubl. data
MA	Westfield R.	49	64	27	1 : 1.30	0.19	Jones et al., unpubl. data
NJ	Passaic Co.	311	464	-	1 : 1.49	-	Harding & Bloomer 1979
VA	Frederick-Shenandoah	70	80	27	1 : 1.14	0.15	Akre 2010
VA	Shenandoah Co.	38	44	12	1 : 1.16	0.13	Akre and Ernst 2006
VA	Frederick Co.	23	32	9	1 : 1.39	0.14	Akre and Ernst 2006
VA	Fred.-Shen. Co.	43	42	35	1 : 0.98	0.29	Akre and Ernst 2006
VA	Fairfax Co.	38	64	37	1 : 1.68	0.27	Akre (2002)
WV	Cacapon R.	52	49	86	1 : 0.94	0.46	Niederberger & Seidel (1999)
WV	E. Panhandle	16	16	18	1 : 1.0	0.36	Breisch (2006)

Feeding

The wood turtle is an opportunistic omnivore (Surface 1908, p. 161–162; Logier 1939; Oliver and Bailey 1939; Harding and Bloomer 1979, p. 22; Vogt 1981, p. 96; Farrell and Graham 1991, p. 7; Klemens 1993, p. 173) that feeds from April to October (Ernst 2001b). Like many terrestrial or semi-terrestrial turtles, the wood turtle is able to feed on land or in water (Castellano et al. 2008).

Surface (1908, p. 161) reported that 76% of turtles examined in Pennsylvania had eaten vegetable material, and 80% had consumed "animal matter." Oliver and Bailey (1939) report that New Hampshire wood turtles eat "a variety of vegetable as well as animal food. Berries, seeds, earthworms, and insects are favored articles in this turtle's diet." Lagler (1943) reported that Michigan adults had consumed filamentous algae, mosses, willow leaves (*Salix* sp.), insects (including black flies [Simuliidae], caddisfly [Trichoptera] larvae, and beetles), mollusks, snails, earthworms, bluegill (*Lepomis macrochirus*) and trout (Salmonidae), and tadpoles (*Lithobates* sp.). Countless authors have essentially reported that wood turtles opportunistically eat a wide range of green leaves, fruits, arthropods and other invertebrates, eggs, and carrion, including Harding and Bloomer (1979, p. 22), who reported collectively on turtles in natural or semi-natural conditions in Michigan and New Jersey had eaten blueberries (*Vaccinium* spp.), blackberries and raspberries (*Rubus* spp.), strawberries (*Fragaria* sp.), green leaves of willow and alder (Salix and Alnus spp.), as well as grasses, mosses, and algae and a variety of animal matter including molluscs, insects, earthworms, tadpoles, fish carrion, and newborn mice. Gilhen and Grantmyre (1973) and Graf et al. (2003), respectively, reported apparent consumption of blueberries and choke-cherries (*Prunus virginiana*) by wood turtles on Cape Breton Island, and Compton et al. (2002) speculated that raspberries were an important food in western Maine. Farrell and Graham (1991, p. 4) observed wood turtles eating green leaves of strawberries (*Fragaria* sp.) and strawberry and blackberry (*Rubus* sp.) fruits, fish carrion, and slugs, and Niederberger and Seidel (1999) reported wood turtle stomach contents as follows: vegetation (68%); earthworms (46%); other invertebrates (38%) and carrion (23%).

Among the foods taken by multiple individuals reported by Surface (1908, p. 162) were leaves and seeds of flowering plants (including *Ilex verticillata* and *Plantago major*, beetles, snails and slugs, bird carrion (7.6%). Green leaves (including cinquefoil, *Potentilla* sp.; and violets, *Viola* sp.) and fungi were prevalent in the foot items reported by Strang (1983, p. 45). Vogt (1981, p. 96) reported spruce (*Picea* sp.) needles eaten by a female in Wisconsin, and James Harding (pers. comm. to R. Farrell *in* Farrell and Graham 1991, p. 7) reported wood turtles feeding on willow (*Salix* sp.) leaves. Jones and Sievert (2009, p. 433), reported 395 recorded instances of identifiable food items in Massachusetts wood turtles. Slugs and other invertebrates comprised the majority of known food items (N=246), followed by the green leaves of at least 24 species plants (N=90). Corn, apples, raspberries, blackberries, and dewberries (*Rubus* spp.) and grapes were also eaten. Additional food items reported by Jones and Sievert (2009) included spotted salamander (*Ambystoma maculatum*) eggmassess, trout carrion, bird carrion, and the fungi genera *Russula* and *Lactarius*. In New Hampshire, Wicklow (unpublished data) reports that in early spring adult wood turtles feed extensively on bracken (*Pteridium aquilinum*) as well as tadpoles in vernal pools, and in fall wood turtles feed heavily on elderberries (*Sambucus* spp.), grapes (*Vitis* spp.)., and silky dogwood (*Cornus amomum*) fruits and drupes.

In Iowa, Tamplin (2006) reports that wood turtles routinely feed on prairie ragwort (*Senecio plattensis*), which is a highly toxic plant known to kill fish, lizards, and livestock.

A female wood turtle was reported to eat her own egg after depositing it prematurely in a hayfield (Jones and Sievert 2009, p. 434) and captive turtles have been observed to eat the eggs of *Terrapene carolina* (Ernst and Lovich 2009, p. 260). Ernst and Lovich (2009, p. 260) present a complete list of food items and a list of other references (Ernst and Barbour 1972; Czarnowski 1976; Ernst and McBreen 1991; Ernst 2001a; Castellano and Behler 2003).

Zeiller (1969) first reported "worm-stomping" foraging behavior in captive wood turtles, in which adult turtles use their front feet and plastron to drum worms to the surface, and this behavior was described in depth in wild Pennsylvania adults by Kaufmann (1986; 1989). This has since been reported in Maine (K. Rolih, University of Massachusetts, pers. comm.), New Hampshire (B. Wicklow, St. Anselm College, unpublished data; Tuttle 1996); Massachusetts (M.T. Jones and D.T. Yorks, unpublished data); New Jersey (S. Angus, pers. comm.) and Virginia (T. Akre, Smithsonian Conservation Biology Institute, unpublished data), and in captivity (Kirkpatrick and Kirkpatrick 1996).

Hatchling wood turtles are probably opportunistic omnivores, although most observations of feeding suggest invertebrate carnivory. Castellano et al. (2008) reported seven instances of radio-equipped hatchlings eating slugs (*Arion subfuscus;* six of these events were during overcast weather with light to heavy rain). Tuttle and Carroll (2005) also reported hatchling wood turtles eating slugs, as well as green leaves. Patterson et al. (2012) did not observe foraging or feeding behavior in 295 behavioral observations of radioequipped hatchling wood turtles in Ontario. Based on fecal analysis, Wicklow (unpublished data) observed hatchlings to eat riffle beetles (Elmidae) and larvae of the caddisfly (Trichoptera) genus *Helicopsyche*.

Seasonal Activity Patterns

Active Season

Wood turtles are active in streams throughout their northeastern range from March or April to November or December in most years, depending on elevation, latitude, and annual variation in weather. Arvisais et al. (2002) noted pronounced activity periods from May to October, including prenesting, nesting, postnesting, and prehibernation periods. Akre and Ernst (2006) report activity in northern Virginia during the late fall, winter, and early spring in addition to the window from March to November. Based on their data and regional reports, they propose two primary annual periods: hibernation (December–February) and the activity season (March–November). They break the latter season into five distinct periods of activity: 1) emergence (March); 2) prenesting (April – May); 3) nesting (June); 4) postnesting (July – September); and 5) prehibernation (October – November).

Below water temperatures of about 6˚C, wood turtles are generally inactive in streams (see Overwintering; Harding and Bloomer 1979; Ernst and McBreen 1991; Kaufmann 1992b; Akre 2002; Pulsifer 2012). In the southern portion of their range, wood turtles emerge and become active in March and begin feeding when water temperatures reach 4–5˚C and air temperatures reach 12–15˚C (Akre, unpublished data). Niederberger (1993, p. 13) reported that wood turtles were typically dormant when water temperatures ranged from 2–9˚C, but observed at least one instance of mounting at water temperature of 1˚C, and noted that while juveniles and females tended to be dormant at low temperatures, males sometimes moved underwater and appeared active. Anecdotal accounts of wood turtle moving under the ice of streams in January in northern New Jersey were provided by R. Farrell (Herpetological Associates) and S. Angus (pers. comm.).

Emergence and spring activity in Maine and northern New Hampshire may be determined by ice-out (Jones and Willey 2013b). White (2013) reported no activity between 19 December and 12 March in Nova Scotia. Activity in Michigan is rare after mid-October (Holman 2012, p.128). Graham and Forsberg (1991) reported extended periods of inactivity with only minor repositioning from December–February in Massachusetts. Klemens (1973, p. 172) reports that wood turtles become active in Connecticut in late

March and early April. In western New York, Wright (1918) noted that wood turtles generally emerged and were found in streams around April 20 (a range of dates are reported, from the earliest of 20 March [1915] to 14 May [1906]), and were found again near streams between 20 September–15 October.

Male wood turtles generally become active earlier in the season and remain active later (Akre and Ernst 2006). By September, most turtles have returned to their home streams (Saumure et al. 2007).

Mating Season

Courting and copulation takes places commonly in both the spring and fall in Minnesota (Breckenridge 1958, p. 170); Wisconsin (Brewster 1985); Massachusetts (Jones 2009); New York (Wright 1918, p. 55), New Jersey (Farrell and Graham 1991; Harding and Bloomer 1979); Pennsylvania (Kaufmann 1992a; Ernst 2001b); Virginia (Ernst and McBreen 1991); and West Virginia (Niederberger and Seidel 1999). In Venango County, Pennsylvania, near the western margin of the wood turtle's range in Northeast region, Swanson (1952, p. 47) reports "clasping pairs in trout streams in the middle of April," and reports mating in captivity in March and September. Autumnal mating was reported to be more common in Québec (Walde 1998), Vermont (Parren 2013, p. 179) and Virginia (Akre 2002). Harding (1991) reported that mating is most common in June and September in Michigan. Kleopfer (VDGIF, pers. comm.) reports wood turtles mounted under ice in December in Virginia.

Nesting Season

Throughout the Northeast region and adjacent areas, wood turtles generally nest in June, although observed dates range from mid-May to mid-July (Thoreau 2009 [entries from 1855–1860, see Historical and Current Distribution, this document]; Harding and Bloomer 1979; Compton 1999; Walde et al. 2007; reviewed by Bowen and Gillingham 2004, Table 2; Akre 2010). Wood turtles in Ontario observed by Brooks et al. (1992) nested between 7–19 June, and Walde (1998) reported nesting dates between 9–28 June in Québec; this range closely mirrored the dates reported by Harding (1991; 1994) of 10–29 June. In Maine, Compton (1999, p. 21) reported a mean nesting date of 20 June, with half of all nests deposited between 12–25 June. In New Hampshire, Tuttle and Carroll (1997) reported a range of nesting dates from 2–13 June. Parren (2013) recorded most nesting activity between 23 May and 21 June. In Massachusetts, Jones (2009, p. 156) reported nests deposited between 28 May and 4 July. Median deposition dates for each year (2004–2008) ranged from 7–20 June; the average of these was 12 June. Castellano et al. (2008) reported nesting during the last two weeks of May and the first two weeks of June in New Jersey. Buhlmann and Osborn (2011) reported that nesting in a Morris County, New Jersey population ranged from 21 May to 13 June during the period 2007 to 2010. Ernst (2001b) observed a range of nesting from June 4–19 in Lancaster County, Pennsylvania, while in Centre County, Kaufmann (1992) observed nesting from 4–16 June. In Frederick-Shenandoah counties, Virginia, Akre (2010) reported nesting from 23 May–22 June, 2010.

Walde et al. (2008) reported that 38.5% of nests in Québec are initiated between 0500 and 0900 hr. Jones found that 90% of nests in Massachusetts and New Hampshire were initiated in the late afternoon and evening. Akre (2010) reported that in northwestern Virginia, nesting activity is most common in the early morning, late afternoon, and evening, with some nesting activity continuing through the night.

Hatchlings typically emerge in August (Castellano et al. 2008; Akre 2010), but may emerge in September or October (See Incubation, earlier).

Aestivation

Aestivation is not well documented to occur in the wood turtle. Most authors report continuous activity throughout the summer months (Strang 1983, p. 43). Even in the southern part of their range and at low elevations, wood turtles remain active through the summer although they move much less than during the spring (Akre 2002; Akre and Ernst 2006), and fine-scale movements appear to decrease during the warmest months of July and August. Some limited evidence of individual turtles becoming inactive on land during hot spells was also reported by S. Angus (unpublished data) in New Jersey.

Overwintering

Despite 19th and early 20th century accounts of terrestrial brumation[3] (e.g., Surface 1908), all recent telemetry studies have documented overwintering in streams, rivers, and associated aquatic habitats (Farrell and Graham 1991; Tuttle and Carroll 1997; Niederberger and Seidel 1999; Ultsch 2006; Akre and Ernst 2006; Greaves and Litzgus 2008; White 2013). Many authors have noted the propensity of wood turtles to overwinter, or brumate, in association with deep pools, rootmasses of large trees, and undercut banks. In New Hampshire, Wicklow (pers. comm.) reports that wood turtles keep their heads free of debris when hibernating even when much of the shell may be covered with leaves, sticks, or sand.

White (2013), in a study of overwintering site selection in Nova Scotia wood turtles, reported that most telemetered wood turtles overwintered in riverine habitats, although marsh and oxbow habitats were used, and that wood turtles overwintered at a mean water depth of 0.67±0.35 m. Most turtles overwintered in reaches dominated by fine sediments. Wood turtles often overwintered in close proximity to large woody structure such as log jams, single logs, large branches, woody material, and root balls, as well as undercut banks, underwater rock ledges, and boulders. In northern populations, such structures are likely to protect turtles from potentially lethal scouring ice sheet flows and/or being washed downstream during spring run-off events (Saumure, pers. comm.; Jones and Sievert 2009). Most turtles (16 of 19 and 21 of 24 in years one and two, respectively) overwintered within 2.0 m from shore. In White's study, the mean dissolved oxygen (DO) across all overwintering sites for 20 turtles (year one) and 29 turtles (Year 2), respectively, was 13.12±1.56 ppm (n=88 measurements) and 11.97±3.50 ppm (n=133 measurements), although turtles were observed overwintering in an oxbow at DO of 9.65±2.25 ppm.

Graham and Forsberg (1991) reported aquatic oxygen uptake by overwintering wood turtles in central Massachusetts, and noted that turtles typically rested on the stream bottom, near submerged logs or rocks, in 0.3–0.6 m of water. In Connecticut, wood turtles hibernate in muskrat dens and on the gravel bottoms of pools in woodland streams (Farrell and Graham 1991), and amongst tree roots (Klemens 1993, p. 172). Farrell and Graham (1991) report an important overwintering site associated with the roots of a large sycamore (*Platanus occidentalis*) at a bend in a stream in Sussex County, New Jersey. In Virginia, Akre and Ernst (2006) reported a range of key overwintering features including leaf packs in deep pools, undercut banks, logjams, and large deadfalls such as sycamore (*Platanus occidentalis*).

Aggregations.—The wood turtle is noted for its large aggregations associated with late fall and early winter, often near overwintering sites (Bloomer 1978). Klemens (1993, p. 172) reported an aggregation of 20 wood turtles in Tolland County, Connecticut. Farrell and Graham (1991) reported an aggregation of 28 wood turtles in a New Jersey stream. Niederberger (1993) reported an aggregation of 80 turtles, with 35 turtles visible on a pool bottom and others scattered under banks with their carapaces visible.

Daily activity patterns

With the exception of nesting females, which are frequently active well after dark throughout the region, wood turtles are primarily diurnal, although whether their activity patterns are unimodal (peak mid-day) or bimodal (more active in mornings and afternoon) appears to vary by season, geographic location, and

3 Brumation is the functional equivalent of hibernation in reptiles, driven by cold-induced torpor rather than physiologically-induced torpor.

weather conditions. Ernst and Lovich (2009) report that wood turtles in Virginia may use creeks on a daily basis.

Thermoregulation

Thermoregulation is a critical component of wood turtle behavior and activity, especially during emergence from brumation in the spring (Dubois et al. 2009). Thermoregulation in the wood turtle reflects the interaction of temperature, humidity, and weather. When wood turtles become active in the spring, they are first unimodal (active during the warmest part of the day), moving to bimodal with increasing temperatures and greater risk of water loss, and moving back to unimodal with decreasing temperatures in the fall. Combined with foraging opportunities, access to basking sites probably drives wood turtle habitat selection at the fine scale (Compton et al. 2002; Saumure 2004).

(WILL EXPAND WITH SUMMARIES OF DUBOIS' PAPERS)

Paleontological, Prehistoric and Archaeological Records

The genus *Glyptemys* is known from the middle to Late Barstovian of Nebraska (ca 14.5–11.5 million ybp, Holman and Fritz 2001; Ernst and Lovich 2009, p. 251). *Glyptemys valentinensis* may have given rise to *G. insculpta* between the Late Barstovian and Late Hemphillian times (11.5–5.5 million ybp).

Molecular studies indicate at least one southern Pleistocene refugium for *G. insculpta* (Amato 2006), but fossil evidence is rare (Ernst and Lovich 2009, p. 251). Evidence suggests that some populations of wood turtles ranged south along the Appalachians during the Pleistocene. Late Pleistocene (Rancholabrean, 12,000–16,000 ybp) wood turtle remains (a partial carapace) were recovered from Cheek Bend Cave along the Duck River, Maury County, central Tennessee (Parmalee and Klippel 1981, p. 413). Wood turtle remains (partial plastron and pleural bones) from Ladd Quarry, Bartow County, Georgia were also believed to be late Pleistocene (Rancholabrean) in age (Holman 1967 in Parmalee and Klippel 1981, p. 414). Together, these remains provide additional evidence for a southern Appalachian refugium occupied by *G. insculpta* during the late Pleistocene.

Several Pleistocene fossil records suggest that wood turtles occupied at least part of their modern range during interglacial events. These include Rancholabrean (70,000–80,000 BP) remains of *G. insculpta* from the East Milford mastodon site near the current Shubenacadie River in Halifax County, Nova Scotia (Holman and Clouthier 1995), Middle Pleistocene (Late Irvingtonian) wood turtle remains from the Port Kennedy Cave, Montgomery County, Pennsylvania, and Pleistocene (Irvingtonian) wood turtle remains recovered from the Frankstown Cave, Blair County, Pennsylvania (Peterson 1926)—all in watersheds where they are historically reported (Pennsylvania Natural Heritage Program, unpublished data). These data suggest that wood turtles occupied at least part of their modern range during interglacial events of the Pleistocene (Hay 1923; Parris and Daeschler 1995, p. 564).[4]

Wood turtles have been reported from numerous mid- to late-Holocene archaeological sites throughout the northeastern United States. In Ontario, wood turtle remains were recovered from a Native American site near Roebuck, Leeds and Grenville counties (Bleakney 1958, p. 4). Adler (1968) reported wood turtle remains from archaeological sites in Raddatz rockshelter, Sauk County, Wisconsin; and Juntunen, Mackinac County, Michigan. In Maine, evidence of a single wood turtle was recovered from the Little Ossipee North site in Oxford County, dating from approximately 1000 ybp (Sobolik and Will 2000). Wood turtle fragments accounted for 33% of turtle remains in a midden at the Olsen Site near Cushing,

4 Fossils of wood turtle, box turtle (*Terrapene carolina*), Blanding's turtle (*Emydoidea blandingii*), and a *Hesperotestudo* tortoise were recovered from the Port Kennedy Cave, providing some insight into the complexity of reconstructing ancient turtle faunal assemblages.

Knox County, Maine—a coastal site, with no currently confirmed populations within 30 km (Downs 1987 *in* Rhodin 1995; Maine Department of Inland Fisheries and Wildlife, unpublished data, 2012). In southern New Hampshire, wood turtle remains accounted for 61% of all turtle remains in shell middens at Sewall's Falls, Merrimack County, New Hampshire—a region of the Merrimack River still occupied by the species (Howe 1986 *in* Rhodin 1995; New Hampshire Natural Heritage Bureau and New Hampshire Fish and Game Department, unpublished occurrence data, 2012). By contrast, wood turtles account for only 11% of the large sample from the Concord Shell Heap on the bank of the Sudbury River, Concord, Middlesex County, Massachusetts (Rhodin 1995), and are even more rare in the turtle bone fauna at Flagg Swamp, Middlesex County, Massachusetts (Huntington and Shaw 1982) and the Cedar Swamp, Middleborough, Plymouth County, Massachusetts (Rhodin 1992).

Historical and Current Distribution

Here follows a brief summary of the recent (1850–present) range of wood turtles. Extant populations span at least 9˚ of latitude from the southernmost populations in the northern third of West Virginia and Virginia (38.5˚N) to the northernmost confirmed populations in Québec and New Brunswick (47.5˚N). Witmer and Fuller (2011) include the wood turtle in an appendix of vertebrates that have been introduced to portions of the United States, but we have not found corroboration of successful introduction to a new site. Despite strong interest in the species by 19th century scientists and naturalists, a complete picture of the wood turtle's native range was not firmly in place until the mid-20th century. In fact, a major range extension to Cape Breton Island, Nova Scotia—the only confirmed offshore occurrence of wood turtles—was only published in 1973 (Bleakney 1958b, p. 28 [reports absence of turtle sightings on Cape Breton]; Gilhen and Grantmire 1973; Gräf et al. 2003). Question remains as to the recent native status, and current population status, of wood turtles in at least two states (Delaware and Ohio; see Part 2).

The wood turtle's general extent of occurrence now strongly overlaps with the regions glaciated by the Laurentide glacial advances of the Pleistocene epoch. This is—and certainly was, three centuries ago— a heavily forested region of about 725,000 km^2 (280,000 mi^2), straddling the northern reaches of the Eastern Temperate Forest ecoregion and the southern tier of the Northern Forest ecoregion.[5] Just over half of this area, occurs within the Northeast Region from Virginia to Maine, encompassing some of the most densely populated areas in North America, including dozens of large cities from New York and Washington, D.C. to Albany, Harrisburg, and Rochester, New York (the latter is approximately the geographic center of the wood turtle's range).

Northeastern United States

A complete analysis of the distribution of wood turtles in the Northeastern United States is presented in Part 2 of this document. We find that a descriptive summary of our current knowledge provides useful context, and so we here summarize the knowledge of the range of the wood turtle at the outset of this cooperative project. A descriptive account of the distribution of the wood turtle further provides context for the following sections, which contain original analyses. In New England, the wood turtle's range encompasses most of the five large New England states but is absent from much of the coastal plain in Connecticut, Rhode Island and Massachusetts—especially in the vicinity of Buzzards Bays and Cape Cod —and are evidently absent from all of the major offshore islands, including Martha's Vineyard, the Elizabeth Islands, and Nantucket in Massachusetts and Mount Desert Island in Maine (but see discussion under Maine, later). Wood turtles are absent from mountain areas, but few isolated populations occur

5 Ecoregional descriptions in this book follow the Level I, II, and III subcategories of the Commission for Environmental Cooperation (1997)

within the uplifted massifs of the White Mountains and in the vicinity of Baxter State Park, but they are generally absent from these high-elevation and high-relief regions. Wood turtles are also now absent from the greater Boston area.

Wood turtles are prominently absent from most major islands within their generalized range, including Anticosti, Prince Edward Island (Logier and Toner 1961, p. 51), Martha's Vineyard, Nantucket, and Long Island. The only major island in North America with confirmed occurrences of wood turtle is Cape Breton, Nova Scotia.

Maine.—Wood turtles have been reported from all but Sagadahoc County (Hunter et al. 1999; Maine Department of Inland Fisheries and Wildlife, unpublished occurrence data 2012). Early accounts of wood turtles in Maine include Say (1825) and perhaps Williamson's (1832) account of "speckled land turtle," and the reports of Agassiz (1857, p. 443), who reported a northern specimen from the Little Madawaska River in Aroostook County,[6] Fogg (1862), and Verrill (1863, p. 196), who noted that wood turtles were "common" in vicinity of Norway, Oxford County, but that it was apparently uncommon east of the Penobscot River. Boardman (1903) reported wood turtles from Calais. The wood turtle is not native to the islands of the Maine coast: records from Isle au Haut (Knox County) in August 1999 and Mount Desert Island (Hancock County) in 1958 and 1989 (Brotherton et al. 2004, p. 98; Maine Department of Inland Fisheries and Wildlife, unpublished occurrence records 2012), almost certainly represent released or escaped animals. Historical accounts of wood turtles (and other species) in Maine are summarized by McCollough (1997), who also noted that wood turtles are less abundant near the coast.

New Hampshire.—Wood turtles are known from every county in New Hampshire (Taylor 1993; Taylor 1997; New Hampshire Department of Fish and Game and New Hampshire Natural Heritage Bureau, unpublished data 2012). Huse (1901, p. 49) reported wood turtles as common in New Hampshire. Oliver and Bailey (1939) provided records from eight of New Hampshire's ten counties (except Strafford and Carroll). Wood turtles are known from only four occurrences within the White Mountain National Forest (WMNF) proclamation boundary, which includes large portions of Carroll County. At nearly 304,000 hectares, the WMNF is the largest block of federal land in New England—probably the result of a combination of climatic exclusion (the White Mountain region is largely above 500 m) and scarcity of low-gradient stream habitats not subject to severe flooding related to steep upstream basins (Bowen and Gillingham 2004; Jones and Sievert 2009).

Vermont.—Wood turtles are reported from all of Vermont's fourteen counties, in both the Champlain Valley (St. Lawrence watershed) and the Connecticut watershed, along both the west and east slopes of the Green Mountains (Vermont Reptile and Amphibian Atlas, unpublished data 2013; J. Andrews, unpublished data). The earliest confirmed specimen from Vermont maybe an animal collected at Sharon in Windsor County in 1900 by M. Parker (CAS 54480), although wood turtles were reported from Vermont by Thompson (1853), together with painted and snapping turtles. A specimen collected in South Hero, Grand Isle County on July 29, 1934 by L.H. Babbitt (Boston Museum of Natural History 51 8451) is the only record from the Hero Islands (Grand Isle County) and one of relatively few from an island anywhere in the range. DesMeules (1997) notes that wood turtles are found throughout the state but that little more is known about its distribution or abundance.

Massachusetts.—Wood turtles occur throughout all mainland counties of Massachusetts (Massachusetts Natural Heritage and Endangered Species Program, unpublished occurrence data 2012), but are not

6 Agassiz's specimen from the Little Madawaska River, Aroostook County, Maine, was provided by Sanborn Tenney, a former student, who also provided Agassiz with "hundreds" of specimens from Lancaster, Worcester County, Massachusetts.

known from Cape Cod, Barnstable County (Klemens 1993); or the islands of Martha's Vineyard (Dukes County) or Nantucket Island, Nantucket County (Lazell 1976). Lazell (1976) discredited a single recordsfrom Mashpee, Barnstable County, on Cape Cod.

Several nineteenth century accounts of wood turtle populations in Massachusetts are among the earliest such records available. The wood turtle was included in the early list of seven native turtles of Smith (1833). Storer (1840, p. 27) reported the wood turtle from Walpole (Norfolk County), Concord (Middlesex County), Amherst (Hampshire County), and Andover (Essex County). Louis Agassiz (1857) described wood turtles as common near Lancaster, Worcester County, circa 1854; Henry David Thoreau (2009) provided many accounts of abundant wood turtles in Concord, Middlesex County, circa 1855–1860[7]; and J.A. Allen (1868, p. 175) reported wood turtles to be "common" in the vicinity of Springfield, Hampden County, in the 1860s. Through the 20th century, anecdotal reports appear to indicate a gradual decline. Babcock (1919, p. 404) indicates that is not common around Dedham, Essex County.

Connecticut.—Wood turtles have been reported from every county in Connecticut, but are rare in the coastal zone and in eastern Windham and New London counties (Klemens 1993, p. 171–172). They are reported to reach their greatest abundance in the hills of eastern Connecticut, between the "eastern escarpment of the Central Connecticut Lowland and the Quinebaug Valley (Klemens 1993, p. 172)." Early data were provided by Babcock (1919) and Finneran (1948).[8] The species historically was broadly distributed throughout the entire state.

Rhode Island.—The wood turtle has been consistently reported as rare in Rhode Island (e.g., Drowne 1905, p. 5; Klemens 1993, p. 172), where it is known to occur in Providence, Kent, and Washington counties. There is a single record from Bristol County in 1983 (C. Raithel, Rhode Island Department of

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7 Observations of wood turtles (referred to sometimes as "*Emys insculpta*" and, more frequently, "wood tortoise") by Henry David Thoreau in the Assabet River, from West Concord to the confluence with the Sudbury River in Concord, Middlesex County, Massachusetts, between 1855 and 1860 (locations mentioned in Thoreau's journals are spatially referenced using Gleason [1906], and references in the text): 4/6/1855: individual basking on bank of Assabet River; 5/4/1855: "Yesterday a great many spotted & wood tortoises in the Sam[uel]. Wheeler--birch fence mead--pool which dries up..." (MTJ comment: Samuel Wheeler lived due west of the Sudbury River crossing at Route 2, according to Gleason [1906]), but this may be the "brush fence pond" referred to on 5/14/1857, below; 6/19/1855: mated pair in Assabet River; 9/15/1855: mated pair in Assabet River; 10/14/1855: mated pair in Assabet River; 11/9/1855: individual basking near Merrick's pasture, along Assabet River; 11/11/1855: individual rustling on the bank; 4/27/1856: individual observed; 7/6/1856: individual eating wood sorrel on bank at "Assabet Bath," near the One Arch Bridge; 3/27/1857: individual on the edge of Dodge's Brook along Assabet River; 5/14/1857: 13 wood turtles near the "brush fence pond" in young forest near Assabet River (this pond is referred to as ½ acre; three floodplain pools of this size are still visible in aerial photographs from 1938–present along the river right bank upstream of the confluence); 10/21/1857: mated pairs along Assabet River; 11/17/1857: individual out on the bank; 4/17/1858: individual basking on shore; 5/7/1858: a wood turtle by Tarbell's along the Assabet northeast of West Concord; 5/28/1858: individual observed; 6/6/1858: 3 or 4 nesting on gravel bank south of Assabet Bath; 6/10/1858: a nest near the Assabet Bath; 6/11/1858: 6 wood turtles nesting near the Assabet Bath and 6 nesting in Abel Hosmer's rye fields, also 2 nests discovered at A. Hosmer's (Abel Hosmer evidently owned land on both sides of the Union Turnpike's One Arch Bridge [now Route 2], and wood turtles nested in his rye fields south of the road and on sandy outwash north of the road); 7/19/1858: 3 or 4 nests of wood turtle and *Sternotherus odoratus* on sandbank; 5/17/1859: individual on bank; 6/10/1860: present in Hosmer's sandy bank field north of Assabet River and near the One Arch Bridge (note: on 7/15/1859, Thoreau makes a series of insightful observations concerning the influence of the One Arch Bridge on the downstream environment in the Assabet River, stating: "Contract the stream & make it swift & you will wear a deep hole & make sand bars & islands below--"); 6/12/1860: 2 or 3 wood turtle nests on sandbank along Assabet River. An additional observation from the vicinity of Nashoba Brook, a tributary of the Assabet River: 6/3/1856: southwest or west of Lorings Pond, "south of the brook." An additional observation, possibly in the vicinity of the "White Cedar Swamp" above Spencers Brook: 6/10/1858: nesting female observed while on a trip to the White Cedar Swamp. Furthermore, Thoreau apparently made several observations of wood turtles in the vicinity of Dugan Brook (then called Nut Meadow Brook), or the Dugan and W. Miles properties: 9/16/1854: a wood turtle in the woods, possibly near "Dugan Dessert (sic)," apparently in the upper Nut Meadow Brook (Dugan Brook) basin; 4/24/1856: at Warren Miles' new mill; 5/7/1856: In Miles' mill-pond (according to Gleason [1906], near Nut Meadow/Dugan Brook)—"The water thus suddenly let off, there were many spotted and wood tortoises seen crawling about on the bottom."; 6/14/1860: a wood turtle nest is found at "Dugan Desert." Additionally, wood turtles were observed by Thoreau in the Mill Brook drainage near Concord center: 3/26/1855: a wood turtle in "the brook" near Hubbard's Close (shown by Gleason [1906]) to be immediately south of Mill Brook; 6/17/1858: "coming across the level pasture west of E. Hubbard's swamp, toward Emerson's, I find a young Emys insculpta..."

8 A brief ecological description from Branford, New Haven County, was provided by Finneran (1948) indicating that wood turtles were "most frequently taken in the spring of the year from woodland streams of the northern section [of Branford]". Wood turtles are still known to occur in North Branford today (H. Gruner, unpublished data).

Environmental Management, unpublished data) and an anecdotal account of a dead wood turtle on a beach in Newport County ca. 1991–92 (D. Yorks, Maine Department of Inland Fisheries and Wildlife, pers. comm.) Consistent with regional trends, there are no records from the islands of Narragansett Bay.

New York.—Wood turtles range throughout New York from the Hudson Valley to Lake Erie and eastern Lake Ontario with the exception of Long Island (Klemens 1993). Corroborated occurrences of multiple turtles, or population data, are rare in some westernmost counties such as Chautauqua, Orleans, Gennessee, Monroe, Livingston, Yates, and Seneca (New York Herp Atlas 2013), and the lake plain south of Lake Ontario. Wood turtles appear to be rare on the southern lake plain of Lake Ontario, but evidently occur in most of the suitable drainages on the west shores of Lake Champlain as well as throughout the entire Hudson Valley. Although many distribution maps (e.g., Ernst and Lovich 2009, p. 251) indicate that wood turtles are absent from a large portion of the Adirondacks, especially central Essex County, scattered populations have been confirmed throughout the Adirondack massif (G. Johnson, SUNY Potsdam, unpublished data; NY Herp Atlas, unpublished data; see Part 3). Wood turtles were described as "common" in the Hudson Highlands of southeastern New York by Mearns (1898, p. 329) and as "fairly common" in Essex County, between Lake Placid and Tahawus in the Adirondacks, in the 1920s (Weber 1928). Wright (1918, p. 54–56) described wood turtles as relatively common in the vicinity of Ithaca, New York, at the southern end of Cayuga Lake. Ditmars (1905, p. 137; 1907, p. 53) vaguely reports wood turtles from the vicinity of New York City but does not provide specific locality data. Clausen (1943) reports three specimens from Tioga County on the Pennsylvania border.

Wood turtles have been reported on at least three occasions from Long Island but none of these reports are sufficient to demonstrate that a population occurred there (Murphy 1916, p. 57). Five wood turtles found washed ashore at Orient, Mattituck, Riverhead, and East Marion, eastern Long Island, between 1919–1926 may have originated from the Connecticut River watershed of New England, displaced during floods (Latham 1971). An individual collected from the Southern State Parkway northwest of Islip, Suffolk County, in the 1980s, may have been a released captive (Price 1982). No further specimens from Long Island have been documented (Al Breisch, New York State Department of Environmental Conservation [retired], pers. comm.)

New Jersey.—Wood turtles range throughout all of northern New Jersey north of Camden, southern Burlington, and southern Ocean counties. Agassiz (1857, p. 443), reported that New Jersey encompassed the southernmost records of wood turtle and subsequently Stone (1906, p.169) noted specimens from Delaware Gap, Warren County, and Woodbury, Gloucester County, New Jersey. The record from Gloucester County in 1906, and two records from Atlantic and southern Burlington counties in 1945 and 1978, cannot be replicated today. Stone (1906, p. 169) commented that no specimens from the Pine Barrens were known to him.

Pennsylvania.—The wood turtle ranges across almost all of central and eastern Pennsylvania. Surface (1908, p. 160–161) provided records from 22 counties ranging as far west as Venango County. Typical range depictions and descriptions (e.g., Surface 1908, p. 160; McCoy 1982; Ernst and Lovich 2009, p. 251) suggest that the wood turtle ranges west nearly to the Ohio border. In fact, there are historic records from Erie Harbor and the Presque Isle peninsula at Erie (CM 6880, Collections of S.H. Williams, Carnegie Museum of Natural History, Pittsburgh; McKinstry et al. 1987). However, from the information provided, it is impossible to confidently assign the Erie County records to typical stream habitats. Reportedly, small streams once entered Lake Erie where the city of Erie is now situated, and the historic records in the region may reflect populations formerly present along the Erie shore (M. Lethaby, Tom Ridge Center for the Environment, Erie, PA, pers. comm.) Interestingly, there is a record in the Royal Ontario Museum from

Long Point, Norfolk County, Ontario, 40 km due north across Lake Erie and possibly encompassing a similar dune ridge island environment (Logier and Toner 1961, p. 52), although this specimen is believed to represent a released captive animal (R.A. Saumure, pers. comm.). The nearest record to Erie, and one of the westernmost specimens from south of the Great Lakes, was collected at Linesville, Crawford County, by Daniel A. Atkinson (who collected wood turtles across Pennsylvania in the spring of 1906) on June 9, 1906 (CM2985, Coll. D. Atkinson).[9] The Shenango River, which flows along the Pennsylvania-Ohio border and was dammed in 1934 to create the Pymatuning Reservoir, may have supported one of the most western population of wood turtles in our region. Other early reports of the wood turtle from Pennsylvania include Stone (1906, p. 169), who reported specimens from Chester and Fulton counties, Bristol, Bucks County, and Round Island, Clinton County; Dunn (1915), who reported two individuals from Delaware County; and Evermann (1918) reported three individuals from Pike County. Conant (1942) reported anecdotal sightings from Dutch Mountain, Sullivan County. A series of excellent behavioral studies by John Kaufmann (1986; 1992a; 1992b; 1995) were conducted in Centre County; and important studies by Carl Ernst (1986; 2001b) were conducted in Lancaster County. Strang (1983) studied wood turtles in Cumberland County.

Delaware.—The historic status of wood turtles in Delaware is not clear and extremely poorly substantiated (NatureServe 2012; H. Niederitter, pers. comm. 2012; but see Part 2). Stone (1906, p. 169), in his summary of reptiles and amphibians from Pennsylvania, Delaware, and New Jersey, and who reported the earliest records of wood turtle from adjacent Chester County, did not report any specimens of wood turtles from Delaware. Several turtle biologists have surveyed northern Delaware for other turtle species, including bog turtles (Arndt 1977) and box turtles (Kipp 2003; Nazdrowicz et al. 2010) and did not report the occurrence of wood turtles. A noteworthy archeological occurrence of wood turtle was reported by the Delaware Department of Transportation during excavations near Dover: faunal remains recovered from the Thomas Dawson farm at Coopers Corners, Kent County, Delaware, reportedly included one fragment of wood turtle. The assemblage was dated to 1740–1780 (Bedell 2002, Ch. 3).[10] If confirmed, this occurrence is remarkable because it is one of only two records from the Delmarva Peninsula. Wood turtles very likely occurred in New Castle County, along the borders with Pennsylvania and Maryland, where there have been recent unconfirmed reports and negative follow-up surveys (H. Niederriter, pers. comm.). Suitable habitat, albeit fragmented, remains in northern Delaware (see Part 2 and Part 3). It appears that the wood turtle is currently extirpated from the state.

Maryland.—In Maryland, as in Pennsylvania and Virginia, wood turtles evidently occurred naturally in the Central Appalachians, Ridge and Valley, Blue Ridge, and Northern Piedmont Ecoregions (Conant 1958; Harris 1975; Miller 1993). Wood turtles occur through all of the western counties, reaching into portions of the Piedmont ecoregions in the east.

Norden and Zyla (1989) presented a series of 12 records from Coastal Plain counties, including the first for Anne Arundel County, voicing support for a native population of wood turtles on the Coastal Plain. Their conclusions were questioned by R.W. Miller four years later (1993), largely on the grounds of a lack of historical data and museum specimens. However, it remains clear that wood turtles were once native to the lower Susquehanna in Maryland and the lower Potomac in Maryland and Virginia, and several creeks in the vicinity of Washington, D.C., and Arlington, Virginia (Akre and Ernst 2006; T. Akre, SCBI, pers.

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9 Interestingly, on the same day that he collected the Linesville wood turtle, Atkinson also collected the second confirmed Blanding's turtle from Crawford County (also at Linesville).

10 Concurrent work in New Castle County revealed Blanding's turtle remains near the Appoquinimink River and Augustine Creek in colonial assemblages dated to 1750–1830; these have not been reported in mainstream turtle literature and represent the first records of Blanding's turtle from Delaware.

comm.). Wood turtles collected from near Havre de Grace, Cecil County (e.g., McCauley 1955, p. 55) were presumed by Reed (1956) to be waifs displaced from farther upstream in those respective watersheds (in the case of the Susquehanna, well into Pennsylvania); these were considered feasible by Miller (1993) because of "strong" support for the occurrence of wood turtles upstream in the Susquehanna watershed.[11] According to Scott Smith (MD DNR, pers. comm.), wood turtle populations have been recently confirmed from the vicinity of Aberdeen, and wood turtles were reported in the vicinity of the Conowingo Dam by Cooper (1949), strongly indicating their native occurrence in the lower Susquehanna. These stations, as well as the population reported from Elk Neck, are biogeographically significant because of their proximity to Delaware and the Delmarva Peninsula, where the native status of wood turtles is problematic. The Elk Neck population is probably extirpated (Scott Smith, Maryland Department of Natural Resources, pers. comm.).

A single record near Easton, Talbot County, Maryland, has prompted much discussion because of its potential biogeographical significance as the only record from Maryland's eastern shore (NHSM R-529). The record was dismissed by McCauley (1955, p. 155 in Reed 1956, p. 80). Conant (1958, p. 51) agrees with McCauley's dismissal of this record. Reed (1956, p. 80) argued that the Talbot County wood turtle location also supports some plants typical of the Piedmont Plateau, and that the vicinity of Easton may have similarly supported a natural occurrence of wood turtles; this line of logic was summarily dismissed by Miller (1993; p. 90) on many points, among them that the localized occurrence of Piedmont plants is insufficient grounds to validate such an isolated and unusual record, and that the wood turtle is not a piedmont species in Maryland but rather a montane species, and so the connection is more tenuous.[12] Miller (1993, p. 90) is also skeptical of the Talbot County record and of the tendency for authors to repeat the anomalous location without critical review or corroborating evidence. The current opinion of state managers is that wood turtles are not native to the eastern shore and Delmarva Peninsula (Scott Smith, MD DNR, pers. comm.). Historic records in the vicinity of Great Falls, Fairfax County, VA, apparently represent a natural historic population, and numerous small creeks on the Virginia side of the lower Potomac once provided suitable habitat for wood turtles (Akre and Ernst 2006). The Potomac River has many sidearms and sidestreams that reduce the average flow volume and may have provided better habitat than the main channel. Available evidence suggests that there was once a network of populations that lived in sidestreams on both sides of the Potomac River, both up- and downstream of Great Falls. The quantity of historic sightings and records along the lower Potomac River (as well as evidence that wood turtles nest on the river) suggests that some individuals did live on the Potomac itself, in addition to sidestream areas.

Washington, D.C.— Although reliable documentation of wood turtles within the District of Columbia, and adjacent Anne Arundel County, Maryland, is minimal, substantial evidence from Maryland, Virginia, and the District of Columbia indicate that wood turtles were native to Washington, D.C. Wood turtles are now considered "possibly extirpated" by the District Department of the Environment. There have been no recent confirmed reports, although there have been unconfirmed sightings (L. Rohrbaugh, wildlife biologist, District Department of the Environment, pers. comm.). A specimen from Washington in the

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11 Museum specimens from Cecil County include FLMNH41137 (D.M. Carver 1969, no location data); AMNH69045 (1948 no location data); UZ99002 (L. Lemay and J. Cooper 1948)

12 Reed's (1956) observation that the Talbot County wood turtle observation is associated with disjunct Piedmont vegetation is not captured by the USA Level III Ecoregions, which classify the entire Delmarva Peninsula as "Middle Atlantic Coastal Plain," or the Level IV Ecoregions, which categorize this part of Talbot County as "Chesapeake-Pamlico Lowlands and Tidal Marshes" (USEPA 2011).

National Museum (USNM 62556) was believed by Miller (1993) to be an animal referred to by Shufeldt (1919) as originating near Bennings in eastern Washington, D.C.

Two sight records from the Anacostia watershed along the eastern border district in Maryland (Norden and Zyla 1989) may provide additional support for the natural historic occurrence of wood turtles in the Anacostia drainage, but these were questioned by Miller (1993, p. 91). Suitable (though fragmented) habitat still exists at several locations in the District.

West Virginia.—Wood turtles occur in the panhandle of West Virginia including Jefferson, Berkeley, Morgan, Mineral, Hampshire, and Hardy counties, reaching the southernmost confirmed populations in Pendleton County (38.6°N). Outlying occurrences in Grant County (K. O'Malley, WV DNR, unpublished data) are noteworthy. Bond (1931, p. 54) reports wood turtles as "not uncommon" in Monogalia County, although this record was discounted by Breisch (2006). Recent sightings in Beaver County, Pennsylvania, suggest that wood turtles may have occurred in neighboring Hancock County, West Virginia, and surveys may be warranted here.

Virginia.—Wood turtles occurred historically throughout most of Virginia's northernmost counties, including Fairfax, Loudoun, Clarke, Frederick, Warren, Shenandoah, Page, and Rockingham (Akre 2002, p. 2; Akre 2010, p. 3). An early record from Fairfax County was provided by Dunn (1940, p. 8). In the 1980s, wood turtles were reported by U.S. Forest Service personnel in the southern part of Rockingham County (Buhlmann and Mitchell 1989). A recent record from the Blue Ridge Parkway in Nelson County was judged to be a released or escaped captive (T. Akre, pers. comm.). Extensive areas of formerly suitable habitat in Virginia have become unsuitable and fragmented by urban sprawl from the Washington, D.C. metropolitan area (see Part 4), and only one population is known to persist in the area east of the Blue Ridge (Akre 2010, p. 3). The majority of records and populations known to be reasonably large come from west of the Blue Ridge and the Shenandoah River (Akre 2010, p. 3). An Arlington record from the mouth of Four Mile Run near the Potomac River and US-1 in 1953 (USNM 136639) is substantiated by a recent (1993) record in the records of the Virginia Department of Game and Inland Fisheries from approximately 8 km upstream. Much of the discussion of wood turtles in the Lower Potomac under Maryland, earlier, applies to Virginia as well.

Canada

New Brunswick.—Wood turtles are patchily but widely throughout New Brunswick with the exception of southwestern portions of the province and the highland plateau of northern New Brunswick (McAlpine and Gerrietts 1999; McAlpine 2010; D.F. McAlpine, pers. comm.). In the north, wood turtles have been documented from the Restigouche watershed near Cambellton and the St. Francis basin near the Maine border. Wood turtles have also been documented throughout the Miramichi drainage on the Gulf of St. Lawrence coast (M. Toner, New Brunswick Department of Natural Resources, pers. comm.; Atlantic Canada Conservation Data Centre Rare Species Database 2013). Wood turtles were reported by Bleakney (1958, p. 66 & 69) from south-central and northern New Brunswick. Wood turtles are apparently rare on the highland plateau of northern New Brunswick, although they apparently occur in many streams around the periphery of this highland massif. It seems likely that New Brunswick harbors some of the most intact and productive wood turtle habitat remaining in Canada—and all of North America—but the populations in this region have not been intensively studied (Heward and McAlpine 1994; McAlpine and Gerriets 1999).

Nova Scotia.—On the peninsula of Nova Scotia, Canada's easternmost mainland province, wood turtles occur throughout the northern half of the mainland including Cumberland, Halifax, Hants, and Kings counties (Bleakney 1952, p. 127; Bleakney 1958b; Bleakney 1963; Nova Scotia DNR 2003) and

Guysborough County (Bleakney 1958b; Pulsifer et al. 2006; White et al. 2010). Wood turtles occur in several drainages of the southern third of Cape Breton Island, where they were only documented in the 1970s (Logier and Toner 1961, p. 51; Gilhen and Grantmire 1973; Gräf et al. 2003). Wood turtles are not native to Prince Edward Island or Newfoundland (Bleakney 1958b).

Ontario.—Wood turtles are widely distributed in watersheds throughout central Ontario from those draining into Lake Superior near Sault Ste. Marie (Algoma District) in the west (Logier and Toner 1961, p. 51), to basins draining into Gore Bay on Lake Huron to the St. Lawrence Valley east of Lake Ontario (Ontario Wood Turtle Recovery Team 2009), although Logier (1939) suggested the east (Appalachians) and west (Great Lakes) populations may be isolated from one another because of land conversion in southern Ontario. They are known throughout eastern portions of Algonquin Provincial Park and adjacent areas, where they have been intensively studied (Quinn and Tate 1991; Brooks and Brown 1992 *in* Foscarini and Brooks 1997; Brooks et al. 1992; COSEWIC 2007). Relatively isolated occurrences have been documented near Midland on Georgian Bay and in Huron County on Lake Huron (Logier 1939; Oldham and Weller 1989). Greaves and Litzgus (2009) studied the demographic structure of a wood turtle population in the Sudbury District. In south-central Ontario wood turtles formerly occurred along the north shore of Lake Erie (Logier and Toner 1961), but populations near Wheatley, Hamilton, Burlington, Mississauga, Toronto, and Oshawa have apparently been extirpated (COSEWIC 2007). Farther north, historic occurrences near Ottawa, Midland, Brechin, and Georgina have also been extirpated (COSEWIC 2007).

Québec.—Wood turtles occur widely throughout Québec south of the 48th parallel (Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs, unpublished occurrence data 2013), on both sides of the St. Lawrence River, a vast saltwater gulf. Bleakney (1958b) reported that wood turtles reach their northernmost range limit in the “St. Maurice” Valley. Biogeographically, various regions of southern Québec share affinities with the eastern Great Lakes Region of Ontario and New York, with which western Québec shares vast exposures of Precambrian shield rock as part of the Mixed Wood Shield ecoregion; the St. Lawrence and Champlain Valleys of New York and Vermont, composing the northern tier of the Mixed Wood Plains ecoregion; the Green and White Mountains of Vermont and New Hampshire; and the Madawaska watershed of western New Brunswick (encompassing part of the Atlantic Highlands ecoregion). Denman and Lapper (1964) report wood turtles from Mont St. Hilaire, Rouville County. Isolated northern occurrences (above the 48th parallel) have been reported from the vicinity of Val-d’Or in western Québec, La Tuque, Sanguenay, and Cap-Chat on the north coast of the Gaspé Peninsula, although Provancher (1874) reports an absence of turtles in the Sanguenay Region (Bleakney 1958b) and the northern Gaspésie record is highly questionable (W. Bertacci and Y. Dubois, Québec Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs, pers. comm.). Québec populations are primarily constrained to the watersheds of the Ottawa River, the lower St. Lawrence River (including the Missisquoi and Lake Champlain basin of Vermont and the Restigouche watershed of New Brunswick), and St. John River near the Maine and New Brunswick borders. In several cases, streams shared by both Québec and the United States, and in some cases forming the border itself, harbor populations of wood turtles. In the past two decades, Québec has established itself as a leading supporter of wood turtle research (Arvisais et al. 2002; Walde et al. 2003; Arvisais et al. 2004; Saumure et al. 2007). Wood turtles do not occur on Anticosti Island (Bleakney 1958b).

Great Lakes Region

Wood turtles occur throughout small regions of eastern Minnesota, and as a disjunct population in northeastern Iowa, and occur across relatively large areas of northern Wisconsin, Michigan and southern

Ontario. Despite the enormous area of suitable habitat surrounding the Great Lakes and Upper Mississippi River watershed—it is some 1,100 km from western Lake Ontario to the isolated Iowa populations—wood turtles went largely unnoticed by scientists until the 1920s–1940s. This is not surprising given that the major cities of Detroit, Chicago, and Milwaukee lie outside the range of the wood turtle.

Ohio.—The natural history and distribution—and even the native status—of wood turtles in Ohio is poorly understood, and supported by very few observations. The species was attributed to Ohio by Smith (1899, p. 30) and repeated by Ditmars (1907, p. 53) and Surface (1908, p. 160). Conant (1938, p. 8) considered the native status of wood turtles in Ohio to be "doubtful", although 13 years later, Conant (1951, p. 13) states of northeast Ohio that "probably *Clemmys insculpta* and *Clemmys muhlenbergii* occur in this region; they have been found in the adjacent part of Pennsylvania but repeated search for them in Lake, Geauga, and Ashtabula counties has resulted in failure." Ernst (1972) include northeastern Ohio is his range description. There have been at least two, and possibly three individuals observed in the Rocky River watershed near Cleveland in Cuyahoga County (Thompson 1953; Rice, pers. comm. to J. Iverson, *in* Iverson 1992).[13] Rocky River is large stream enters Lake Erie about 150 km (90 mi) west of the nearest corroborated occurrences in Pennsylvania, and is otherwise isolated from the continuous main range in Ontario. Anecdotal accounts of wood turtles from Greene and Suit counties are unconfirmed (Salzberg, pers. comm. to Iverson 1992). A record in Stark County, Ohio in Iverson (1992) is a mislabeled record from Butler County, Pennsylvania (CM31215). Conant (1951) searched for wood turtles unsuccessfully in the northeast corner of Ohio, but determined that wood turtles likely occur in that part of the state. As noted above, a specimen from Linesville, Crawford County, Pennsylvania, provides limited evidence of a historic population in the Linesville Creek–Shenango River Watershed (since 1934, flooded by the Pymatuning Dam), which straddles the Pennsylvania–Ohio border. Conant's (1951, p. 13) repeated searches in the northeasternmost counties, and Thompson's (1953) report of two wood turtles in Rocky River, Cuyahoga County, may indicate the recent persistence of an isolated relict population not contiguous with populations in Pennsylvania. Recent sightings in Beaver County, Pennsylvania (PA NHP 2013) bear relevance to determining the native status of wood turtles in Ohio.

Illinois.—There are at least two enigmatic records of wood turtle from Illinois. One series of two specimens were from Evanston, Cook County, where shipped to the MCZ between 1864 and 1872 (MCZ 4056). As Evanston is the location of Northwestern University, it seems possible that these records were either released captives or mislabeled with the University of origin rather than the capture site. Another specimen was observed in the Des Plaines River Ship Canal, Cook County (Miller 1993, pers. comm. to Iverson 1992), which is clearly atypical habitat in addition to being widely disjunct, and must represent an anomalous occurrence.

Iowa.—The wood turtle is narrowly restricted to the Cedar River drainage of northeastern Iowa. In 1924, E.L. Palmer of Cornell University reported a juvenile wood turtle from Ames, Story County, Iowa, extending the range south and west from recently discovered sites on the Wisconsin-Minnesota border (Wagner 1922; Palmer 1924). This unusual occurrence—not only a new state record, but near the geographic center of the state, and squarely within the Temperate Prairies ecoregion—was subsequently repeated in large-scale compendia, such as Clifford Pope's Turtles of the United States and Canada (Pope 1939). The observation was discredited (Bailey 1941) as a misidentified juvenile Blanding's turtle (*Emydoidea blandingii*). Nonetheless, by the mid-1940s, wood turtles were well-known to occur in the Cedar watershed of northeastern Iowa, and the populations in Black Hawk and Butler counties are the subject of long-term research by biologists the University of Northern Iowa (Tamplin et al. 2006; Tamplin

13 One adult female from Rocky River was accessioned in the Cleveland Museum of Natural History by Thompson in 1953 (specimen #500).

et al. 2009; Spradling et al. 2010; Tamplin, pers. comm.). These populations, and those in extreme southeastern Minnesota and southwestern Wisconsin, represent the only occurrence of wood turtles within the prairie ecoregions of the middle United States—noteworthy for what is otherwise a creature of cool, northern forests. In these peripheral prairie regions it is common for the floodplains of larger rivers to support heavily forested floodplains.

Minnesota.—Wood turtles reach their westernmost extent of occurrence in the Mississippi drainage of south-central Minnesota (Breckenridge 1958; Ernst 1973; Iverson 1992; Ernst and Lovich 2009). In this state, wood turtles are known primarily from three distinct regions: (1) watersheds draining into Lake Superior in St. Louis and Lake counties; (2) those from Pine and Chisago counties in the St. Croix watershed; and (3) those along the Cannon and Mississippi Rivers in Rice, Goodhue, Steele, Dodge, Olmsted and Mower counties in the southern part of the state, reaching almost to the Iowa border in Mower County (Ernst 1973).

Wisconsin.—Wood turtles occur widely throughout the forested regions of northern and western Wisconin (Vogt 1981). Though known from the state for less than a century—first confirmed near St. Croix Falls in Polk County by George Wagner (1922) and subsequently reported by Edgren (1944) from Bayfield County. Wood turtles are now known to occur throughout the northern two-thirds of Wisconsin, including Douglas and Bayfield counties on the shores of Lake Superior, and known from at least seven major drainages within the Chequamegon National Forest (St. Pierre (2008). Wood turtles occur in southwestern Wisconsin in portions of the Wisconsin River watershed, but they are absent entirely from the southeastern part of the state and southern Lake Michigan drainages, including Door, Kewaunee, Fond du Lac, Green Lake, Dane, and Lafayette counties (Wisconsin Herp Atlas 2011). Two Wisconsin specimens collected in the "Fox River" (UA R107 and UA R108) in 1951 by W.A. Lemberger have been attributed to Kenosha County on the Illinois border (e.g., HerpNet 2012), which would lend weight to Illinois specimens (see discussion of Illinois records, earlier), but these more likely originated in a different Fox River watershed, such as the one that flows through Outagamie and Brown counties to reach Lake Michigan at Green Bay. A single record from the Rock River, south of Janesville in Rock County, has not been replicated and is an unusual outlier (Cahm 1937).

Michigan.—Wood turtles occur widely throughout the northern half of Lower Michigan and much of the Upper Peninsula (Harding and Holman 1990; Harding 1997). The presence of wood turtles in Michigan has been established at least since 1915, when Alexander Ruthven and Crystal Thompson reported the species from Schoolcraft County in the Upper Peninsula as well as Manistee and Missaukee counties in the Lower Peninsula (Ruthven and Thompson 1915). The Upper Peninsula of Michigan is ecologically and geologically an extension of northern Wisconsin. With the exception of the Keweenaw Peninsula, wood turtles occur continuously throughout the Upper Peninsula from the border of Wisconsin in Gogebic County to Schoolcraft counties. On the Lower Peninsula, wood turtles occur from the northernmost counties (Cheboygan and Presque Isle) as far south as Muskegon, Montcalm, and Saginaw counties (Vogt 1985; Lee 1999). Isolated records from Allegan and Ingham counties in southern Michigan were discredited (Vogt 1985; Lee 1999).

Population Estimates and Status

Population Status and Trends and Northeast Occurrence Data

As with other Northeastern turtles (Compton 2007, p. 30), quantifying the size and trend of wood turtle populations in the Northeastern United States is made difficult by the broad distribution across at least twelve states, prevalence of wood turtle occurrence on private lands, cost of standardized surveys and travel between sites, and a lack of a coordinated effort with centralized data analysis. There is also a clear lack of quantitative historical data. A complete analysis of Northeastern United States occurrence data is presented in Part 2. A pilot effort to standardize survey protocols and begin a regionwide monitoring effort is presented in Part 3.

Population Size and Density

Wood turtle populations have been quantitatively assessed, or minimum population sizes reported, in Nova Scotia (Pulsifer et al. 2006), Québec (Daigle 1997; Walde 1998; Walde et al. 2003; Daigle and Jutras 2005); Ontario (Brooks and Brown 1992; Foscarini and Brooks 1997); New Hampshire (Tuttle and Carroll 1997; Jones 2009); Vermont (Parren 2013); Massachusetts (Jones 2009); Connecticut (Garber and Burger 1995); New Jersey (Harding and Bloomer 1979; Farrell and Graham 1991); Virginia (Akre and Ernst 2006); and West Virginia (Niederberger 1993; Niederberger and Seidel 1999). Estimates of population density are typically provided as one of four metrics: turtles per hectare of available habitat (e.g., Farrell and Graham 1991); turtles per hectare of river surface area ("river-ha", e.g., Foscarini and Brooks 1997, p. 204), turtles per linear km (or m) of meandering river ("river-km," e.g., Jones 2009, Ch. 4) and turtles per km (or m) of linear floodplain transect (Pulsifer et al. 2006; M. Pulsifer, Nova Scotia Department of Natural Resources, pers. comm. to M.T. Jones). Often, model estimates are provided for discrete areas that form coherent management units or natural landscapes (Akre and Ernst 2006). Comparisons across these different estimation techniques are difficult, and are made further confusing because researchers variably report population estimates for both adults and juveniles or only adults. Foscarini and Brooks (1997, p. 204) proposed that density estimates be standardized by stream surface area (stream length x average stream width). Population density estimates from throughout the Northeast are summarized in Table 7.

Density per hectare of available habitat.—Density estimates provided as turtles per hectare of available habitat (usually extent of floodplain vegetation) range from 0.4/ha (for 538 ha) in the Mauricie region of Québec (Walde 1998, p. 9), to 4.4/ha in Pennsylvania (Ernst 2001b); 10.6/ha for 62 ha in Sussex County, New Jersey (Farrell and Graham 1991), and about 12.5/ha for an unspecified area in Passaic County, New Jersey (Harding and Bloomer 1979, p. 18). Again, these figures are problematic because of the difficulty in standardizing measures of available habitat.

Stream-based density estimates.—For stream-based density estimates, Daigle (1997) and Daigle and Jutras (2005) reported densities of 9.7 turtles/river-km. Brooks and Brown (1992, in Foscarini and Brooks 1997) estimated densities of 35.0 turtles/river-ha and 35.5 turtles/river-km, Jones (2009, Ch. 4) provided density estimates at 31 stream segments in Massachusetts and New Hampshire ranging from 0.4–52.3 adult wood turtles/ha of stream surface area and 0.6–40.4 adult wood turtles per kilometer of meandering stream, and reported several streams where repeated surveys could not reveal sufficient animals for recapture analysis, suggesting extremely low population size. Pulsifer et al. (2006; M. Pulsifer, Nova Scotia Department of Natural Resources, pers. comm. to M.T. Jones) reported estimated minimum densities of 2.5–11.3 wood turtles per transect km in Nova Scotia. The highest density estimates reported are probably Farrell and Graham (1991; R. Farrell pers. comm. to M.T. Jones), whose estimates are equivalent to about 545 turtles per river-ha and 284.3 turtles per river-km, or Niederberger and Seidel (1999), whose estimate of 337 turtles appears to translate to 198.2 turtles per river-km. The largest known population in the wood turtle's range may be found in the St. Mary's River of Nova Scotia, where extrapolated estimates suggest a population size of between 1083–4000 turtles (Pulsifer et al. 2006; M. Pulsifer, pers. comm.).

Total population size.—No estimates have been generated for the total North American or United States population (van Dijk and Harding 2011). The total population size for the four eastern Canadian provinces has been roughly estimated at 6,000–12,000 adults based on estimates from Canadian researchers (COSEWIC 2007, p. v).

Historical references.—Limited historical data indicates that some populations in the 19th century may have been relatively large. In Massachusetts in the 1850s, wood turtles were reported by Louis Agassiz (1857)[14] and Henry David Thoreau (ca. 1855–1860) to be relatively abundant in certain streams in Worcester and Middlesex counties. Subsequently, J.A. Allen (1868, p. 175) reported wood turtles as "common" in the vicinity of Springfield, Hampden County. Nash (1908, p. 18) reports the wood turtle "tolerably common" in western Ontario, less frequently found eastward." Oliver and Bailey (1939) reported the wood turtle to be one of the most common turtle species in New Hampshire. In New Jersey, however, Fowler (1906, p. 243) reports the wood turtle to be "scarce".

Population Viability Analysis

Undertaking a regionwide, spatially explicit Population Viability Analysis (PVA) is not a straightforward undertaking because of the small proportion of known sites that have been sampled, the long-standing tendency to select study sites and study animals nonrandomly, the expense of radiotelemetry, the short term of radiotelemetry studies, temporal and spatial variation in nest depredation rates, and the difficulty assessing hatchling and juvenile life stages without influencing survival rates. Compton (1999, Ch. 3) built a demographic model for a theoretical wood turtle population in Maine, and modeled the effect of harvesting or removing of one, two, and three adults annually from a starting population of 100 turtles. The three-turtle harvest resulted in extinction within 50 years; the two-turtle harvest model resulted in extinction in 75 years, and the one-turtle harvest model had declined by over 60% in 100 years (Compton 1999, p. 73).

Direct Evidence for Population Decline

Several studies in the Northeast or adjacent regions have presented quantitative evidence of decline of wood turtles. Almost all studies with a long-term component appear to report detectable or apparent declines. In the Missisquoi watershed of Québec, which is shared with Vermont, Daigle and Jutras (2005) reported a 50% decline in the estimated adult population over 7 yr. The study took place in the same stream as the studies undertaken by Saumure and Bider (1998), Saumure (2004), and Saumure et al. (2007), and the combined conclusion of these four studies is that the population is declining because of adult mortality associated with hay mowing and other agricultural activities. According to the most recent COSEWIC (2007, p. v) status assessment, the overall trend in wood turtle abundance across Canada has been a decline. Approximately ten historic occurrences near the Ontario shores of Lakes Erie, Huron, and Ontario have been extirpated, which represents a major range contraction in that part of Canada (COSEWIC 2007, p. 18). The single remaining population in "southern" Ontario has shown clear signs of decline since it was first studied by Dina Foscarini in 1991–1992 (Foscarini 1994; COSEWIC 2007, p. 18).

In Michigan, Harding (1991) reported population declines in remote and relatively undisturbed areas, and proposed that illegal collection may have contributed to the declines.

In Maine, Verrill (1863) reported wood turtles to be common near Norway in Oxford County, where wood turtles are today relatively uncommon (T. Akre, pers. comm.).

In central Massachusetts, Jones (2009) reported that most populations appeared to be declining and presented limited evidence of significant declines at three long-term study sites over periods of up to 5

14 Agassiz (1857) reported "I am indebted to Mr. Tenney for hundreds of specimens from Lancaster, Massachusetts… Emys insculpta is so common in the neighborhood of Lancaster, about forty miles from Boston, that I have at times collected more than a hundred specimens in one afternoon…"

years. Jones and Sievert (2009b) presented evidence that wood turtles in western Massachusetts were declining by as much as 11.2% annually. Jones and Sievert (2009b) presented evidence that wood turtles were negatively affected by severe floods, which apparently caused population declines in northwestern Massachusetts. Jones (2010) noted that wood turtles have become very rare inside the Interstate 95 corridor near Boston. Elsewhere in Massachusetts, in Concord, Middlesex County, Henry Thoreau observed wood turtles to be common in the late 1850s, and Rickettson (1911) reported them to be "common in the brooks" in the early 20th century, but Greer et al. (1973) reported wood turtles to be "infrequent" by the 1970s. Further, Windmiller and Walton (1992), Windmiller (2009), and Cook et al. (2011, p. 54) reported that the wood turtle had declined nearly to extirpation, although approximately five individuals have been observed in that town since the 1990s (Windmiller 2009, p. 2; Windmiller, pers. comm.; M.T. Jones, unpublished data). In 2009, researchers reassessed the streams in Lancaster, Worcester County, Massachusetts, where Agassiz (1857) reported capture rates of >100 turtle per afternoon, and had capture rates nearly 1/50th those reported by Agassiz (M.T. Jones, L. Willey, A. Richmond, P. Sievert, University of Massachusetts, unpublished data), suggestive of a localized decline.

In Connecticut, Garber and Burger (1995) interpreted their long-term (1974–1993) survey results as evidence of total population collapse associated with human recreation. Following the allowance of passive recreation near the study site in 1982, two subpopulations in the same stream declined from apparent peaks of 106 and 51 captured turtles, respectively, to 6 and 8 detected in 1991 and none in 1992 or 1993. The authors present a compelling summary of population collapse, although detection rates were not estimated and survey effort by year was not presented. In southwestern Connecticut and adjacent Westchester County, Klemens (1989, p. 1–4) considers the wood turtle functionally extinct. Burger and Garber (1995) emphasize widespread decline but do not present evidence beyond that summarized in Garber and Burger (1995).

Harding and Bloomer (1979) note the collapse of wood turtle populations in eastern and central New Jersey since the 1950s. In Virginia, Ernst and McBreen (1991) reported the extirpation of three wood turtle occurrences in Fairfax and Loudoun counties since 1979, and noted that 33% of known localities were threatened by development. Akre and Ernst (2006) and Akre (2010) reported that two populations persist on the Piedmont east of the Blue Ridge. Of these, one site in Fairfax County appears stable, but the authors provide evidence of decline at a known site in Loudoun County. Akre and Ernst (2006) resampled three streams in the coastal plain of northeastern Virginia where wood turtles had been reported historically, but detected no turtles. Further, they provide a detailed analysis of the probable range contraction of wood turtles on the coastal plain.

Monitoring and Inventory

Existing Monitoring Protocols

Visual encounter surveys.—As outlined in the literature review in the proceeding pages, the wood turtle has been intensively studied at sites widely distributed throughout the northeastern States. However, sampling procedures vary. Typically, researchers report searching for wood turtles on foot in streams and riparian areas in the spring and fall in groups of one to four.

Boat surveys.—Some researchers (e.g., Saumure and Bider 1998; Walde 1998) report searching for wood turtles within one observer in a canoe and one observer on each bank, or with two observers alternately in a canoe or small motorboat or searching upland bank habitats (Jones and Willey 2013b).

Trapping.—Trapping is infrequently reported as an effective sampling method, but has been implemented in Virginia (Akre and Ernst 2006) and Maine (Jones and Willey 2013b), with varied success. Akre and

Ernst (2006) describe an interruption-type setup with wing fences constructed from fyke nets, rock walls, or other materials.

Other Sampling Techniques

Viewing underwater.—To improve detection rates, teams throughout the Northeast variably use underwater viewing scopes (Akre, pers. comm., Dragon, pers. comm., Lemmon, pers. comm.), polarized eyeglasses, or facemasks and snorkles (T. Pluto, USACE, pers. comm.; Jones and Willey 2013a; 2013b). The effectiveness of these probably varies in different stream systems based on the type of structural habitats present underwater, the volume of water in the system, and the clarity of the water.

Cameras.—With the recent advent of low-cost, high quality time-lapse models, it has become possible to use cameras to assess relative densities of wood turtles at known features within high-density sites. Wingscapes PlantCams, programmed to record images every five minutes between 1700 h and 2100 h, have been used to assess the relative use of different nesting beaches in New England, and GoPro cameras have been used to record fine-scale, short-term nesting behaviors (Jones and Willey 2013a; 2013b) and may also be used to monitor use and behavior at overwintering sites (faced north, with a polarized lens). The PlotWatcherPro may be a more versatile option for a range of applications including nest- and basking-site behavior and has been used successfully to monitor gopher tortoise activity (T. Radzio, Drexel University, pers. comm.). Motion-sensing cameras have also been used to detect nest predators (Akre 2011).

Decontamination of Field Gear

Although it is generally not mentioned in recent studies of wood turtles, decontamination of field equipment and sampling gear has become part of standard operating procedure in light of widespread outbreaks of *Ranavirus* in wild box turtle populations and unidentified pathogens in bog turtle populations (see Threats to Population Stability, later). Standard decontamination protocols include the following components (Miller and Gray 2009; Appendix I):

1. Remove mud, sand, and debris from equipment, boots, waters, bins, tires and rinse with local or sterile water;
2. Apply disinfectant (3% household bleach; 0.75% Nolvasan [Fort Dodge Animal Health]; or 1% Virkon [DuPort Animal Healthy Solutions]) to equipment and tools for five minutes and rinse with sterile water;
3. Avoid unnecessary contact between turtles during processing (when possible, house turtles in separate sterile bins) and wear gloves during processing.

Other Considerations

Study Design.—In a comprehensive review of sampling design considerations for the western pond turtle (*Actinemys marmorata*), Ashton et al. (2012) note the following major themes that apply equally to monitoring efforts for wood turtle:

1. Clear statement of hypothesis;
2. Appropriate use of available information to frame the question;
3. Rigorous data collection and management standards;
4. Emphasis on sampling all size- (age-) classes using a range of methodologies;

5. Study site selection with consideration for accessibility, elevation, stream size, and habitat suitability;

6. Randomized site selection if all sites cannot be sampled;

7. Classification of sites to allow stratification by human influence and habitat features.

Safety.—On the surface, most wood turtle sites do not appear to pose clear risks to human safety. However, working in streams and rivers pose risks ranging from hypothermia to drowning. It is important that researchers identify potential safety risks and take measures to minimize them. For instance, snorkeling and boating should be undertaken only by qualified and trained personnel. Snorkeling should not occur near potentially unstable structures such as logjams. Surveys should not be conducted during high flows or flood conditions that may result in unsafe conditions for observers. Other safety considerations are enumerated by Bury et al. (2012) for western pond turtle, and these apply equally to wood turtle surveys.

Legal Status and Regulatory Protections

Legal Status in the United States and Canada

The wood turtle was upgraded to "endangered" from "vulnerable" by the IUCN in 2011 (van Dijk and Harding 2011). NatureServe recently (2010) upgraded the wood turtle from G4 to G3 (vulnerable). The wood turtle is listed as "endangered" in Iowa; as "threatened" in Minnesota, New Jersey, Virginia, and Wisconsin; and as a species of special concern/interest in Connecticut, Maine, Massachusetts, New Hampshire, Vermont, Rhode Island, New York, and West Virginia. The wood turtle is not listed, but a protected nongame species, in Maryland and Pennsylvania. In Canada, the wood turtle is listed as "threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Species at Risk Act (SARA), and is further listed as "rare" in Ontario, "threatened" in Québec (Y. Dubois, Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs, pers. comm.), and as "vulnerable" in Nova Scotia. The wood turtle has no formal status in New Brunswick although individuals are protected under the Fish and Wildlife Act and under federal legislation.

Lacey Act.—Because the wood turtle is not federally listed and has no federal protected status, most of the laws and regulations protecting wood turtles and their habitats are enacted and promulgated at the state level. However, the U.S. Lacey Act (18 USC 42–43; 16 USA 3371–3378) applies to the interstate transportation and sale of wood turtles that were collected in violation of state law or regulation. Captive-bred specimens are not exempt from the Lacey Act if the parent stock was illegally harvested. The law applies to living and dead specimens. Private citizens engaged in the sale of wood turtles may be subjected to investigations under the Lacey Act, and prosecuted if it is found they did not exhibit "due care" in determining the legal status of the wood turtles (U.S. Fish and Wildlife Service Office of Law Enforcement 2006). Several recent cases of poaching (see Significant Threats to Population Persistence, later in Part 1) were successfully prosecuted under the Lacey Act, although the penalties have been arguably minor.

CITES.—Wood turtles are afforded some protection internationally as an Appendix II list species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which is currently (2013) adhered to by 179 sovereign states. International trade in CITES Appendix II species is moderately controlled. Exportation may be authorized by the granting of an export permit or re-export certificate, but no import permit is necessary for these species. According to the U.S. Fish and Wildlife Service (2003), which is the United States' managing authority for CITES, export permits for Appendix II species are only be granted if trade will not be detrimental to the species' survival, and that specimens were legally acquired.

U.S. Forest Service.—Wood turtles are designated Regional Forester sensitive species on the White Mountain, Green Mountain, Allegheny, George Washington, and Jefferson National Forests. Under this designation, habitat for this species must be conserved, although not every acre must be protected. When a management action is proposed, a review is completed to analyze potential effects to wood turtles and their habitat. If the analysis indicates a likely adverse impact, then generally the project is modified to avoid the impact or does not proceed (L. Prout, USFS White Mountain National Forest, pers. comm.; F. Huber, USFS George Washington National Forest, pers. comm.). When the White Mountain National Forest revised its management plan ("Forest Plan") in 2005, an extensive review was conducted, which included compiling all known information, questioning species experts, and evaluating the implementation of the Forest Plan on wood turtle viability.

Critical Review of Regulatory Status by State

In this section, we provide a comprehensive state-by-state summary of regulatory measures in effect to protect wood turtles and wood turtle habitat in the 13 northeastern States (Table 8).

Table 8. Summarized regulatory protections in effect for the wood turtle in the Northeastern United States. Y=yes; N=no; SR=state river or wetland regulations only; L=limited.

	ME	NH	VT	MA	CT	RI	NY	NJ	DE	PA	MD	WV	VA
Listing status	SC	SC	SC	SC	SC	SC	SC	T	SR	-	-	SC	T
Possession legal	Y	N	N	N	N	N	N	N	Y	N	Y	N	N
Commercial trade legal	N	N	N	N	N	N	N	N	N	N	N	N	N
Import legal	N	N	N	N	N	N	N	N	N	N	N	N	N
Take legal	N	N	N	N	N	N	N	N	N/A	N	N	N	N
River habitat protected	SR	L	L	Y	L	SR	SR	L	SR	SR	SR	SR	L
Nesting habitat protected	N	L	L	Y	L	N	N	L	N	N	N	N	L
Upland habitat protected	N	L	L	Y	L	N	N	L	N	N	N	N	L
Qualified wood turtle observers are regulated	N	N	N	Y	Y	N	N	L	N	N	N	N	N

Maine.—The wood turtle is a Species of Special Concern in Maine, which is a category assigned by policy and not regulation. Maine Department of Inland Fisheries and Wildlife considers Species of Special Concern "...any species of fish or wildlife that does not meet the criteria of an endangered or threatened species but is particularly vulnerable, and could easily become, an endangered, threatened, or extirpated species due to restricted distribution, low or declining numbers, specialized habitat needs or limits, or other factors." This status is used for planning and informational purposes. The Maine Department of Inland Fisheries and Wildlife "reviews the list of special concern species at the beginning of each calendar year, and, based on criteria in the Maine Endangered and Threatened Species Listing Handbook (ME DIFW 2009), revises the list as appropriate." Large development projects may be reviewed to protect wood turtle habitat under Site Location of Development law (Title 38, Chapter 3, Subchapter 1, Article 6, § 481 and 484; P. deMaynadier, ME DIFW, pers. comm.)

Additional laws in effect protect riparian and riverine habitats, including Shoreland Zoning Rules and the Natural Resources Protection Act (Statutory sections: Title 38, Chapter 3, §§ 480–Z). Other state laws provide specific protections for the Allagash Wilderness Waterway (Title 12, Chapter 206).

Wild Maine wood turtles are protected from export, sale, and commercial use (Title 12, Part 13, SubPart 4, Chapter 915, §12159), but apparently are not protected from collection for personal use by Maine residents (P. deMaynadier, ME DIFW, pers. comm.).

New Hampshire.—The wood turtle is a Species of Special Concern, a category not outlined in the endangered species statute (Title XVIII, Chapter 212-A, Endangered Species Conservation Act). Rules are allowed under the Nongame Act (RSA 212-B). Special Concern Species are determined by the Fish and Game Department following a guidance document (NHFG 2009), which outlines Species of Special Concern in two categories, of which the wood turtle is category A1 (High risk in much of southern NH; vulnerable to development, collection, roads, stream alterations and life history traits. Northeast Regional Conservation Concern):

> "Category A: 'Near-threatened Species': Species that could become Threatened in the foreseeable future if action is not taken.
>
> > Sub-category 1) Existing threats are such that the species could decline to Threatened status if conservation actions are not taken. In some cases, further survey work may support removing a species from the 'special concern' list but existing information must indicate a sufficient level of threat or concern.
> >
> > Sub-category 2) Species which were recently down-listed (i.e. recovered) from the state endangered and threatened species list and where conservation action is desired to ensure the species continues towards full recovery.
>
> Category B: 'Responsibility Species': Species for which a large portion of their global or regional range (or population) occurs in New Hampshire and where actions to protect these species habitat will benefit the species' global population. Species were candidates for being included as Category B if they scored as 'Very High' (>8% of species Northeast range occurs in New Hampshire) in the Species Responsibility vs. Threat Matrix (Hunt 2007) or in subsequent analyses using similar methodologies."

While the presence of a special concern species in an area may improve its competitiveness for land acquisition or grant allocation, and "should be considered when making habitat management decisions," and NHFG may provide recommendations to reduce impacts from proposed activities (e.g., developments, bridge construction or repair) and the NHDES makes a determination on the issuance of permits and appropriate conditions to include (M. Marchand, NHFG, pers. comm.). Special concern species are candidates for consideration in environmental review under the NHDES Wetlands Bureau Dredge and Fill Rules (Env-Wt 302.04(7a), which "require applicants to address impacts to Special Concern species."[15]

Additional protections for wood turtle habitat may be accomplished through the NHDES Wetlands Dredge and Fill permit process (Federal Clean Water Act § 404) and the NHDES Shoreland Protection Act (RSA 483-B), but upland habitat protection is reportedly difficult (M. Marchand, NHFG, pers. comm.).

15 Note that the NHDES is currently in rule revisions and and the process outlined may change in the near future.

Further, the wood turtle may not be possessed (as defined in RSA 207:1), sold, or imported (NHFG FIS 800) without a permit (NHFG FIS 804.02). The possession or take of wood turtles, wood turtle eggs, or any part thereof is prohibited (NHFG FIS 1400).

Vermont.—The wood turtle is listed by the Vermont Fish and Wildlife Department as a Species of Special Concern, a designation that appears to carry relatively little consistent regulatory weight.

It is theoretically possible to specifically protect wood turtle habitat under Act 250, the Land Use and Development Act (S. Parren, Wildlife Diversity Program, VT Fish and Wildlife Department, pers. comm.). Act 250 applies to development projects larger than 4 ha (10 acres), or more than 1 acre in towns without zoning bylaws. Nine District Environmental Commissions have the power to deny or permit large-scale development based on a series of 10 criteria, several of which, if implemented, protect wood turtle habitat, such as water quality (#1); erosion control (#4); aesthetics and endangered species (#8). Subcriterion 8a allows protection of "necessary wildlife habitat." To protect wood turtle habitat, the Vermont Fish and Wildlife Department would have to apply to the relevant District Environmental Commission. To do this consistently, wood turtle habitat would have to be estimated and mapped.

It is illegal to import any wild animal into Vermont without a permit from the Commissioner, including wood turtles (Title 10 Appendix, Chapter 10, §18). It is further illegal to possess, capture, collect, or breed wild animals without a permit, and hence under federal regulations it is illegal to remove wood turtles from Vermont to another state without a state permit in both states. The wood turtle is not protected under the Vermont endangered and threatened species rule (10 V.S.A. App. § 10) because it is not formally listed. However, the regulatory infrastructure for habitat protection and "take" prohibition is in place, and is based on avoidance, minimization, and mitigation for regulatory review. The most likely use of Act 250 to protect wood turtle habitat, a non-listed species in Vermont, would be using subcriterion 8a (necessary wildlife habitat; S. Parren, pers. comm.). Unless the regulatory protections for habitat are improved under the state endangered species statute, this method is likely the most effective for the protection of wood turtle habitat.

Massachusetts.—Under the authority of the Massachusetts Endangered Species Act ("MESA," M.G.L. c. 131A) the wood turtle is regulated as a Species of Special Concern (321 CMR 10.00, revised and implemented October 15, 2010). Unlike endangered species laws in adjacent states, which generally allow stringent protections for Endangered and Threatened Species, the MESA prohibits the "take" of Endangered, Threatened, and Special Concern species. "Take" is defined as, "in reference to animals to harass, harm, pursue, hunt, shoot, hound, kill, trap, capture, collect, process, disrupt the nesting, breeding, feeding or migratory activity or attempt to engage in any such conduct, or to assist such conduct, and in reference to plants, means to collect, pick, kill, transplant, cut or process or attempt to engage or to assist in any such conduct. Disruption of nesting, breeding, feeding or migratory activity may result from, but is not limited to, the modification, degradation or destruction of Habitat." The Division of Fisheries and Wildlife's Natural Heritage and Endangered Species Program (NHESP) maintains a database of element occurrences, from which it develops "Priority Habitat" maps designating riparian and upland landscapes in which all non-exempt development activities and land use conversions are reviewed for the likelihood of a "take."

"Conservation and Management Permits" (CMPs) may be issued to allow a "take" if the applicant meets a standard of "no significant impact" to regional populations, and if the applicant can demonstrate a regional "net benefit" to the wood turtle population. More often, the NHESP provides comments that are incorporated into project design to avoid the necessity of a CMP. Under the take provisions of the MESA, but also under the regulations regarding possession and collection (321 CMR 3.05 [2] and [6]) the wood turtle may not be disturbed, harassed, taken, sold, or possessed.

Connecticut.—As a Species of Special Concern, wood turtles are afforded limited protection under the Connecticut Endangered Species Act (GSC Title 26, Chapter 495) and its regulations (§§ 25-306-3 and 26-306-7 of the *Regulations of Connecticut State Agencies*). According to H. Gruner (CT Museum of Science, pers. comm.), in an environmental review context, a wood turtle site may be identified when a developer requests information from the State Department of Energy and Environmental Protection (DEP) on the presence of state-listed species. In the case of wood turtle, the DEP issues a letter confirming the species' potential presence with a recommendation for the developer to engage an expert to confirm presence and recommend conservation strategies. Developers typically hire consultants to follow-up and then present to the appropriate municipal commission as part of a permit application process. The Department of Energy and Environmental Protection (DEP) is required to review the designation of species as endangered, threatened, or of special concern every five years.

Stream and riparian habitat is afforded protection under the Inland Wetlands and Watercourses Act (GSC §§ 22a-36 through 22a-45).

The wood turtle is a restricted species under DEP regulations (26-55-3), which state that no person shall possess any wood turtle at any time (Conn. Code Sec. 26-55-3-C). No wood turtles may be collected within Connecticut (Conn. Code Sec. 26-66-14-A) at any time.

Rhode Island.—Rhode Island has enacted an endangered species act (Gen. Laws, 1956, 20-37-1–5) Endangered species may be designated by the Director of the Department of Environmental Management. The wood turtle is a Species of Concern, which are defined as: "Native species not considered to be State Endangered or State Threatened at the present time, but are listed due to various factors of rarity and/or vulnerability. Species listed in this category may warrant endangered or threatened designation, but status information is presently not well known."

The sale of native wildlife is prohibited in Rhode Island, and the wood turtle is further covered under regulations of the Rhode Island Division of Fish and Wildlife as a protected species. Under these regulations, wood turtles may not be possessed at any time with out a permit issued by the Rhode Island Division of Fish and Wildlife as provided by Rhode Island General Law, Title 20, Chapters 20-1-18, 20-1-22, and 20-37-3.

New York.—The wood turtle is a Species of Special Concern (as defined in §182.2(i) of 6NYCRR Part 182, Endangered and Threatened Species Regulations) and (as with other native turtles except the snapping turtle, *Chelydra serpentina*) as a small game species with no open season may not be collected, pursued, taken, wounded, killed, sold, transported, or possessed (Environmental Conservation Law [ECL] Article 11, Title 1, §11-0107,[16] and DEC promulgated regulations of the ECL, Chapter 1: Fish and Wildlife, Section 3.2: Native Turtles). In essence, the wood turtle may not be collected or possessed but there are no strong protections for habitat (A. Ross, NYS DEC, pers. comm.). Under these regulations and the federal Lacey Act, between 2006–2009, New York State Department of Environmental Conservation conducted "Operation Shellshock," an undercover investigation of the reptile trade in New York State, which led to seizures of wood turtles and criminal charges against 17 people, including members of the "turtle

16 1. No person shall, at any time of the year, pursue, take, wound or kill in any manner, number or quantity, any fish protected by law, game, protected wildlife, shellfish, harbor seals, crustacea protected by law, or protected insects, except as permitted by the Fish and Wildlife Law. 2. No person shall, at any time of the year, buy, sell, offer or expose for sale, transport, or have in his possession any fish protected by law, game, protected wildlife, shellfish, harbor seals, crustacea protected by law, or part thereof, or protected insect, whether taken within the state or coming from without the state, except as permitted by the Fish and Wildlife Law.

conservation community" (A.G. Sulzberger, *State officials charge 17 in illegal animal trade*, New York Times, March 19, 2009). Wood turtle habitat is not afforded specific, formal protections from development, forestry, or agricultural activities. Limited protections to riverine habitats, and special provisions for the Adirondack region, exist under the Stream Protection Act (ECL, Title 5, Article 15), Freshwater Wetland Act (ECL, Title 23, Article 71), Solid Waste Disposal Act (Laws of 1988, Chapter 70), State Environmental Quality Review Act ((8 NYCRR Part 314; A. Breisch, NYS DEC, pers. comm.) The presence of wood turtles in a proposed project area is noted, but barring other factors lends little weight to the decision to issue a development permit (A. Breisch, NYS DEC [ret.]).

Interestingly, in 1905, New York State amended its "Forest, Fish, and Game" law to prohibit the "taking, killing, or exposing for sale of all land turtles or tortoises, including the box and wood turtle," becoming the first state to enact legislation to protect the species (Breisch 1997; Gibbs et al. 2007, p. 293).

New Jersey.—The wood turtle is protected as a Threatened species under the Endangered and Nongame Species Conservation Act ("State Act," or ENSCA; New Jersey Statutes Annotated 23:2A-1, et seq.), implemented in 1973, under which the Commissioner of the Department of Environmental Protection may promulgate and periodically review a list of endangered species, and adopt regulations with respect to the taking, possession, transportation, exportation, processing, and sale of endangered and threatened species (New Jersey Administrative Code 7:25-4). "Take" is defined as "harass, hunt, capture, kill, or attempt to do so (N.J.S.A. 23:2A-3(e)). Regulations designed to protect critical habitat for listed species were promulgated in 2003. The regulations require Habitat Management Plans when development will result in degradation of habitat for state-listed threatened or endangered species, extending the regulatory authority beyond wetlands, floodplains, coastal zones, and the Pinelands. Habitat for Threatened and Endangered Species is depicted on "Landscape Project" maps. All validated occurrences of wood turtle are used to model critical wildlife habitat, which is a base layer for environmental review. All projects that intersect critical habitat for wood turtle are reviewed by the state when there may be impacts to wetlands or wetland buffers (B. Zarate, NJ DFW, pers. comm.).

Other statutes providing protections for riverine and riparian habitats used by the wood turtle in New Jersey include the Freshwater Wetlands Protection Act (N.J.S.A. 13:9B-1, et. seq.) and its implementing Rules (N.J.A.C. 7:7A-1.1, et. seq.), which restrict landowners' ability to "destroy, jeopardize, or adversely modify a present or documented habitat for threatened or endangered species." Wetlands with critical habitat for rare species are classified as of exceptional resource value. Under the Flood Hazard Area Control Act (N.J.S.A. 58:16A-50, et. seq.) and its enabling regulations (N.J.A.C. 7:13-1.3 and N.J.A.C. 7:13-3.9), the wood turtle is considered at "water dependent species" (S. Angus, pers. comm.) and the NJ DEP is authorized to regulate development activities in flood prone areas and to control stream encroachments with consideration for threatened and endangered species habitat (B. Zarate, NJ DFW, pers. comm.). Last, the Highlands Water Protection and Planning Act ("Highlands Act," N.J.S.A. 13:20-1 et seq.) and its rules (N.J.A.C. 7:38) regulates development in the northwestern Highlands region.

As noted above, the possession of threatened and endangered species, including wood turtle, is regulated, and is prohibited without a permit (N.J.A.C. 7:25-4.10 and N.J.A.C. 7:25–4.14).

Pennsylvania.—The wood turtle is not listed by Pennsylvania and is not afforded habitat protections except those provided to streams through regulations promulgated by the Department of Environmental Protection (PA Code Title 25, including Chapters 91, 92, 93, 95, 96, 102, and 105) under the Pennsylvania Clean Streams Law (35 P.S. §691.1 et seq.). Regulations allow for the designation of "High Quality (HQ)" and "Exceptional Value (EV)" waters, as defined in PA Code Title 25 §93.4b. HQ waters are based either on geochemistry indicating long-term water quality better than threshold standards for dissolved oxygen, iron and dissolved metals (copper, arsenic, lead, nickel, cadmium, zinc), temperature, pH, etc., 99% of the time; or on biological data indicating a "high quality aquatic community" based on benthic macroinvertebrate and fish communities. Further, streams may be designated as HQ waters if they have been designated a Class A wild trout stream by the PA Fish and Boat Commission. EV Waters must first qualify as HQ waters, and also meet additional criteria, such as location within a wildlife refuge, state park of forest, of national significance, or qualification as a Wilderness Trout Stream (another designation given by PFBC; PA DEP 2003). Streams may also meet the EV criteria by demonstrating elevated biological parameters or "exceptional ecological significance" (J. Drasher, Aqua-Terra Environmental Ltd., pers. comm.)

The wood turtle is protected from harvest and possession with no open season under the Fish and Boat Code (30 Pa. C.S. § 2102) regulations (58 Pa. Code §§ 79.2 and 79.3). These state:

- It is unlawful to damage or disrupt the nest or eggs of a reptile or to gather, take or possess the eggs of any reptile in the natural environment of this Commonwealth (i.e., Pennsylvania).
- It is unlawful to take, catch, kill or possess for the purposes of selling or offering for sale, importing or exporting for consideration, trading or bartering or purchasing an amphibian or reptile whether dead or alive, in whole or in parts, including the eggs or any life stage that was taken from lands or waters within this Commonwealth.
- It is unlawful to transport or import into or within this Commonwealth a native species from another jurisdiction. It is also unlawful to receive a native species that was transported or imported into or within this Commonwealth from another jurisdiction.

Delaware.—The wood turtle is not currently considered a native species in Delaware, no populations or occurrences are known or confirmed, and the species is not afforded protection.

Maryland.—The wood turtle is not listed in Maryland. According to the Reptile and Amphibian Possession and Permit regulations, wood turtles may not be collected from the wild. Maryland residents are allowed to possess 1 wood turtle.

In western Maryland, wood turtle habitat is considered in management decisions on state forest lands (E. Thompson, MD DNR, pers. comm.)

Virginia.—The wood turtle is state-listed as a threatened species under the Endangered Species Act (VA ST §§ 29.1-563–570); it was listed in 1992 (Akre 2010). Two state agencies have authority for administering and implementing the Act: the Department of Game and Inland Fisheries has authority for the protection and management of listed wildlife species the Department of Agriculture and Consumer Service (VDACS) has authority for the protection and management of listed plants and insects.

Under the authority of §§ 29.1-103 and 29.1-521 of the Code of Virginia it shall be unlawful to take, possess, import, cause to be imported, export, cause to be exported, buy, sell, offer for sale, or liberate within the Commonwealth any wild animal unless otherwise specifically permitted by law or regulation.

The Department of Environmental Quality (DEQ) also regulates wetland, open water, and stream impacts associated with development projects under the Virginia Water Protection (VWP) permit program (authorized by § 62.1-44.15:20). If the activity requires a permit from the DEQ, the permit writers will coordinate review of the project with a number of consulting agencies including DGIF and DCRNH to determine whether there are Threatened or Endangered Species documented within two miles of the proposed project. If it is determined that wood turtles have been documented from the project area and that the project may resulting impacts upon them, VDGIF may recommend to the DEQ that project activities adhere to time of year restrictions (TOYR), and/or other actions, to avoid or minimize impacts to wood turtles and the resources upon which they depend. DEQ makes the final decision about which, if any, of VDGIF's recommendations become permit requirements. If there are no water resources to be impacted by the proposed development, VDGIF would only have an opportunity to review the project if it falls under other regulatory process such as SCC projects, large state projects, NEPA, transportation or energy projects, etc. (J.D. Kleopfer, DGIF, pers. comm.).

West Virginia.—The wood turtle is not listed in West Virginia, and West Virginia does not have state-level Endangered Species legislation. Chapter 20 of the West Virginia Code includes "reptiles" in the definition of Wildlife and, as such, the West Virginia Department of Natural Resources (WVDNR) is authorized to promulgate laws and/or regulations. In April 2013, the West Virginia Natural Resource Commission passed an amendment (under the authority to WV Code §20-1-17) prohibiting the take and possession of wood turtles, which goes into effect on January 1, 2014. Prior to the implementation of this regulation, the regulation had been amended in 1992 to prohibit commercial collection of turtles. Prior to that, individuals were allowed to collect up to 100 turtles in West Virginia provided they had a valid fishing license.

Significant Threats to Population Stability

Summary of factors affecting the species

There are numerous documented threats to adult wood turtles, and it appears extremely likely that many populations have been impaired as a result of urbanization and its associated effects (Part 4). It is apparent that the major threats, causes for decline, or other factors affecting the extant populations are the combined effects of habitat fragmentation and degradation, namely: roadkill of adults; mortality associated with agricultural machinery; collection (especially of adults) for commercial and personal trade; dams; severe floods; stream stabilization; aggressive beaver control; pollution, and disease. As noted by Klemens (1997, p. 23), "Too little is done to sustain adult longevity. Habitat fragmentation, roads, commercial collecting, education/museum collecting are major problems for adults; usually a combination of these."

Destruction and modification of wood turtle habitat

Habitat fragmentation and degradation.—Although it takes many forms, and the proximate causes of decline may be roadkill, crushing by agricultural machinery, or collection, the greatest ultimate threat facing most wood turtle populations is habitat fragmentation and degradation (Vogt 1981, p. 96). Because wood turtles primarily occupy broad, level valleys, their habitats have been converted to agriculture and development at high rates throughout the region (see Part 4 for an original analysis of land conversion). Historically, widespread declines or extirpations must have been caused by the major dam projects of the 19th and 20th centuries. Subsequently, widespread declines have been facilitated by road networks and urbanization. In the following sections we have outlined a brief summary of factors associated with habitat destruction or modification that are known or strongly suspected to negatively influence the distribution and abundance of wood turtles.

Roadkill.—Roadkill of adults, juveniles, and hatchlings is a major factor negatively affecting the species throughout its range (see Part 4 for an original analysis of road density within known and estimated wood turtle habitat). Breckenridge (1958, p. 169) speculated that roadkill ("traffic") caused wood turtle mortality, but noted an absence of roadkill records in Minnesota, which he attributed to the species' relative rarity. Akre and Ernst (2006) attributed most of their observed mortalities (5 of 7) to roadkill in

Virginia, and remaining mortalities to crushing by vehicles under powerlines, and further considered roadkill one of the most severe threats facing wood turtles in Virginia. Although there is a distinct lack of baseline data, roadkill is the likely proximate cause of population declines throughout the urbanized areas of the east coast. Further, where roads serve as nesting areas, as on the George Washington National Forest of northwestern Virginia, the nesting sites themselves may function as ecological traps (Kleopfer, VDGIF, pers. comm., Akre 2011).

Agricultural Machinery.—Abundant evidence strongly suggests that mortality of adults resulting from crushing injury by agricultural machinery is a leading threat to many rural populations and a serious management challenge (Saumure 2004; Saumure et al. 2007; Castellano 2007; Tingley and Herman 2008; Tingley 2009; Jones 2009; Erb and Jones 2011). Saumure and Bider (1998) first noted the potentially severe effects of agricultural machinery on wood turtle survival. At their paired agricultural and forested sites in Québec, they noted that shell injuries were twice as common, and juveniles and adults were less common, at the agricultural site.

Based on bivariate tests, Jones (2009, Chapter 4) in Massachusetts reported that instream wood turtle density was associated with low crop cover and higher forest cover at riparian and watershed scales (228 m and 1000 m, respectively), suggesting that densities are depressed in heavily farmed areas.

Forestry.—Although small-scale or selection forestry may create valuable microhabitats for disturbance-dependent wood turtles, most authors caution that the negative effects of large-scale cutting, or conducting forestry activities during the active season, would likely far outweigh the benefits through crushing of individuals and degradation of the stream (Akre and Ernst 2006; Tingley and Herman 2008).

Nest and hatchling predators.—Depredation of nests and hatchlings by mesopredators (mid-sized carnivores) such as raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), and foxes (*Vulpes vulpes*) is a complex and major threat in many regions (Brooks et al. 1992; Klemens 2000; Buhlmann and Osborn 2011; NatureServe 2013; K. Buhlmann, pers. comm.). In some areas, certain mammalian mesopredators have been subsidized by human development (Klemens 2000). In New Hampshire, Tuttle and Carroll (2005) reported apparent depredation of hatchlings by chipmunks (*Tamias striatus*) and birds, and speculated that great blue herons (*Ardea herodias*) eat hatchlings. Wicklow (pers. comm.) repeated observations of chipmunk depredation, and Jones and Sievert (2012) reported heavy chipmunk depredation of Blanding's turtle hatchlings in nearby northeastern Massachusetts. At some sites where adult survivorship is relatively high, or the adults are at least provided some level of protection from cars, mowers, and collection, recruitment may be minimal. Akre and Ernst (2006) speculate that raccoons (*Procyon lotor*), red fox (*Vulpes fulva*), striped skunk (*Mephitis* sp.) and opossum (*Didelphis virginiana*) depredate wood turtle nests in Virginia.

Predators of adults.—Although the primary risk of elevated depredation rates appears to affect nests and hatchlings disproportionately, several authors have noted that mid-sized predators pose risks to adult wood turtles by mutilating them or killing them outright (Harding and Bloomer 1979; Saumure and Bider 1998; Walde et al. 2003; Akre and Ernst 2006; Jones 2009). This appears to vary by site and region, but depredation of adult wood turtles by carnivores is a major conservation concern in many areas and warrants consideration in management planning.

Streambank stabilization.—Massive bank collapse and failure can threaten roads, structures, agricultural fields, and energy infrastructure. Where these resources are at risk, aggressive bank stabilization is common throughout the Northeast region. Streambank stabilization takes many forms, and can range from the historical use of debris, broken cement, and boulders, to recent use of gabion and riprap, to bioengineering techniques. A wide range of streambank stabilizations occurred widely in New England and New York in the wake of Hurricane Irene in 2011 and Tropical Storm Sandy in 2012 (Murphy 2013), many of which were undertaken under emergency authorization. Extensive bank stabilization appears to degrade wood turtle habitat in several ways. Illegal bank stabilization has been shown to kill individual turtles through crushing or entombment (Saumure 2004; Saumure et al. 2007). Banks hardened with large riprap (>20 cm) are probably of low habitat quality for several decades (Jones and Sievert 2011, p. 4). By slowing or obstructing the development of sandy or gravelly point bars on the inner bends of wide meanders, the overall site quality is degraded (Buech et al. 1997; Bowen and Gillingham 2004). In one large stream system totaling 17.1 km in length in western Massachusetts, Jones and Sievert (2011) found that 7.5% of the streambanks had been converted to hardened structures of little ecological value to wood turtles, and over 3% of the river bank was exhibiting evidence of massive collapse suggesting that stream stabilization might be employed. However, the effects of stabilizing structures on floodplain habitat quality for wood turtles have not been empirically tested.

Pollution.—Although the wood turtle is often reported from clear, clean streams (Ernst and Lovich 2009), little work has specifically examined the influence of pollution on wood turtle populations. Northern wood turtle populations are frequently associated with streams high in tannins (R.A. Saumure, pers. comm.). Akre and Ernst (2006) note the potential for poultry farms and logging in Rockingham County, Virginia, to degrade stream quality for wood turtles through point-source nutrient pollution and flow-rate degradation.

Dams and reservoirs.—Dams have negatively influenced the distribution and abundance of wood turtles by converting suitable stream habitat to deep reservoirs, and through a broad suite of downstream effects. In Part 4, we present an original analysis of the potential effect of dams on wood turtles throughout the Northeast Region. More than 1,400 major dams, and many thousands of smaller dams, remain in place on streams and rivers of the Northeastern United States (National Dam Inventory, U.S Army Corps of Engineers 2009), including those with the primary purpose of storing drinking water, generating power, and providing flood protection.[17] Habitat loss associated with dam construction was among the highest threats to wood turtles identified by Castellano et al. (2009, p. 1783), and Compton (1999) reported that dams were a major threat to wood turtle populations in Maine by starving sediments that would build downstream gravel bars, moderating high springtime flows that would scour nesting areas and deposit new gravel, but generating midsummer high flows that flood low-lying nests. In other cases, the influence of dams on habitat suitability for wood turtles depends on other habitat resources available, the size of the dam, and the landscape configuration. There are at least 125 hydropower dams in Maine (D. Mirch, Maine Department of Environmental Protection, pers. comm. to B. Compton, *in* Compton 1999, p. 58). There are also many thousands of smaller dams, including a total of 1,602 dams in Massachusetts alone (National Dam Inventory, U.S Army Corps of Engineers 2009). In some instances, it is possible to demonstrate, or confidently infer, that native wood turtle populations were displaced by flooding associated with dam construction or maintenance, but in most cases, the negative influence of a large dam on wood turtle populations are poorly supported by empirical data.

In the Catskills of southern New York, numerous drinking water supply reservoirs have flooded valleys that likely contained optimal wood turtle habitat prior to flooding. For example, on the north side of the Catskills, where the New York Herp Atlas indicates scattered occurrences in non-dammed portions of the Schoharie watershed, major reservoirs were created at North Blenheim and Gilboa in the 1920s

17 The "Major Dams" shapefile "was created by extracting dams 50 feet or more in height, or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more, from the 79,777 dams in the U.S. Army Corps of Engineers National Inventory of Dams."

(Blenheim-Gilboa Reservoir and Schoharie Reservoir). It appears likely that populations extended throughout the Schoharie Reservoir system prior to the 1920s, but like most cases of impoundment this can't be demonstrated empirically. A nearby case with better empirical support, the Pepacton Reservoir of the interior Catskills now occupies what was once apparently a free-flowing stream supporting wood turtles: in July of 1935, Reeve Bailey collected wood turtles along the East Branch of the Delaware River, which was subsequently flooded between 1954–1955. To the south of the Catskill massif, the Ashokan Reservoir flooded numerous small creeks and Esopus Creek between 1912–1914. Wood turtles were abundant in this wooded section of the Catskill Mountains during the era of the reservoir construction and individual turtles were probably constrained into less optimal habitats by the flooding (Chase 1989).

Quabbin Reservoir in Franklin, Worcester, and Hampshire counties, Massachusetts, likely flooded extensive areas of suitable wood turtle habitat associated with the major branches of the Swift River Valley when it was completed between 1930–1939, evidenced by more than 20 recent (≤30 years) wood turtle records in several tributaries to Quabbin Reservoir and confirmed occurrences downstream in the watershed (Massachusetts Natural Heritage and Endangered Species Program, unpublished occurrence data 2012; M.T. Jones and L.L. Willey, unpublished data). Wachusett Reservoir in Worcester County, which with Quabbin Reservoir forms most of Boston's water supply—must have similarly displaced wood turtles residing in the Nashua River, the watershed of which was historically known to support extant demes both up- and downstream of the reservoir (Massachusetts Natural Heritage and Endangered Species Program, unpublished occurrence data 2012; M.T. Jones and L.L. Willey, unpublished data).

In New Jersey, numerous reservoirs in the Highlands and adjacent regions clearly displaced what were probably large, contiguous areas of occupied stream habitat. An example is the Monksville Reservoir, which flooded portions of the Wanaque River (R. Farrell, Herpetological Associates, pers. comm.).

As already noted in the stream habitat section, earlier, a major reservoir project in Huntingdon County, Pennsylvania, is situated on what was once very likely a large wood turtle stream, as evidenced by historic data downstream and current records from the reservoir (T. Pluto, USACE; R. Nagle, Juniata College).

Major power dams have likely exerted strong negative influences on upstream and downstream riparian areas. An example of a power dam with a large ecological footprint is the Conowingo Dam on the Susquehanna River in Cecil County, Maryland, where wood turtles were documented in the 1940s (Cooper 1949.). In western Maine, Compton (1999) reported several ways in which a large power dam affected downstream wood turtles: by reducing springtime flows, downstream beaches were starved of sediments and overgrown. By increasing the rate and severity of summer floods, the dam caused low-lying downstream nests to flood.

Flood control facilities maintained by the U.S. Army Corps of Engineers are strategically placed to minimize property damage and loss of life within flood-prone urban areas. Army Corps flood storage projects include both reservoirs that are permanently flooded, and many that are flooded only during major storm events, and both may negatively influence local wood turtle populations (Dickerson et al. 1999). Although it has not been studied, it is likely that large flood control projects negatively influence wood turtle populations by creating dramatic shifts in water levels during seasonal periods of high sensitivity to water fluctuations (late winter) and changing the downstream redistribution of sand and gravel. Permanent flood-storage reservoirs located in close proximity to extant populations, it may be inferred, have likely resulted in long-term loss of free-flowing riverine habitat for local wood turtle populations, and in some cases may have caused interruptions in gene flow (e.g., Surrey Mountain Lake, Cheshire County, New Hampshire; New Hampshire Fish and Game Department and New Hampshire Natural Heritage Bureau, unpublished occurrence data, 2012). Temporary flood-storage facilities with known wood turtle populations nearby are also numerous on the New England landscape (M.T. Jones, unpublished data) and include several designed to protect the cities of Westfield and Springfield, Massachusetts, and Concord and Manchester, New Hampshire, from flooding.

The local influence of smaller dams can be counterintuitive. In Massachusetts, at least one small subpopulation (deme) of 10–15 adults was found to occur in free-flowing stream habitat immediately upstream of a late-19th century power dam, which had filled in with sediment and no longer formed a reservoir (M.T. Jones, unpublished data; Jones 2009; Jones and Sievert 2009). Individual turtles within this population were frequently displaced downstream and over the dam by repeated flood events, which appeared to result in reduced survival and reproductive output, although the small reservoir remaining behind the dam appeared to "capture" turtles being displaced by floods (Jones and Sievert 2009). A similar configuration, in which a 1930s power dam had partially filled in, and braided deltaic channels were occupied by a deme of ca. 50 adults, was observed by Jones (2008) in the White Mountain National Forest of New Hampshire.

Beaver control.—While it seems clear that at heavily fragmented, isolated sites, dam construction and stream-channel flooding by beavers may degrade site quality for wood turtles, at the watershed scale, beavers are an important driver of structural complexity within wood turtle waterways. For example, beavers create openings in northern, coniferous forests through tree removal and flooding, and create deeper pools for overwintering (R.A. Saumure, pers. comm.). In States and regions where beavers have been aggressively controlled or hunted, these disturbance regimes are no longer present and can be difficult to replicate. At most of the remote, isolated sites studies by Jones and Willey (2013b), turtles exhibited heavy use of beaver-created openings and clearings.

Invasive plant species.—Several species of invasive vascular plants are present in the major watercourses (HUC4) of the Northeast region, but the negative effects of invasive species on wood turtles are poorly documented, and the relative threat posed by these species probably varies geographically and according to the past land use and disturbance history of the site, as well as current management techniques. Invasive plant species also influence the habitat quality of floodplain areas in different ways, depending on their growth form. The most problematic invasive species for wood turtle is probably Japanese knotweed (*Fallopia japonica*), which is known to overtake sandy nesting areas within the floodplain in Vermont and Massachusetts (M. Powell, Vermont Adult Learning, pers. comm.; M.T. Jones, unpublished data). Multiflora rose (*Rose multiflora*) is widespread and common in wood turtle habitats from Massachusetts (Jones 2009) to West Virginia (Niederberger 1993, p. 11) and Virginia (Akre and Ernst 2006), and appears to present a threat to wood turtles mostly when landowners to undertake intensive land-clearing operations that may crush or injure wood turtles if undertaken during the active season. Other invasive plant species that may exert negative influence on vegetation structure or sunlight availability in the river corridor include autumn olive (*Eleagnus umbellata*), which has colonized wood turtle streams in Virginia (Sweeten 2008), greenbrier (*Smilax* sp.), which is present in riparian areas in West Virginia (Niederberger 1993, p. 27); and mile-a-minute (*Persicaria perfoliata*), which has become problematic in wood turtle habitat in Pennsylvania (J. Drasher, pers. comm.) and Virginia (Akre and Ernst 2006). At Great Swamp NWR in New Jersey, wood turtle nesting areas are negatively affected by common mugwort (*Artemisia vulgaris*). Other potentially problematic species in important wood turtle riparian habitats include: phragmites (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), Japanese stiltgrass (*Microstegium vimineum*), several species of honeysuckle (*Lonicera* x *bella*, *L. japonica*, *L. morrowii*, and *L. tatarica*), garlic mustard (*Alliaria petiola*), bishop's goutweed (*Aegopodium podagraria*), purple loosestrife (*Lythrum salicaria*), glossy buckthorn (*Frangula alnus*), and oriental bittersweet (*Celastrus orbicularis*) (PDEP 2004; Akre and Ernst 2006). Despite widespread concern, quantitative studies of the effects of invasive plant species on habitat quality for wood turtles are lacking, although the greatest risk posed by invasive vascular plants may occur when they reduce light availability and aggressively colonize open, friable substrates in nesting areas. However, it is important to reiterate that in many cases the process of controlling invasive species may involve greater risk for adult wood turtles than the plants themselves. Seasonal habitat use by wood turtles, potential impacts to sensitive species, and proper implementation methods should be determined prior to any invasive control actions.

Kleopfer (VDGIF, pers. comm.) reports instances of wood turtles feeding on autumn olive berries and considers the negative impact of autumn olive on wood turtles to be minimal. Jones and Sievert (2009b) report instances of wood turtles feeding on a wide variety of plants considered invasive in Massachusetts.

Overutilization for commercial, recreational, scientific, or education purposes

Collection for food was apparently an important local factor that led to perceived declines in the 19th and early 20th century (Klemens 1993; Breisch 1997). In the mid-1900s, biological supply houses became a major factor influencing the abundance of wood turtles (Vogt 1981, p. 96; A. Richmond, University of Massachusetts, pers. comm.). In recent decades, collection for domestic and foreign pet trades has become a major threat (Compton 1999; NatureServe 2013). Incidental take of adults was identified as a severe threat to the persistence of wood turtles in Virginia (Akre and Ernst 2006) and has been noted in most Northeastern States (see Appendix VI).

Wood turtles were heavily collected by biological supply houses across the country in the mid-20th century, reflecting a trend that probably went back several decades. The real price of wood turtles in the early 1960s was about $20.00 (details and sources are provided in Table 9). This has climbed to more than $300.00 as of this report writing, an increase of more than 15 fold and possibly reflecting the perceived decline in abundance (and availability). According to NatureServe (2013), the Chelonian Advisory Group of the American Association of Zoological Parks and Aquariums has adopted a resolution ceasing the collection of the former *Clemmys* spp. complex.

Recent commercial collection of wood turtles has been documented in most states in the Northeast, and there is widespread evidence of illegal collection and trade throughout the range (Harding, pers. comm. *in* NatureServe 2013). In Maine, collectors removed ≥44 wood turtles from the St. John watershed of northern Maine in 1994 and attempted to sell them on the waterfront at Portland (P. deMaynadier, ME DIFW; McCollough 1997), and in 1995 55 wood turtles were confiscated in Virginia after being collected from Maine (McCollough 1997). No instances of commercial collection are known in New Hampshire, but incidental or casual collection has been documented (M. Marchand, NHFG, pers. comm.) and commercial collection suspected (B. Wicklow, St. Anselm College, pers. comm.). Vermont Fish and Wildlife undertook a sting operation in 2003 when it was reported that wood turtles were being advertised for sale on the internet; the turtles were seized and released in their native stream (VT DFW 2004; Parren 2013; S. Parren, pers. comm.). Recent commercial collection is suspected, but poorly documented, in Massachusetts and Connecticut (L. Erb, MA DFW, pers. comm.; J. Dickson, CT DEEP, pers. comm; H. Gruner, CT Science Center, pers. comm.), although collection for sale by biological supply houses was common in the 1960s and 1970s (A. Richmond, University of Massachusetts Amherst, pers. comm.). In New York, wood turtles were one of the species most frequently collected and traded illegally as exposed by "Operation Shellshock", an undercover law enforcement action taken by New York State Department of Environmental Conservation (A. Breisch, NYS DEC [ret.], pers. comm.). New Jersey environmental law enforcement recently (2008) raided the home of a commercial reptile breeder and found >20 wood turtles in his collection after he purchased four wood turtles from undercover agents (B. Zarate, NJ DFW, pers. comm.; United States v.s Albert Roach, USDOJ/ECS 2011, p. 15). This enforcement action against a New

Jersey resident was assisted by efforts from the Pennsylvania Fish and Boat Commission. The Pennsylvania Fish and Boat Commission itself supported "Operation Herp Scam," which in 1998 detected a widespread network of trade in wood turtles (Sajna 1998) through which >290 wood turtles taken from western and southwestern Pennsylvania (J. Drasher, Aqua-Terra Environmental Ltd., pers. comm.; T. Akre, pers. comm.). Researchers in eastern Pennsylvania have reported direct evidence of incidental collection within high-density sites (S. Angus, pers. comm.). Kaufmann (reviewing CITES listing *in* NatureServe 2013) reports that Canadian collectors had illegally collected hundreds of specimens from a stream in Pennsylvania over the course of a few days.

Recent (ca. 2010) commercial or large-scale collection is suspected in western Maryland (E. Thompson, MD DNR, pers. comm.). Commercial collection has occurred in Virginia, but the extent and frequency is unknown (J.D. Kleopfer, VDGIF, pers. comm.).

There have been multiple instances of commercial collection in West Virginia. In 1992, two individuals from Indiana were arrested in the eastern panhandle of West Virginia for possession of a "large number of aquatic turtles without a fishing license (WVDNR 1992)," including approximately five wood turtles (K. O'Malley, WV DNR, pers. comm.). In 2008, Michael P. Ellard of Estero, Florida, and his associates Kelly Stoops II and Eric Diana, were arrested in Virginia with 108 wood turtles he had captured illegally in Hampshire County, West Virginia. In December 2009 Ellard was sentenced to five years probation and ordered to pay restitution in the amount of $12,000 (Jividen 2009; USDOJ ESC 2010, p. 17). The wood turtles were released at the reported capture location. In November 2013, David C. Matton, a resident of Windsor, Ontario, paid >$2,200.00 in fines for violations including possession and transportation of wood turtles from West Virginia. The investigation was conducted by the USFWS in conjunction with the West Virginia Division of Natural Resources Law Enforcement Section, who determined that Matton had purchased wood turtles from an undercover agent and transported them to Ontario in violation of the Lacey Act and CITES (WV DNR 2013).

During the course of this project, a pair of wood turtles was confiscated in Hong Kong with notches (K. Buhlmann, University of Georgia, pers. comm.). These animals subsequently were identified as possibly from New York (S. Poirier, Wildlife Enforcement Directorate, Environment Canada, pers. comm.).

As this document was finalized in December 2013, three open classified advertisements on kingsnake.com announced the sale or purchase of adult wood turtles, for which the rate was $350.00 per adult turtle was listed; no evidence is presented or requested that the animals are legally obtained. According to McCollough (1997), wood turtles were selling for $250 in the late 1990s, representing twice the price at the time of the RESTORE (1994) petition to list wood turtles as federally Threatened. Compton (1999, p. 54), pairs of wood turtles were sold for $350 in late 1997, which may have represented an increase since 1996, when the average cost per wood turtle was $131 (Hoover 1998). In 2008, federal undercover agents sold Albert Roach three wood turtles for $375, indicating a price per wood turtle of $125 (USDOJ/ESC 2011, p. 15), and suggesting that the price for wood turtles is highly variable (Figure 12, Table 9).

Table 9. Prices for wood turtles traded openly, 1961–2014, adjusted to the present relative value.

Year	Source	Size	Qty	Price	Price per turtle	Real price, 2012–2013	Real value, 2012–2013	Labor value, 2012–2013	Income value, 2012–2013
1961	Quivira	n/a	1	$2.50	$2.50	$19.20	$22.50	$21.70	$42.20
1961	Quivira	n/a	12	$24.00	$2.00	$15.30	$18.00	$20.90	$33.70
1962	CT Valley Biol. Supply	8–10"	1	$2.50	$2.50	$19.00	$21.80	$25.00	$39.80
1962	CT Valley Biol. Supply	8–10"	12	$25.00	$2.08	$15.08	$18.20	$20.80	$33.20
1964	CT Valley Biol. Supply	8–10"	1	$2.50	$2.50	$18.50	$20.00	$23.50	$36.20
1964	CT Valley Biol. Supply	8–10"	12	$25.00	$2.08	$15.40	$16.70	$19.50	$30.10
1972	Midwest Supply	yearling	1	$20.00	$20.00	$30.80	$33.40	$39.00	$60.20
1972	Midwest Supply	hatchling	1	$10.00	$10.00	$54.90	$53.20	$59.10	$84.60
1973	Midwest Supply	6–8"	1	$15.00	$15.00	$77.50	$79.90	$71.50	$115.00
1973	Midwest Supply	2–4"	1	$20.00	$20.00	$103.00	$106.00	$110.00	$153.00
1996	Hoover (1998)	adult	1	$131.00	$131.00	$192.00	$196.00	$211.00	$225.00
1997	McCullough (1997)	adult	1	$250.00	$250.00	$358.00	$364.00	$363.00	$410.00
1997	Compton (1999)	adult	2	$350.00	$175.00	$250.00	$255.00	$262.00	$287.00
1998	New England Reptile	hatchling	1	$125.00	$125.00	$176.00	$178.00	$187.00	$196.00
1999	Glades Herp	adult	1	$250.00	$250.00	$345.00	$342.00	$362.00	$373.00
1999	RESTORE (1994)	adult	1	$125.00	$125.00	$194.00	$200.00	$205.00	$233.00
1999	Glades Herp	hatchling	1	$125.00	$125.00	$172.50	$171.00	$181.00	$186.50
2000	Glades Herp	adult	1	$250.00	$250.00	$333.00	$333.00	$351.00	$355.00
2000	Glades Herp	adult (CB)	1	$275.00	$275.00	$367.00	$366.00	$386.00	$390.00
2001	Glades Herp	adult	1	$225.00	$225.00	$292.00	$288.00	$315.00	$312.00
2001	Glades Herp	4"	1	$175.00	$175.00	$227.00	$224.00	$245.00	$243.00
2001	Glades Herp	hatchling	1	$125.00	$125.00	$162.00	$160.00	$175.00	$173.00
2002	Glades Herp	adult	1	$225.00	$225.00	$287.00	$280.00	$291.00	$305.00
2002	Glades Herp	4"	1	$175.00	$175.00	$223.00	$218.00	$226.00	$237.00
2004	Glades Herp	hatchling	1	$95.00	$95.00	$115.00	$111.00	$112.00	$117.00
2008	USDOJ (2011)	adult	3	$375.00	$125.00	$133.00	$125.00	$131.00	$134.00
2010	Glades Herp	6"	1	$350.00	$350.00	$369.00	$368.00	$359.00	$375.00
2010	Glades Herp	4"	1	$225.00	$225.00	$237.00	$237.00	$231.00	$241.00
2013	Kingsnake (2013)	adult	1	$350.00	$350.00	$350.00	n/a	n/a	n/a
2014	TurtleSource	4"	1	$395.00	$395.00	$395.00	n/a	n/a	n/a
2014	TurtleSource	juvenile	1	$199.95	$199.95	$199.95	$199.95	n/a	n/a
2014	TurtleSource	yearling	1	$249.95	$249.95	$249.95	$249.95	n/a	n/a
2014	TurtleSource	2 year old	1	$295.00	$295.00	$295.00	$295.00	n/a	n/a

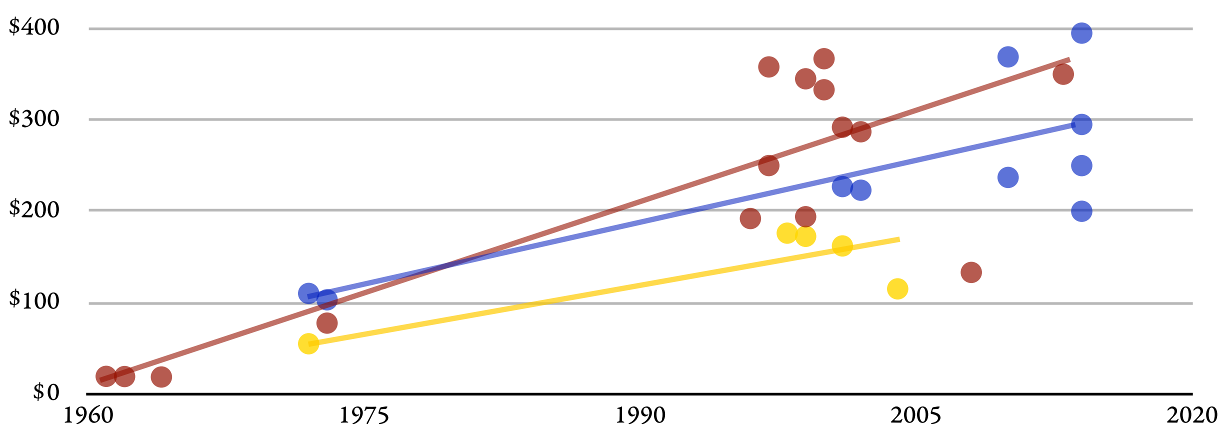

Figure 12. Real price (adjusted by year using algorithm of measuringworth.com) for adult (red), juvenile (blue), and hatchling (yellow) wood turtles traded openly by biological supply houses and reptile companies or as reported in the literature (see Table 9). Additional data from the late 1970s and 1980s would clarify trends in real price. The increasing trend in all groups may suggest increasing demand and/or scarcity.

Disease

Disease has not yet been reported to be a major problem influencing wood turtle population status (but see Smith and Anderson 1980 and Upton et al. 1995). Emerging pathogens clearly warrant strong precautions by researchers. An unidentified pathogen may be causing mortality in wild bog turtle populations in Massachusetts and New York (USFWS 2009).

The presence of *Ranavirus* in captive and in wild box turtle (*Terrapene carolina*) populations, which co-occur with wood turtles from Massachusetts to West Virginia, is becoming a growing concern (De Voe et al. 2004; Johnson et al. 2008; Allender et al. 2011; USGS 2013; Kiester and Willey 2015). Although prevalence seems to be low (Allender et a. 2011), several die-offs of unknown cause have occurred (Rossell et al. 2002), and incidents in New York, Pennsylvania, Georgia, and Florida may have been caused by Ranavirus (Johnson et al. 2008). Several instances of limb paralysis, thinning skin, and emaciation have been reported by the public (R. A. Saumure, pers. comm.). In these cases, the sick captive wood turtle were being housed with asymptomatic *Terrapene carolina*.

A mass die-off of about a dozen wood turtles was reported in Monroe County, Pennsylvania during the course of this project (S. Angus, pers. comm.) but the cause has not been determined, although bog turtles were also affected (K. Gipe, PFBC, pers. comm.). Diseases and epidemics appear to have the potential to become a major conservation challenge for wood turtles at some sites. Researchers should take extreme caution not to introduce pathogens into wild wood turtle populations by sterilizing equipment (especially calipers and scales, which may contact the face and tail of multiple turtles), not removing turtles from the wild to the laboratory, restraining wild turtles individually in sterile containers during processing in the field, and following all recommended decontamination protocols (see Appendix I, Miller and Gray 2009, SEPARC Decontamination Procedures).

Inadequacy of existing regulatory mechanisms

The level of regulatory protections provided to wood turtle habitat in the Northeast are surprisingly minimal and do not appear to correspond to the high level of regional concern for wood turtle conservation, the widespread evidence of decline and extirpation, and the documented aspects of wood turtle life history that render populations susceptible to unregulated land conversion (late maturity, low reproductive output, long lifespan, high site fidelity). The three critical aspects of wood turtle habitat—nesting, foraging, and overwintering habitat—are strongly protected under state-level endangered species legislation in only one Northeastern state, Massachusetts. Limited protections for wood turtle habitat are in effect under endangered species legislation in Connecticut, New Jersey, and Virginia. Wood turtle habitat is functionally protected only by state and federal wetland regulations, and not endangered species legislation, in Maine, New Hampshire, Vermont, New York, Pennsylvania, Maryland, and West Virginia.

Fortunately, all states in the Northeast (except Delaware, which has no documented wood turtle populations) prohibit commercial collection. However, surprisingly, Maine still apparently allows collection by residents (note that Compton [1999] considered this "clearly inadequate"). Life history studies and recent population studies in Maine indicate that even incidental harvest by Maine residents would be a major conservation challenge (as noted later).

Only two or possibly three states appear to actively screen biologists conducting mitigation- or development-related wood turtle surveys, which may result in improperly completed habitat assessments or population assessments.

Other natural or manmade factors affecting the wood turtle's continued existence

Floods.—Flood severity in the northeast region may be increasing as a combined result of volatile precipitation and landuse changes such as streambank stabilization and increased impervious surface area in the watershed. Floods may exert strong influences on habitat quality for wood turtles, and depending on the season and whether wood turtles are inactive in the stream, may directly harm or displace turtles. Severe flooding can influence wood turtle habitat in several important ways. Floods may alter or disrupt channel geomorphology, damage floodplain vegetation, or redistribute sand, gravel, and other sediments (Compton 1999)—which may either augment or decrease the available nesting habitat.

Severe floods may also displace individual wood turtles from their resting places in the stream channel, resulting in drowning or injury. Recent observations of long-distance displacement or mortality during floods from across the range of wood turtles may be a result of increased impervious surfaces and bank stabilization within wood turtle watersheds, or the removal of beavers (R.A. Saumure, pers. comm.). Jones and Sievert (2009) observed 17 displacements of 12 turtles ranging from 1.4 to 16.8 km during large large floods in a large stream system in western Massachusetts, and reported that mortality rates were elevated and reproductive rates depressed in flood-displaced animals. The smallest flood that resulted in displacement was approximately 14.5 times the average daily flow, or 24.4 m3/s, although flows exceeding 248.0 m3/s were observed. Disruptive floods in this system occurred at a rate of 1.7 per year during the study (2004–2008), higher than the annual rate (0.5) of similar floods over the the 38 years previous (1966–2004). On the other hand, floods may influence genetic structure within watersheds and provide a source of connectivity between lower-watershed populations and isolated demes in the upper watershed. The authors report that most turtles displaced more than 2 km did not return to their home stretch within one year. In the system studied by Jones and Sievert (2009), beaver populations appeared to be robust during the study period.

Sweeten (2008, p. 27) observed likely flood displacement of three (of 36) adult wood turtles in November 2006 at a site in northwestern Virginia. Two males were displaced 13.6 and 19.8 km, several km into the mainstem of a larger river downstream, and one female displaced 1 km. The author speculated that the displacement occurred because the turtles had returned to the river but had not yet "embedded" themselves in the rootmasses or undercut banks. Both males subsequently made large upstream movements, although neither returned to their home stream within one year and one eventually ended up at a different site—coincidentally, one of the author's other study sites.

Severe floods in the winter of 1996 displaced wood turtles in at least two basins in western Maryland, depositing moribund turtles onto the floodplain (T. Akre and E. Thompson, pers. comm.). In the same flood, displaced wood turtles were observed in the Shenandoah watershed (F. Frenzel to T. Akre, pers. comm.).

Latham (1971, p. 32) reported five large adult wood turtles washed ashore dead at four beaches on Long Island between 1919–1926, clustered in a small area directly across Long Island Sound from the mouth of the Connecticut River. Sightings occurred in May, June, July, and August, the inverse of the range of displacements observed by Jones and Sievert (2009), who reported most displacements in late fall, winter, and early spring. Latham reports that the sightings correspond to "freshets" in Connecticut, in which "trash, logs, broken trees..." were washed from the rivers of Connecticut. Additionally, a single wood turtle was collected at Kingstown, Washington County, Rhode Island, on the shore of Narragansett Bay, circa 1980 (MCZ 166324), and a dead turtle was observed on the beach at Little Compton, Newport County, Rhode Island, in the 1990s (D. Yorks, Maine Department of Inland Fisheries and Wildlife, pers. comm.)

This location is several dozen kilometers from the nearest confirmed location and may represent a flood-displaced individual from the Taunton River watershed or another coastal drainage.

Further, floods can exacerbate the downstream colonization of aggressive vascular plant species (see Invasive Species, above, and control recommendations in Part 6) such as Japanese knotweed (*Fallopia japonica*), which can be particularly invasive in flood-prone ecosystems because of its propensity to root from plant fragments containing live nodes, and its deep root system (B. Colleran, Invasive Species Biologist, Vermont Agency of Natural Resources, Department of Fish and Wildlife, pers. comm.). Japanese knotweed appears to reduce overall habitat quality for wood turtles by reducing structural diversity and crowding out nesting areas near streams (M. Powell, Vermont Adult Learning Center, pers. comm.; M.T. Jones, unpublished data).

Summary of Threats

It is well documented that wood turtles are negatively affected by a wide range of anthropogenic stressors, the greatest of which are those associated with **habitat fragmentation** and **degradation**. Important proximate causes of adult mortality include **roadkill** and **crushing by agricultural machinery**, which have been demonstrated to be major threats throughout the Northeast region. Collection for commerical and noncommercial purposes is documented to occur throughout the region. An original landscape-scale land use analysis based on empirical abundance and occurrence data is presented in Part 4.

Examples of Conservation Projects Targeting Wood Turtles

Maine.—Five small watersheds of regional significance were identified through the course of this project and efforts are underway to network with stakeholders to improve the long-term conservation outlook for these important populations (Jones and Willey 2013b).

New Hampshire.—Efforts by private conservation groups in Hillsborough County have resulted in the protection of an important wood turtle nesting area and stream frontage (B. Wicklow, St. Anselm College, pers. comm.). At least one town in Grafton County is actively trying to protect priority habitats within a known wood turtle site (Jones and Willey 2013a). One large population on the White Mountain National Forest in Grafton County was provided additional, temporary protection when a popular campground was closed following Hurricane Irene in August 2011. There are also land conservation efforts underway throughout New Hampshire in which the wood turtle was listed on grant applications as benefiting from the action (M. Marchand, pers. comm.). These aren't currently tracked and probably range from very high to very low in conservation value for wood turtle.

Vermont.—Parren (2013; pers. comm.) reports that the Vermont River Conservancy protected important habitat for wood turtles in 2010.

Massachusetts.—The Natural Heritage and Endangered Species Program (NHESP) initiated a conservation planning process for wood turtle in conjunction with this regional RCN project. The conservation plan includes a statewide assessment of abundance and a network of Long-Term Reference sites (L. Erb, pers. comm.; Erb et al. 2013). In 2006, the Turtle Conservation Project, a Connecticut-based program, purchased a significant wood turtle site in Hampshire County, Massachusetts, effectively protecting an important population and setting a helpful precedent of proactive conservation. The permanent or long-term status of this reserve is not finalized. In 2007, the Division of Fisheries and Wildlife attempted to implement a grazing program (to reduce the need for mowing) at one priority site owned by the Division in Franklin County. This project was terminated because of logistical difficulties.

New Jersey.—A range of conservation actions for wood turtle are underway in New Jersey. At a federally-owned site in Morris County, an artificial nesting mound was created to replace nesting habitat threatened by (but not yet lost to) development (Buhlmann and Osborn 2011). Female wood turtles at this site demonstrated a willingness to use the new mound. At the same site in 2011, Buhlmann et al. (2013) initiated a population augmentation program with a direct release component (approx. 50% of hatchlings) and a one-year headstart component. Headstarts were released in 2012 and 2013 and the project is ongoing with early signs of successful recruitment.

Pennsylvania.—Pennsylvania has initiated a data-gathering effort to map the distribution of the wood turtle following NatureServe guidelines and initiated long-term monitoring (Part 3) at four sites in the central and eastern part of the state (K. Gipe, PFBC, pers. comm.). Further, the wood turtle will be included in the new revision of the state Wildlife Action Plan (SWAP; K. Gipe, pers. comm.).

Virginia.—The Virginia Working Landscapes program will use the wood turtle as a flagship species for riparian conservation in northern Virginia (T. Akre, pers. comm.). In the western mountains, the U.S. Forest Service has designated "wood turtle emphasis" areas for special conservation and management (Kleopfer et al. 2009).

Part 2. Historic Distribution of Wood Turtles in the Northeast

Summary

In this chapter, we analyze the historic (1850–present) distribution of wood turtles (*Glyptemys insculpta*) in the northeastern United States using corroborated occurrences associated with streams and logistic regression. We built species distribution models (SDMs) for states, watersheds (USGS HUC4), and EPA Level III ecoregions, and summed these to obtain a regional SDM. We combined a wide variety of available datasets from natural heritage programs, museum databases, published literature, technical reports, reptile and amphibian atlas programs, expert interviews, private datasets, and standardized regional surveys. The quality, density, and consistency of occurrence data varied substantially throughout the Northeast Region. To reduce error and improve consistency across states, watersheds, and ecoregions, we developed a database of "corroborated" occurrences within the Northeast Region. Multiple wood turtle observations within 10 km along the same stream system were considered "corroborated", and observations within 2 km were pooled into one occurrence to reduce autocorrelation effects in subsequent models. Through this approach, we developed a database of 1077 high-precision, corroborated occurrences of wood turtles in the Northeast. We used the standardized dataset of occurrences, along with stream variables including stream gradient, flow accumulation, sinuosity and a principal component of broad landscape-scale climatic variables (January minimum temperature, average July temperature, and average annual precipitation) to assess stream characteristics of segments known to support wood turtles and to build stream-based SDMs for wood turtle, removing lakes and ponds from the final output.

According to the final SDM, 127,000 stream kilometers in the Northeast (or 24% of NHD stream segments) are similar to the 85th percentile of segments known to support wood turtles. Massachusetts was the most heavily sampled state, with one corroborated occurrence/155 km of stream within the species range, while Maine was the least sampled, with one corroborated occurrence/1020 km of stream. Because of Maine's potential to harbor regionally significant populations, it is considered a priority region for standardized surveys. At the watershed scale, the Maine Coastal, St. Francois, Lake Erie, and Southwestern Lake Ontario, and Monongahela all have four or fewer corroborated occurrences. Several ecoregions had relatively few occurrences, and these may represent meaningful or significant ecological lineages. For example, the Atlantic Coastal Pine Barrens (n=13), the Western Allegheny Plateau (n=7), and the Central Appalachians (n=5)(Figure 12). Large areas of western New York and western Pennsylvania near the species' range limit have low densities of corroborated occurrences and are considered priorities for standardized surveys and monitoring. Historic occurrences on the coastal plain of New Jersey are noteworthy in a regional context because of the general lack of occurrences in other coastal plain areas from Massachusetts to Virginia. Occurrences in the Allegheny and Monongahela River watersheds of western Pennsylvania and Maryland (n=15) are noteworthy as the only occurrences in the Ohio watershed, and the only Mississippi watershed occurrences south of the Great Lakes.

The number of suitable stream kilometers is further summarized by state, watershed, and ecoregion. At the regional scale, wood turtles occur in stream segments that are lower gradient, higher flow, and more sinuous than what is generally available on the landscape, though the squared terms of these variables were often important, suggesting a unimodal, rather than monotonically varying relationship with likelihood of occurrence. Stream segments where wood turtles occur vary climatically across the region, and SDMs were locally fit and applied to account for this non-stationarity. The final SDM produced in this chapter allows

us to assess broadscale patterns of data deficiency, unique and isolated populations, and provides the spatial foundation for subsequent analyses of habitat quality and degradation in Part 4.

Introduction

Species Distribution Models (SDMs), combined with analyses of land use and landscape integrity, are frequently employed by biologists and managers as one tool of many to assess the status and projected trends of at-risk vertebrates (Guisan and Thuiller 2005). Ideally, SDMs are trained with empirical field data, which are obtained through standardized field surveys in randomly selected habitat areas. However, when the species in question is wide-ranging and difficult to sample, or occurs in many states with different data collection procedures, or is unusually rare or difficult to detect, it may be necessary to develop SDMs using nonrandom or opportunistically-collected occurrence data or expert opinion, or a combination of both. In the case of the North American wood turtle (*Glyptemys insculpta*), a wide-ranging semiaquatic turtle of the northern Appalachians and Piedmont with extant populations in at least 12 states in the Northeast Region (Part 1), assessing regional status is challenging because of the wide range of data collection procedures implemented by the different States. In 2011, the Northeast Wood Turtle Working Group determined that one necessary component of a regional status assessment was to assemble a standardized, comprehensive database of wood turtle occurrences in order to evaluate the quality of known occurrences and modeled habitat areas. Further evaluation of element occurrence and other data indicated a high level of disparity between data sources, indicating the need for a database representative of the full range of the wood turtle in the Northeast and could also be used to train SDMs.

In this section we develop a regionally consistent database of corroborated wood turtle occurrences, assess the climatic and geomorphic characteristics of these stream segments, evaluate how stream and climate characteristics vary across the region, and develop a spatially explicit GIS model to identify and quantify the stream segments in the northeast region that are most similar to areas of known occurrence.

Methods

Data Sources

Between 2011 and 2013, we amalgamated databases of wood turtle occurrence information for the entire Northeast Region of the United States. The primary focus area encompasses all or part of CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VA, VT, and WV and adjacent regions in in Ontario, Québec, New Brunswick, and Ohio. We sent information requests to state agencies, natural heritage programs, and other partners beginning in October 2011 and continued to solicit data from new sources until October 2013. We obtained data primarily from the following sources: 1) natural heritage programs and state wildlife agencies; 2) online and printed databases of museum collections; 3) peer-reviewed literature; 4) technical reports and gray literature; 5) state-based reptile and amphibian atlases; 6) unpublished datasets obtained from herpetologists; 7) results of standardized field surveys conducted in 2012–2013 (Part 3). Because all or most of the sources listed above have quality control measures in place to avoid misidentifications, we assume that the records we received represent verified or high-confidence observations of *G. insculpta*. However, in rare instances we incorporated new data from amateur naturalists who provided photographic evidence and location data of wood turtles. We further assume that erroneous and extralimital records are unlikely to be corroborated by other observations as outlined below. In ME, NH, VT, MA, NY, NJ, PA, DE, MD, VA, and WV, results from ongoing standardized surveys initiated as part of this project were incorporated as the data were submitted (Part 3).

Regional Occurrence Data

We obtained several regional datasets of wood turtle occurrence, including the dataset prepared by Iverson (1992) and its more recent, expanded iteration (EMYSystem 2012). We also reviewed summary of participating museum collections through HerpNet (2013) and BISON (2013), and reviewed the online catalogs of the Museum of Comparative Zoology (Cambridge, MA); the University of Michigan (Ann Arbor, MI), the California Academy of Sciences (San Francisco, CA), and other leading institutions with searchable online catalogs. Although it has become a common practice in the peer-reviewed literature not to report the locations of wood turtle studies as a hedge against poaching, we reviewed wood turtle literature (and references therein) available through Web of Science; JSTOR; Google Scholar, and BioOne, recording any published evidence of spatially-explicit wood turtle occurrence, and searched the Geographic Distribution section of Herpetological Review for site-specific data.

Maine

The wood turtle is formally tracked in Maine as a species of special concern. We received current element occurrence records from the Department of Inland Fisheries and Wildlife (IF&W) in 2012 (updated in 2013 through correspondence with D. Yorks, pers. comm.). We further incorporated occurrence data generated during the course of this project by Jones and Willey (2013b). We obtained additional occurrence information from the literature (Agassiz 1857, p. 443; Verrill 1863, p. 196). Further context and county records were obtained from Hunter et al. (2000). We updated occurrence data based on personal communications from J. Mays, P. deMaynadier, and D. Yorks (ME IF&W), and B.W. Compton (University of Massachusetts, Amherst, MA).

New Hampshire

The wood turtle is formally tracked in New Hampshire as a species of a special concern. We received the official database of wood turtle element occurrences from the New Hampshire Fish and Game Department Nongame & Endangered Wildlife Program (Concord, NH) and the New Hampshire Natural Heritage Bureau, Forest & Lands Program, Department of Resources and Economic Development (DRED; Concord, NH) in 2011 and received an update in 2012. We also incorporated datasets received from B. Wicklow (St. Anselm College; Manchester, NH) and Jones and Sievert (2007; Massachusetts Cooperative Fish and Wildlife Research Unit; Amherst, MA) and Jones and Willey (2013a; Massachusetts Cooperative Fish and Wildlife Research Unit; Amherst, MA. Additional records were obtained from the literature (Oliver and Bailey 1939) and several museums including the University of Michigan and the U.S. National Museum. We updated occurrence data and minimum numbers based on personal communications and site visits with M. Marchand, W. Staats, and J. Kilborn (NHFG), D.M. Carroll (Warner, NH) and correspondence with L. Prout (Biologist, White Mountain National Forest, U.S. Forest Service; Laconia, NH), D. Zeh (Antioch University New England; Keene, NH).

Vermont

The wood turtle is listed as a species of special concern in Vermont, but is not rigorously tracked by the Vermont Wildlife Diversity Program of the Fish and Wildlife Department (the VWDP maintains a subset of data from the Reptile and Amphibian Atlas; S. Parren, pers. comm.). The largest database of wood turtle occurrences in Vermont is maintained by the Vermont Reptile and Amphibian Atlas, and data were provided by J. Andrews, Atlas Director, in 2011 and 2012. Specimen data were incorporated from the U.S. National Museum, the Carnegie Museum, and the Boston Natural History Society. We updated the database based on personal communications and site visits with J. Andrews (VT Reptile and Amphibian Atlas); S. Parren (Vermont Wildlife Diversity Program); Mark Powell (Vermont Adult Learning Center); and Lillian Shen (Town of Thetford, VT Conservation Commission).

Massachusetts

The wood turtle is formally tracked as a species of special concern in Massachusetts. We received element occurrence data from the Massachusetts Natural Heritage and Endangered Species Program of the Division of Fisheries and Wildlife, which included the records of the Massachusetts Herp Atlas from 1992–1998 (Tyning et al. 1998) in 2012. These records were compiled with the unpublished datasets of Jones (2009) and Jones et al. (2009–2013; Massachusetts Cooperative Fish and Wildlife Research Unit; Amherst, MA). Additional observations were obtained from the literature (Thoreau 2009, see Part 1; Agassiz 1857; Allen 1868, p. 175; Babcock 1919; Lazell 1976; Graham and Forsberg 1991; Kiviat and Barbour 1996; Siart 1999). We also obtained Massachusetts wood turtle occurrence data from numerous museums in the United States, with the largest series from Harvard's Museum of Comparative Zoology (MCZ; Cambridge, MA). We updated the occurrence database based on field visits and correspondence with L. Erb (MA NHESP); M. Grgurovic (Swampwalkers, Inc.); L. Johnson (New England Environmental, Inc.); S. Johnson (New England Environmental, Inc.); A. Richmond (University of Massachusetts Amherst); D. Yorks (ME IF&W), and others.

Connecticut

The wood turtle is formally tracked in Connecticut as a state species of special concern. We received and compiled element occurrences from the Connecticut Natural Diversity Database (NDDB), Department of Energy and Environmental Protection (CT DEEP) and the personal datasets of Hank Gruner (Vice President of Programs, Connecticut Science Center; Hartford, CT). We received other important occurrence information from the American Museum of Natural History (AMNH), the Peabody Museum's Division of Vertebrate Zoology at Yale University (YPM), and the United States National Museum (USNM). Additional records were obtained from the literature (Babcock 1919; Finneran 1948; Garber and Burger 1995). Further context was obtained from Klemens (1993).

Rhode Island

The wood turtle is state-listed as a species of special concern and is tracked informally by Chris Raithel (Rhode Island Department of Environmental Management; Providence, RI), who provided data to this project in 2012. Raithel's dataset encompasses most of what is currently known of the distribution of wood turtles in Rhode Island (C. Raithel, pers. comm.). Additional historical context and locational data were obtained from Drowne (1905, p. 5) and Babcock (1919).

New York

Although the wood turtle is listed as a species of special concern, it is not formally tracked by either the New York Natural Heritage Program or the Department of Environmental Conservation (A. Chaloux, NY Natural Heritage Program, pers. comm., W. Hoffman, NYSDEC, pers. comm.). We obtained records from the New York Herp Atlas database, administered by A. Breisch and J. Ozard at NYSDEC. We received and incorporated additional datasets from G. Johnson (Chair, Biology Department, SUNY; Potsdam, NY); M.N. Miller-Keas, (Natural Resources Technician, Natural Resources Branch, West Point Military Academy; West Point, NY). We also recorded locations mentioned in the literature (Mearns 1898, p. 329; Murphy 1916, p. 57; Wright 1918, p. 56; Bishop and Schoonmacher 1921; Latham 1971; Carroll and Ehrenfeld 1978; Price 1982, Kiviat and Barbour 1996). Additional records were obtained from the Cornell University Division of Biological Sciences (CU); Carnegie Museum (CM); California Academy of Sciences

(CAS); and the University of Michigan Museum of Zoology (UZ). We refined and updated records based on conversations with A. Breisch (NYS Department of Environmental Conservation [retired]; Albany, NY); G. Johnson (SUNY-Potsdam); W.S. Hoffman (Fish & Wildlife Technician, Wildlife Services, NYS DEC; Albany, NY); M.N. Miller-Keas (West Point); and S. Angus.

New Jersey

The wood turtle is formally tracked in New Jersey as a threatened species. We obtained element occurrence records of wood turtle from the New Jersey Endangered and Nongame Species Program, Division of Fish and Wildlife, Department of Environmental Protection (Trenton, NJ). We obtained additional population data for documented occurrences from the literature (Farrell and Graham 1991) and unpublished theses (Castellano 2008). We refined and updated occurrence data based on conversations and site visits with B. Zarate (NJ DFW); T. Duchak and R. Burke (Hofstra University; Hempstead, NY); R. Farrell (Herpetological Associates; Jackson, NJ); S. Angus (Northeast PARC); and C. Castellano (Hogle Zoo of Utah; Salt Lake City).

Pennsylvania

The wood turtle has recently become a formally tracked species in Pennsylvania. We obtained records from the Pennsylvania Natural Heritage Program and the Pennsylvania Amphibian and Reptile Survey, and received additional datasets from T. Pluto (U.S. Army Corps of Engineers [retired]), J. Drasher (Aqua-Terra Environmental Ltd.; Reading, PA), R. Farrell (Herpetological Associates; Jackson, NJ) and S. Angus (Northeast PARC). We also recorded locations from the literature (e.g., Surface 1908; Dunn 1915; Evermann 1918; Pawling 1939; Baldauf 1943; Hudson 1954; McCoy 1982; Strang 1983; Ernst 1986; Kaufmann 1992a; Kaufmann 1992b; 1995; Lovich 1997; Miller 2004; Williams 2009). We obtained a large series of important historical occurrence data from the Carnegie Museum via Iverson (1992) and EMYSystem (2012), which includes an extreme western specimen collected at Linesville, Crawford County by Daniel Atkinson in 1906 (CM2985). Additional records were obtained from the University of Kansas and the U.S. National Museum.

Delaware

The wood turtle is not currently considered native to Delaware (NatureServe 2013) and records are **tracked informally** by H. Niederriter (Non-game Wildlife Biologist, Delaware Natural Heritage and Endangered Species Program, Division of Fish and Wildlife), who provided two anecdotal and unsubstantiated reports of wood turtles from northern Delaware. We reviewed selected references of turtle studies within the potential range of the wood turtle in northern Delaware (e.g., Arndt 1977; Kipp 2003), but we have not found evidence of recent or historic sightings, published accounts, or museum specimens from Delaware.

Maryland

The wood turtle is not listed in Maryland (though it is under consideration; MD DNR 2010; Appendix III) and is **not formally tracked** by the Department of Natural Resources (S. Smith, MD DNR, pers. comm.) We obtained occurrence data in western Maryland from the datasets of E. Thompson (Forest Ecologist, Natural Heritage Program, MD DNR) and the Maryland Biological Stream Survey (MBSS; a program of the DNR). Additional corroborative evidence was provided by T. Akre (Smithsonian Conservation Biology Institute) and M. Martin. We obtained additional records from the literature (Cooper 1949; McCauley 1955, p. 155, in Reed 1956; Conant 1958; Harris 1975; Norden and Zyla 1989; Miller 1993), and from museums including the Florida Museum of Natural History (FLMNH), the American Museum of Natural History (AMNH), and the University of Michigan (UZ).

District of Columbia

The wood turtle is informally tracked as a "possibly extirpated" species within the District of Columbia. We received anecdotal, unsubstantiated, recent reports of wood turtle in the District from Lindsay Rohrbaugh (Wildlife Biologist, Fisheries and Wildlife Division, District Department of the Environment; Washington, D.C.). We reviewed relevant literature, including Shufeldt (1919), Norden and Zyla (1989), and Miller (1993). There are two specimens from the District in the United States National Museum: a specimen with no further location data (USNM62556) and a specimen collected in 1953 from the mouth of Four Mile Run (USNM136639) in the Potomac River—technically within the District as part of National Airport but surrounded by Virginia.

Virginia

The wood turtle is formally tracked in Virginia as a threatened species. We obtained element occurrence data from the Virginia Department of Game and Inland Fisheries (DGIF); and combined these with a large regional dataset provided by T. Akre (Smithsonian Conservation Biology Institute [SCBI]), the latter of which synthesized Akre's own surveys with field surveys undertaken by both DGIF and the U.S. Forest Service. A multiyear dataset derived from standardized surveys conducted in 2012–2013 was provided by Lorien Lemmon and Jeff Dragon (Smithsonian Conservation Biology Institute / George Mason University). We obtained additional occurrence records from the literature (Dunn 1920) and the U.S. National Museum. We revised, updated, and corrected the database following field visits and correspondence with T. Akre, L. Lemmon and J. Dragon (SCBI/GMU), J.D. Kleopfer (VDGIF), and others.

West Virginia

The wood turtle is state-listed as a species of special concern, and it is formally tracked by the Department of Natural Resources (K. O'Malley, West Virginia Division of Natural Resources [WV DNR], pers. comm.). We received occurrence datasets primarily through K. O'Malley (WV DNR) and T. Akre (SCBI) from three major sources: 1) field surveys conducted between 2003 and 2008 by Jeff Tamplin (University of Northern Iowa); 2) field survey data compiled by Katy McCoard under the direction of Jim Anderson (West Virginia University); 3) element occurrence data from the West Virginia Department of Natural Resources. We revised, updated, and corrected our database based on correspondence with K. O'Malley.

Adjacent Regions

To assess the distribution of wood turtles in peripheral areas adjacent to the northeastern United States, we obtained the official records for Québec from the Direction de la biodiversité et des maladies de la faune, Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs and for bordering areas of New Brunswick from the Atlantic Canada Conservation Data Centre (AC CDC) Rare Species Database (Sackville, NB).

Database of Corroborated Wood Turtle Occurrences

Assembling a standardized database of wood turtle occurrence across all 13 participating northeastern States was identified as a primary objective of the Northeast Wood Turtle Working Group in 2011. We undertook a standardized process of reviewing all available occurrence data to generate a database of "corroborated" occurrences, in which multiple animals have been observed in the same area in appropriate habitat context.

Some of the occurrence records in any given wood turtle occurrence database are of single turtles observed a single time. Sometimes, these are observed in a context consistent with the well-documented life history of the wood turtle (e.g., a streambank in a forested area) and in other instances the turtle is recorded in a non-natural or semi-natural setting (such as a roadway or lawn). Biologists in most states have found that these isolated observations are of value when guiding future surveys, validating model outputs, evaluating activity trends from pooled data (e.g., evaluating when and where turtles are most likely to cross roadways), and many other applications. On the other hand, several investigators have reported instances in which wood turtles may be found more than a kilometer from their overwintering streams as a result of displacement by floods, extended overland movements repeated in multiple years, long-distance migrations, and release of captive animals, indicating that some single animals may not represent stream segments typical of those supporting wood turtles, and suggesting that a high degree of caution be used when interpreting single observations (Sweeten 2008; Jones and Sievert 2009).

Occurrences, sightings, specimens, and observations were amalgamated into a "Corroborated Occurrences Database" in Microsoft Excel. Geo-referenced databases were spatially projected, and visually compared, in ArcGIS 10 and Google Earth. While these records were open, the text-only databases were sorted by county, town, or quadrangle, and the description fields searched to identify potential areas of overlap in the combined datasets. Non-georeferenced data were selectively georeferenced using the text description of the observation site (where available). In some cases, corroborating evidence was found in town natural resource inventories, state wildlife action plans, mitigation-related reports, and other unpublished documents. Gray literature was evaluated on its own merits to augment or corroborate other primary evidence of occurrence, but was not typically used as the primary source of information.

Multiple occurrences within the same section of stream were assigned to new "corroborated occurrences" as a method of taking initial steps to minimize pseudoreplication, to create spatially consistent data across the region, and to develop a database useful for building models of suitable stream habitat at the regional scale using the following criteria:

1. Two or more wood turtle observations within 10 km of one another along the same stream were considered corroborated occurrences;
2. Multiple observations within 2 km of each other, and within the same local basin, were pooled into a single corroborated occurrence for which the first and last observation dates and minimum number of turtles are tracked together;
3. All observations within 2 km of each other and within the same 30-year timeframe were combined under the same occurrence record;
4. Observations within 2 km of each other, but more than 30 years apart, were managed as two separate occurrence records with different observation dates and "minimum number (of turtles)" fields;
5. In each case, a single point was chosen to represent the confirmed occurrence, by randomly selecting existing along-stream observations where they were available, and moving ("snapping") a randomly selected observation to the nearest stream in situations where all of the observations were in the upland.

The resulting layer is a comma-space delimited (.csv) file of corroborated occurrences attributed with the following fields:

unique_id. individual identifier for all records

site_name. stream name or site name

site_code. unique site code based on state (e.g., ma for Massachusetts) plus first letters of county (e.g., es for Essex County), plus identifying river code (e.g., ir for "Ipswich River".)

state. state or province of occurrence

northeast. indicates whether the occurrence is within the northeast USFWS region

glin_observed_in_context. denotes (0 or 1) whether wood turtles were observed in natural context, as opposed to roadways or urban habitats;

stream_habitat_onsite. denotes (0 or 1) whether the record(s) occur(s) within close association (≤200 m) of a stream

corroborated. denotes (0 or 1) whether the occurrence is corroborated by within 10 km along the same stream course

location_extent. denotes one of four categories of precision: precise (from GPS or GoogleEarth or other GIS); town; county; or river

data_type. indicates whether the observations are primarily incidental sightings, survey results, long-term study, historical, or unknown data collection method

observer. record of the observer(s), if known or reported in the original source(s)

min_num. the minimum number of independent observations apparent in the original source data

first_obs. first known date of observation within a 30 year timeframe (observation periods greater than 30 years are separated into different occurrence records)

last_obs. most recent observation date within a confirmed occurrence area

report_date. date of a prepared report or data summary, if original observation date(s) are not known

lat: latitude in decimal degrees (WGS 84)

long: longitude in decimal degrees (WGS 84)

reference. original data source or literature reference

comments. comments pertaining to the data source or observation history.

We recorded 1,077 corroborated, precisely mapped occurrences in the northeastern United States, accounting for a minimum of 6,886 wood turtles since the 1850s (Table 1). We identified 110 towns, counties, or river/town/county combinations in the Northeast as corroborated occurrences with insufficient location data to train the logistic regression models, but sufficient data to define the boundaries of the models' application. In the course of data collection, we identified 180 occurrences in the remainder of the species' range in Minnesota, Iowa, Wisconsin, Michigan, Ontario, Québec, New Brunswick, and Nova Scotia. Peripheral occurrences within the northeastern United States, or highly disjunct occurrences, were flagged. Large areas absent of records in apparently suitable habitat were also identified for future field surveys.

Review of Layer

The corroborated occurrence layer used for training the spatial models was sent on a state-by-state basis to state agency project leads and/or major contributors for review and comment, and corrections and additions are included in the final database. Comments were received from the twelve state agency leads and major contributors, representing a majority of the range of the wood turtle in the Northeast.[18]

Analysis of Distribution

We used the final corroborated occurrences layer to evaluate the relationship between wood turtle occurrence and several environmental variables and to assess how those relationships change throughout the region. This was done by developing a network of stream segments to use as the sampling network, attributing each segment with seven environmental variables, evaluating probability density functions of stream segment characteristics, comparing means of occupied and random segments using t-tests, evaluating differences in the characteristics of wood turtle streams across subregions using ANOVA, and developing a logistic regression-based SDM. All statistical comparisons were completed R statistical software (R core team 2012).

Developing the stream layer segments for habitat evaluation

To develop a GIS layer of stream segments that could be used for evaluating wood turtle habitat in the Northeast Region, we began with a stream layer based on the National Hydrography Dataset (NHD), a 1:24,000 resolution, national dataset (USGS 1999). The flowlines of the NHD were divided into segments of approximately 1 km in length.[19] We used the 1 km reaches as the sampling units, since this is the approximate scale at which many wood turtle populations function, and it was the length of the visual surveys conducted across the Northeast Region (see Part 3). Kilometer-length reaches are also sufficiently large to measure stream gradient (due to errors in the digital elevation model, gradient at finer scales is often unreliable) and are similar to the scale at which the climatic variables were available (800 m cells). We limited the evaluation area to the known range of the wood turtle in the Northeast, which we defined as areas within 50 km of a known occurrences at the edge of the range (i.e., along the southern boundary and in coastal areas) (Figure 1). Fifty kilometers approximates the maximum distance an individual wood turtle is capable of moving its lifetime (97th percentile of distance between annual home range centroids in New England = 1223 m; generation time = 45 yr; see Part 1; Jones and Willey, unpublished data). Visual inspection of the periphery of the range also confirmed that using a 50 km buffer around known occurrences encompassed nearly all historic (but uncorroborated) records. Only four records were not

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18 Thomas Akre, Smithsonian Conservation Biology Institute (VA, WV, MD); James Andrews, VT Reptile and Amphibian Atlas (VT); Al Breisch, NYSDEC (NY); Jeff Dragon, SCBI/GMU (VA); Kathy Gipe, PFBC (PA); Lorien Lemmon, SCBI/GMU (VA); Michael Marchand, NHFG (NH); Kieran O'Malley, WV DNR (WV); Steve Parren, VTDFW (VT); Ed Thompson, MD MNR (MD); Derek Yorks, ME IFW (ME); Lisabeth Willey (UMass/MA Coop Unit) (ME/NH/MA)

19 To divide the NHD into segments, the following steps were taken. NHD flowlines were dissolved based on the stream name attribute and the reach code attribute. This allowed rivers and streams to be continuous features. All features were then merged into a single feature and segmented at 1km intervals using the "divide" tool in the ArcGIS editing toolkit. Multipart features were then converted to single part features. At the beginning or end of named or numbered features, the remaining line segments, which were less than 1km, were retained as separate line segments. This division process yielded 1039704 segments on 568,685 km of stream.

included: Rocky River, Cayuga County, Ohio; Talbot, Maryland; Dover, Delaware; and Mashpee, Barnstable County, Massachusetts, the latter three of which are not accepted as likely recent occurrences.

Each 1 km stream segment was attributed with the following variables:

Elevation. Maximum, minimum, and average elevation (m) was evaluated for each segment by sampling the USGS National Elevation Dataset (NED; Gesch et al. 2002; Gesch 2007), 30 m digital elevation model using Spatial Analyst in ArcGIS.

Gradient. Gradient was evaluated for each segment by dividing the difference in maximum and minimum elevation by the stream length (m). Stream length was often 1 km, but was less in approximately half of all instances.

Sinuosity. Sinuosity of the line segment, a measure of meandering distance divided by straight line distance, was calculated using Hawth's Tools, Analysis Tools, Line Metrics (Beyer 2004).

Flow accumulation. Flow accumulation was measured for each line segment by sampling a flow accumulation grid from the NHD Plus, Version 2 (Horizon Systems Corporation 2012). Because the flow accumulation grid does not perfectly overlap with the line segments, focal statistics were first calculated for each grid cell, and the maximum flow accumulation in a 150 m radius circle was measured, averaged, and assigned to the line segment.

Minimum January Temperature. Minimum January temperature was measured for each line segment by sampling the 30 year normal, 800 m resolution PRISM dataset (Daily et al. 2008). Values are expressed as ˚Celsius x 1000.

Average July Temperature. Average July temperature was measured for each line segment by sampling the 30 year normal, 800 m resolution PRISM dataset (Daily et al. 2008). Values are expressed as ˚Celsius x 1000.

Precipitation. Precipitation was measured for each line segment by sampling the 30 year normal, 800 m resolution PRISM dataset (Daily et al. 2008). Values are expressed as mm x 1000.

Attributing the Occurrence Database

The corroborated occurrence database (described above) was joined to the stream reach database by spatial location. Each occurrence was attributed with the characteristics of the 1 km stream segment that it was closest to. The distance from the selected reach was calculated, and all occurrences greater than 200 m from the line segment or in the 90th percentile of any raw variable were examined for plotting errors. To visually assess differences in the environmental variables at occupied wood turtle streams across states, we plotted environmental characteristics using boxplots (Figures 2–8).

Sub-regional Divisions

In addition to evaluating wood turtle habitat at the regional and state scale, we also evaluated wood turtle habitat at other sub-regional scales, so that local variation in relationships could be evaluated for two reasons:

1. Occurrence data are clumped due to variable effort in data collection, and some areas are sampled more heavily than others so that data resolution varies across the region, and

2. The relationship between wood turtle occurrence and environmental variables is also likely spatially non-stationary and varies across the region.

We broke the Northeast into subregions using 3 biological or political (and therefore data-availability driven) divisions.

1. State – Much of the occurrence data are collected at the state-level, and therefore data availability varies by state. By assessing habitat for each state, we are able to make the best use of available data.
2. Hydrologic Unit Code (HUC) 4 Watershed – Because wood turtles are stream-dwelling, their occurrence may vary locally by watershed, and therefore we evaluated habitat for each HUC4 watershed area. This approach also allows us to specify uncommon watershed occurrences that may signify genetic distinctiveness.
3. EPA Level 3 Ecoregion – The relationship between wood turtle occurrence and environmental variables likely varies by ecoregion, as factors limiting their survival and dispersal likely changes over the region as well. This approach also allows us to identify unusual, ecologically significant units of occurrence.

In this way, each 1km segment, where data were available, was placed into three distinct divisions, and evaluated as part of three different datasets. For each sub-regional class, we chose the scale (i.e., level 4 HUC and level 3 ecoregion) at which relationships with environmental variables were likely to be relatively homogenous, and sample sizes of greater than or equal to 30 could be achieved, as suggested by Wisz et al. (2008). In some instances where a subregion did not have sufficient occurrences, subregions were pooled with adjacent subregions for analysis (see below), for a total of 33 subregions within the three divisions.

Corroborated occurrence points were also attributed with the State, HUC 4 Watershed, and EPA Level 3 Ecoregion in which they were located. We developed maps (Figures 9–11) to evaluate data sufficiency and gaps across the region at the scale of the state, HUC 4, and Level 3 Ecoregion.

Random Segment Selection

A database of random segments was created for use as "pseudo-absence", or "available habitat" to compare the occupied stream segments with what is generally available on the landscape. As noted above, occurrence data are inconsistently available across the region (i.e., some areas are well-sampled and others are not, see Figures 9–11), so we sampled random points in proportion to occurrence points on the landscape, sampling more heavily in areas with more occurrence data. For each State, HUC4, and Ecoregional subregion, we selected a number of random segments equaling five times the number of occurrences in that subregion. Random segments were also confined to areas within 50 km of a known corroborated occurrence.

Evaluating environmental variable distributions

For each of the seven variables, we used a probability density function to plot the occurrence segments in conjunction with the random segments. We did this at the regional scale (i.e., across the entire Northeast region – Figure 13), and at the sub-regional level for each of the 33 subregions within the three division types.

In addition to visually assessing these distributions, differences in the sample means between occupied and random segments were evaluated across the region, and at the sub-regional level using t-tests. To control family-wise error experiment-wide, these tests were evaluated at the Bonferroni corrected alpha value of 0.05 / number of tests (238) = 0.00021.

We also evaluated differences in stream characteristics and climatic variables of wood turtle streams across the region using ANOVA, with states as the predictor variable. A Bonferroni adjusted alpha of 0.05/7 = 0.007 was used in this case.

Modeling Framework

SDMs are often used to evaluate distribution of species (Guisan and Thuiller 2005), and there are a wide range of techniques available for developing them (Elith et al. 2006, Gibson et al., 2007; Elith and Graham, 2009; Roura-Pascual et al., 2009; Marini et al., 2010). In conjunction with information on landuse change, they can be used to help assess habitat change and species status.

Our goal in this chapter was not to identify the best wood turtle habitat in the region (see Part 3 for an analysis of relative habitat quality of stream segments), but to quantify a footprint of streams in the northeast region that are geomorphically and climatically suitable for wood turtle. That is, we aimed to identify stream segments that have the same flow characteristics (size, gradient and sinuosity), and climatological regime of segments that are known to support wood turtles in the Northeast primarily in recent times but extending back to the 1850s in towns where wood turtles are still known to occur. We limited the predictor variables to those associated with stream flow characteristics and climate regime, rather than including variables associated with landuse or landcover, so that we could develop a footprint of potential stream habitat, and later evaluate the status of this footprint with regard to land use and landcover (see Part 4). There are, of course, serious pitfalls with this approach. Anthropogenic alteration has affected several of these variables, such as gradient and sinuosity. This effect is spatially autocorrelated.

We developed a SDM using a logistic regression framework, applied in a non-stationary way across the region, and combined multiple, spatially overlapping models to make the best use of data and avoid boundary effects. Although there are many modeling frameworks available to develop SDMs, and some have been shown to outperform logistic regression in some instances (Elith et al., 2006; Gibson et al. 2007; Elith and Graham, 2009; Roura-Pascual et al., 2009; Marini et al., 2010), the logistic regression framework performs almost as well under most conditions, and in many cases there were no significant differences between it and higher ranked approaches (Wisz et al. 2008), particularly when evaluated using sensitivity (Segurado and Araujo 2004). Logistic regression is among the most widely used approaches for SDMs (Guisan et al. 2006), it has been used to successfully model other stream-dwelling vertebrates (Cox and Nelson 2009), and for our purposes, it offers several advantages over many of the other available modeling frameworks. Logistic regression allows us to:

1. Easily evaluate assumptions and assess model fit;
2. Build and apply the model in a vector framework, using the stream segments as sampling units, rather than the raster framework required of many other modeling techniques. Since wood turtles are stream dwelling, and our goal was to evaluate available stream habitat, a vector analysis approach is more appropriate in this case;
3. Easily build and apply the model to subregions, allowing us to assess and model the non-stationarity in the relationship between wood turtles and stream characteristics;

4. Easily build multiple models with different sets of data and combine those models to make the best use of limited data and minimize boundary effects at subregion edges;
5. Establish a cutpoint that most appropriately meets our model objectives and apply it to achieve consistent results across models and regions;
6. Conservatively interpret results based on the data used to build the model along with the determined cut point.

In addition, two cooperating research teams in the Northeast are also currently undertaking wood turtle modeling efforts. A research team led by Kevin McGarigal at the University of Massachusetts Amherst is currently modeling wood turtle as a representative species as part of the North Atlantic Landscape Conservation Cooperative (LCC), Designing Sustainable Landscapes Project. A research team at the University of Maine is modeling wood turtle habitat using a MaxEnt approach as part of the Priority Areas for Amphibian and Reptile Conservation (PARCA) initiative (P. deMaynadier and A. Moody pers. comm.). Using a third approach will allow us to compare these three modeling frameworks, rather than duplicating efforts.

To build the logistic regression models, we used known occurrence data in conjunction with the randomly generated pseudo-absence data described above, and compared models using an information theoretic approach as suggested by Wisz and Guisan (2009). To choose a final model among models ranked highest based on AIC, however, we used 5-fold cross validation to ensure against overfitting. Models were fit and applied at each of the 33 subregions outlined above, and then combined as described below.

Sub-regional divisions

Given the differences in environmental variables at wood turtle sites across the region (Figs 1–7), and the differences in the relationship between occupied and random sites (Figs 12–13), we chose to build models at the subregional scale, for each of the three division types. This allows each model to be built, selected, and parameterized by a different subset of data. In this way, data-rich locations are used to inform models at the state, watershed, and ecoregion level, data-poor areas can be informed by 3 different models, and spatial non-stationarity can be accounted for. Each stream segment was then predicted by 3 different models, each built with a different data subset. These models were combined as described below. We elected not to develop a global model for two reasons: the highest resolution data were clustered near the center of the species' range in New Jersey, southern New York, and Massachusetts. Also, we anticipate that significant populations will be found near the range periphery and want to maximize the model's performance in these areas.

Some states, watersheds, and eco-regions did not have sufficient data to build a unique model for them (i.e., less than 20 occurrence points). In each case, that subregion was pooled with the nearest subregion until sufficient data were available. In the case of 3 peripheral subregions (1 state and 3 watersheds) with less than 3 substantiated occurrences, models were not built explicitly for these areas to keep random segments from these unoccupied areas from dominating the adjacent models. Instead models from adjacent areas were applied to these peripheral areas, even though they were not used in model building. Subregions were specifically pooled for model building in the following ways:

States:

Rhode Island and Connecticut were grouped

Delaware was not included in building any model

Ecoregions:

8.1.3, 5.3.3, and 8.4.3 were grouped as the Allegheny Plateau

8.4.1, 8.4.4, and 8.4.2 were grouped as the Ridge and Valley

8.5.4, 8.3.1, 8.3.5, and 8.3.4 were grouped as the Piedmont and Coastal Plain

Watersheds:

103 and 104 were grouped

101 and 102 were grouped

111 and 201 were grouped

414 and 415 were grouped

No models were created for 502 and 206

Evaluation of variable multi-collinearity and normality

Prior to building the models, we evaluated the model assumptions of normality and lack of multi-collinearity among the predictors. We assessed multi-collinearity of the seven predictor variables by measuring variable inflation factors. The variables associated with temperature (i.e., minimum January temperature, mean July temperature, and elevation) were highly correlated (VIF>10 and correlation coefficients=0.8 and above). We conducted a principle components analysis with these three variables and used the first component as a variable in the models instead of using them each individually.

For each of the seven variables and the thermal principle component, we plotted distributions across the region to visually evaluate normality. Gradient, Elevation, and Flow accumulation were all right skewed. We used an arcsine transformation to transform gradient, which was measured as percent slope, and a log scale to transform flow accumulation. Elevation was not used directly in the model, but was incorporated into the thermal principle component, which was normally distributed. Sinuosity was also slightly right skewed, but no transformation improved its distribution, so it was not transformed.

Model Building

For each state, HUC4 watershed, and EPA Level 3 ecoregion (with the exceptions noted above), a logistic regression model was fit using the occurrences and the randomly selected reaches that fell in that subregion. The number of randomly selected stream segments was equal to five times the number of occurrences in the subregion. Logistic regression models were built and parameterized in the following way.

For each subregion, we used an all-subsets approach to identify the models with the lowest AIC values. Visual assessment of species occurrence relationships suggested that probability of presence did not necessarily monotonically increase with all of the variables, rather many variables appeared to have a unimodal relationship with species presence. Consequently, we allowed squared terms in the model for all variables. We then cross validated all models within ten AIC points of the best model using a 5-fold cross validation procedure. Because we are interested in how well the models predict occurrences, rather than absences, since absences are random segments and not true absences, we used sensitivity (true positive rate) as the metric for model fit in this round of model selection. For each subset in the cross-validation we determined the cutpoint that produced 85% sensitivity in the training data (using the optimal.thresholds function in the PresenceAbsence package in R (Freeman and Moisen 2008). We averaged these cutpoints across all data subsets and evaluated the sensitivity of the hold-out predictions at that cutpoint. We then selected the model with the highest sensitivity of the holdout samples. The sensitivity, as well as specificity (the true negative rate;the proportion of random stream segments classified as unoccupied) and Cohen's Kappa (a measure of correct classification rate that takes into account chance agreement; Cohen 1960) of the hold-out values are presented in Table 3.

The selected model was then re-fit using the complete set of occurrences and random segments from that subregion, and each squared term was evaluated using a Chi square test to determine whether it added significantly to a model with only simple terms. If it did not, the squared term was not included in the final model. Squared terms that did significantly improve a model were included in the final model. A final model was refit with the complete set of occurrences and random segments from that subregion, and fit statistics were calculated for this final model (Table 3).

The optimum cutpoint was determined for the final model in each subregion by calculating the point at which specificity = 0.85 for the complete set of training data. These values are also presented in Table 3.

Model Application

The selected model and its calculated cutpoint were then applied to all of the stream segments in each subregion, such that each stream segment had 3 values of 0 or 1 assigned to it, one value from a state model, one value from a watershed model, and one value from an ecoregion model. Additionally, models were applied to adjacent regions for which there was no equivalent model due to lack of occurrence data. For instance, the Maryland model was applied to Delaware, and the watershed model for HUC4 101 and 102 was applied to HUC4 105 as well.

By varying the cutpoint locally, so that it was equal to a specificity of 0.85 in the training data, the resulting layer is consistent in that segments classified as habitat are similar to 85% of the occupied segments around it, regardless of how rich or sparse the local dataset is.

Removing reservoirs, lakes, and ponds from the SDM

The NHD includes flowlines through areas of standing water, including lakes, ponds, and reservoirs. As with the other flowlines in the dataset, these areas were attributed with the environmental variables. In some cases (as with many reservoirs), the habitat may have at one time been suitable for wood turtles, but is no longer, and for other features (natural lakes and ponds), the habitat was likely never suitable for wood turtles. As a final step, we removed all segments that fell completely within reservoirs, lakes, and ponds, as classified in the NHD waterbodies layer, so they were not counted as habitat. Prior to sending the outputs to state biologists, we removed estuarine habitats that had been inadvertently retained in Maine and other portions of HUC Region 1 (New England).

Results

Occurrences

We recorded 1,086 corroborated, precisely mapped occurrences in the northeastern United States (Table 1), of which nine were dropped because they were more than 200 m from a USGS stream segment (*n*=1,077).

Significant Data Deficiencies

Massachusetts was the most heavily sampled state, with one corroborated occurrence/155 km of stream within the species range, while Maine was the least sampled, with one corroborated occurrence/1020 km of stream (Table 1). Obtaining a complete understanding of the distribution of wood turtles in Maine is of critical importance because of Maine's relatively unfragmented habitat context. As an aside, we note the relatively small number of sites with robust population data in Vermont and the lack of robust population data for any site in Rhode Island.

Western New York and western Pennsylvania are apparently undersampled, and the current distribution is poorly documented in the western counties of both states. This will likely be resolved through ongoing coordination and continued standardized surveys. The status of wood turtles in Delaware is an important question, as well as the status of wood turtles in Ohio and counties in West Virginia and Pennsylvania bordering Ohio.

At the watershed scale, the Maine Coastal, St. Francois, Lake Erie, and Southwestern Lake Ontario, and Monongahela all have four or fewer corroborated occurrences.

Several ecoregions appear underrepresented, suggesting that the occurrences there may represent meaningful or significant ecological lineages. For example, at the ecoregional scale: the Atlantic Coastal Pine Barrens (*n*=13), the Western Allegheny Plateau (*n*=7), and the Central Appalachians (*n*=5)(Figure 12).

Stream Characteristics

For each of the seven variables, we used a probability density function to plot the occurrence segments in conjunction with the random segments. We did this at the regional scale (i.e., across the entire Northeast region; Figure 13), and at the sub-regional scale for each of the three division types. With the exception of flow accumulation, there was not a great deal of visual separation between wood turtle stream segments and random segments at the regional level. At the subregional level, however, differences between wood turtle stream segments and random segments were more apparent and varied from state to state and subregion to subregion. For instance, in New Jersey, wood turtle stream segments tended to be generally cooler, drier, and higher in elevation that what is generally available in the state, and occupied segments tended to be intermediate in terms of available gradient (Figure 14). In Vermont, by contrast, occupied wood turtle stream segments tend to be at lower elevations with warmer summer temperatures, though winter temperatures were no different than random. Wood turtle segments were also much more sinuous than streams in general in Vermont, and like New Jersey, they tended to be at low gradients, but not flat sections (Figure 15).

At the Bonferroni adjusted alpha of 0.00021, at the regional scale, wood turtles occur in stream segments that are significantly lower in elevation and warmer in July, and have lower gradient and higher sinuosity and flow accumulation than random stream segments (Table 2). Within most subregions, turtle segments were generally lower gradient, higher sinuosity, and higher flow than average, but the strength of the relationship varied. Climatically, wood turtles streams varied considerably by subregion, in places occurring in the warmest, low elevation parts of the subregions (e.g., West Virginia), while occurring in higher elevation, cooler locations in other subregions (e.g., Massachusetts). In still other subregions, there were no significant climatic differences between wood turtle streams and random stream (e.g., Virginia, though it should be noted that only northern Virginia, where wood turtles are known to occur, was assessed).

In evaluating the variation in environmental characteristics of wood turtle streams across the region using ANOVA with state as the independent variable, differences existed between groups for all 7 variables at the Bonferonni adjusted alpha level of 0.007 ($F_{11,1042} > 5.7$, $P<0.001$ in all cases). Consequently, a SDM framework that is able to fit locally varying relationships with environmental variables would be most appropriate.

Species Distribution Model

Models were fit for 11 states (excluding Delaware) or groups of states (Connecticut + Rhode Island), 15 watershed (or groups of watersheds), and seven ecoregions (or groups of ecoregions), using an average of 97 occurrences (range=16–346) (Table 3). Model complexity ranged from only flow accumulation (Watershed model 106 and 109) to including all five variables and their squared terms (e.g., Watershed model 108). An example of the relationship between predictor variables and relative probability of wood turtle occurrence is presented as partial effects plots for the New Hampshire state model in Figure 16. D^2 (percent deviance explained) averaged 0.40 (range=0.26–0.63), and area under the curve (AUC) averaged 0.91 (range = 0.85–0.97). Cross validated sensitivity (using a cutpoint that achieved a sensitivity of 0.85 in the training data) averaged 0.84 (range=0.78–0.88), suggesting that the models were able to correctly classify novel data at a rate similar to training data, and were not overfit. Specificity for these same cross validated data averaged 0.82 (range = 0.62–0.95), and kappa averaged 0.52 (range = 0.26–0.76). A visual example of model classification error at the cutpoint designated for 85% specificity in the training data is presented for New Hampshire in Figure 17. Fit statistics did not change significantly with sample size ($P>0.05$, Figure 18).

Using a cutpoint that achieves a sensitivity of 0.85 in the training data (i.e., correctly classifies 85% of wood turtle occurrences), the state models combined classify 114,000 stream km as habitat (or 21.4% of streams), watershed models combined classify 109,000 km, or 20.5% of stream segments as potential wood turtle habitat, while the ecoregional models classify 110,000 km, or 20.7% of stream segments as suitable habitat. 7,731 (of 184,108) stream segments (or 5,063 km of 132,441 km) that were modeled as suitable habitat were removed because they were located under lakes, ponds, or reservoirs, according to the NHD waterbodies layer.

The three models were combined and any segment classified as suitable habitat in all three models was considered a high confidence suitable stream (i.e., it shared characteristics with 85% of wood turtle streams in all three cases), while those classified in 2 out of 3 models were also classified as suitable with moderate confidence.

Using this final classification regime, 127,378 km (or 24%) of stream km in the Northeast region can be classified as similar to wood turtle streams with moderate (9%) to high confidence (15%). That is, approximately 24% of the streams in the northeast region share thermal and geomorphic characteristics with 85% of known wood turtle occurrences. The spatial distribution of habitat classified as suitable using the three models is presented in Table 4 and Figs 18–21.

Evaluation of protected wood turtle habitat in the Northeast region

We used the corroborated occurrences database and the SDM layer developed in Part 2 in conjunction with the USGS GAP Program's Protected Areas Database of the United States (PADUS; GAP 2012) to evaluate how much wood turtle habitat in the Northeast region is already protected. We buffered all corroborated occurrence points, and all suitable stream segments by 300m (the average annual movement distance of wood turtles away from streams). We then used the PADUS to evaluate how much buffered habitat is in conservation (in any type of permanent protection status). Approximately 27% of the habitat surrounding all corroborated occurrences is protected (compared to 19% of the region at large) and approximately 25% of occurrences are at least 50% protected. Approximately 15% of habitat surrounding suitable stream segments is protected (compared to 19% of the region at large) and 14% of suitable stream segments are more than 50% protected.

Discussion

Environmental correlates of wood turtle habitat in the Northeast

Although wood turtle streams are lower gradient (but >0%), higher flow, and more sinuous on average than those randomly available on the landscape, quadratic terms proved important in logistic regression models, suggesting a unimodal response and that wood turtles are most associated with intermediate levels of these variables. Additionally, the specific relationships between environmental variables and wood turtle occurrences were highly variable throughout the Northeast. The large differences observed in climatic variables across the region illustrate the need for locally trained and applied models, and our approach allowed adjustment for such variation.

Choice of Modeling Framework

Although there are many approaches to SDMs, the logistic regression approach worked well in this instance for several reasons. It allowed the model to be constructed and applied in a vector (stream segment) framework, allowing us to make use of the nationally available NHD. It allowed models and parameters to vary regionally, so that regionally specific models could be built and applied. It allowed multiple, overlapping models to be built across the region so that models could be combined, increasing our confidence in the results, and making the best use of available data. It allowed us to set a cutpoint that could be consistently applied and interpreted across the region.

In addition, by using a cutpoint based on a constant measure of specificity, all presence points were treated consistently, regardless of whether the area was well sampled or not. One potential disadvantage to using a constant specificity, however, is that models that fit particularly well could introduce unneccesary false positives by using such a low cutpoint, though this effect will be consistent across the region.

Model Fit and Interpretation of Results

Portions of the Northeast Region yielded better fitting models than other areas. New England and West Virginia generally had the best fitting models. In these areas, AUC was greater than 0.91, cross validated kappa was greater than 0.53, and the state, watershed, and ecoregional models mostly agreed. Better separation between occupied and random segments may have been possible in these areas that are at the edge of the species range and topographically (and climatically) diverse. At the center of the species range, particularly in Pennsylvania and Maryland, models fit less well (AUC < 0.88 and cross validated kappa < 0.43). Because sensitivity was set constant across the region, where models fit more poorly, specificity was lower, yielding a larger footprint of suitable wood turtle habitat. Because there is less difference between occupied and random streams in these areas, these larger areas may, in fact, represent the reality that wood turtles are capable of occurring in a larger proportion of streams in these regions. Alternatively, it may be an artificial result of poor model fit, and once more data are available, additional iterations of this model should be built with a greater amount of cross validation. Model fit improved slightly with data sufficiency (i.e., areas with more occurrences / stream km had slightly better fitting models), but this relationship was not significant for any metric (Figure 16), so additional occurrence data may not necessarily improve model fit. It may be true that in the central of the species' range or in the central area of the multivariate space, other key variables have greater explanatory power.

In a use-availability model such as this, without the use of random sampling, it is impossible to determine how prevalent wood turtles truly are on the landscape or to estimate conditional probability (Keating and Cherry 2004). Results can be used, however, to rank habitats and identify those strongly correlated with occupied areas, as we have done in this case. Consequently, interpretation of our model is narrow; areas classified as suitable are those that share thermal and flow characteristics with 85% of known occupied habitats. It is also important to note that in addition to false positives (incorrectly classified unoccupied habitat as occupied), which cannot be accurately estimated without the use of random sampling, because we used a specificity of 0.85, there are about 15% of wood turtle occurrences that are incorrectly classified as areas of non-occurrence using this approach. This ratio remained true for hold-out samples as well as training data.

Limitations and Future Directions

It should be noted that source data were collected in a haphazard and potentially biased way, and inconsistent sampling occurred throughout the region. Further, we evaluated occupied vs. available habitat, rather than randomly selected true absence data. For these reasons, model results must be cautiously interpreted, as discussed above. In an effort to account for these concerns, we collected data from as many disparate, diverse sources as possible, built models with multiple subsets of training data, pooled results, and used cross validation to evaluate model performance. Still there are many ways the modeling approach could be improved in future iterations. In particular, randomized stream surveys, based on the predictive outputs of these models, could be used to greatly improve the model and expand its interpretability and evaluate true presence of wood turtles on the landscape. The use of an independent validation dataset would also greatly enhance confidence in model results. Exploration of additional methods of SDMs is warranted in future iterations.

In addition to sources of error from the occurrence data, there is error inherent in the stream network itself. In particular, headwater streams are represented inconsistently in the NHD, so some arbitrary regions have more stream km/area, and channel and gradient configurations can change over time as beavers impound certain areas, floods disturb the stream channel, and streams are anthropogenically straightened—none of which are accurately reflected in the NHD. In particular, this will result in underestimating "historically suitable" habitat in urbanized areas where there were extensive stream channelizations prior to the development of the NHD stream layers, and over estimating "currently suitable" habitat in areas that have been altered since. In addition, the digital elevation model and PRISM datasets may also introduce error into the environmental variables used in the model.

Still, this model may provide a "footprint" for statewide planning purposes, guide future surveys at multiple coordinated scales, and provide a basis for landscape analysis to assess the habitat quality for wood turtles at multiple scales (Part 4). Alternative approaches to logistic regression should continue to be explored, the model should be refit as better occurrence data become available, the effects of urbanization should be critically examined through field validation, and our results will be compared with those of other teams working on modeling wood turtle habitat in the Northeast.

Tables

Table 1. Corroborated wood turtle occurrences in the Northeast, by state, watershed, and ecoregion.

	State	Number of corroborated occurrences
	Connecticut	52
	Delaware	0
	Maine	83
	Maryland	43
	Massachusetts	168
	New Hampshire	87
	New Jersey	116
	New York	131
	Pennsylvania	161
	Rhode Island	10
	Vermont	87
	Virginia	68
	West Virginia	69
	Watershed	**Number of corroborated occurrences**
101 & 102	St. John & Penobscot	38
104 & 103	Kennebec & Androscoggin	27
106	Saco	24
107	Merrimack	82
108	Connecticut	166
109	Massachusetts-Rhode Island Coastal	25
110	Connecticut Coastal	72
111 & 201	St. Francois & Richelieu	49
202	Upper Hudson	77
203	Lower Hudson-Long Island	67
204	Delaware	101
205	Susquehanna	104
207	Potomac	173
414 & 415	Northeastern And Southeastern Lake Ontario-St. Lawrence	36
501	Allegheny	12
	Ecoregion	**Number of corroborated occurrences**
5.3.3, 8.1.3, & 8.4.3	North Central Appalachians & Allegheny Plateau	52
8.4.1, 8.4.2 , & 8.4.4	Ridge and Valley, Central Appalachians, and Blue Ridge	316
8.3.1, 8.3.4, 8.3.5, & 8.5.4	Piedmont and Coastal Plain	85
5.3.1	Northern Appalachian and Atlantic Maritime Highlands	381
8.1.1	Eastern Great Lakes Lowlands	59
8.1.7	Northeastern Coastal Zone	190
8.1.8	Acadian Plains and Hills	9

Table 2a. Differences in the means of environmental characteristics in wood turtle stream segments and random segments by state, watershed, and ecoregion, and for the Northeast as a whole.

		Elevation (m)				Minimum January Temperature (degress C * 1000)				Average July Temperature (degress C * 1000)				Annual Precipitation (cm*1000)			
Subregion type	Subregion	Mean value for wood turtle segments	Mean value for random segments	Direction	P value	Mean value for wood turtle segments	Mean value for random segments	Direction	P value	Mean value for wood turtle segments	Mean value for random segments	Direction	P value	Mean value for wood turtle segments	Mean value for random segments	Direction	P value
State	1 Maine	192	190	+	0.9081	-1573	-1531	-	0.3101	1857	1928	-	0.0599	9156	9380	-	0.2722
State	2 New Hampshire	192	297	-	**<0.0002**	-1254	-1228	-	0.2295	2061	2026	+	0.0032	9536	9776	-	0.0014
State	3 Vermont	199	324	-	**<0.0002**	-1363	-1407	+	0.0060	2031	1962	+	**<0.0002**	9055	9567	-	**<0.0002**
State	4 Massachusetts	163	119	+	**<0.0002**	-1032	-877	-	**<0.0002**	2155	2189	-	**<0.0002**	10307	10386	-	0.0372
State	5 Connecticut & Rhode Island	98	114	-	0.0722	-848	-782	-	0.0003	2230	2240	-	0.2247	10880	10869	+	0.8288
State	6 New York	197	344	-	**<0.0002**	-1088	-1178	+	**<0.0002**	2144	2037	+	**<0.0002**	9655	9541	+	0.3406
State	7 Pennsylvania	238	358	-	**<0.0002**	-748	-814	+	**<0.0002**	2248	2168	+	**<0.0002**	9508	9352	+	0.0277
State	8 New Jersey	124	62	+	**<0.0002**	-729	-562	-	**<0.0002**	2295	2398	-	**<0.0002**	10702	10384	+	**<0.0002**
State	9 Maryland	226	145	+	0.0196	-574	-459	-	**<0.0002**	2366	2455	-	0.0003	8916	9453	-	**<0.0002**
State	10 Virginia	277	281	-	0.8595	-559	-524	-	0.0023	2356	2383	-	0.0763	8588	9127	-	**<0.0002**
State	11 West Virginia	288	513	-	**<0.0002**	-597	-690	+	**<0.0002**	2330	2199	+	**<0.0002**	8262	8973	-	**<0.0002**
Watershed	101 & 102 St. John & Penobscot	218	211	+	0.6897	-1681	-1634	-	0.5339	1755	1828	-	0.3322	8332	8670	-	0.3594
Watershed	103 & 104 Kennebec & Androscoggin	284	244	+	0.2032	-1644	-1525	-	**<0.0002**	1861	1948	-	0.0013	9335	9508	-	0.2523
Watershed	106 Saco	85	116	-	0.0805	-1237	-1161	-	0.0688	2069	2084	-	0.6058	10340	10337	+	0.9883
Watershed	107 Merrimack	132	182	-	**<0.0002**	-1112	-1099	-	0.4834	2134	2112	+	0.0262	9923	10013	-	0.1095
Watershed	108 Connecticut	185	327	-	**<0.0002**	-1162	-1246	+	**<0.0002**	2108	2008	+	**<0.0002**	9916	10123	-	0.0100
Watershed	109 Massachusetts-Rhode Island Coastal	63	44	+	0.0509	-809	-702	-	0.0003	2239	2252	-	0.1246	10534	10505	+	0.5894
Watershed	110 Connecticut Coastal	168	133	+	0.0104	-947	-795	-	**<0.0002**	2170	2231	-	**<0.0002**	10652	10867	-	0.0004
Watershed	111 & 201 St. Francois & Richelieu	185	266	-	**<0.0002**	-1367	-1391	+	0.2459	2048	2008	+	0.0144	8713	9061	-	0.0153
Watershed	202 Upper Hudson	174	293	-	**<0.0002**	-1000	-1123	+	**<0.0002**	2183	2083	+	**<0.0002**	10037	9751	+	0.0162
Watershed	203 Lower Hudson-Long Island	118	93	+	0.0194	-722	-643	-	**<0.0002**	2303	2351	-	**<0.0002**	11030	10828	+	**<0.0002**
Watershed	204 Delaware	171	178	-	0.6179	-781	-677	-	**<0.0002**	2251	2298	-	0.0044	10349	10113	+	**<0.0002**
Watershed	205 Susquehanna	243	348	-	**<0.0002**	-742	-856	+	**<0.0002**	2253	2154	+	**<0.0002**	9166	9051	+	0.0871
Watershed	207 Potomac	271	285	-	0.2863	-580	-554	-	**<0.0002**	2346	2359	-	0.1369	8471	8825	-	**<0.0002**
Watershed	414 & 415 NE & SE Lake Ontario-St. Lawrence	197	326	-	**<0.0002**	-1323	-1321	-	0.9409	2062	2002	+	0.0008	9003	9488	-	0.0542
Watershed	501 Allegheny	345	456	-	**<0.0002**	-802	-888	+	0.0005	2170	2080	+	**<0.0002**	9361	9473	-	0.4922
Ecoregion	5.3.3, 8.1.3, & 8.4.3 N. C. Appalachians & Allegheny Plateau	323	406	-	**<0.0002**	-938	-944	+	0.7754	2103	2077	+	0.0624	9170	9163	+	0.9436
Ecoregion	8.4.1, 8.4.2 , & 8.4.4 Ridge & Valley, Central Appalachians& Blue Ridge	71	75	-	0.4157	-570	-499	-	**<0.0002**	2410	2435	-	0.0034	10272	9983	+	**<0.0002**
Ecoregion	, 8.3.4, 8.3.5, & 8.5.4 Piedmont and Coastal Plain	252	365	-	**<0.0002**	-686	-720	+	**<0.0002**	2291	2233	+	**<0.0002**	9105	9286	-	0.0028
Ecoregion	5.3.1 N. Appalachian & Atlantic Maritime Highlands	235	364	-	**<0.0002**	-1251	-1388	+	**<0.0002**	2040	1940	+	**<0.0002**	9872	9918	-	0.5136
Ecoregion	8.1.1 Eastern Great Lakes Lowlands	101	151	-	**<0.0002**	-1313	-1234	-	**<0.0002**	2123	2117	+	0.4427	8110	8457	-	0.0009
Ecoregion	8.1.7 Northeastern Coastal Zone	86	82	+	0.3656	-942	-852	-	**<0.0002**	2214	2224	-	0.0737	10336	10329	+	0.8830
Ecoregion	8.1.8 Acadian Plains and Hills	95	100	-	0.6965	-1519	-1451	-	0.3538	1880	1954	-	0.3081	9030	9357	-	0.3735
	Northeast Region	195	254	-	**<0.0002**	-966	-1010	+	**<0.0002**	2183	2136	+	**<0.0002**	9654	9661	-	0.8390

Table 2b. Differences in the means of stream geomorphic characteristics in wood turtle stream segments and random segments by state, watershed, and ecoregion, and for the Northeast as a whole.

		Gradient (m/m)				Sinuosity (curvilinear distance / straight line distance)				Flow accumulation (number of 30m cells that drain through the cell)			
Subregion type	Subregion	Mean value for wood turtle segments	Mean value for random segments	Direction	P value	Mean value for wood turtle segments	Mean value for random segments	Direction	P value	Mean value for wood turtle segments	Mean value for random segments	Direction	P value
State	1 Maine	0.10	0.15	-	**<0.0002**	1.33	1.12	+	**<0.0002**	10.38	6.13	+	**<0.0002**
State	2 New Hampshire	0.12	0.21	-	**<0.0002**	1.45	1.15	+	**<0.0002**	10.17	6.20	+	**<0.0002**
State	3 Vermont	0.09	0.20	-	**<0.0002**	1.34	1.14	+	**<0.0002**	9.92	5.46	+	**<0.0002**
State	4 Massachusetts	0.13	0.15	-	**<0.0002**	1.33	1.13	+	**<0.0002**	9.33	5.47	+	**<0.0002**
State	5 Connecticut & Rhode Island	0.13	0.16	-	**<0.0002**	1.27	1.15	+	**<0.0002**	10.02	5.08	+	**<0.0002**
State	6 New York	0.10	0.16	-	**<0.0002**	1.36	1.15	+	**<0.0002**	9.44	6.55	+	**<0.0002**
State	7 Pennsylvania	0.16	0.20	-	**<0.0002**	1.17	1.11	+	**<0.0002**	9.78	7.12	+	**<0.0002**
State	8 New Jersey	0.13	0.13	-	**<0.0002**	1.28	1.14	+	**<0.0002**	8.39	4.59	+	**<0.0002**
State	9 Maryland	0.16	0.16	+	**<0.0002**	1.25	1.11	+	**<0.0002**	10.15	6.79	+	**<0.0002**
State	10 Virginia	0.16	0.19	-	**<0.0002**	1.21	1.09	+	**<0.0002**	9.85	6.42	+	**<0.0002**
State	11 West Virginia	0.15	0.25	-	**<0.0002**	1.25	1.10	+	**<0.0002**	11.11	6.79	+	**<0.0002**
Watershed	101 & 102 St. John & Penobscot	0.09	0.12	-	**<0.0002**	1.27	1.12	+	**<0.0002**	10.18	6.64	+	**<0.0002**
Watershed	103 & 104 Kennebec & Androscoggin	0.10	0.19	-	**<0.0002**	1.52	1.12	+	**<0.0002**	10.43	5.98	+	**<0.0002**
Watershed	106 Saco	0.12	0.16	-	**<0.0002**	1.34	1.17	+	**<0.0002**	10.11	6.07	+	**<0.0002**
Watershed	107 Merrimack	0.12	0.17	-	**<0.0002**	1.36	1.16	+	**<0.0002**	9.86	6.41	+	**<0.0002**
Watershed	108 Connecticut	0.14	0.22	-	**<0.0002**	1.33	1.13	+	**<0.0002**	9.70	6.16	+	**<0.0002**
Watershed	109 Massachusetts-Rhode Island Coastal	0.13	0.12	+	**<0.0002**	1.21	1.12	+	**<0.0002**	8.79	5.08	+	**<0.0002**
Watershed	110 Connecticut Coastal	0.13	0.17	-	**<0.0002**	1.37	1.14	+	**<0.0002**	9.88	5.52	+	**<0.0002**
Watershed	111 & 201 St. Francois & Richelieu	0.03	0.16	-	**<0.0002**	1.38	1.16	+	**<0.0002**	9.99	5.44	+	**<0.0002**
Watershed	202 Upper Hudson	0.12	0.19	-	**<0.0002**	1.39	1.17	+	**<0.0002**	9.44	6.75	+	**<0.0002**
Watershed	203 Lower Hudson-Long Island	0.13	0.16	-	**<0.0002**	1.29	1.15	+	**<0.0002**	8.34	5.13	+	**<0.0002**
Watershed	204 Delaware	0.15	0.14	+	**<0.0002**	1.18	1.13	+	**<0.0002**	8.39	5.74	+	**<0.0002**
Watershed	205 Susquehanna	0.16	0.20	-	**<0.0002**	1.18	1.11	+	**<0.0002**	10.36	7.33	+	**<0.0002**
Watershed	207 Potomac	0.16	0.21	-	**<0.0002**	1.23	1.11	+	**<0.0002**	10.44	6.60	+	**<0.0002**
Watershed	414 & 415 NE & SE Lake Ontario-St. Lawrence	0.02	0.11	-	**<0.0002**	1.47	1.17	+	**<0.0002**	9.83	6.52	+	**<0.0002**
Watershed	501 Allegheny	0.17	0.20	-	**<0.0002**	1.19	1.10	+	**<0.0002**	10.07	7.37	+	**<0.0002**
Ecoregion	5.3.3, 8.1.3, & 8.4.3 N. C. Appalachians & Allegheny Plateau	0.16	0.20	-	**<0.0002**	1.16	1.13	+	**<0.0002**	10.19	6.88	+	**<0.0002**
Ecoregion	8.4.1, 8.4.2 , & 8.4.4 Ridge & Valley, Central Appalachians& Blue Ridge	0.12	0.14	-	**<0.0002**	1.23	1.13	+	**<0.0002**	8.77	5.69	+	**<0.0002**
Ecoregion	, 8.3.4, 8.3.5, & 8.5.4 Piedmont and Coastal Plain	0.15	0.22	-	**<0.0002**	1.23	1.12	+	**<0.0002**	10.00	6.99	+	**<0.0002**
Ecoregion	5.3.1 N. Appalachian & Atlantic Maritime Highlands	0.12	0.19	-	**<0.0002**	1.37	1.14	+	**<0.0002**	9.61	6.24	+	**<0.0002**
Ecoregion	8.1.1 Eastern Great Lakes Lowlands	0.02	0.12	-	**<0.0002**	1.47	1.19	+	**<0.0002**	10.23	6.40	+	**<0.0002**
Ecoregion	8.1.7 Northeastern Coastal Zone	0.13	0.15	-	**<0.0002**	1.30	1.17	+	**<0.0002**	9.66	5.52	+	**<0.0002**
Ecoregion	8.1.8 Acadian Plains and Hills	0.10	0.14	-	**<0.0002**	1.25	1.15	+	**<0.0002**	10.20	5.82	+	**<0.0002**
	Northeast Region	0.13	0.17	-	**<0.0002**	1.29	1.14	+	**<0.0002**	9.73	6.24	+	**<0.0002**

Table 3a. The final logistic regression model fit for each state, watershed, and ecoregion, along with model fit statistics.

Model Type	Subregion	Formula	Squared Deviance	AUC	total stream segments (km)	Number of corroborated occurrences	Number of random points in the training dataset	Required cutpoint to reach sensitivity level 0.75	0.85	0.9
State	1 Maine	~gradient+sinuosity+FAC+gradient^2+sinuosity^2+FAC^2	0.41	0.91	82586	81	405	0.35	0.16	0.08
State	2 New Hampshire	~climate+gradient+sinuosity+FAC+climate^2+gradient^2+sinuosity^2-	0.55	0.95	29330	87	435	0.43	0.32	0.24
State	3 Vermont	~gradient+precip+sinuosity+FAC+precip^2+sinuosity^2+FAC^2	0.47	0.93	37152	85	425	0.43	0.36	0.31
State	4 Massachusetts	~climate+precip+sinuosity+FAC+climate^2+sinuosity^2+FAC^2	0.42	0.92	26092	168	840	0.34	0.25	0.19
State	5 Connecticut & Rhode Island	~climate+precip+FAC+climate^2+FAC^2	0.49	0.94	24107	62	310	0.44	0.37	0.3
State	6 New York	~climate+gradient+precip+sinuosity+FAC+climate^2+gradient^2+sinu	0.34	0.89	106152	126	630	0.25	0.18	0.14
State	7 Pennsylvania	~climate+precip+sinuosity+FAC+climate^2+sinuosity^2	0.29	0.86	130964	153	765	0.21	0.12	0.08
State	8 New Jersey	~climate+gradient+sinuosity+FAC+climate^2+gradient^2+FAC^2	0.40	0.91	27471	114	570	0.29	0.17	0.11
State	9 Maryland	~gradient+precip+FAC+gradient^2+FAC^2	0.33	0.88	22384	43	215	0.24	0.13	0.11
State	10 Virginia	~climate+precip+FAC+precip^2+FAC^2	0.34	0.89	26841	68	340	0.31	0.17	0.13
State	11 West Virginia	~climate+gradient+FAC+climate^2+gradient^2+FAC^2	0.51	0.94	16512	69	345	0.53	0.32	0.2
Watershed	101 & 102 St. John & Penobscot	~sinuosity+FAC+FAC^2	0.36	0.87	33397	38	190	0.28	0.06	0.04
Watershed	103 & 104 Kennebec & Androscoggin	~climate+gradient+precip+sinuosity+FAC+gradient^2	0.63	0.97	30266	27	135	0.5	0.34	0.19
Watershed	106 Saco	~FAC	0.35	0.90	13839	22	110	0.28	0.19	0.12
Watershed	107 Merrimack	~gradient+FAC+gradient^2+FAC^2	0.34	0.89	15349	81	405	0.32	0.26	0.2
Watershed	108 Connecticut	~climate+gradient+precip+sinuosity+FAC+climate^2+gradient^2+prec	0.50	0.94	41255	164	820	0.42	0.33	0.25
Watershed	109 Massachusetts-Rhode Island Coastal	~FAC	0.31	0.88	12827	25	125	0.26	0.21	0.17
Watershed	110 Connecticut Coastal	~gradient+FAC+gradient^2+FAC^2	0.48	0.93	19063	72	360	0.46	0.28	0.24
Watershed	111 & 201 St. Francois & Richelieu	~climate+gradient+sinuosity+FAC+gradient^2+FAC^2	0.50	0.94	22733	50	250	0.42	0.31	0.2
Watershed	202 Upper Hudson	~climate+gradient+precip+sinuosity+FAC+climate^2+gradient^2+sinu	0.53	0.95	42331	75	375	0.38	0.27	0.2
Watershed	203 Lower Hudson-Long Island	~climate+gradient+FAC+climate^2+gradient^2+FAC^2	0.33	0.89	13554	65	325	0.34	0.27	0.15
Watershed	204 Delaware	~climate+gradient+FAC+climate^2+gradient^2+FAC^2	0.26	0.85	44192	101	505	0.2	0.12	0.08
Watershed	205 Susquehanna	~climate+precip+sinuosity+FAC+climate^2+sinuosity^2+FAC^2	0.30	0.86	79273	100	500	0.3	0.11	0.05
Watershed	207 Potomac	~climate+gradient+FAC+climate^2+gradient^2+FAC^2	0.35	0.89	50099	173	865	0.31	0.19	0.16
Watershed	414 & 415 NE and SE Lake Ontario-St. Lawrence	~climate+FAC+climate^2+FAC^2	0.35	0.89	19153	32	160	0.35	0.33	0.29
Watershed	501 Allegheny	~gradient+FAC+gradient^2+FAC^2	0.49	0.94	37568	16	80	0.39	0.37	0.26
Ecoregion	5.3.3, 8.1.3, 8.4.3 N.C. Appalachians & Allegheny Plateau	~climate+precip+FAC+FAC^2	0.27	0.85	96843	56	280	0.2	0.15	0.12
Ecoregion	8.4.1, 8.4.2 , 8.4.4 Ridge & Valley, Appalachians & Blue Ridge	~climate+gradient+FAC+gradient^2+FAC^2	0.28	0.86	60868	90	450	0.26	0.11	0.09
Ecoregion	8.3, 8.5.4 Piedmont and Coastal Plain	~climate+gradient+precip+sinuosity+FAC+climate^2+gradient^2+sinu	0.27	0.86	90780	312	1560	0.26	0.17	0.13
Ecoregion	5.3.1 N. Appalachian & Atlantic Maritime Highla	~climate+gradient+sinuosity+FAC+gradient^2+sinuosity^2+FAC^2	0.41	0.92	131592	344	1720	0.34	0.25	0.17
Ecoregion	8.1.1 Eastern Great Lakes Lowlands	~gradient+sinuosity+FAC+sinuosity^2+FAC^2	0.58	0.96	25261	39	195	0.58	0.45	0.26
Ecoregion	8.1.7 Northeastern Coastal Zone	~climate+gradient+precip+sinuosity+FAC+climate^2+gradient^2+prec	0.39	0.91	59338	186	930	0.34	0.23	0.17
Ecoregion	8.1.8 Acadian Plains and Hills	~gradient+sinuosity+FAC+gradient^2	0.41	0.91	47429	29	145	0.4	0.32	0.03
Minimum			0.26	0.85	12827	16	80	0.20	0.06	0.03
Mean			0.40	0.91	45958	96	478	0.35	0.24	0.17
Maximum			0.63	0.97	131592	344	1720	0.58	0.45	0.31

Variable key: FAC= flow accumulation, precip= mean annual precipitation, climate = the PCA climate variable

Table 3b. The final logistic regression model fit for each state, watershed, and ecoregion, along with model fit statistics.

Table 4. Results of model application for each state, watershed, and ecoregion, and the Northeast as a whole.

Subregion	Total modeled stream km	km of suitable habitat	% of stream segments modeled as suitable	km of habitat under state model	km of habitat under watershed model	km of habitat under ecoregional model	km of habitat under 2 models	km of habitat under all 3 models
1 Maine	82586	18211	22%	17765	16497	13453	6917	11294
2 New Hampshire	29330	4627	16%	3862	4280	4499	1240	3387
3 Vermont	37152	2983	8%	2829	2147	2737	1237	1746
4 Massachusetts	26092	6172	24%	4924	5642	5975	1975	4197
5 Connecticut	21068	3537	17%	2623	3225	3513	1250	2287
6 Rhode Island	3039	650	21%	459	648	626	216	434
7 New York	106152	21414	20%	19908	17704	17041	9588	11826
8 Pennsylvania	130964	46169	35%	40108	40454	40378	17566	28603
9 New Jersey	27471	8197	30%	7498	6295	7261	3537	4660
10 Delaware	2684	438	16%	394	66	438	415	22
11 Maryland	22384	5762	26%	5564	3488	5476	2758	3003
12 Virginia	26841	6037	22%	5607	5278	5530	1698	4339
13 West Virginia	16512	3182	19%	2396	3141	3171	838	2344
101 St. John	13695	3465	25%	3391	3465	2115	1423	2042
102 Penobscot	19703	5026	26%	4950	5026	3226	1875	3150
103 Kennebec	20714	2751	13%	2721	1995	2197	1341	1410
104 Androscoggin	9552	1769	19%	1709	1167	1570	861	908
105 Maine Coastal	12483	3077	25%	3007	3077	2241	907	2171
106 Saco	13839	3281	24%	2918	2827	3239	860	2421
107 Merrimack	15349	3355	22%	2997	3047	3266	756	2599
108 Connecticut	41255	6233	15%	5528	5393	6035	1743	4490
109 Massachusetts-Rhode Island Coastal.	12827	2555	20%	1330	2529	2522	1284	1271
110 Connecticut Coastal	19063	3450	18%	2729	3175	3347	1098	2352
111 St. Francois	1780	196	11%	195	149	187	56	139
201 Richelieu	20954	1270	6%	1222	793	1005	790	480
202 Upper Hudson	42331	9802	23%	9780	7973	7577	4078	5725
203 Lower Hudson-Long Island	13554	5177	38%	5147	3620	4706	2060	3118
204 Delaware	44192	16770	38%	14072	15723	13377	7137	9633
205 Susquehanna	79273	25551	32%	22764	24972	22258	6659	18892
206 Upper Chesapeake	9989	2033	20%	2011	867	2018	1201	831
207 Potomac	50099	12951	26%	11972	10899	12411	3572	9379
208 Lower Chesapeake	6864	1227	18%	909	1128	1049	595	632
411 Southern Lake Erie	12		0%					
412 Eastern Lake Erie-Lake Erie	3693	774	21%	695	653	615	359	415
413 Southwestern Lake Ontario	4298	604	14%	234	564	540	474	130
414 Southeastern Lake Ontario	5843	976	17%	812	923	623	569	407
415 NE Lake Ontario-Lake Ontario-St. Lawrence	13310	1509	11%	1374	1347	761	1044	465
501 Allegheny	37568	9004	24%	7111	5196	8827	5879	3126
502 Monongahela	10408	1915	18%	1796	1108	1727	1112	802
503 Upper Ohio	9615	2657	28%	2564	1248	2657	1503	1155
5.3.1 N. Appalachian & Atlantic Maritime Highlands	131592	21245	16%	20108	17771	17661	8194	13050
5.3.3 North Central Appalachians	30020	7120	24%	4284	6490	6703	3882	3238
8.1.1 Eastern Great Lakes Lowlands	25261	3349	13%	3347	3272	639	2788	561
8.1.10 Erie Drift Plain	12457	3162	25%	2987	1120	3162	2217	945
8.1.3 Northern Allegheny Plateau	46249	9522	21%	7233	8443	9111	3779	5744
8.1.7 Northeastern Coastal Zone	59338	13594	23%	11178	12624	12439	4543	9051
8.1.8 Acadian Plains and Hills	47429	10774	23%	10518	9896	8382	3525	7249
8.3.1 Northern Piedmont	38397	15831	41%	13698	13021	15300	5474	10357
8.3.4 Piedmont	2045	197	10%	197	55	195	143	54
8.3.5 Southeastern Plains	6865	1149	17%	1149	90	1147	1061	88
8.4.1 Ridge and Valley	71945	28936	40%	27918	28365	23593	6932	22004
8.4.2 Central Appalachians	15358	2837	18%	2741	2540	2197	1032	1805
8.4.3 Western Allegheny Plateau	20575	6166	30%	5996	3051	6166	3285	2881
8.4.4 Blue Ridge	3477	846	24%	646	800	757	335	511
8.5.1 Middle Atlantic Coastal Plain	7707	665	9%	665	6	665	659	6
8.5.4 Atlantic Coastal Pine Barrens	13561	1986	15%	1271	1321	1979	1387	599
Northeast Region	532275	127378	24%	113936	108866	110098	49236	78143

Figures

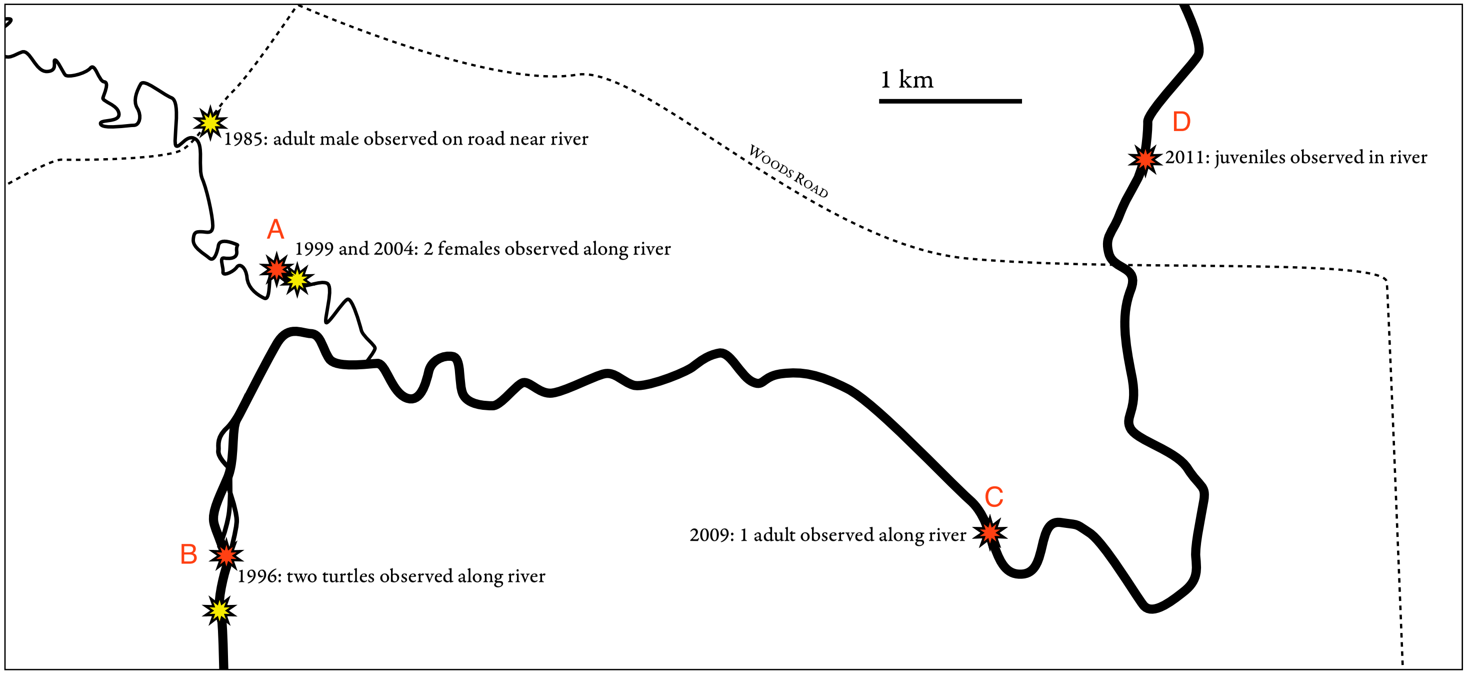

Figure 1. Example configuration of element occurrences for wood turtle. Both red and yellow stars indicate reported sightings of wood turtles to natural heritage programs, herp atlases, and museums. Red stars indicate sightings that became precise corroborated occurrences for the logistic regression models. Corroborated occurrences used for the regression models meet the following criteria: additional sightings within 10 km along the same stream course. Multiple records within 2 km were pooled into a single occurrence to reduce autocorrelation.

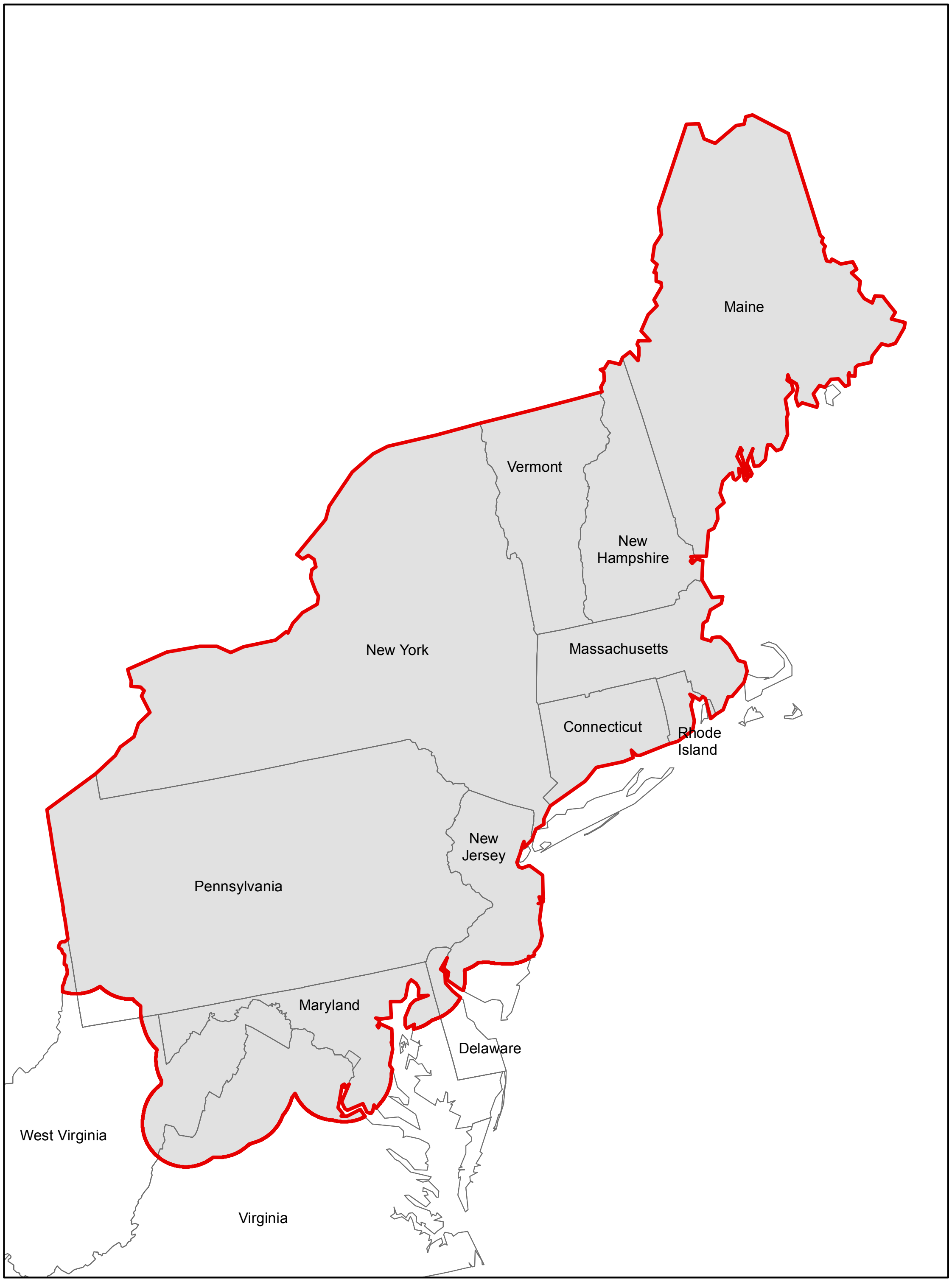

Figure 2. The estimated extent of occurrence of the wood turtle in the northeastern United States is delimited by the red line, produced by buffering all corroborated occurrences by the estimated maximum potential lifetime travel distance of a wood turtle (50 km).

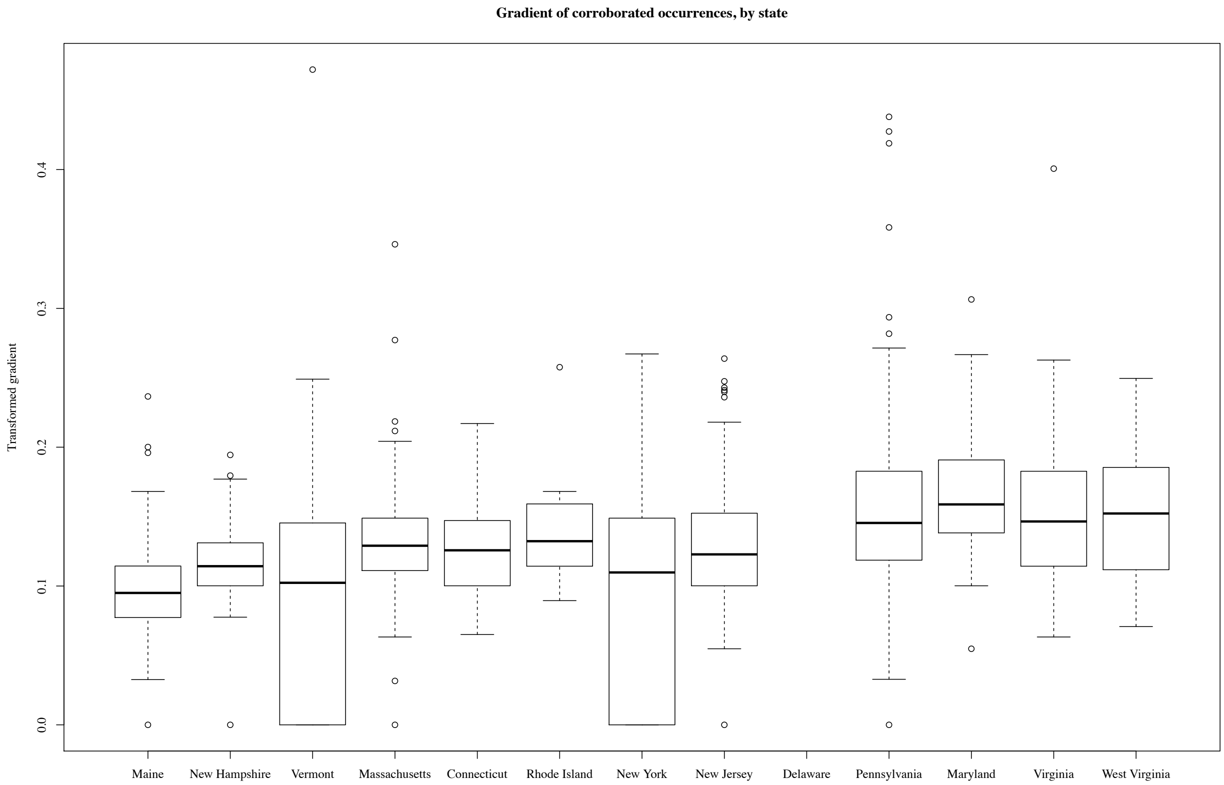

Figure 3. Stream gradient (log transformed) of corroborated occurrences, by state.

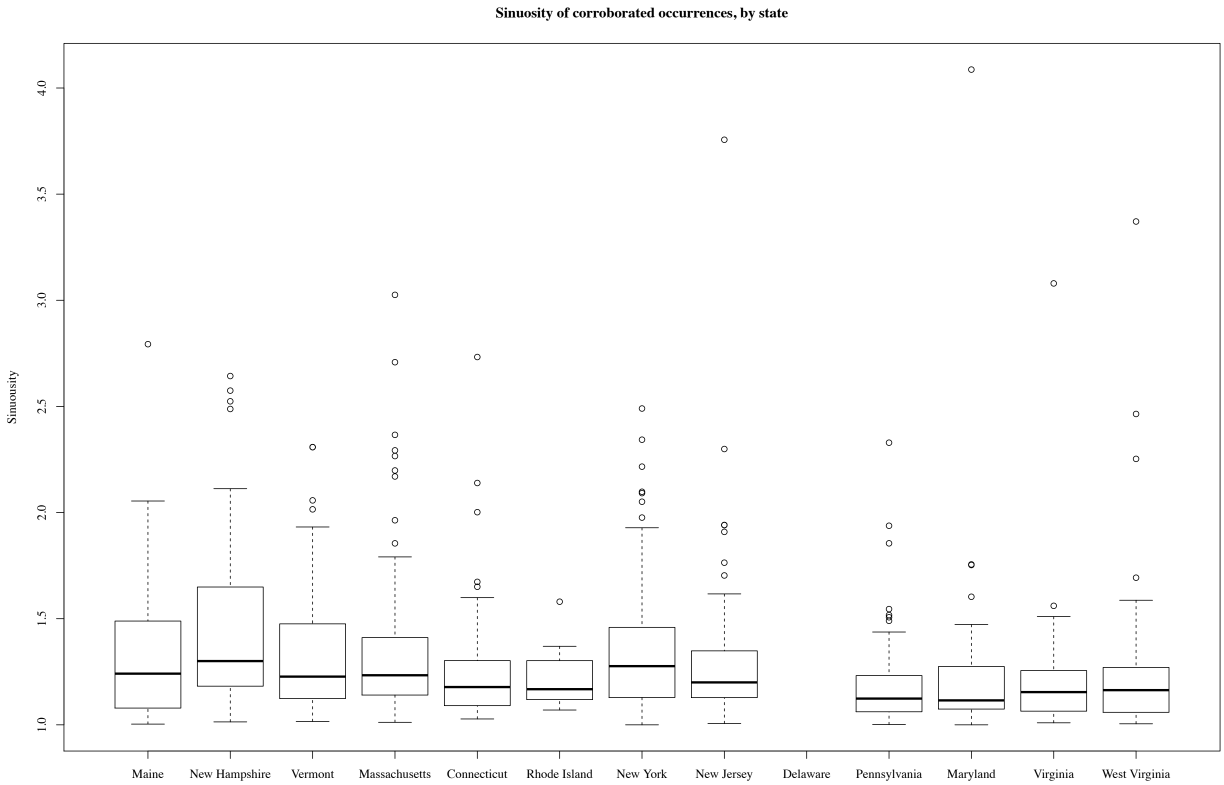

Figure 4. Stream sinuosity of corroborated wood turtle occurrences, by state.

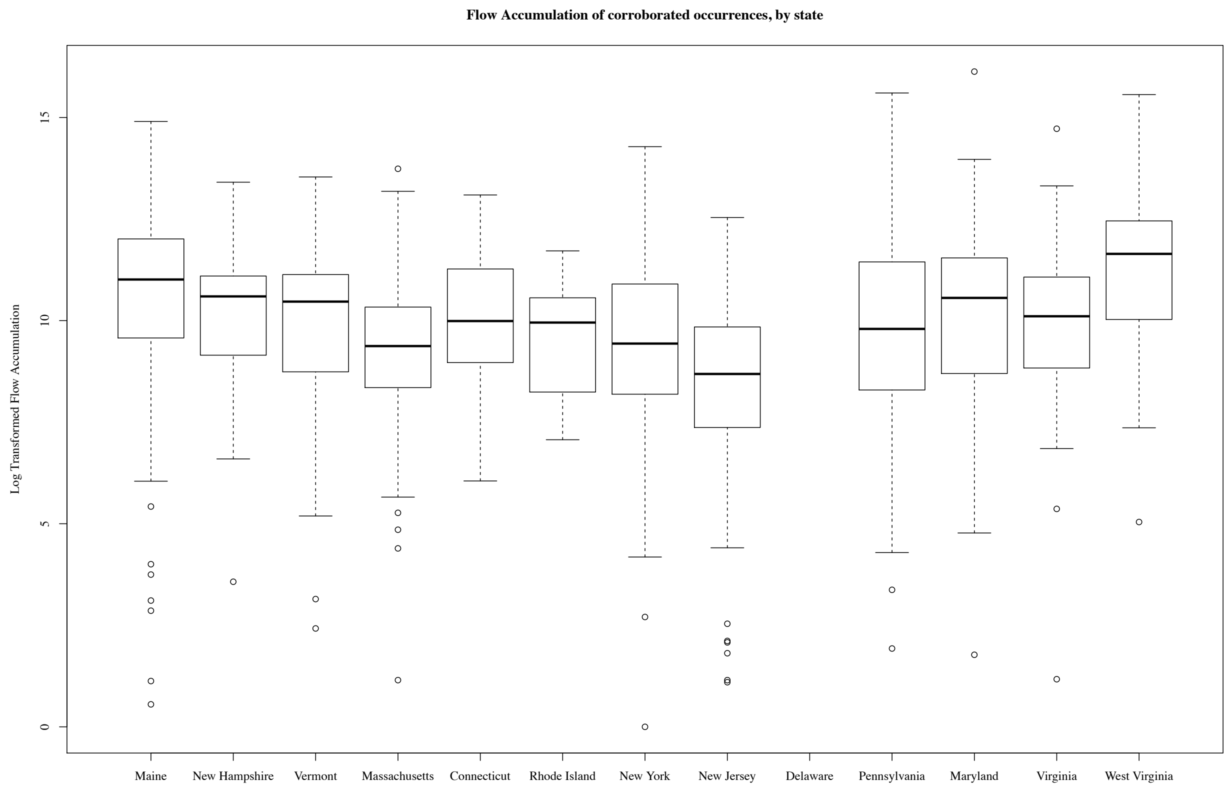

Figure 5. Flow accumulation (log transformed) of corroborated occurrences, by state.

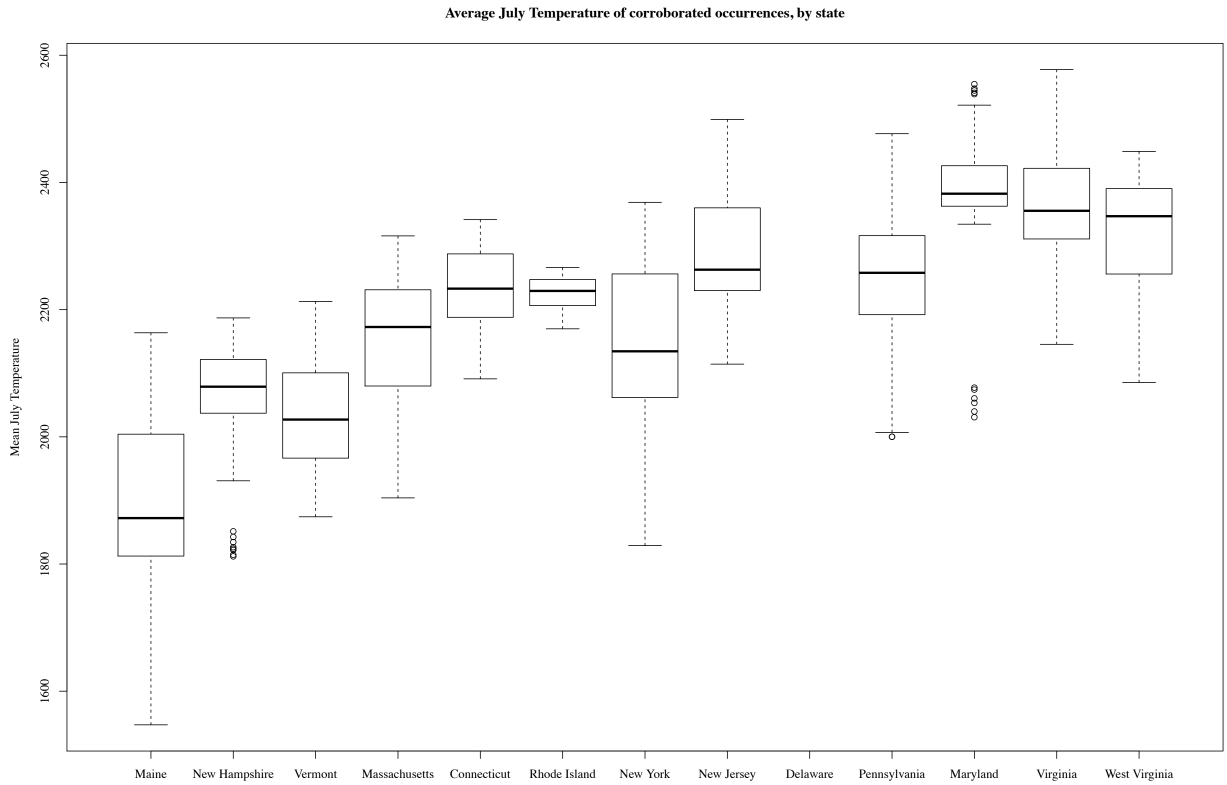

Figure 6. Average July temperature of corroborated occurrences, by state. Temperatures on the *y* axis are degrees celsius x 1000.

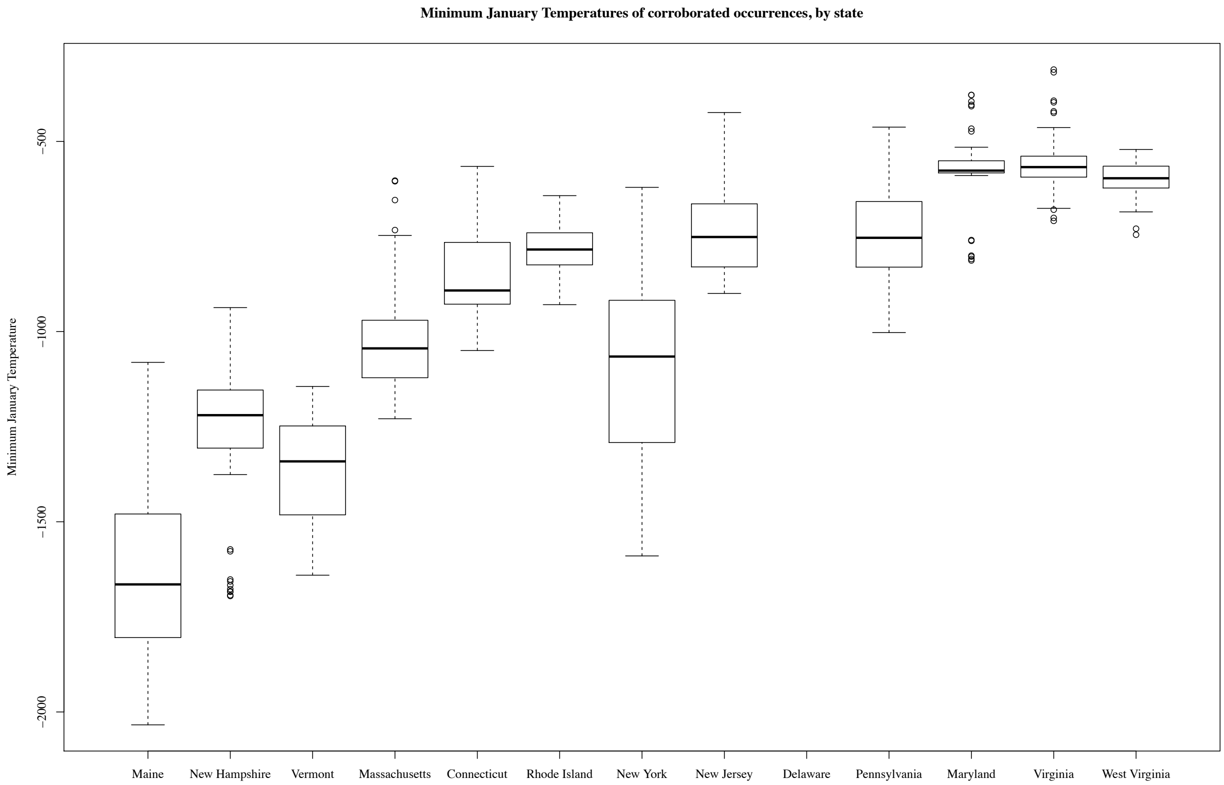

Figure 7. Minimum January temperatures of corroborated wood turtle occurrences, by state. Temperatures presented on the *y* axis are degrees Celsius x 1000.

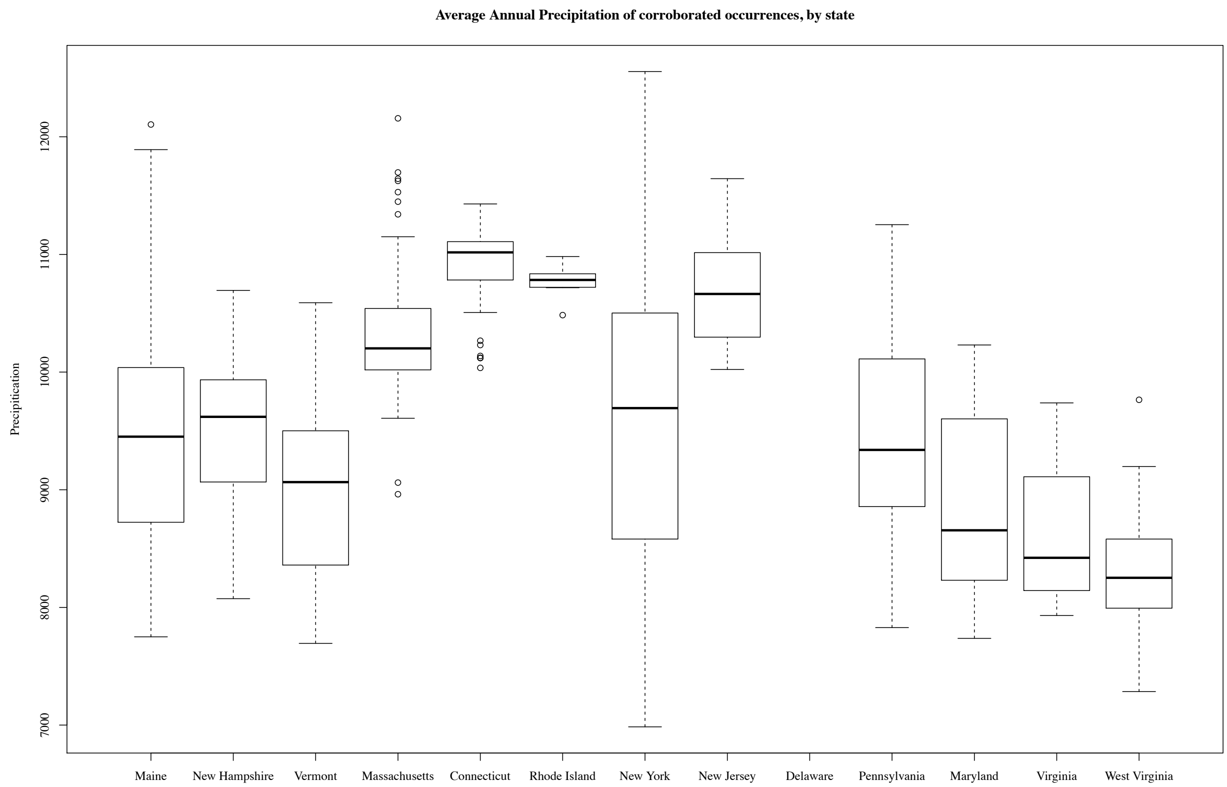

Figure 8. Average annual precipitation of corroborated wood turtle occurrences, by state. Precipitation amounts are mm x 1000.

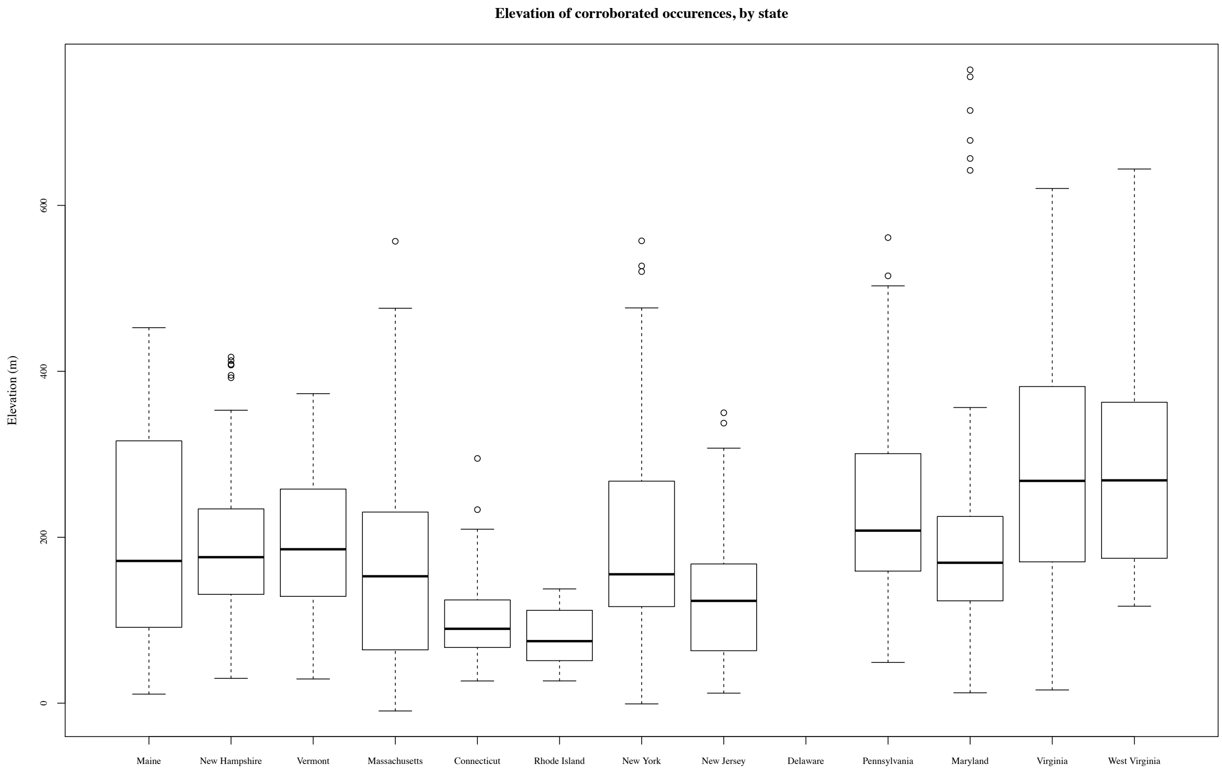

Figure 8. Elevation of corroborated occurrences, by state.

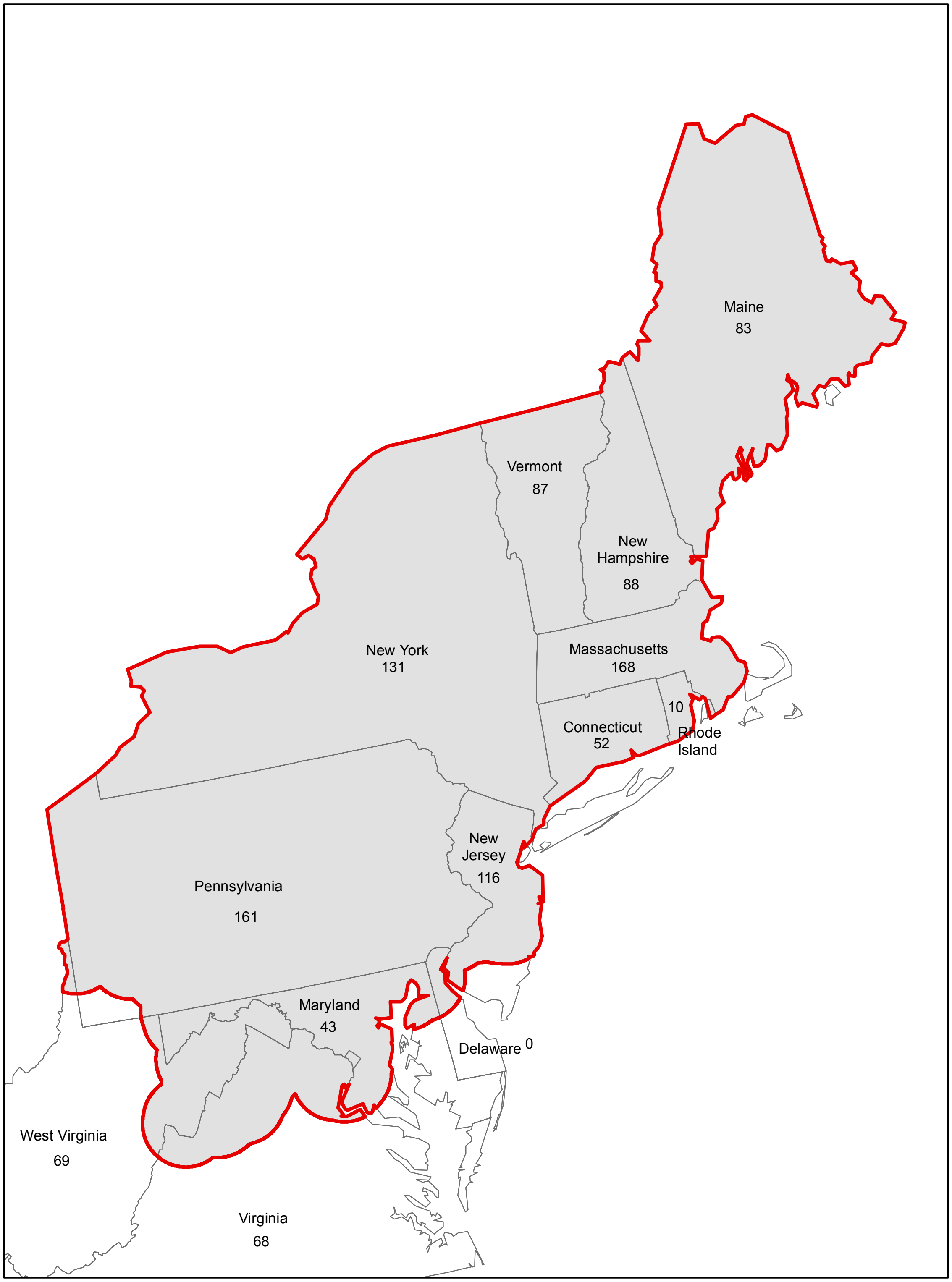

Figure 10. Distribution of corroborated wood turtle occurrences by state. The red line denotes the wood turtle's extent of occurrence in the northeastern States.

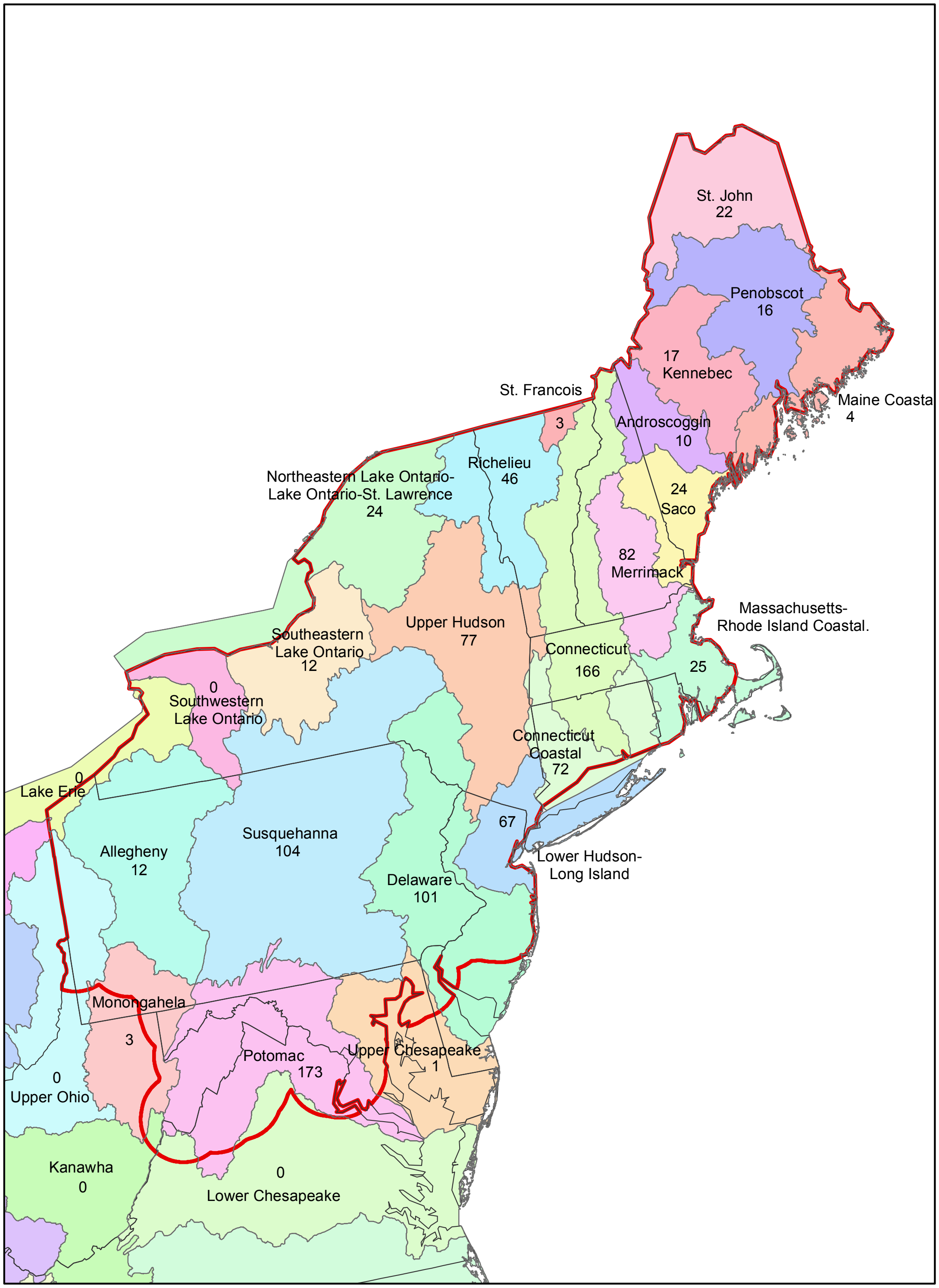

Figure 11. Distribution of corroborated wood turtle occurrences by watershed (HUC 4). The red line denotes the wood turtle's extent of occurrence in the northeastern States.

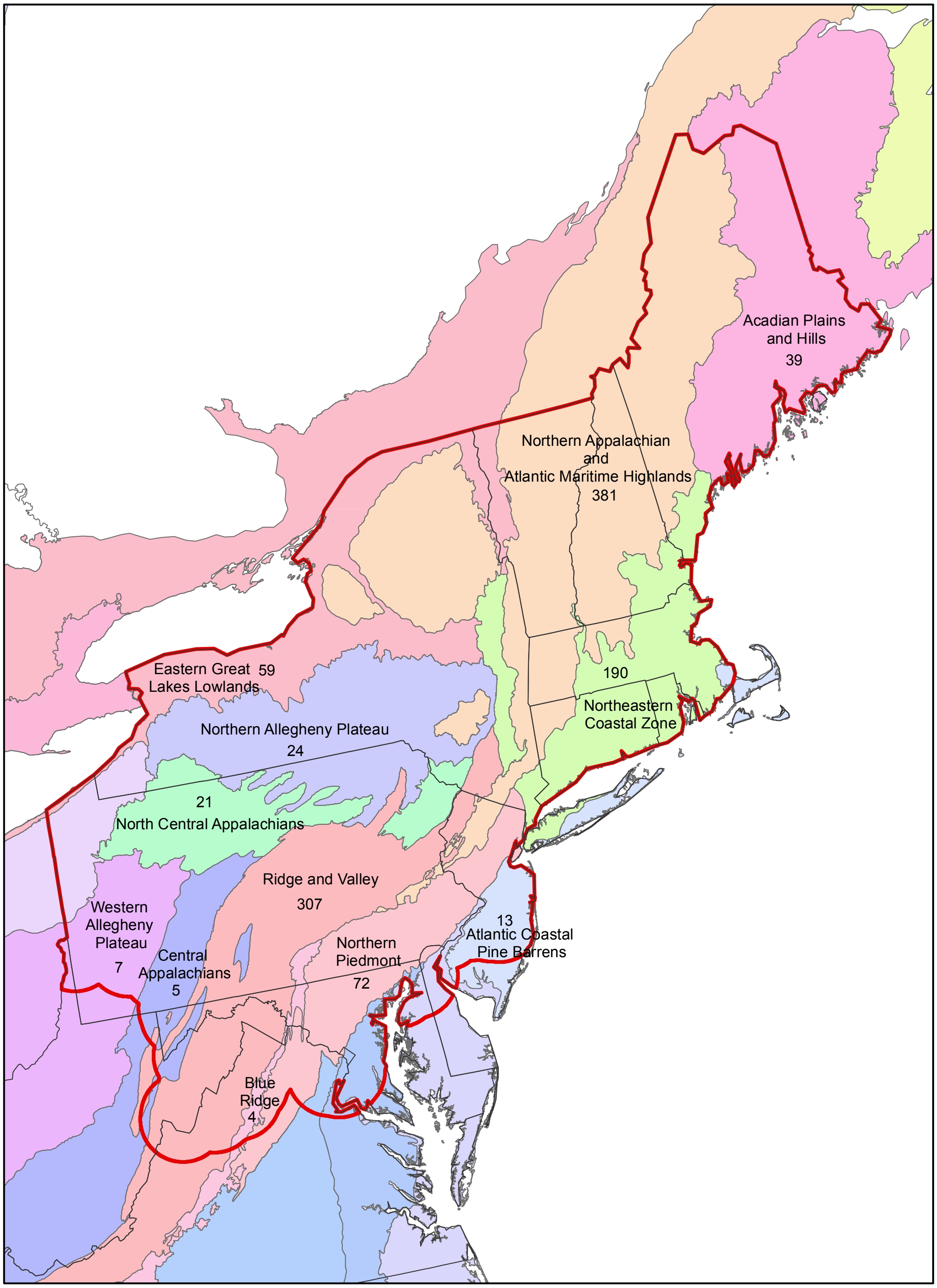

Figure 12. Distribution of corroborated wood turtle occurrences by EPA Level III Ecoregion. The red line denotes the wood turtle's extent of occurrence in the northeastern States.

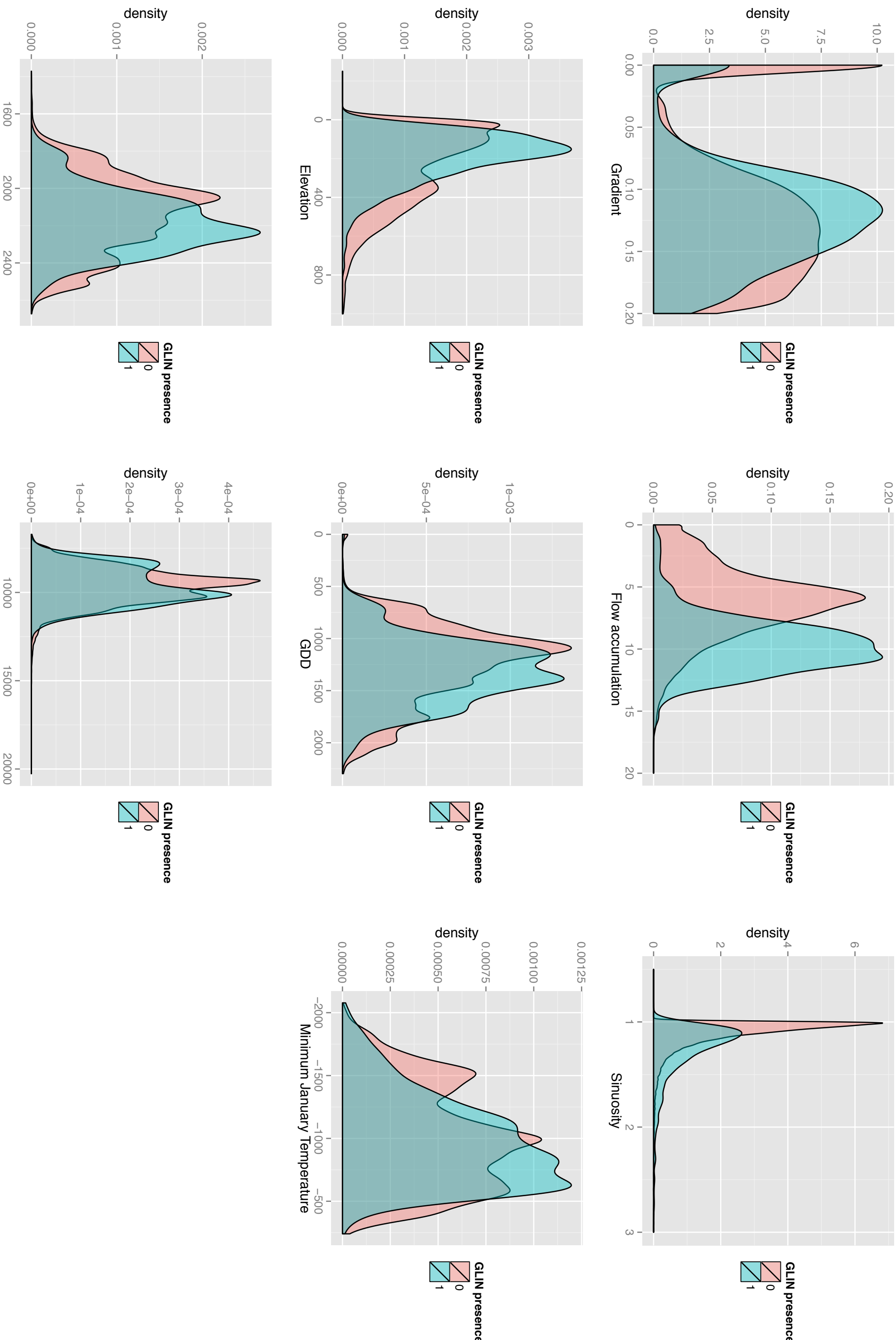

Figure 13. Probability density functions for environmental variables of wood turtle streams and random segments throughout the Northeast.

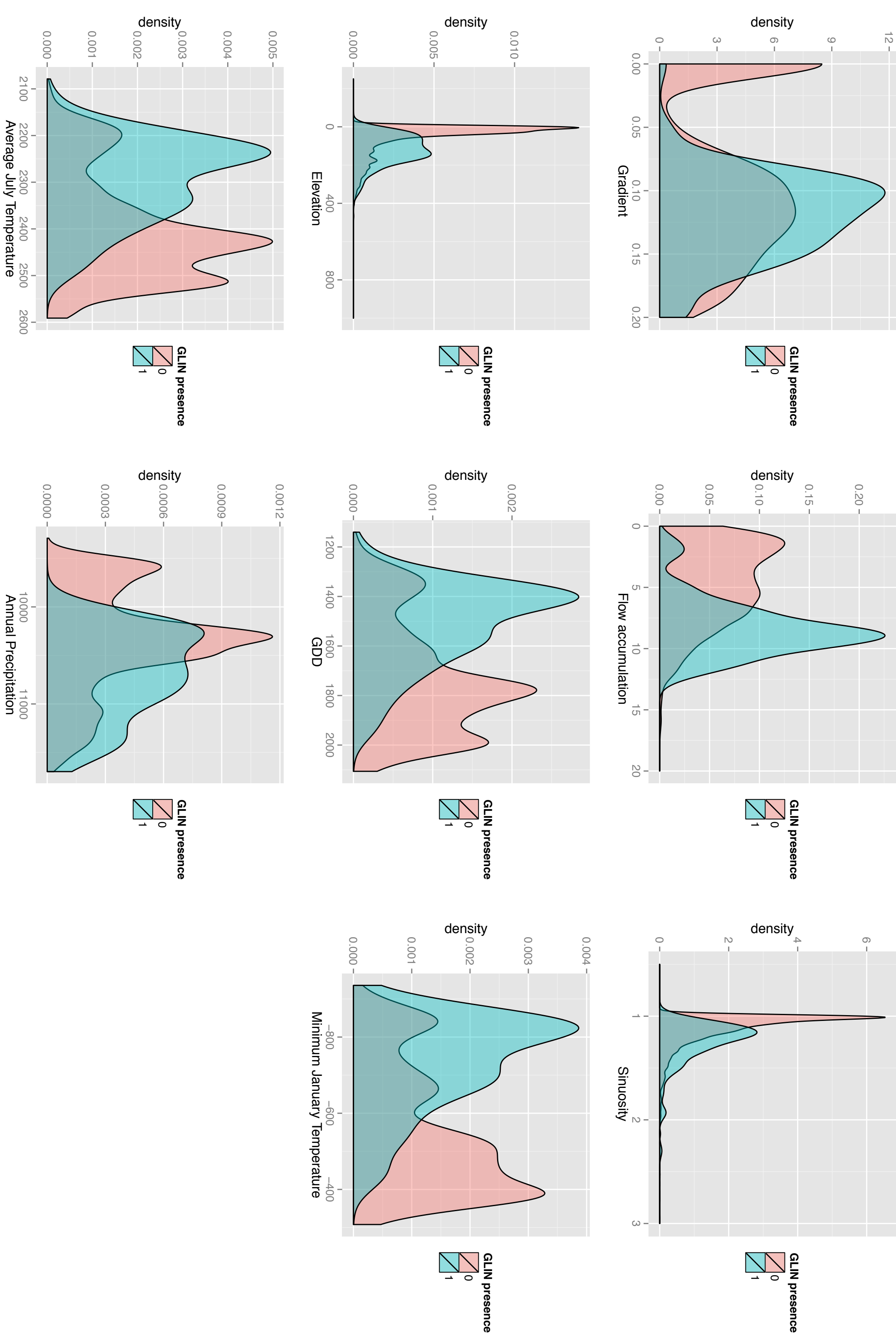

Figure 14. Probability density functions for environmental variables of wood turtle streams and random segments in New Jersey.

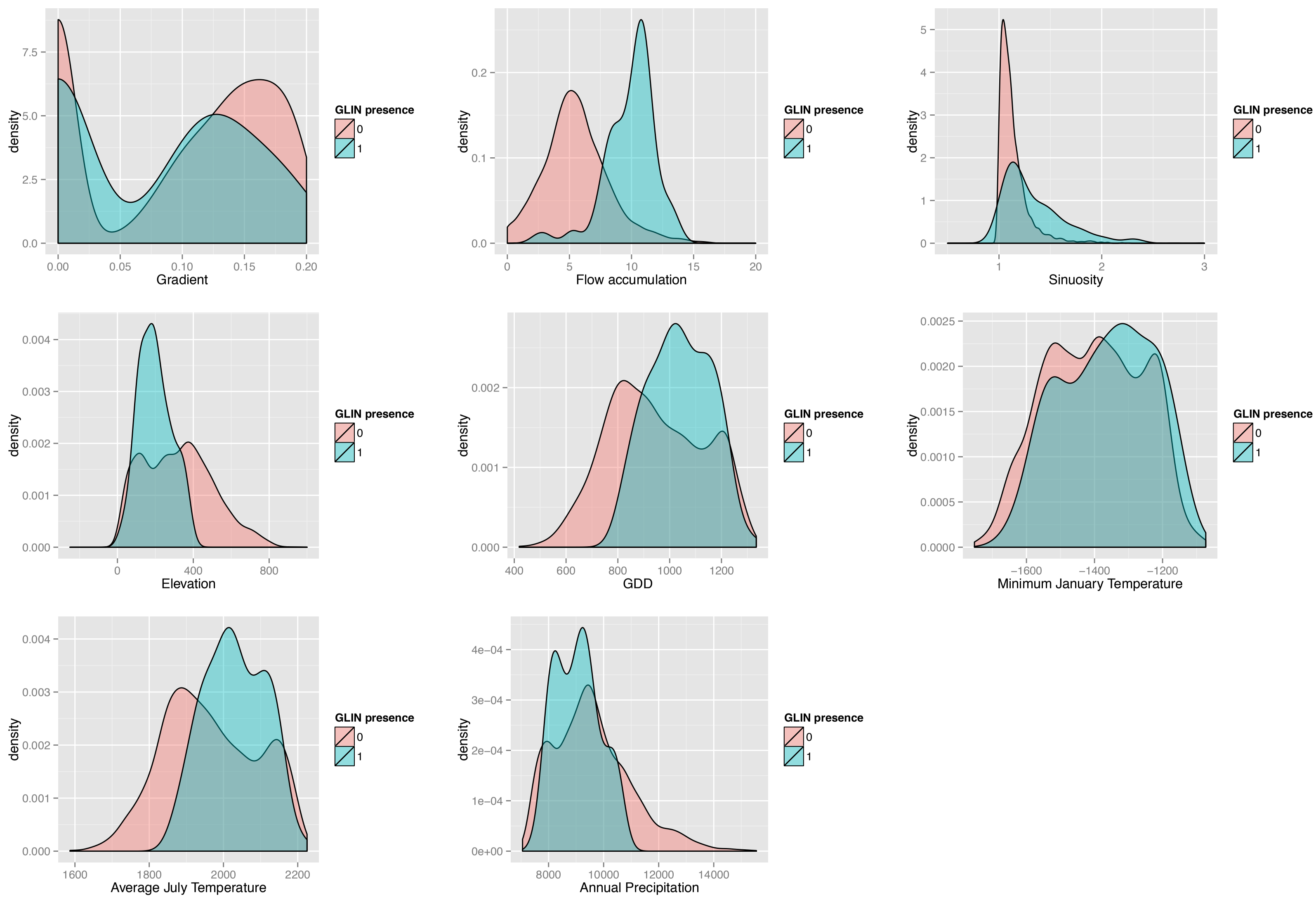

Figure 15. Probability density functions for environmental variables of wood turtle streams and random segments in Vermont.

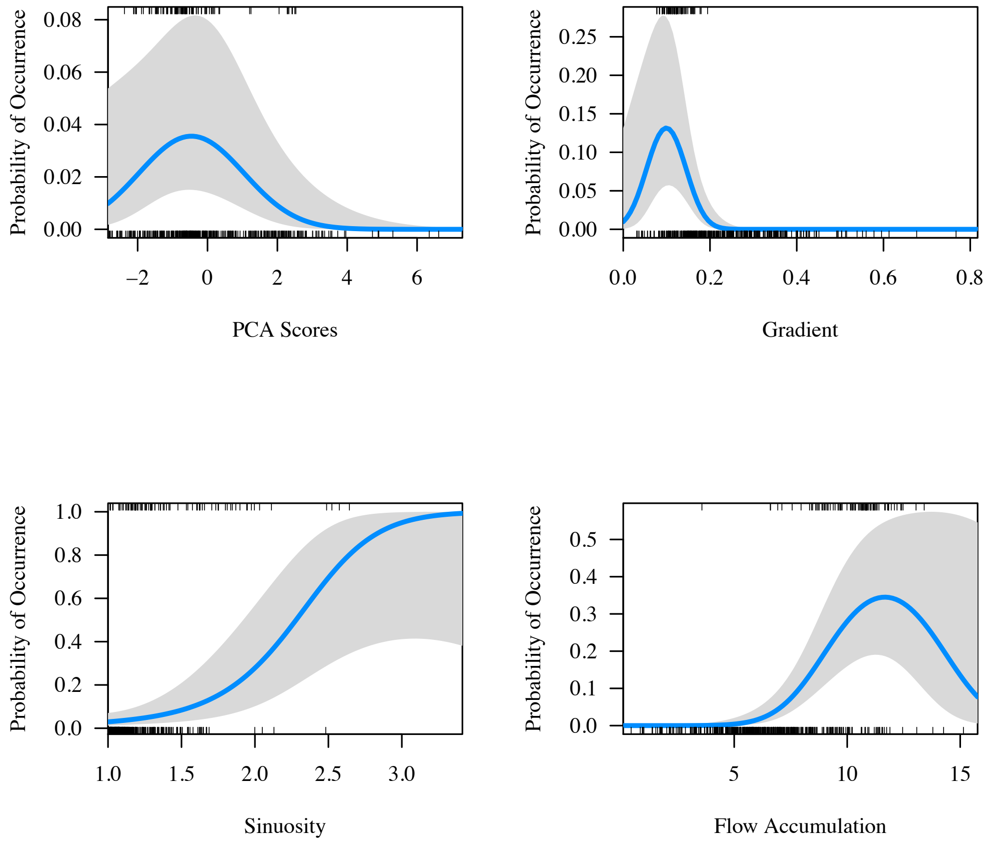

Figure 16. Partial effects plot for New Hampshire state model.

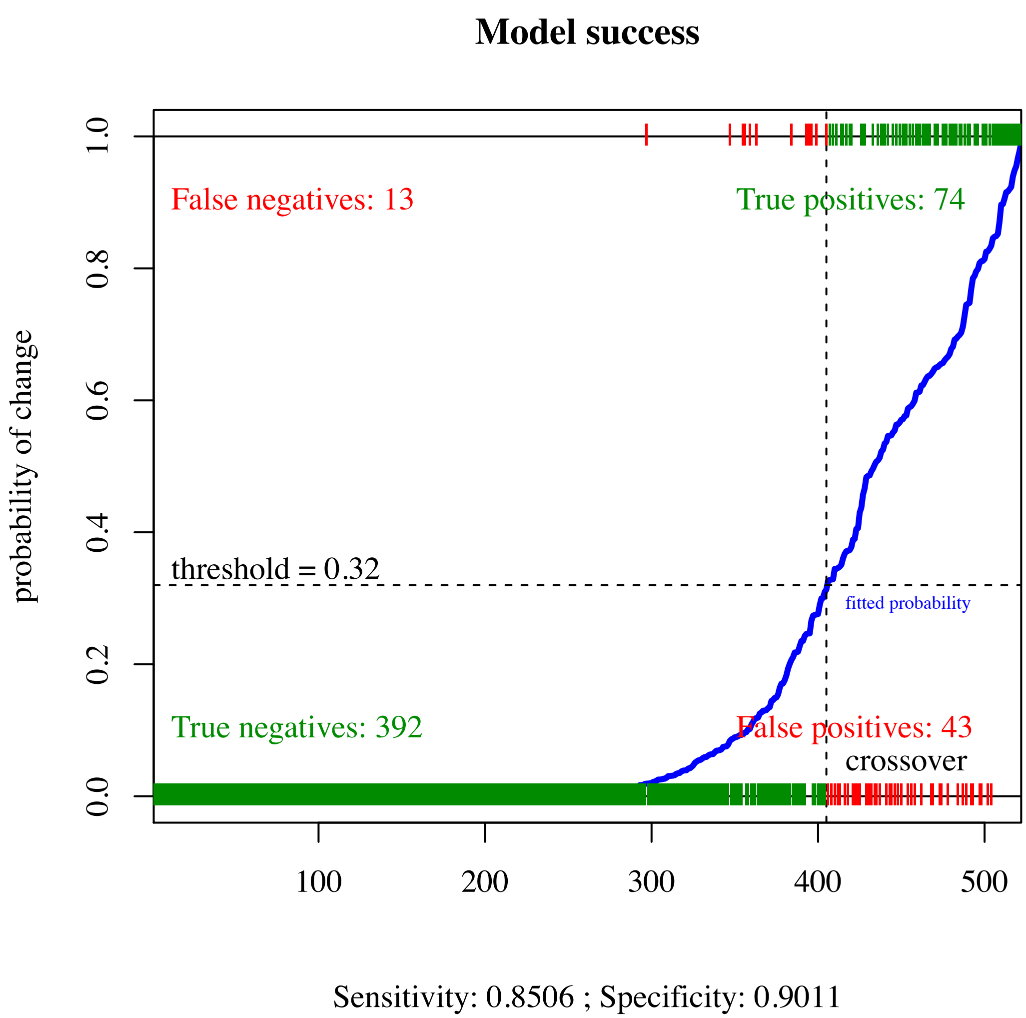

Figure 17. Model classification error for training data used to build the final New Hampshire model.

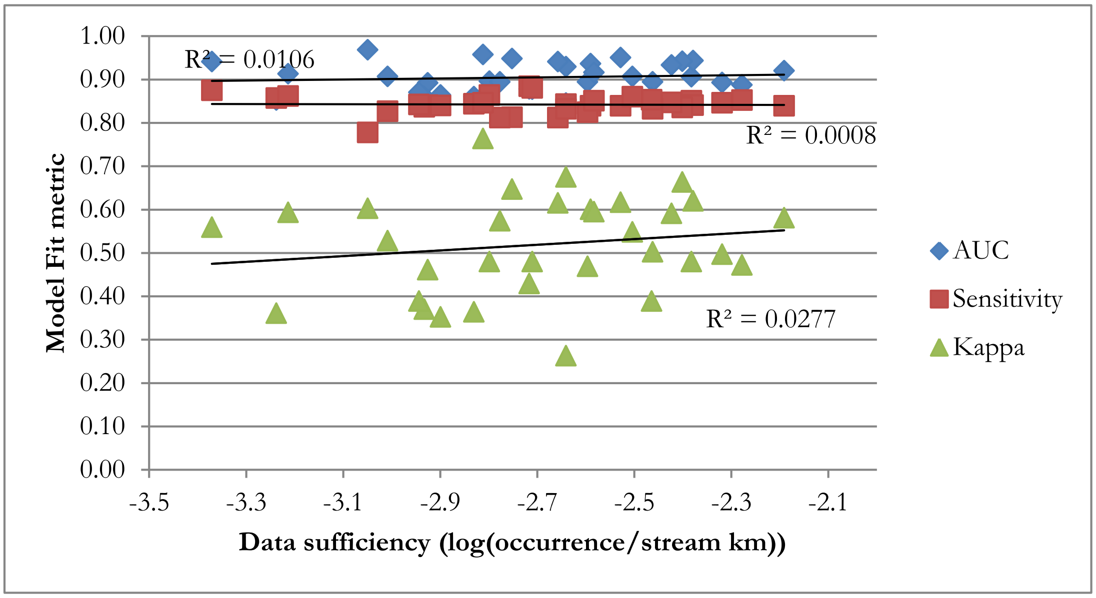

Figure 18. Effect of data sufficiency (occurrences/stream km) on model fit.

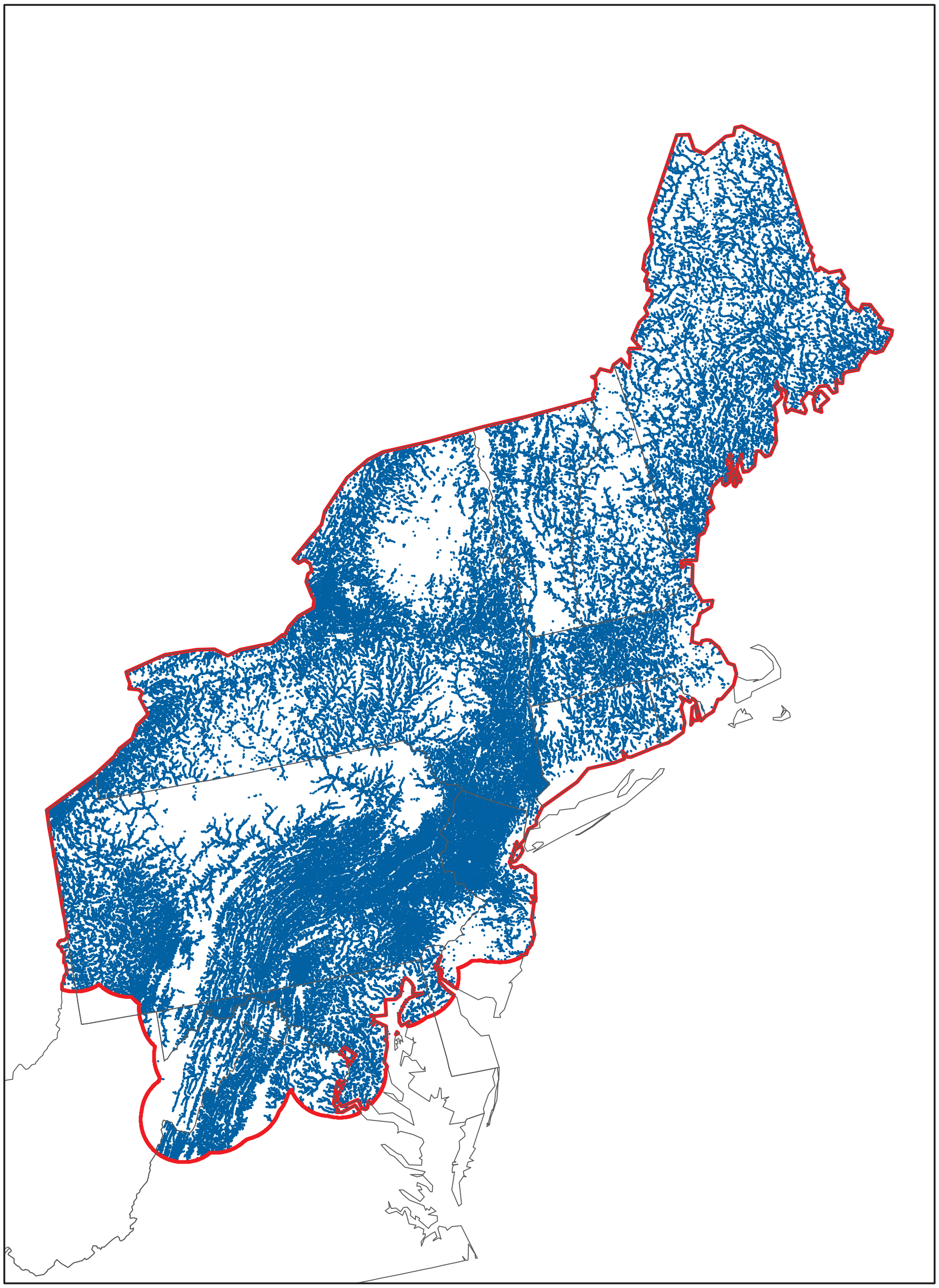

Figure 19. Results of the state SDMs applied across the region

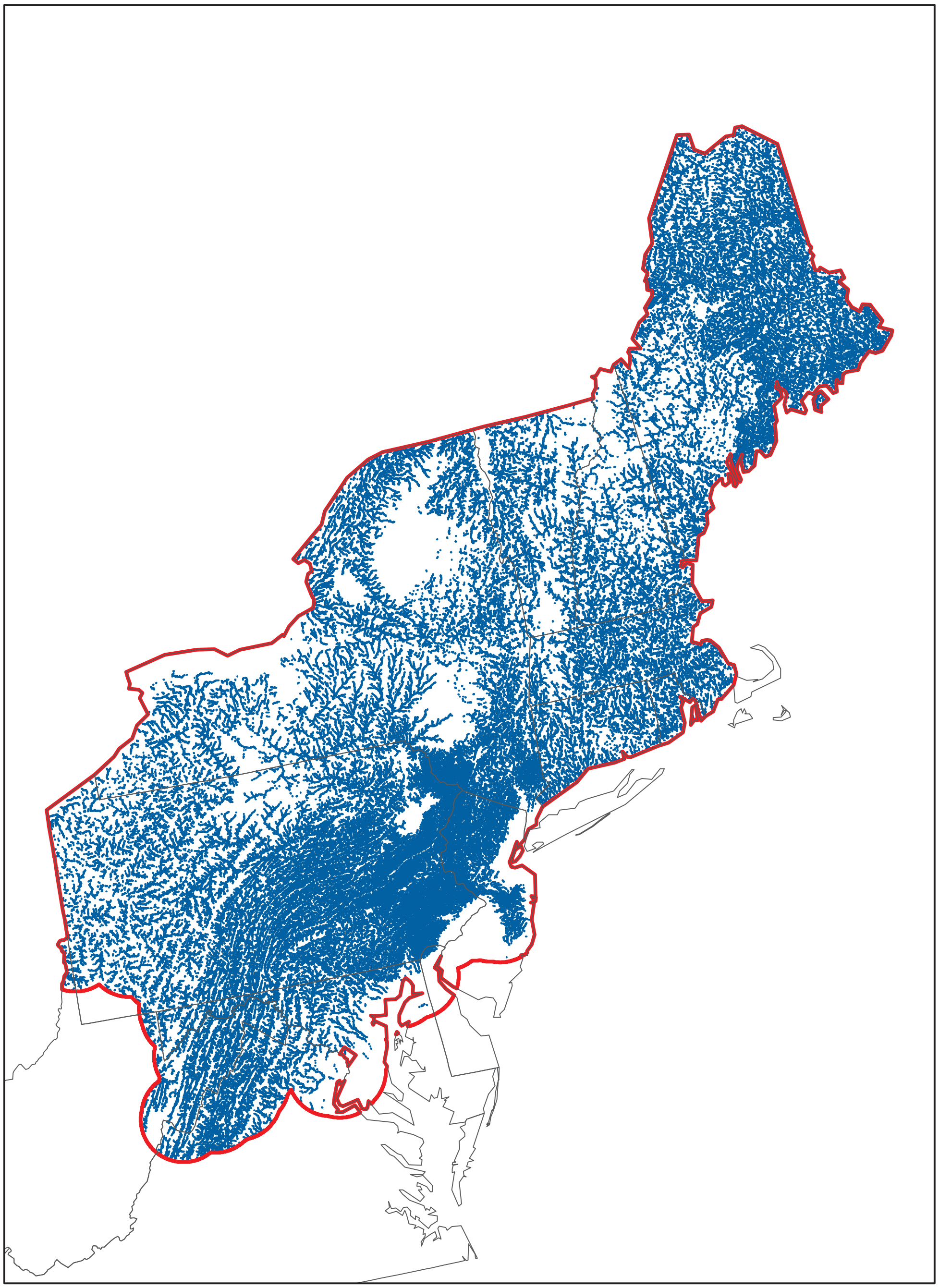

Figure 20. Results of the watershed SDMs applied across the region.

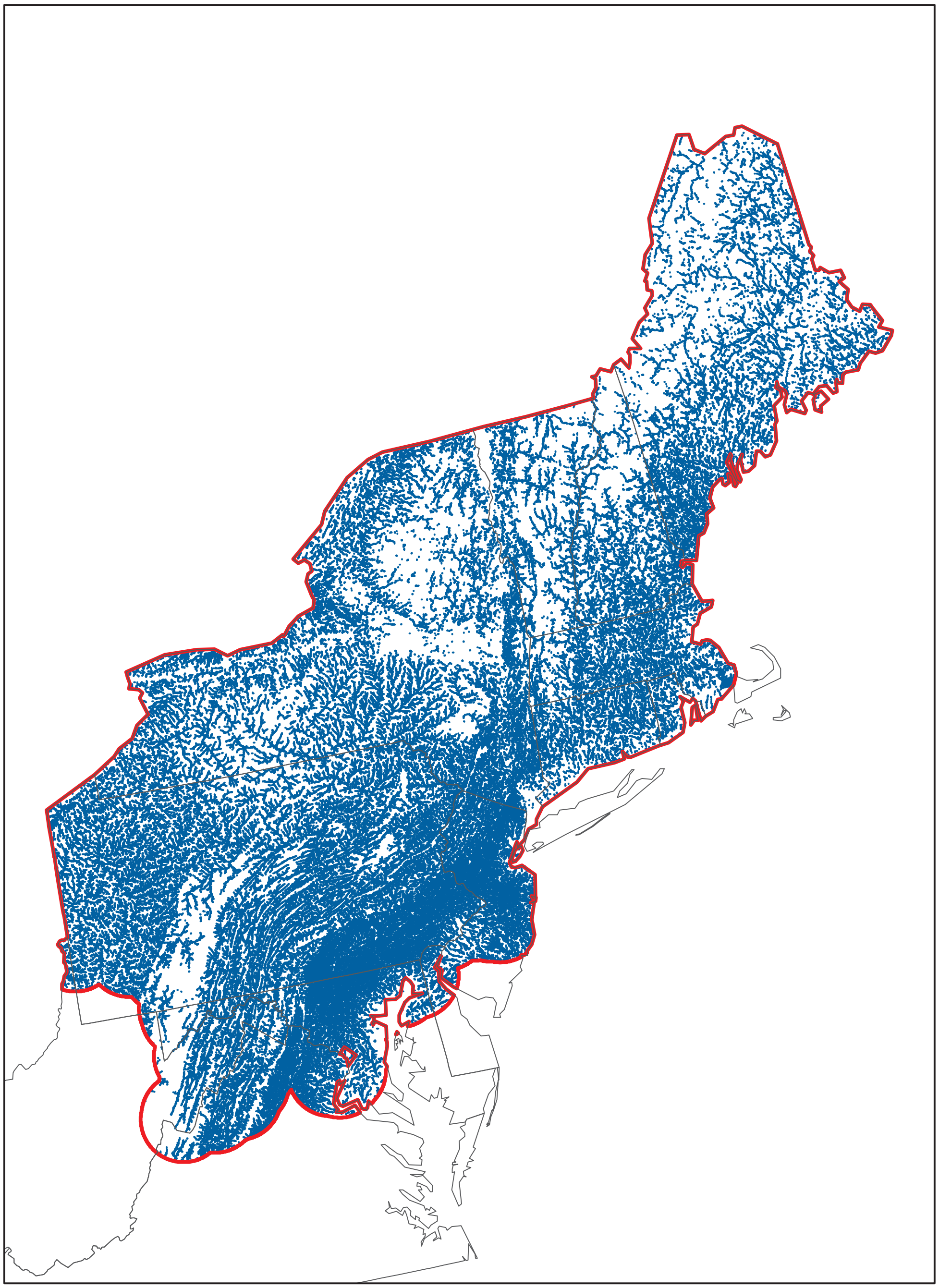

Figure 21. Results of the EPA Level III ecoregional SDMs applied across the region.

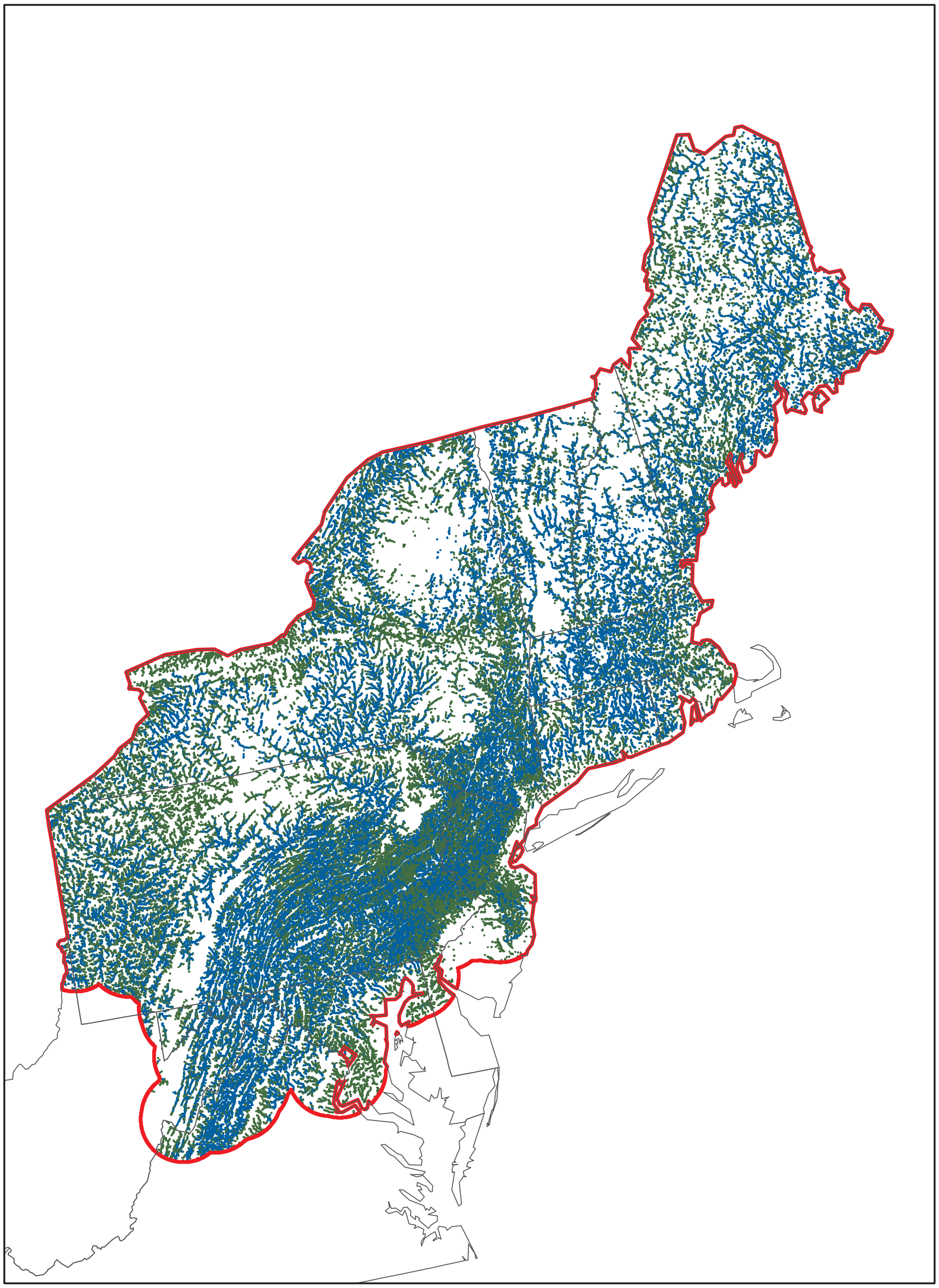

Figure 22. Results of all subregional models combined. Blue indicates the segment was modeled as habitat for all three models, green indicates it was modeled for 2 of 3 models.

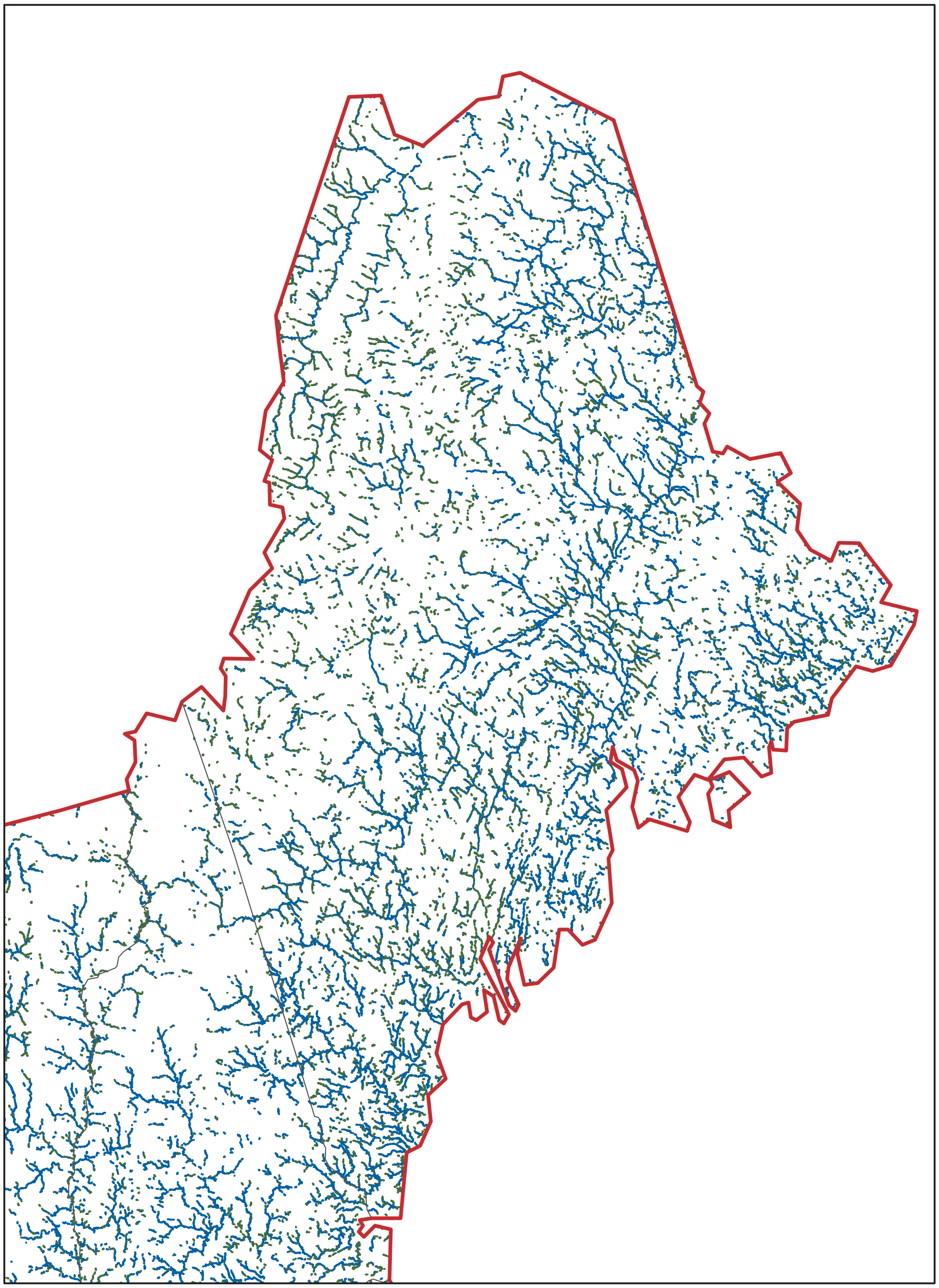

Figure 23. Results of all subregional models combined for Maine and adjacent areas of New Hampshire and Vermont. Blue indicates the segment was modeled as habitat for all three models, green indicates it was modeled for 2 of 3 models.

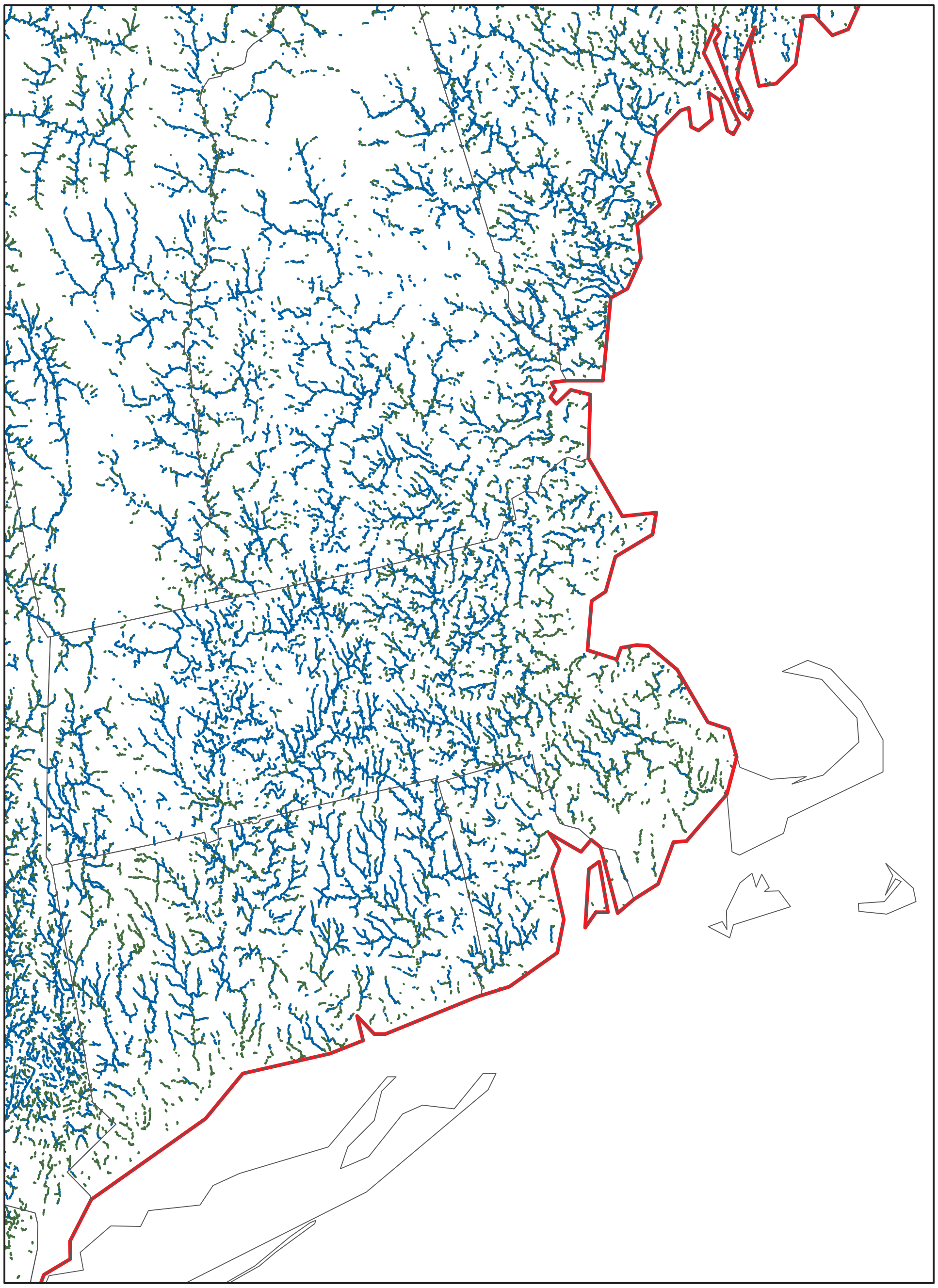

Figure 24. Results of all subregional models combined for Massachusetts and adjacent areas of central and southern New England. Blue indicates the segment was modeled as habitat for all three models, green indicates it was modeled for 2 of 3 models. Cape Cod, Nantucket, Martha's Vineyard, and Long

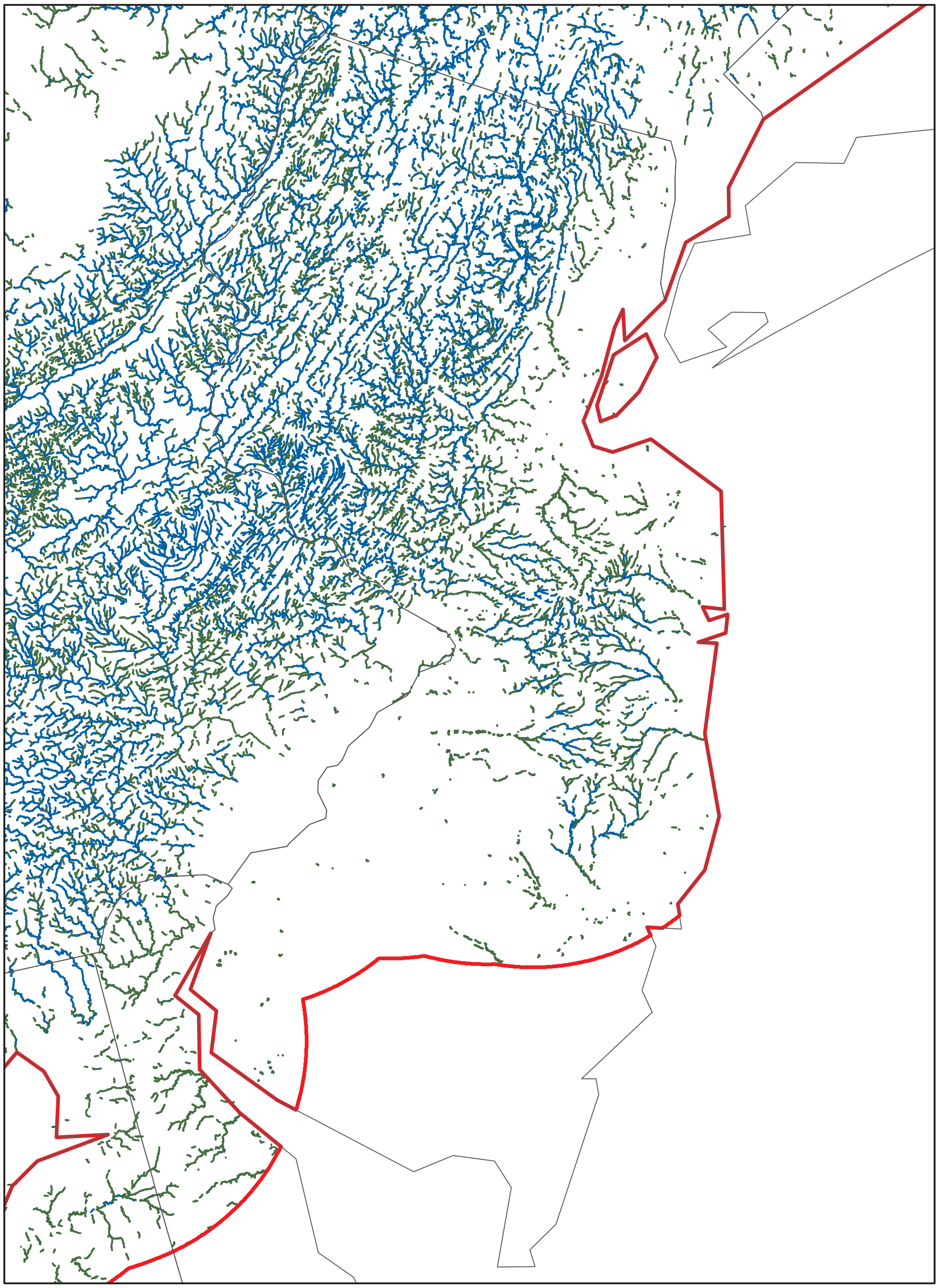

Figure 25. Results of all subregional models combined for New Jersey and adjacent areas of New York, Pennsylvania, Delaware, and Maryland. Blue indicates the segment was modeled as habitat for all three models, green indicates it was modeled for 2 of 3 models.

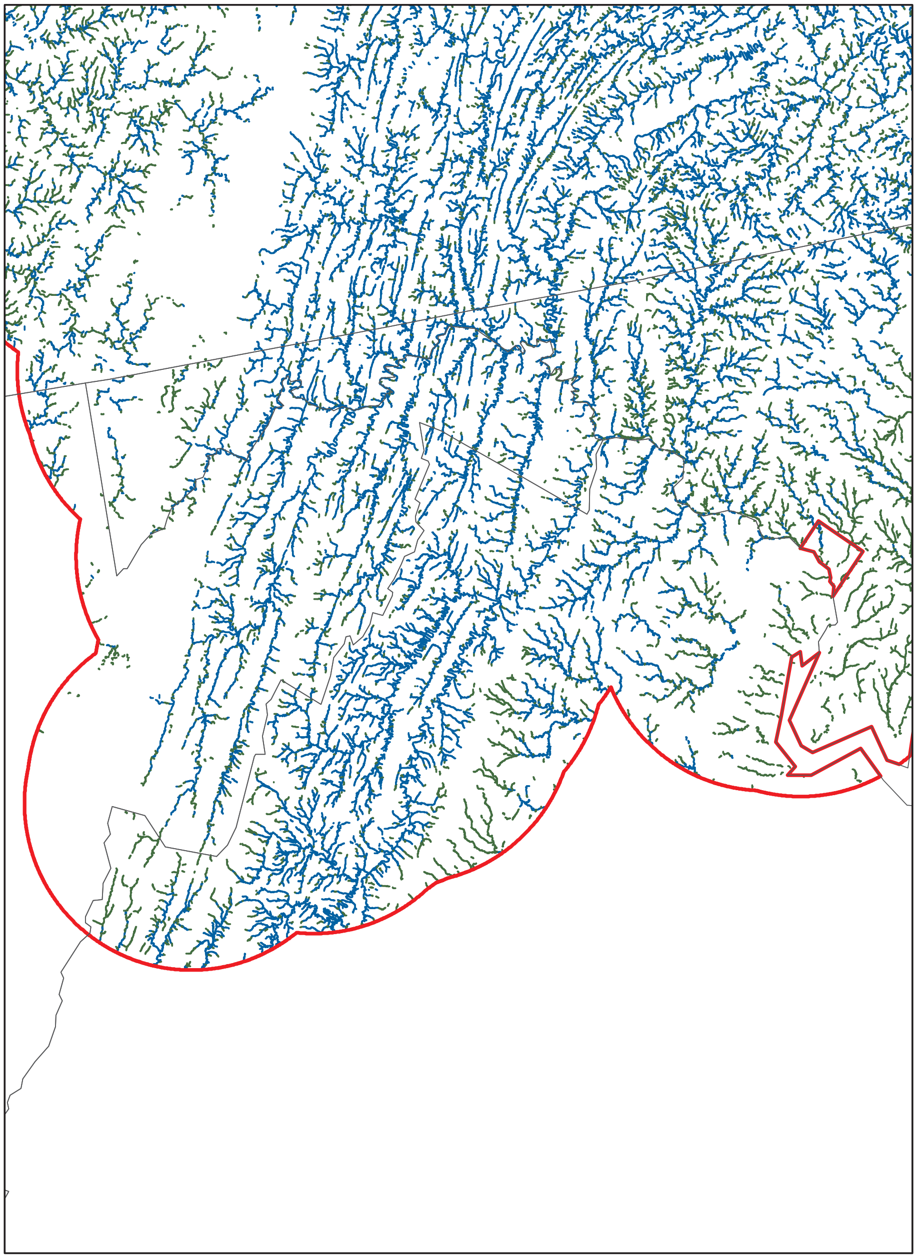

Figure 26. Results of all subregional models combined for Virginia and West Virginia and adjacent areas of Pennsylvania and Maryland. Blue indicates the segment was modeled as habitat for all three models, green indicates it was modeled for 2 of 3 models.

Part 3. Regional Research Strategy and Evaluation of Detection Protocols

Abstract

We summarize and analyze coordinated, regional, wood turtle monitoring protocols and survey results for the 2012–2013 field seasons, and present elements of a proposed Coordinated Monitoring Strategy (CMS) for 2014 or beyond. We designed a flexible survey protocol designed to 1) work in a variety of stream and field conditions; 2) fit easily within existing research programs; and 3) use nested sampling periods for multiple levels of population assessment. The standard spatial sampling unit is one kilometer of meandering stream and adjacent riparian habitats, measured along the stream centerline. The segment is surveyed by one or more experienced observers in one hour. A lead observer is designated for each survey regardless of total number of observers. Three surveys are undertaken in a single season when detection probabilities are highest and wood turtles are present in the immediate vicinity of the stream corridor (e.g., spring and autumn). Survey start and end times, and start/end locations, are recorded (the start and end locations are fixed across all surveys), and time spent not surveying is subtracted. Air and water temperature and weather observations are recorded (˚C) at the beginning and end of the survey. Surveys are conducted at a network of survey sites across the Northeast Region, and are designated either Long-Term Reference (LTR) and Rapid Assessment (RA) sites. LTR sites are sampled in both the spring and fall seasons over the course of multiple years (i.e., 3 surveys in each season, e.g., 3 in spring 2012, 3 in fall 2012, 3 in spring 2013, etc.). All sites that are sampled three times in both a spring and fall season in at least one year are considered LTR sites. RA sites are sampled three times in one single season only (spring or fall). We added a random site selection component by surveying sites in New Hampshire, Massachusetts, New Jersey, and Virginia that were selected from a Classification and Regression Trees (CART) model of suitable stream habitat, empirically trained with confirmed occurrence data from Maine to Virginia. Further, we overlaid the LTR sampling protocol onto five wood turtle sites studied in previous decades, from the 1970s to the 2000s. Data collected through the coordinated effort are maintained in a centralized, web-based data repository at the University of Massachusetts.

During the 2012 and 2013 field seasons, 825 surveys (383 in the spring, 71 during nesting, and 371 in the fall) were conducted on 196 stream segments. Each steam segment was surveyed between 1 and 15 times (mean = 4.2), and a total of 1567 wood turtles sightings occurred on 73 of the 96 streams. Almost half the surveys (43.9%) yielded no turtles, and the average survey yielded 1.9 turtles (sd=3.17), 1.33 (sd=2.03) of those were seen by the lead observer. Using zero inflated poisson mixture models, the detection rate was estimated to be 0.06 when evaluating all sites with three or more surveys and 0.07 when evaluating only spring surveys, and site abundance decreased significantly with impervious surface cover at 3km around the site. The total abundance across all 78 sites sampled at least three times in the spring was estimated to be 1461 (95% CI = 1003 – 2074).

Total survey success improved with number of observers (though primary observer success did not change with number of observers). Survey success varied by observer, and surveys conducted by experienced surveyors yielded significantly more turtles. Survey success was significantly higher when air temperature increased rapidly during a survey, longer surveys produced significantly more turtles than shorter surveys, and spring surveys produced significantly more turtles than fall surveys, though fall surveys were still effective. In the spring, surveys earlier in the day produced significantly more turtles than those occurring

later, and warmer fall surveys, earlier in the season generally produced larger counts, but this was not significant.

We used classification trees to tease apart the complex interactions between geographic location, time of year, time of day, and air temperature and their correlation with survey success in the spring. Surveys conducted at air temperatures less than 11.85˚C were rarely productive. The interaction terms between the growing degrees at the site location and Julian day, as well as the interaction between Julian day and air temperature also proved important predictors of survey success, in addition to air temperature and the air/ water temperature differential.

We were able to estimate population size using CMR models at 17 sites using open population models and 24 using closed population models. Estimates ranged from 6.4 to 198.4 turtles / segment (mean=66 for open population models and 63 for closed population models). We resampled thirteen sites that were assessed by previous researchers between the 1970s and the early 2000s, and found evidence that seven sites had decreased in density and five had increased, but these are extremely tentative results because of differences in sampling protocol and project duration. Further study at these important long-term sites is warranted.

Introduction

As a result of widespread conservation concern, abundant evidence of site-specific declines, and increasing trends in most threat categories (Part 1), it is necessary to gather standardized baseline data on the distribution and abundance of wood turtles in the Northeast Region, and to identify populations of regional significance. There have not been prior efforts to standardize and test detection protocols or coordinate survey effort in the northeastern States, and a wide range of techniques, methods, and protocols were in use at the outset of this project. We developed a flexible, feasible, robust, and repeatable monitoring protocol that reflected the protocols already in use throughout the region.

Current wood turtle survey and monitoring protocols

At the beginning of the project, protocols varied widely throughout the Northeast (see Monitoring, Part 1). As of 2012, distributional surveys or long-term population monitoring was underway or recently completed (within three years) in Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, New Jersey, Delaware, Maryland, West Virginia, and Virginia (Appendix VI, Wood Turtle Expert Questionnaire), as well as within adjacent areas of Québec and Ontario. As outlined in Part 1 of this report, researchers typically employ a combination of visual encounter surveys on foot along stream corridors and adjacent floodplain habitats. Within streams, features such as pools, logjams, debris packs, and cutbanks are searched. In some instances, researchers have used interruption traps set in the stream corridor and cameras targeting nesting areas, but these are rarely employed (Akre and Ernst 2006; Jones and Willey 2013a, 2013b). In Virginia, Akre and Ernst (2006) used a combination of terrestrial visual encounter surveys, targeted instream surveys, and trapping. During stream surveys, they searched root masses, long deep runs, pools, "debris packs," and logjams, often with a viewscope. On larger rivers, two observers may walk on opposite banks, with an observer in the stream channel in a canoe or on foot (Daigle 1997).

For precedents and monitoring implementation scenarios with turtles, see also Daigle and Jutras (2005); Walde et al. (2007); Erb et al. (2010); USFWS (2011). In particular, see the discussion pertaining to the federal recovery strategy for desert tortoise (e.g., GAO 2002).

Methods

Through coordinated regional surveys, our specific objectives were to:

1. Establish a network of non-random "long-term" reference (LTR) sites throughout the Northeast region as a baseline for future evaluation and as a means of interpreting regional rapid assessments;
2. Begin to assess the current abundance of wood turtles at the Northeast regional scale through a network of random and non-random rapid assessment (RA) sites, as a baseline for future comparison;
3. Initiate a pilot study to determine the feasibility of a randomized site selection component based on predictive landscape modeling (see Part 2);
4. Use the survey protocol to obtain standardized information from data-deficient areas throughout the Northeast region, including peripheral areas and regions with low levels of high-quality occurrence data;
5. Revisit previous intensively studied or long-term monitoring sites to evaluate recent population trends;
6. Use results from the pilot phase to explore relationships between the relative abundance of wood turtles and landuse (Part 4);
7. Repeat the monitoring protocol at 10 to 20 year intervals (outlined in Part 5).

Overview of Sampling Framework

Our basic monitoring framework consists of two tiers of sampling intensity. The network of study sites encompasses both long-term reference (LTR) sites and rapid assessment (RA) sites. The LTR sites are not randomly selected, but typically encompass long-term study sites and regional conservation priorities, although any site with a known occurrence of wood turtles (Part 2) may be surveyed as an LTR site. Rapid Assessment sites are selected through one of two methods; they are either selected non-randomly in an opportunistic fashion, or selected randomly from GIS-based models of suitable stream habitat. The briefer of the two protocols (RA) are nested within the recommended LTR protocols, so that the LTR protocols are simply replicates of the RA methodology. Both LTR and RA survey protocols are described in narrative form, below. For a simple, step-by-step itemization of both protocols see Appendix II (Long-Term Monitoring Protocol) and Appendix III (Rapid Assessment Survey Protocol).

Site selection

Long-Term Reference and Rapid Assessment Site Selection

We identified potential study sites at the state level, and final study sites were chosen primarily by state agency lead biologists with consideration for geographic dispersion, watershed representation, expiring element occurrences, stratified landuse (urban vs. forested vs. agricultural) and opportunistically (e.g., mitigation-related project sites). With the exception of random sites (described below), all sites had documented wood turtle occurrences within the past 30 years, but most were not randomly selected. Site allocation was governed in large part by individual state resources.

At each study site (LTR and RA) we demarcated a 1 km segment of stream in GoogleEarth using leaf-off (generally April) aerial images (Figure 1). The upstream and downstream bounds of each segment were placed to correspond to natural barriers to regular annual movement where possible such as roads or major changes in vegetation or landuse. Ideally, 1 km survey segments could be surveyed continuously from one end to the other. Further, multiple 1 km segments of meandering stream were sometimes selected adjacent to one another (usually LTR sites) to cover a geographic area specified by another question or purpose (e.g., a former study). Distribution of Sites

Distribution of study sites

We broadly distributed study sites throughout the Northeast region according to resources available in each state. Generally, the LTR sites were identified as those either with existing research programs or regional conservation value, or in some cases, sites with confirmed occurrences of wood turtles. In some instances, sites were selected based on access permissions and suspected wood turtle presence. In instances where multiple segments were established they were numbered in sequence (1, 2, 3, etc.). Each site was then assigned a project code designed to not reveal sensitive location data that could facilitate poaching, which is a major conservation concern (see "Threats," Part 1; Litzgus and Brooks 1996).

Random site selection

We selected randomly generated 1 km stream segments identified by Classification and Regression Tree (CART; De'ath and Fabricus 2000) models, generated at the state- and Level III ecoregion level for surveys in New Hampshire, Massachusetts, New Jersey, and Virginia. The CART models were trained from 800 corroborated occurrences (an iteration of the analysis outlined in Part 2, using CART instead of logistic regression).

Survey protocols

The actual survey protocols at LTR and RA sites were essentially the same except where noted otherwise, below. The annual LTR protocol consisted of six visits to a site, repeated in multiple years, while the investment in an RA site was variable (ideally three visits in spring). This was in an effort to create a protocol that did not necessarily require a scientific collection permit in every state.

Observers were instructed to generally follow the stream channel for the designated 1 km, and to move through the survey segment in one hour of active searching. To maximize detection (constrained by time and space), observers were allowed to 1) search all visible areas underwater; 2) move up to 10 m away from the stream and associated riverine features (sidearms, side channels, braided streams, oxbows, floodplain ponds). Accordingly, observers surveying very large streams were presented with a much larger potential search area than those in very small streams and we anticipated that detection rates would decrease as stream size (a proxy for floodplain area) increased.

Search image

Observers were instructed to walk upstream, with polarized lenses, and with their back to the sun to maximize visibility (when possible). Observers were instructed to search the following habitat areas: bank areas with high solar exposure, open scrub and herbaceous riparian areas adjacent to the river, deep pools, logjams, rootmasses, fallen trees, debris, and other structural features heavily used by wood turtles (Harding and Bloomer 1979; Akre and Ernst 2006). Early in the spring season and late in the fall, turtles were observed primarily in the water. By the end of the spring survey window and early in the fall survey window, turtles were primarily observed on land. The basic search guidelines do not change, except that heavier emphasis was placed on underwater habitats on cold days (air temperature < approximately 9°C).

Lead observer

Teams consisted of one to four people, but in all cases a "Lead Observer" was designated. The Lead Observer (aka Observer 1) surveyed in front of Observer 2 to maximize the independence of their survey effort. In this way, "Observer 1" counts could be compared across sites that were sampled by 1, 2, and 3 observers by assuming the lead observers had equal ability to survey the stream segment independent of other observers. Observer 2 followed within sight of Observer 1, and Observer 3 within sight of Observer 2, and so on. Observer 2 generally surveyed different areas than the lead observer, who was able to survey wherever they choose. For example, observers may survey on opposite banks if the stream was large, or the lead observer may proceed first, followed by remaining observers. In any case, it was essential that Observers 2, 3, and 4 not compromise the independence of Observer 1. We evaluated the effects of multiple observers on overall survey success as well as the effects of multiple observers on the survey results of the lead observer using ANOVA.

Observer overlap

In any broadscale study of cryptic species, observer bias or level of experience may influence detection rates. To incorporate observer effects into models of abundance and detection, it is proper to have perfect overlap between all observers and all sites. Because of the pilot nature of this broad geographic effort, we were unable to properly control for observer effects. However, we attempted to maximize our ability to investigate the effect of observer on detection probabilities by switching Lead Observers wherever feasible. Typically, this occurred within institutional research teams that typically worked together, but where possible observers switched across research groups. In this pilot effort, individual teams representing agencies or institutions visited from one to >50 sites, so the opportunities for observer overlap were varied. We made a concerted effort to force overlaps between teams in New England and Virginia and within region.

Observer effects were evaluated by comparing each Lead Observer's time-corrected observation rate to the mean of that site. Their mean value was then averaged. All Observer 1s with overlap were then assigned a metric expressed as a distance away from 1. From these values, a variance was obtained to indicate the potential magnitude of observer effects for future planning.

Boating on Large Rivers

Surveys of large rivers were facilitated with a canoe or small motorboat. During boat-based surveys, observers followed all standard protocols outlined here and endeavored to spend as much time on foot as possible. For example, Observer 1 walked on the bank and the other observers followed in the boat or played a support role to transport Observer 1 across the river. When two observers were in a boat, the bow position was considered Observer 1.

Processing Turtles

Upon capturing a wood turtle, we stopped the survey clock. Turtles were measured, weighed, marked, and photographed. We handled wood turtles in the field for <30 minutes, and note that handling appears to cause stress in wood turtles (Cabanac and Bernieri 2000). We recorded the animal's sex, number of visible plastral annuli, and shell wear condition (not worn; partly [<50%] worn ; ≥50 worn; >90% worn). At some RA sites, animals were not captured.

Morphometrics and mass.—We recorded straight-carapace length (SCLmin); straight plastron length (SPLmin); carapace width at 8th marginal scute (CW) and plastral width at humeral-pectoral seam (PW) in millimeters (mm) using 12" (300 mm or greater) dial calipers (or comparable). We recorded animal mass in grams using a variety of scales, primarily 2500 g Pesola scales (for turtles >1000 g).

Marking turtles.—We individually marked all captured turtles ≥1 yr in age with a triangular file (Cagle 1939) or hand drill (Akre 2002) using regionally defined carapace notching systems. Generally where sites were continuations of long-term research, the original notching code was retained. Generally when new sites were established, the notching code Ernst et al. (1974) was used. Most notching systems were based on consecutive groups of numbers rather than alphanumerics (e.g. A1) or right side/left side (e.g., R1L2), and we note that this is the preferable method from a data management perspective.

Photography for identification.—To establish a means of secondary identification beyond the notch code and morphometrics, we photographed turtles with identifying codes visible in the photograph. Photographs were taken of carapace and plastron (first noted by Harding and Bloomer 1979). The carapace and plastron of every turtle was individually photographed (Harding and Bloomer 1979; Jones 2009) so that future recaptures could be confirmed through multiple mechanisms.

Injuries and health.—Record missing or injured limbs, tail, or eyes. Record the presence of skin or upper respiratory tract infection, and/or lethargic condition.

Time of Year and Weather Constraints

We conducted surveys in all months except January, but primarily from March–June and September–November. Surveys took place primarily when wood turtles were known or believed to be in or immediately adjacent to the overwintering stream.

Defining Biological Seasons

Under both protocols (LTR and RA) we attempted to undertake three surveys within one biological season. Suitable biological seasons for survey were roughly defined as follows: Emergence/Spring begins in late winter and continues until May 27. Nesting is defined as May 28 to July 8, although nesting movements may occur well before and after this window, and have greater influence at certain sites. Fall is defined as 19 August to brumation or winter dormancy, but these windows vary greatly from Virginia to Maine and were adjusted locally based on expert opinion.

The purpose of these seasons is to disperse the LTR sampling bouts to improve independence of the turtle capture histories, and to provide a framework in which to group the RA surveys, which should be conducted in the same general season while populations are strongly closed.

Decontamination of Field Gear

To minimize the potential for disease transfer, standard decontamination protocols were recommended (Miller and Gray 2009) and implemented at a majority of sites (but not all). Bryan et al. (2009) reported that the following solutions were appropriate for the control of Ranavirus: 3% household bleach, 0.75% Nolvasan (Fort Dodge Animal Health, Fort Dodge, IA), or 1% Virkon (DuPont Animal Health Solutions). The active ingredient in these products ranges from sodium hypochlorite, chlorhexadine diacetate, and potassium peroxymonosulfate (Miller and Gray 2009). For additional considerations, see "Decontamination of Field Gear" in Part 1.

Data Management

Field forms

We used four standardized field forms (Appendix V) to record (a) RA survey site characteristics and survey results and (b) individual turtle capture histories and morphometrics, injuries, photo reference numbers, etc. All data forms were made available to collaborating researchers as PDFs on the website http://northeastturtles.org.

Data Entry

We used web-based data entry and photo upload functions (http://jotform.com) to create a centralized, password-protected database and a simple web-based data entry interface. Researchers entered data shortly after collection.

Data Analysis and Results

Throughout the RCN project, 825 surveys (383 in the spring, 71 during nesting, and 371 in the fall) were conducted on 196 stream segments between 3/12/12 and 11/24/13. Each steam segment was surveyed between 1 and 15 times (mean = 4.2), and a total of 1567 wood turtles sightings occurred on 73 of the 96 streams (Table 1).

Almost half (362 of 825, or 43.9%) of surveys yielded no turtles, and the average survey yielded 1.9 turtles (sd=3.17), 1.33 (sd=2.03) of those were by the lead observer (Figure 2).

Effects of Variation in Survey Protocols on Survey Success

Although survey protocols were standardized as described above to reduce variation in detection rate, it was not always logistically feasible to follow the protocols exactly, and often differing numbers of observers would conduct the survey, stream segments were longer or shorter than 1km, and surveys were more than or less than 1 hour. To explore the effects of varied survey methodology on survey success, we used a subset of the data: only the results from 48 sites (471 surveys) that were surveyed at least six times between 2012 and 2013 and where at least 1 turtle was observed.

Number of observers

We first evaluated the effect of multiple surveyors on survey success using ANOVA on square root transformed count data, with the number of observers as the categorical predictor variable. As expected, surveys with more observers yielded significantly more turtles ($F_{1,466}$=56.26, P<0.001) (Figure 3).

As noted above, in designing the monitoring protocol, we anticipated that using multiple observers might affect survey results, and so we implemented a "primary observer" component as part of the sampling protocol. The primary surveyor walks ahead of the others, and is not influenced by secondary observers. The turtles that he or she observes are recorded as such, and are considered independent of the actions of the secondary observers. To evaluate the effectiveness of a using a "primary observer" to standardize surveys, we again used ANOVA on the transformed counts of turtles found by the primary observer only, using number of observers as the predictor variable. The number of turtles found by the primary observer was not significantly different across surveys performed by 1, 2, 3, or 4 or more surveyors ($F_{1,322}$= 2.956, P = 0.0865) (Figure 4). Similarly, number of turtles observed by secondary and tertiary observers was not significantly different, regardless of whether there were 2, 3, or 4 or more surveyors were present ($F_{1,169}$=0.247, P=0.62; $F_{1,51}$=0.082, P=0.776).

Across all surveys at sites with 6 or more surveys conducted, lead observers found an average of 2.5 turtles (SD=2.42), secondary observers found 1.13 (SD=1.47), third observers found 0.70 (SD=0.98), and 4th found 0.61 (SD=0.98). For surveys with 2 observers, lead observers found on average of 67% of the turtles, for 3 observer surveys, they found an average of 61%, and for 4 or more person surveys, they found an average of 54%.

Individual observer effects

In addition to the effects of multiple observers, we were concerned that there might also be effects as a result of variation among primary observers, and more experienced observers may have higher detection rates than those with less experience. To evaluate this we, calculated the average number of turtles found by the primary observer at each site, and normalized the primary observer's results during each survey by the average results at that site. We then averaged the results for each observer and evaluated observers that conducted at least 3 surveys at sites where there was observer overlap and at least one turtle was observed. Results ranged from 0.25 to 1.625. That is, on average, observers may find as few as 25% the number of turtles of the average observer, or as many as 63% more.

To evaluate the effect that experience has on survey results, we classified surveyors as "experts" if they had found 20 wood turtles at 5 or more sites prior to the beginning of the 2012 season, and "novices" if they had not. We then evaluated the normalized survey success of experts compared to novices, using only the 11 surveyors who had completed more than 3 surveys and surveyed as part of a team where overlap occurred between experts and novices. We compared means of these two groups using a one-tailed t-test assuming unequal variances between the two groups. Experts were significantly more successful, averaging scores of 0.97 (variance = 0.11) compared to novices who averaged 0.55 (variance = 0.05). (t_9=-2.515, P=0.017).

Duration of survey

In an effort to minimize the effects of varying levels of effort on survey success, the sampling protocol called for a standardized 60 minute survey. This was not possible in all cases, however, and survey length varied from 10 minutes to 130 minutes. To evaluate the effect of survey duration, we modeled the square root transformed count of turtles observed by the lead observer using survey time (in minutes). Longer surveys resulted in significantly more turtles ($F_{1,450}$=16.9, P<0.001), suggesting that surveys should be normalized by survey duration.

We normalized the results of each survey by the total duration of the survey, such that the response variable became number of turtles observed by the first observer, per hour of survey time for the environmental variable analysis below.

Length of stream segment

To further standardize surveys, the protocol called for delineation of stream segments that were 1km in length. This was not feasible in all cases, however, and stream segments varied from 0.29 to 1.55km. To evaluate the effect that steam segment length had on survey success, we again predicted square root transformed counts of turtles found by observer 1 by stream length using ANOVA. Survey success actually decreased with survey length, but this result was not significant ($F_{1,450}$=0.8356, P=0.3612). We therefore did not normalize by stream segment length in the remaining analyses of environmental variables.

Environmental variables

To evaluate effects of environmental variables (e.g., season, Julian day, time of day, and weather) on survey success, we continued to use only sites that were surveyed at least six times and where at least 1 turtle was observed.

Effect of season

To evaluate seasonal variability in survey success we tested all sites with more than 6 surveys and with surveys conducted in both the fall and spring (426 surveys on 47 streams), and normalized each survey by the maximum number of turtles found by observer one on that stream segment. We then evaluated the effect of season using ANOVA with stream as a cofactor. Spring surveys were significantly more successful ($F_{1,417}$=14.48, P=0.00016), with 12.6% of a stream's total turtles found on any given spring survey, vs. 7.8% during fall surveys, or the average spring survey turned up 38% of turtles found during the best survey at a given site, while fall surveys averaged 26% (Figure 5). Spring surveys were also more successful than nesting season surveys (38.1% vs. 34.5%), but this was not significant ($F_{1,84}$=0.2522, P=0.6169).

Plotting probability density functions

To evaluate how environmental conditions varied during excellent surveys compared to poor surveys, we divided the dataset into two classes: 1) the best surveys at a site, that is surveys yielding the highest turtles/ search hour for the primary observer for a given site, and 2) surveys where no turtles were found by the primary observer.

All other surveys (i.e., those yielding intermediate results) were excluded. Again, only sites with more than 6 surveys and at least 1 turtle were included in this analysis. We used probability density functions to plot these two groups against 9 environmental variables during two sampling seasons: spring (3/19 – 5/18) and fall (7/16 – 11/12/13), to evaluate whether the influence of environmental variables on survey results varies from season to season. The fall/winter date (11/12) was determined by the date of the last wood turtle observed on land, while the winter/spring date was determined by the first turtle observed on land. Plots are presented in Figures 6 and 7.

In the spring, the environmental variable exhibiting the largest difference between poor surveys and excellent surveys was the air temperature differential. That is, when the air temperature increased rapidly throughout the course of the hour-long survey, surveys tended to produce the best results, and this result was significant ($F_{1,28}$=7.157, P=0.0123), though sample size was small for this variable. The air temperatures of excellent surveys averaged 17.4C (SD=4.12), and differences between the air and water averaged 5.7C (SD=4.15), but these were not significantly different than temperatures during poor surveys.

In the fall, more excellent surveys were conducted earlier in the season and when temperatures were warmer (mean=16.11, SD=5.4), but this was not significantly different than conditions that resulted in poor surveys.

Although air and water temperatures and air/water differential did not vary significantly with survey results, they were significantly correlated with the proportion of turtles that were observed on land vs. in the water (Table 2)

Despite the lack of evidence that survey results varied with Julian day, it should be noted that all spring surveys were conducted before July 4th and all fall surveys were conducted after August 14th, so we have no evidence that surveys outside this window are as effective. Therefore we suggest continuing to survey during the dates initially specified. In addition, location in the species range probably affects the Julian day, time of day, and temperature at which surveys are most effective, so these complex relationships may not be evident when exploring survey results region-wide.

Modeling the best time to detect wood turtles

We used the divided dataset described above in conjunction with classification trees to tease apart the complex relationships between environmental factors affecting the outcome of wood turtle surveys in the spring (site location, day of the year, time of day and weather conditions). Analyses were conducted using the unofficial R library cartware (Compton 2006). The chosen, 8-leaved tree (Figure 8) had a correct classification rate of 80%, Kappa=0.59, and a Monte Carlo resampling test revealed the model to be significantly better than chance ($P<0.001$).

The CART model demonstrates that surveys conducted at temperatures less than 11.9°C were not likely to produce excellent survey results, regardless of location in the range of the wood turtle, and this represented the first split in the tree. Though it should be noted again that only spring surveys, and not winter surveys (i.e., those occurring before March 20th, before turtles were generally observed on land) were included in the analysis. The product of Julian day, air temperature, and start time provided the second split, and values less than 867.2 produced excellent surveys 75% of the time. Values greater than 867.2 led to more complex splits where the product of Julian day and growing degree days at the site, air temperature, and the air/water temperature differential proved important. These data can be used to help improve survey efficiency by guiding the conditions under which spring surveys are conducted.

Modeling detection rate

To further evaluate the effects of environmental as well as site covariates on detection rates, and to estimate region-wide abundance on surveyed streams, we used N-mixture models (Royle 2004; Kery and Royle 2005). N-mixture models make use of repeated count data to estimate 2 parameters: detection (p) and average site abundance (Lamba). The counts observed at a site are assumed to be the result of a series of Bernoulli trials where probability of detection of an individual turtle is constant across sites, and the number of trials is a function of site specific abundance, which is treated as a random effect and follows a specified underlying distribution. Royle (2004) used binomial, negative binomial, or poisson distributions to model the underlying distribution of site-specific abundance. Wenger and Freeman (2008) and Joseph et al. (2009) extended these models to use zero inflated poisson and zero inflated negative binomial distributions, which incorporate a third parameter for zero-inflation. Regardless of the underlying distribution chosen, detection is assumed to be constant across individuals and sites, and abundance is assumed to be constant at a site throughout the sampling period. Covariates can be included to explain variation in either detection or abundance, though abundance covariates are assumed to be constant across all visits to a site.

In an effort to evaluate the underlying distribution of site-specific abundance, we fit null models (i.e., models without covariates) to the complete dataset of sites evaluated 3 times (127 sites visited 725 times) using the package unmarked (Fiske and Chandler 2011) in R (R development core team 2013). Of the distributions evaluated (binomial, poisson, negative binomial and zero inflated poisson), the zero-inflated poisson regression yielded the best fit, and was the only distribution that showed no evidence for lack of fit using a boot strapped goodness of fit test (Fiske and Chandler 2011).

Next, we fit a series of models to evaluate hypotheses about factors affecting detection and abundance across the region. We included 7 variables that we thought might influence detection (number of observers, Julian day, start time, air temperature, water temperature, steam length, and steam width), as well as logical combinations of those variables. We did not include air-water differential or air differentials because these variables were collected during few surveys and sample size was not large enough. We also included three variables as proxies for development or habitat fragmentation, which we thought might influence abundance: the percent forest cover within 90m of the stream segment, the percent impervious surface cover within 90m of the stream segment, and the percent impervious surface cover within 3 km of the stream segment.

Models were fit with the zero inflated poisson distribution and ranked using AIC. The model with the lowest score was a model that included modeled abundance as a function of impervious surface cover and detection as a function of season, Julian day, start time, number of observers, and stream width. The goodness of fit test for this model was not significant (t_0=114228, $mean_{[t0-tb]}$=-213222, sd=411010, P=0.545), showing no evidence for lack of fit. The final model indicated that nesting and spring surveys had significantly higher detection rates than fall surveys, the number of turtles found increased significantly with number of observers and Julian day, but decreased with time of day and stream width. Average site abundance was estimated to be 17.5 (SE=3.4) when impervious at 3km was set to its average value, and detection was estimated at 0.0579 when estimates detection covariates were set to their mean value. Empirical Bayes estimation yielded at total population size across all 127 sites of 1422 (95% CI=901–2188).

Because the model assumes that abundance at a site is constant during the sampling period, it is more appropriate to evaluate results during a single season only. To do this, we evaluated the subset of data for 78 sites with at least 3 spring surveys (Table 3). Again there was no evidence for lack of fit (P=0.548) for the final model, which included impervious surface cover as a covariate with abundance and number of observers, Julian day, and total time as a predictor of detection (Table 4). Average site abundance was estimated to be 30.1 (SE=11.6) when impervious surface cover was set to its mean value, and detection was estimated to be 0.0662 (SE=0.0253) when all detection covariates were set to their means. Total population across all 78 sites was estimated to be 1461 (95% CI = 1003–2074). Again, site abundance decreased significantly with increased impervious surface cover (Figure 9), and detection decreased throughout the season, and increased significantly with survey duration (Figure 10).

Capture – Mark – Recapture (CMR) at LTRs

At intensively sampled sites (LTRs), individual turtle recapture data were analyzed where possible using Jolly-Seber open-population models and closed-population loglinear models using the Rcapture package (Baillargeon and Rivest 2012) in R (R core team 2012). These results were compared with results from the mixture models and the raw survey results.

We were able to estimate population size using CMR models at 17 sites using open population models and 27 using closed population models, but only sites with at least 9 survey events could generally be modeled. Population estimates ranged from 6.4 to 198.4 turtles / standardized segment, and averaged 67 for open population models and 63 for closed population models (Table 1). We modeled survey results (average results of observer 1 per search minute) as a predictor of population size estimate in order to evaluate the effectiveness of using survey results as a proxy for relative population density. Average survey results were a significant predictor of population size ($F_{1,22}$=44.64, P<0.001), and explained 67% of the variance in population (R^2=0.67), suggesting that for sites sampled at least 9 times, average search results were a good indication of population size (Figure 11). The slope of this model was 33.1, suggesting that on average, a turtle observed during a 1 hour survey represents 33 turtles in the population, yielding a detection rate of 0.03, lower than the detection rate estimated using the mixture models, suggesting that regional population estimates from the mixture models may be an underestimate. Open population models were less well predicted by the normalized survey results ($F_{1,15}$=11.38, P=0.004, R^2=0.4314) (Figure 12), but both relationships were much stronger than the relationship between the ZIP mixture model results and the closed and open population models ($F_{1,22}$=11.55, P=0.001, R^2=0.3442)

Reassessment of previous study sites

Eleven LTRs, plus two RA sites likely to become LTRs in 2014, were the sites of former intensive work. These include the study site of Farrell and Graham ([nj11a] 1991) and Kaufmann ([pa3a] 1992) and Sites B, F, G, H(Lower), H(Upper), J, M, P, W of Jones ([ma13c, ma13b, ma14b, ma10a, ma12a, ma12c, ma19, nh6a, nh6c; 2009) and Sites C and E of Akre and Ernst ([va28] 2006) and Akre ([va7] 2002). The original sites varied in length from 650 m of stream (Kaufmann 1992) to 3.0 km of stream (Akre 2002), while the current overlaid LTRs are generally about 1 km of stream. The original density estimates are also variable, for instance, Kaufmann (1992) reported 84 turtles known to use his 0.65 km study segment, and Akre (2002) reported 139 turtles from his 3.0 km study segment at Site E, but neither reported population estimates. Jones (2009) reported only estimates for the adult population size. In all cases, the new LTR segment was embedded within the previous site, although the Kaufmann segment was placed at the eastern end of his study area. Turtles marked by the previous researchers were detected at all follow-up segments (Figure 13). Current density estimates suggest that seven of thirteen sites may have declined in overall density (assuming density was constant across the original study segment). Increases were noted at five sites. Overall, this aspect of the regional project appears to have merit and should be expanded and continued.

Discussion

Results from 2012-2013 suggest that despite the many, varied factors that affect detection across the region, the survey protocol was able to successfully evaluate detection rates, variability across environmental conditions, and estimate population size at key sites, as well as across the region. By continuing to build the sampling network in the future, particularly with the addition of a stronger random component, we will be able to more accurately assess wood turtle occupancy and abundance on the landscape, rates of detection, and evaluate how these factors vary across landscape and environmental conditions. We will also be able to use this strong baseline to evaluate change over time.

Results from the ZIP mixture models suggest that abundance decreases significantly with impervious surface cover surrounding a site. Because survey returns were a significant predictor of population size, we will use survey results to more fully explore this relationship in Part 4.

Caveats

It should be noted that many of the sites visited multiple times (and therefore form the majority of the data for many of the analyses) were relatively high density sites, and are not necessarily representative of populations throughout the region. Consequently, detection rates and regional abundance estimates are biased with respect density and should be interpreted with caution.

In fact, of the 196 sites visited, 73 (37%) returned no turtles and an additional 27 (13.8%) returned only 1 turtle. This suggests that although the most intensively visited sites appeared to support large populations (estimated up to 198.4 turtles), and although many of the lower density sites were sampled less frequently, the majority of segments may not support large populations, and future work should continue to evaluate the distribution of turtles at low density sites. We suggest that future work incorporate a larger proportion of random sites in order to a) effectively evaluate the background occupancy of wood turtles in stream segments on the landscape, b) evaluate the success of survey protocols at lower density sites, and c) evaluate more effectively the relationship between population abundance and other landscape factors.

Although it is difficult to estimate abundance at low density sites, the sampling protocol appears to work well at high density sites, and it is easy to distinguish between low and high density sites using this protocol. Therefore these groups can serve as the basis for evaluating the effects of landscape on population abundance as we do in Part 4.

Recommendations

Detection rates varied across the landscape and were a function of season, number of observers, survey duration, stream width, and environmental conditions. When possible, survey protocols should be followed as closely as possible, lead observers should always be designated, experienced surveyors should be used when possible, observer overlap should be instituted, and time and temperature variables should be recorded at the beginning and end of surveys. Air temperatures and water temperatures did not significantly affect survey success or detection rates in a predictable way, but their change throughout the survey proved to be important, so these should continue to be measured before and after the survey. Julian date and time of day also did not consistently affect surveys, but combined with each other and with growing degree days at the survey location, they proved and important predictor of survey success, and therefore it is important to note that surveys were constrained by time and date, and should continue to be going forward.

The effect of observer on survey results varied substantially, and experienced surveyors found significantly more turtles. In the future, surveys should be conducted by trained observers and survey overlap should be utilized wherever feasible.

Several methods of data recording made analysis more efficient. The submission of standardized data collected using the field form allowed data entry, tabulation, and QA/QC to be more efficient. Therefore we recommend continued use of standardized field forms. In addition, when possible, number turtles sequentially using numeric codes rather than left/right designations or alphanumerics – this aids in determining whether turtles were recaptures or seen only a single time.

As noted above, many of the segments surveyed in this study were relatively high density sites. To reduce bias and evaluate a more representative portion of the landscape, in order to allow for generalizations at the landscape scale, we propose increasing the effort at random sites.

Tables

Table 1a. Standardized wood turtle (*Glyptemys insculpta*) sampling sites in the Northeast Region, 2012–2013

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
Connecticut	Fairfield	264	237	90%	1	0%	5.55	4	4	0	2011
Connecticut	Hartford	690	605	88%	12	2%	4.58	12	9	2	2012
Connecticut	Litchfield	717	379	53%	83	12%	0.77	12	10	0	2011
Connecticut	Middlesex	187	106	57%	19	10%	1.68	0			
Connecticut	New Haven	318	277	87%	2	1%	5.42	9	7	1	2009
Connecticut	New London	404	232	57%	13	3%	1.50	2	2	0	2006
Connecticut	Tolland	348	203	58%	23	7%	1.40	8	8	0	2009
Connecticut	Windham	501	256	51%	25	5%	0.87	6	6	0	2012
Delaware	Kent	61	61	100%	0	0%	0.98	0			
Delaware	New Castle	328	328	100%	0	0%	4.60	1	1	0	2011
District of Columbia	District of Columbi	2	2	100%	0	0%	33.74	0			
Maine	Androscoggin	442	191	43%	3	1%	0.83	0			
Maine	Aroostook	3310	687	21%	1521	46%	0.04	19	14	3	2013
Maine	Cumberland	704	383	54%	28	4%	1.18	5	4	1	2013
Maine	Franklin	689	109	16%	319	46%	0.06	5	5	0	2010
Maine	Hancock	667	95	14%	319	48%	0.12	1	0	0	
Maine	Kennebec	487	190	39%	17	4%	0.49	0			
Maine	Knox	212	71	34%	12	5%	0.42	0			
Maine	Lincoln	312	52	17%	61	20%	0.27	2	2	0	2004
Maine	Oxford	1308	157	12%	706	54%	0.10	8	7	1	2011
Maine	Penobscot	2452	387	16%	757	31%	0.16	6	6	0	2004
Maine	Piscataquis	1788	104	6%	905	51%	0.01	15	15	0	2013
Maine	Sagadahoc	135	64	48%	11	8%	0.49	0			
Maine	Somerset	1982	249	13%	593	30%	0.05	23	22	0	2013
Maine	Waldo	490	93	19%	112	23%	0.20	1	1	0	1999
Maine	Washington	1672	362	22%	518	31%	0.04	4	4	0	1998
Maine	York	973	429	44%	58	6%	0.79	9	9	0	2013
Maryland	Allegany	425	141	33%	220	52%	0.61	17	16	0	2011
Maryland	Anne Arundel	136	135	100%	0	0%	5.05	0			
Maryland	Baltimore	337	315	93%	0	0%	5.17	2	1	1	2011
Maryland	Baltimore City	34	34	100%	0	0%	30.26	0			
Maryland	Calvert	36	30	83%	0	0%	1.63	0			
Maryland	Caroline	1	1	100%	0	0%	0.38	0			
Maryland	Carroll	479	479	100%	0	0%	1.53	0			
Maryland	Cecil	185	185	100%	0	0%	1.11	1	0	1	1947
Maryland	Charles	205	111	54%	1	0%	0.92	1	1	0	1995
Maryland	Frederick	873	826	95%	16	2%	1.40	2	0	2	1972
Maryland	Garrett	246	48	19%	135	55%	0.16	5	4	1	2010
Maryland	Harford	373	371	100%	0	0%	2.23	5	2	2	2010
Maryland	Howard	173	173	100%	0	0%	4.69	0			
Maryland	Kent	83	83	100%	0	0%	0.25	0			
Maryland	Montgomery	526	521	99%	0	0%	7.53	5	2	1	2012
Maryland	Prince Georges	352	328	93%	0	0%	6.88	1	1	0	1995
Maryland	Queen Annes	78	78	100%	0	0%	0.49	0			
Maryland	St Marys	11	5	46%	0	0%	0.65	0			
Maryland	Washington	537	441	82%	25	5%	1.17	10	9	0	2012
Massachusetts	Barnstable	1	1	100%	0	0%	2.17	0			
Massachusetts	Berkshire	626	343	55%	94	15%	0.51	25	25	0	2010
Massachusetts	Bristol	302	296	98%	0	0%	3.72	3	3	0	2010
Massachusetts	Essex	357	352	99%	0	0%	5.63	7	7	0	2013
Massachusetts	Franklin	489	181	37%	155	32%	0.38	30	29	1	2013
Massachusetts	Hampden	465	297	64%	63	14%	2.85	18	18	0	2013
Massachusetts	Hampshire	508	300	59%	105	21%	1.12	23	21	1	2013
Massachusetts	Middlesex	801	712	89%	12	2%	6.76	21	13	8	2012
Massachusetts	Norfolk	308	308	100%	0	0%	6.21	1	1	0	2010
Massachusetts	Plymouth	454	444	98%	0	0%	2.83	1	1	0	1993
Massachusetts	Suffolk	2	2	100%	0	0%	47.34	0			
Massachusetts	Worcester	1592	966	61%	106	7%	1.96	34	33	1	2012
New Hampshire	Belknap	116	33	28%	39	34%	0.52	4	4	0	2010
New Hampshire	Carroll	454	99	22%	207	46%	0.19	0			
New Hampshire	Cheshire	492	125	25%	206	42%	0.41	14	13	1	2009
New Hampshire	Coos	354	67	19%	158	45%	0.06	15	11	0	2013
New Hampshire	Grafton	657	167	25%	296	45%	0.19	25	24	0	2013
New Hampshire	Hillsborough	741	356	48%	187	25%	1.87	18	15	0	2012
New Hampshire	Merrimack	585	171	29%	200	34%	0.62	15	14	1	2013
New Hampshire	Rockingham	489	361	74%	20	4%	1.68	5	5	0	2010
New Hampshire	Strafford	239	149	62%	16	7%	1.27	5	5	0	2010
New Hampshire	Sullivan	333	75	23%	145	44%	0.29	4	4	0	2006

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State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
New Jersey	Atlantic	40	36	92%	0	0%	2.07	0			
New Jersey	Bergen	337	325	96%	3	1%	15.25	4	4	0	2008
New Jersey	Burlington	391	252	64%	11	3%	2.22	1	1	0	2008
New Jersey	Camden	2	2	100%	0	0%	9.14	0			
New Jersey	Essex	142	142	100%	0	0%	25.22	2	0	2	1979
New Jersey	Gloucester	3	3	100%	0	0%	3.36	0			
New Jersey	Hunterdon	1122	1089	97%	0	0%	1.21	17	17	0	2011
New Jersey	Mercer	372	356	96%	0	0%	6.56	2	2	0	2010
New Jersey	Middlesex	269	269	100%	0	0%	10.63	2	1	1	2009
New Jersey	Monmouth	443	439	99%	0	0%	5.43	5	2	3	2001
New Jersey	Morris	937	746	80%	22	2%	4.13	14	14	0	2011
New Jersey	Ocean	576	394	68%	53	9%	3.55	3	1	2	2002
New Jersey	Passaic	320	198	62%	42	13%	10.52	2	2	0	2008
New Jersey	Salem	12	12	100%	0	0%	0.69	0			
New Jersey	Somerset	704	691	98%	0	0%	4.40	7	7	0	2012
New Jersey	Sussex	1154	763	66%	102	9%	1.13	34	30	4	2013
New Jersey	Union	56	56	100%	0	0%	20.64	2	2	0	1998
New Jersey	Warren	729	579	79%	9	1%	1.19	14	14	0	2012
New York	Albany	294	229	78%	8	3%	2.19	3	3	0	1998
New York	Allegany	316	136	43%	45	14%	0.18	0			
New York	Broome	546	317	58%	34	6%	1.02	0			
New York	Cattaraugus	719	259	36%	185	26%	0.23	1	0	1	1968
New York	Cayuga	89	88	99%	0	0%	0.41	0			
New York	Chautauqua	735	572	78%	0	0%	0.47	0			
New York	Chemung	232	138	60%	13	5%	0.79	1	1	0	1998
New York	Chenango	666	295	44%	70	11%	0.21	0			
New York	Clinton	103	61	59%	22	22%	0.28	4	4	0	1999
New York	Columbia	733	590	81%	8	1%	0.36	3	3	0	1999
New York	Cortland	321	211	66%	2	1%	0.36	0			
New York	Delaware	572	165	29%	220	38%	0.11	10	6	2	1999
New York	Dutchess	1180	884	75%	8	1%	1.45	9	8	0	2012
New York	Erie	191	156	82%	0	0%	3.45	1	1	0	1997
New York	Essex	230	23	10%	158	69%	0.07	10	9	0	2001
New York	Franklin	178	74	42%	78	44%	0.11	5	5	0	2009
New York	Fulton	312	200	64%	29	9%	0.38	0			
New York	Genesee	143	141	99%	0	0%	0.43	0			
New York	Greene	411	225	55%	46	11%	0.28	1	1	0	1994
New York	Hamilton	273	1	0%	243	89%	0.01	0			
New York	Herkimer	459	349	76%	14	3%	0.16	1	1	0	2011
New York	Jefferson	290	223	77%	6	2%	0.37	4	3	0	2009
New York	Lewis	435	161	37%	104	24%	0.07	0			
New York	Livingston	113	102	91%	0	0%	0.38	0			
New York	Madison	293	270	92%	0	0%	0.40	0			
New York	Monroe	20	20	100%	0	0%	4.50	0			
New York	Montgomery	251	249	99%	0	0%	0.42	1	1	0	1999
New York	Niagara	23	23	100%	0	0%	1.60	0			
New York	Oneida	682	473	69%	19	3%	0.74	2	2	0	2003
New York	Onondaga	117	114	98%	0	0%	2.32	0			
New York	Ontario	59	45	77%	0	0%	0.61	0			
New York	Orange	1234	974	79%	133	11%	1.91	16	14	2	2013
New York	Orleans	9	9	100%	0	0%	0.42	0			
New York	Oswego	144	67	47%	36	25%	0.48	7	7	0	2006
New York	Otsego	638	407	64%	2	0%	0.23	1	1	0	1999
New York	Putnam	394	247	63%	49	13%	1.67	2	1	0	2005
New York	Rensselaer	631	464	74%	74	12%	0.91	4	3	0	2013
New York	Richmond	2	2	100%	0	0%	36.29	0			
New York	Rockland	257	219	85%	21	8%	6.22	1	1	0	1999
New York	Saratoga	627	492	78%	54	9%	1.03	0			
New York	Schenectady	73	65	89%	0	0%	2.72	0			
New York	Schoharie	178	97	55%	28	16%	0.18	2	2	0	1996
New York	Schuyler	55	35	64%	7	12%	0.19	0			
New York	Seneca	3	3	100%	0	0%	0.32	1	0	1	1931
New York	St Lawrence	650	212	33%	261	40%	0.15	15	14	0	2013
New York	Steuben	309	176	57%	9	3%	0.26	1	1	0	1994
New York	Sullivan	1090	234	21%	627	58%	0.29	6	6	0	1998
New York	Tioga	401	251	62%	3	1%	0.35	0			
New York	Tompkins	121	94	78%	5	4%	0.85	4	1	3	1995
New York	Ulster	1218	580	48%	258	21%	0.62	15	8	7	1999

Table 1a. Standardized wood turtle (*Glyptemys insculpta*) sampling sites in the Northeast Region, 2012–2013

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
New York	Warren	381	73	19%	182	48%	0.27	7	6	0	2002
New York	Washington	455	417	92%	3	1%	0.28	2	1	0	1998
New York	Wayne	8	8	100%	0	0%	0.59	0			
New York	Westchester	341	291	85%	2	1%	8.08	2	2	0	2012
New York	Wyoming	230	221	96%	0	0%	0.26	0			
New York	Yates	90	70	78%	1	1%	0.24	0			
Pennsylvania	Adams	772	682	88%	54	7%	0.76	3	0	1	1944
Pennsylvania	Allegheny	603	593	98%	0	0%	6.39	1	0	0	
Pennsylvania	Armstrong	646	382	59%	12	2%	0.38	6	4	0	2011
Pennsylvania	Beaver	338	290	86%	2	1%	1.46	1	1	0	2005
Pennsylvania	Bedford	1114	543	49%	290	26%	0.17	6	4	1	2011
Pennsylvania	Berks	1737	1660	96%	16	1%	1.88	7	4	2	2009
Pennsylvania	Blair	536	400	75%	35	7%	0.87	4	3	0	2010
Pennsylvania	Bradford	611	453	74%	27	4%	0.19	2	0	2	1912
Pennsylvania	Bucks	1200	1183	99%	0	0%	4.16	5	4	0	2011
Pennsylvania	Butler	688	469	68%	22	3%	0.89	4	3	1	2010
Pennsylvania	Cambria	265	113	43%	51	19%	0.77	1	0	1	1908
Pennsylvania	Cameron	260	9	4%	248	96%	0.05	4	1	1	2013
Pennsylvania	Carbon	646	291	45%	240	37%	0.58	2	1	0	2013
Pennsylvania	Centre	749	386	52%	237	32%	0.56	13	13	0	2012
Pennsylvania	Chester	1492	1475	99%	0	0%	2.68	5	3	0	2013
Pennsylvania	Clarion	594	275	46%	84	14%	0.23	1	1	0	2008
Pennsylvania	Clearfield	724	197	27%	264	36%	0.26	3	2	1	2010
Pennsylvania	Clinton	697	167	24%	445	64%	0.15	4	3	1	2010
Pennsylvania	Columbia	712	572	80%	61	9%	0.49	0			
Pennsylvania	Crawford	731	564	77%	1	0%	0.32	2	1	1	2010
Pennsylvania	Cumberland	593	486	82%	51	9%	1.64	6	3	1	2013
Pennsylvania	Dauphin	799	555	70%	142	18%	1.84	2	0	1	1935
Pennsylvania	Delaware	87	87	100%	0	0%	11.79	1	0	0	
Pennsylvania	Elk	517	55	11%	412	80%	0.13	1	0	1	1940
Pennsylvania	Erie	456	406	89%	0	0%	1.37	0			
Pennsylvania	Fayette	564	314	56%	176	31%	0.67	0			
Pennsylvania	Forest	351	5	1%	325	93%	0.06	2	2	0	2013
Pennsylvania	Franklin	945	724	77%	102	11%	0.68	10	7	1	2009
Pennsylvania	Fulton	595	208	35%	81	14%	0.11	1	1	0	2012
Pennsylvania	Greene	2	2	100%	0	0%	0.24	0			
Pennsylvania	Huntingdon	1043	325	31%	326	31%	0.18	14	13	1	2013
Pennsylvania	Indiana	778	450	58%	34	4%	0.40	5	2	1	2007
Pennsylvania	Jefferson	529	222	42%	82	15%	0.23	0			
Pennsylvania	Juniata	615	345	56%	136	22%	0.21	11	3	0	2008
Pennsylvania	Lackawanna	243	194	80%	19	8%	1.67	1	1	0	2000
Pennsylvania	Lancaster	1444	1437	99%	0	0%	2.03	2	1	1	2002
Pennsylvania	Lawrence	359	346	96%	0	0%	0.90	0			
Pennsylvania	Lebanon	559	490	88%	47	8%	1.32	2	1	0	2013
Pennsylvania	Lehigh	800	792	99%	0	0%	3.74	1	0	0	
Pennsylvania	Luzerne	1119	504	45%	272	24%	1.29	0			
Pennsylvania	Lycoming	1175	593	50%	414	35%	0.35	4	3	1	2010
Pennsylvania	McKean	532	77	15%	359	67%	0.15	0			
Pennsylvania	Mercer	540	493	91%	1	0%	0.64	0			
Pennsylvania	Mifflin	520	277	53%	104	20%	0.39	5	3	1	2010
Pennsylvania	Monroe	957	560	58%	145	15%	1.16	19	13	3	2013
Pennsylvania	Montgomery	851	848	100%	0	0%	6.28	3	0	1	1954
Pennsylvania	Montour	206	206	100%	0	0%	0.46	3	0	2	1978
Pennsylvania	Northampton	726	704	97%	0	0%	3.01	10	5	2	2012
Pennsylvania	Northumberland	731	655	90%	5	1%	0.69	0			
Pennsylvania	Perry	811	445	55%	124	15%	0.30	2	0	1	1982
Pennsylvania	Philadelphia	9	9	100%	0	0%	40.31	0			
Pennsylvania	Pike	654	179	27%	291	44%	0.46	3	1	1	2010
Pennsylvania	Potter	286	60	21%	144	50%	0.05	3	1	2	2012
Pennsylvania	Schuylkill	1394	698	50%	224	16%	0.68	10	7	1	2010
Pennsylvania	Snyder	582	412	71%	43	7%	0.41	1	0	0	
Pennsylvania	Somerset	281	61	22%	136	48%	0.26	0			
Pennsylvania	Sullivan	329	40	12%	241	73%	0.05	0			
Pennsylvania	Susquehanna	562	320	57%	34	6%	0.18	1	0	1	1963
Pennsylvania	Tioga	222	89	40%	77	34%	0.13	1	0	1	1955
Pennsylvania	Union	546	331	61%	163	30%	0.50	3	1	2	1991
Pennsylvania	Venango	576	119	21%	229	40%	0.28	7	4	2	2008
Pennsylvania	Warren	503	122	24%	254	51%	0.16	1	0	0	

Table 1a. Standardized wood turtle (*Glyptemys insculpta*) sampling sites in the Northeast Region, 2012–2013

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
Pennsylvania	Washington	653	581	89%	6	1%	0.88	0			
Pennsylvania	Wayne	534	255	48%	72	14%	0.26	0			
Pennsylvania	Westmoreland	923	701	76%	79	9%	1.32	4	2	2	2004
Pennsylvania	Wyoming	407	232	57%	79	19%	0.24	5	0	4	1982
Pennsylvania	York	1133	1109	98%	0	0%	1.78	5	4	0	2012
Rhode Island	Bristol	0	0	100%	0	0%	8.01	0			
Rhode Island	Kent	112	57	51%	10	9%	3.81	2	1	1	2009
Rhode Island	Newport	9	5	59%	0	0%	2.91	0			
Rhode Island	Providence	267	177	66%	8	3%	5.94	7	6	0	1998
Rhode Island	Washington	213	142	67%	4	2%	1.48	8	7	1	2010
Vermont	Addison	202	161	80%	14	7%	0.17	7	7	0	2012
Vermont	Bennington	208	103	49%	52	25%	0.19	9	8	1	2009
Vermont	Caledonia	198	114	57%	23	12%	0.17	4	3	1	2010
Vermont	Chittenden	118	61	52%	24	20%	0.97	7	7	0	2012
Vermont	Essex	159	15	9%	106	67%	0.04	3	2	0	2006
Vermont	Franklin	213	130	61%	7	3%	0.27	4	4	0	2010
Vermont	Lamoille	135	41	31%	40	30%	0.20	4	1	2	2007
Vermont	Orange	269	107	40%	86	32%	0.15	10	8	0	2008
Vermont	Orleans	201	109	54%	17	9%	0.14	6	5	1	2008
Vermont	Rutland	200	98	49%	22	11%	0.25	8	7	0	2008
Vermont	Washington	145	58	40%	38	26%	0.32	14	13	1	2010
Vermont	Windham	257	56	22%	157	61%	0.20	9	9	0	2010
Vermont	Windsor	463	197	42%	136	29%	0.22	12	11	0	2008
Virginia	Albemarle	10	2	20%	9	90%	0.51	0			
Virginia	Alexandria City	8	8	100%	0	0%	35.38	0			
Virginia	Arlington	5	5	100%	0	0%	30.72	0			
Virginia	Augusta	680	474	70%	191	28%	0.28	0			
Virginia	Bath	31	0	1%	31	100%	0.04	0			
Virginia	Clarke	121	92	76%	3	3%	0.28	0			
Virginia	Culpeper	86	37	43%	0	0%	0.45	0			
Virginia	Fairfax	142	138	97%	0	0%	12.38	5	2	0	2001
Virginia	Fauquier	445	329	74%	6	1%	0.41	0			
Virginia	Frederick	367	194	53%	109	30%	0.70	12	7	0	2013
Virginia	Greene	55	32	58%	7	12%	0.46	0			
Virginia	Harrisonburg City	12	12	100%	0	0%	9.76	0			
Virginia	Highland	272	58	21%	167	61%	0.02	0			
Virginia	King George	6	2	37%	0	0%	0.45	0			
Virginia	Loudoun	430	419	97%	0	0%	2.40	6	4	0	2013
Virginia	Madison	123	80	65%	21	17%	0.14	0			
Virginia	Manassas City	1	1	100%	0	0%	17.80	0			
Virginia	Page	337	200	59%	42	12%	0.27	0			
Virginia	Prince William	179	151	84%	6	3%	4.47	0			
Virginia	Rappahannock	236	93	40%	26	11%	0.11	0			
Virginia	Rockingham	1020	675	66%	267	26%	0.33	14	10	0	2011
Virginia	Shenandoah	658	394	60%	149	23%	0.28	19	16	0	2012
Virginia	Stafford	79	37	46%	1	1%	1.90	0			
Virginia	Staunton City	4	4	100%	0	0%	3.99	0			
Virginia	Warren	257	143	56%	24	9%	0.64	1	1	0	1996
Virginia	Winchester City	5	5	100%	0	0%	11.28	0			
West Virginia	Berkeley	256	151	59%	38	15%	1.19	15	13	1	2011
West Virginia	Brooke	74	57	76%	1	1%	0.84	0			
West Virginia	Grant	289	83	29%	103	36%	0.08	4	4	0	2009
West Virginia	Hampshire	664	77	12%	430	65%	0.13	19	17	0	2012
West Virginia	Hancock	54	43	80%	1	1%	1.14	0			
West Virginia	Hardy	519	118	23%	313	60%	0.08	24	22	1	2012
West Virginia	Jefferson	102	99	97%	0	0%	0.91	0			
West Virginia	Mineral	243	78	32%	93	38%	0.28	1	1	0	2001
West Virginia	Morgan	224	34	15%	106	47%	0.25	4	4	0	2012
West Virginia	Ohio	17	16	97%	0	0%	1.37	0			
West Virginia	Pendleton	357	81	23%	166	47%	0.04	5	4	0	2010
West Virginia	Preston	122	30	24%	31	25%	0.16	0			
West Virginia	Randolph	11	2	18%	7	64%	0.09	0			
West Virginia	Tucker	28	1	3%	25	90%	0.06	0			

Table 1b. Open population models, closed population models, and ZIP mixture model abundance estimates for wood turtle (*Glyptemys insculpta*) sampling sites in the Northeast Region, 2012–2013.

Site Name	Open Population Estimate	Open Population Standard Error	Closed Population Estimate	Closed Population Standard Error	ZIP mixture model estimate	ZIP 95% confidence interval
ma10a	33	20.1	27.2	6.9	21.2	14 - 29
ma12a	31.2	6	40.3	10.1	35.7	28 - 45
ma12c	30	20.9	21	4.5	24.3	17 - 33
ma13b					16.3	11 - 23
ma13c	24.9	20.2	34.7	16.3	17.1	11 - 24
ma14b			16.9	4.9	24.7	18 - 33
ma15		0.03030303				
ma17					20.6	13 - 29
ma18					25.6	17 - 35
ma19					26.2	18 - 36
ma22					3.0	0 17
ma23					24.4	16 - 33
ma24a					17.2	11 - 25
ma24b					20.8	13 - 29
ma25					28.6	20 - 38
ma26					3.2	0 17
ma29					20.1	12 - 29
ma2a					19.6	12 - 28
ma30					12.9	7 - 20
ma31					21.9	14 - 31
ma32					1.2	0 22
ma3b					27.3	19 - 37
ma4					21.2	13 - 30
ma5					2.2	0 18
ma9					21.7	13 - 31
me1e	n/a	n/a	124.9	55.1	29.9	22 - 39
me1f	188.2	94	162.7	57.9	34.1	26 - 43
me1i	n/a	n/a	23.8	4.8	23.9	16 - 33
me8a					19.6	12 - 28
me8b	104.9	65.2	76	32.3	26.2	19 - 35
me8c	33.4	6.9	52.2	13.7	33.7	26 - 43
me8d	n/a	n/a	101.3	29.1	35.6	27 - 45
me8e	69.5	48.8	87.1	37.4	28.2	20 - 37
me8f					24.3	17 - 33
nh10	34.4	21.4	43.8	15.3	31.2	23 - 40
nh11					1.5	0 23
nh3a	n/a	n/a	26.8	12.2	25.8	18 - 35
nh3b	n/a	n/a	27.1	7.7	29.4	21 - 39
nh3c	37	14	89.3	45.4	31.4	23 - 40
nh4					22.7	14 - 32
nh6a	68.2	36.6	58.7	15.7	36.8	29 - 46
nh6c	21.6	9.6	29.7	7.7	20.6	13 - 29
nh7					24.1	17 - 33
nh8b	112.3	52.1	81.4	21.1	37.6	30 - 46
nj12a					23.5	15 - 33
nj12b					18.2	11 - 27

Table 1c. Standardized wood turtle (*Glyptemys insculpta*) sampling sites in the Northeast Region, 2012–2013

Site Name	Open Population Estimate	Open Population Standard Error	Closed Population Estimate	Closed Population Standard Error	ZIP mixture model estimate	ZIP 95% confidence interval
nj6					1.0	0 9
nj9					1.2	0 21
ny3					31.6	23 - 41
pa1					30.3	22 - 39
pa10					25.4	18 - 34
pa11					22.5	14 - 31
pa2					0.0	0 0
pa3a					26.4	18 - 36
pa3b					24.1	16 - 33
pa4	n/a	n/a	6.4	2	21.8	14 - 31
va1					0.2	0 0
va10	149.6	32.6	198.4	43.6	36.3	29 - 44
va12					27.7	20 - 36
va13					26.4	19 - 34
va16					0.2	0 0
va17					0.1	0 0
va18					0.1	0 0
va2					0.2	0 0
va20					18.3	11 - 27
va21					1.9	0 8
va22					0.2	0 0
va23					0.2	0 0
va24b					0.0	0 0
va27	27	8.8	33.1	6.7	29.2	22 - 37
va28	140.6	65.4	119.5	35	28.2	21 - 36
va29	15.8	4	21.8	6.8	22.2	16 - 29
va32					0.1	0 0
va5					0.0	0 0
va6					0.2	0 0
va8					0.1	0 0
vt2					23.2	15 - 32
vt3						
wv1					22.6	14 - 32
wv2					23.6	15 - 33
N	17	18	24	24	78	
Minimum	16	0	6	2	0	
Mean	65.98	29.26	62.67	20.51	18.74	
Maximum	188	94	198	58	38	
St Dev.	53.25	26.15	49.59	17.10	11.95	
Total	1122	527	1504	492	1461	

Table 2. Correlation between environmental variables and normalized wood turtle (*Glyptemys insculpta*) survey success.

	Simple Term			Squared term		
Covariate	df	F-stat	P-value	df	F-stat	P-value
Air temperature	1,572	0.7279	0.7874	2,571	0.5477	0.9467
Water Temperature	1, 541	0.002225	0.9624	2,540	0.01625	0.9829
Air/Water differential	1,540	0.3137	0.5757	2,539	0.1566	0.8551
Air differential	1,267	0.4212	0.5169	2,266	0.311	0.7329
Start time	1,585	8.802	**0.0031**	2, 584	4.656	**0.0099**
Total time	1,585	3.56	0.0634	2,584	1.732	1.1778
Julian day (spring surveys)	1,256	0.2735	0.6015	2,255	0.5643	0.5694
Julian day (fall surveys)	1,282	0.5701	0.4509	2,281	0.2845	0.7526

Correlation between envrionmental variables and % of wood turtles observed on land

Covariate	df	F-stat	P-value	df	F-stat	P-value
Air temperature	1,430	37.49	**<0.0001**	2,429	26.79	**<0.0001**
Water temperature	1,404	12.96	**0.0004**	2,403	30.52	**<0.0001**
Air/Water differential	1,403	10.4	**0.0014**	2, 201	1.177	0.3102

Table 3. Best results of ZIP mixture models for sites with at least three wood turtle (*Glyptemys insculpta*) surveys conducted in the spring of 2012 or 2013.

Model	Number of Parameters
lam(impervious3k)p(~num_observers+julian_day+surveyduration)ZIP	7
lam(impervious3k)p(~num_observers+surveyduration+stream_width_m+julian_day)ZIP	8
lam(impervious3k)p(~num_observers+start_time+julian_day+surveyduration+stream_width_m)ZIP	9
lam(.)p(~num_observers+surveyduration+stream_width_m+julian_day)ZIP	7
lam(forest90m+impervious3k)p(~num_observers+start_time+julian_day+surveyduration+stream width)ZIP	10
lam(impervious3k)p(~num_observers+surveyduration+stream_width_m)ZIP	7
lam(impervious3k+forest90m)p(~num_observers+surveyduration+stream_width_m)ZIP	8
lam(impervious3k)p(~num_observers+start_time+surveyduration+stream_width_m)ZIP	8
lam(forest90m+impervious3k)p(~num_observers+start_time+surveyduration+stream_width_m)ZIP	9
lam(impervious3k)p(~julian_day+surveyduration)ZIP	6
lam(impervious3k)p(~season+num_observers+start_time+julian_day+stream_width_m)ZIP	8
lam(forest90m+impervious3k)p(~num_observers+start_time+julian_day+stream_width_m)ZIP	9
lam(.)p(survey duration)	4
lam(impervious3k)p(~num_observers+stream_width_m+start_time)ZIP	6
lam(impervious3k)p(~num_observers)ZIP	5
lam(forest90m+impervious3k)p(~num_observers)ZIP	6
lam(impervious3k)p(~num_observers+stream_width_m)ZIP	6
lam(forest90m+impervious3k)p(~num_observers+start_time+stream_width_m)ZIP	8
lam(.)p(number observers)ZIP	4
lam(.)p(day)ZIP	4
lam(.)p(gdd*day)ZIP	4
lam(impervious300m)p(.)ZIP	4
lam(impervious3000m)p(.)ZIP	4
lam(forest90m+impervious3k)p(~.)ZIP	5
lam(forest90m+impervious3k)p(~start_time+stream_width_m)ZIP	7
lam(forest90m+impervious3k)p(~stream_width_m)ZIP	6
lam(impervious90m)p(.)ZIP	4
lam(.)p(starttime)	4
lam(.)p(gdd)ZIP	4
lam(.)p(length)	4
lam(.)p(.)	3
lam(.)p(gdd*day*time)ZIP	4
lam(forest90m)p(.)ZIP	4
lam(.)p(elevation)ZIP	4
lam(.)p(width)	4

Table 4. Results of final "spring" ZIP mixture model, using sites with at least three wood turtle (*Glyptemys insculpta*) surveys in the spring of 2012 or 2013.

Abundance:

	Estimate	SE	z	P(>|z|)
(Intercept)	3.405	0.386	8.82	1.16E-18
Impervious within 3km	-0.244	0.113	-2.16	3.04E-02

Detection:

	Estimate	SE	z	P(>|z|)
(Intercept)	-2.646	0.41	-6.45	1.09E-10
Number of observers	0.181	0.0472	3.83	1.27E-04
Julian day	-0.097	0.0559	-1.74	8.24E-02
Survey duration	0.228	0.0462	4.95	7.51E-07

Zero-inflation:

	Estimate	SE	z	P(>|z|)
	-1.05	0.267	-3.93	8.40E-05

Table 5. Reassessments of long-term or intensive wood turtle (*Glyptemys insculpta*) study sites.

Site	Original Site Alias	State	Original Source	Years of Observation	Former density (turtles/rkm)	2012–2013 Project Lead	Current density (turtles/rkm)	Difference	Comments
nh6a	Site H (L)	NH	Jones 2009	2007	37.8	M. Jones and L. Willey	25.5	-12.3	Both original and current estimate are for adults only
nh6c	Site H (U)	NH	Jones 2009	2007	40.4	M. Jones and L. Willey	17.8	-22.5	Both original and current estimate are for adults only
ma13c	Site W	MA	Jones 2009	2006	14.5	M. Jones and L. Willey	21.5	7.0	Both original and current estimate are for adults only
ma13b	Site M	MA	Jones 2009	2006	24.9	M. Jones and L. Willey	n/a	n/a	Both original and current estimate are for adults only
ma14b	Site J	MA	Jones 2009	2005	24.0	M. Jones and L. Willey	14.4	-9.6	Both original and current estimate are for adults only
ma10a	Site B	MA	Jones 2009	2006	20.2	M. Jones and L. Willey	20.1	-0.1	Both original and current estimate are for adults only
ma12a	Site F	MA	Jones 2009	2005	13.0	M. Jones and L. Willey	28.6	15.6	Both original and current estimate are for adults only
ma12c	Site G	MA	Jones 2009	2005	15.4	M. Jones and L. Willey	21.3	5.9	Both original and current estimate are for adults only
ma19	Site P	MA	Jones 2009	2006	21.6	M. Jones and L. Willey	18.8	-2.9	Both original and current estimate are for adults only
pa3a	n/a	PA	Kaufmann 1992	1984–1989	129.2	K. Gipe	29.7	-99.5	Original estimate based on 84 turtles on 0.65 km segment
nj11a	n/a	NJ	Farrell and Graham 1991	1978–1981	261.7	R. Farrell	n/a	n/a	Original estimate from 4 annual estimates divided by 2.5 km (R. Farrell, pers. comm.)
va28	Site C	VA	Akre and Ernst 2006	1999–2002	33.9	L. Lemmon, J. Dragon, T. Akre	125.1	91.2	Original estimate provided for 2.6 km of stream
va7	Site E	VA	Akre 2002; Akre and Ernst 2006	1999–2000	46.3	A. Robinson et al.	25.0	-21.3	Original estimate based on raw capture data for 139 turtles divided by 3.0 km

Figures

Figure 1. Standardized survey site selection, illustrating the delineation of 1 kilometer survey segments in Google Earth. Note that both images are of leaf-off forest conditions. Leaf-off early spring images can be found for most regions using the Time Machine function in Google Earth. Note that both segments are in generally landscapes that are relatively constant even if they are heterogeneous: Segment A flows through an agri-forested landscape and Segment B through a deciduous floodplain forest. When possible we avoided major habitat shifts within a segment, for instance from intensive agriculture to mature forest, except as part of a mosaic landscape. Both sites depicted are believed to represent extirpated populations. Aerial images were obtained from Google Earth.

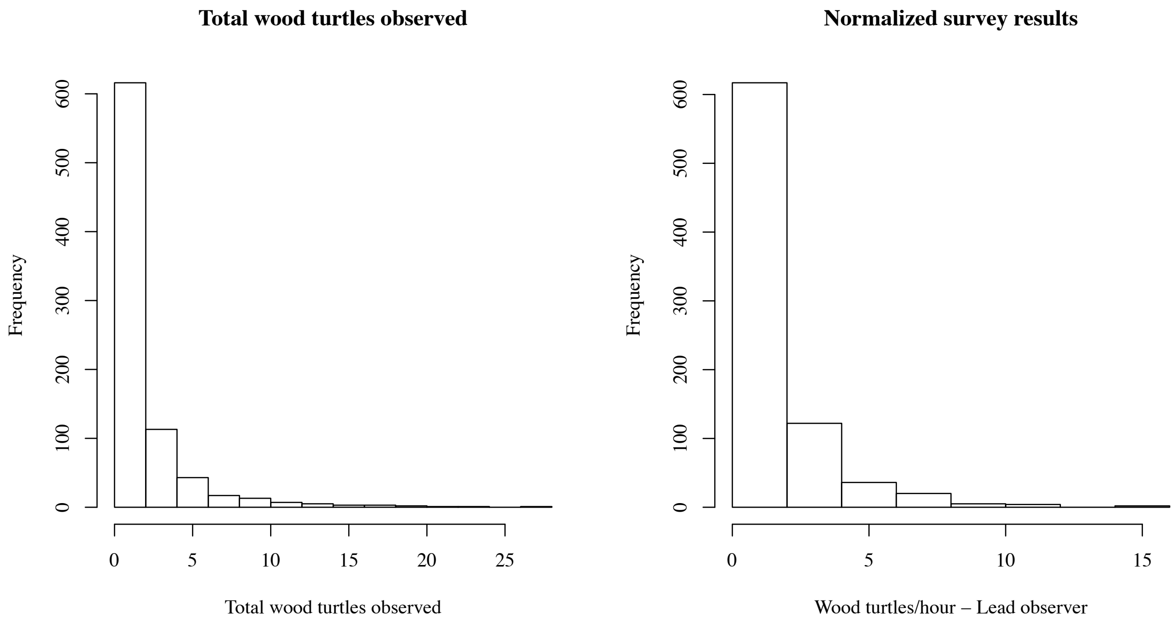

Figure 3. Histograms of total number of wood turtles observed (left) and wood turtles per hour for Observer 1 only (right).

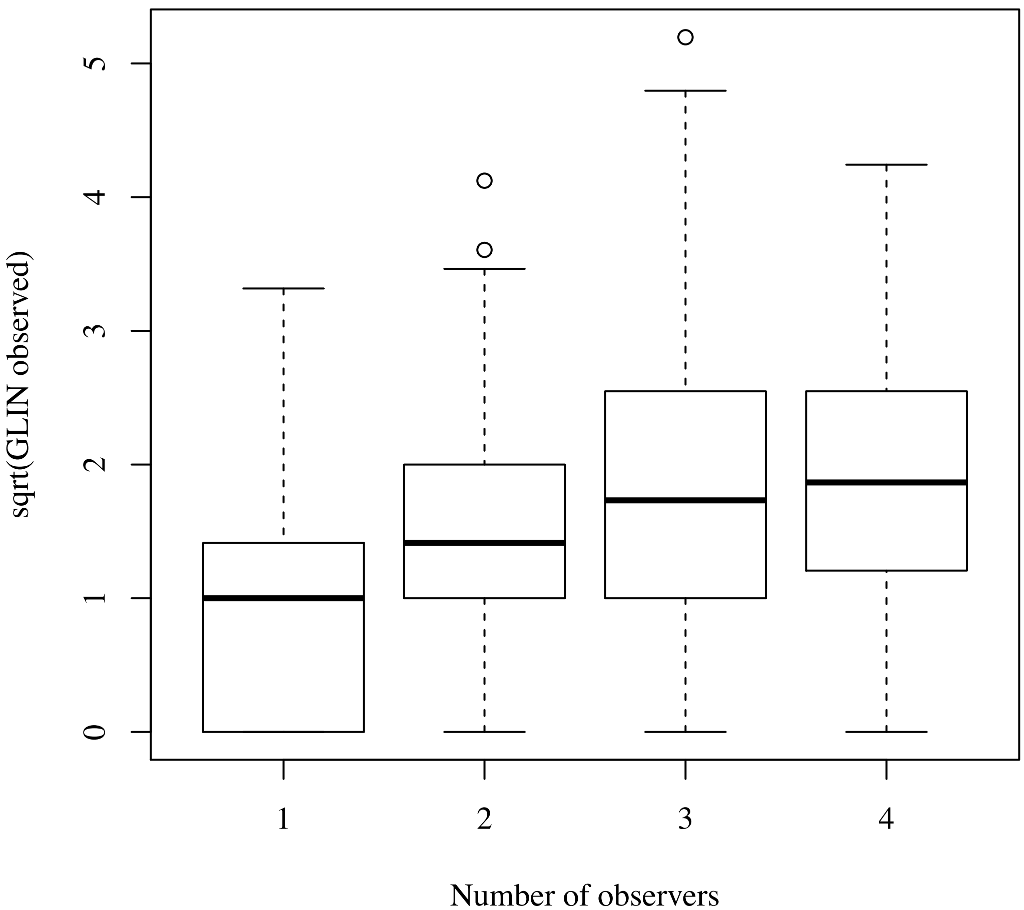

Figure 3. Square-root transformed capture rates of 1, 2, 3, and 4-observer teams.

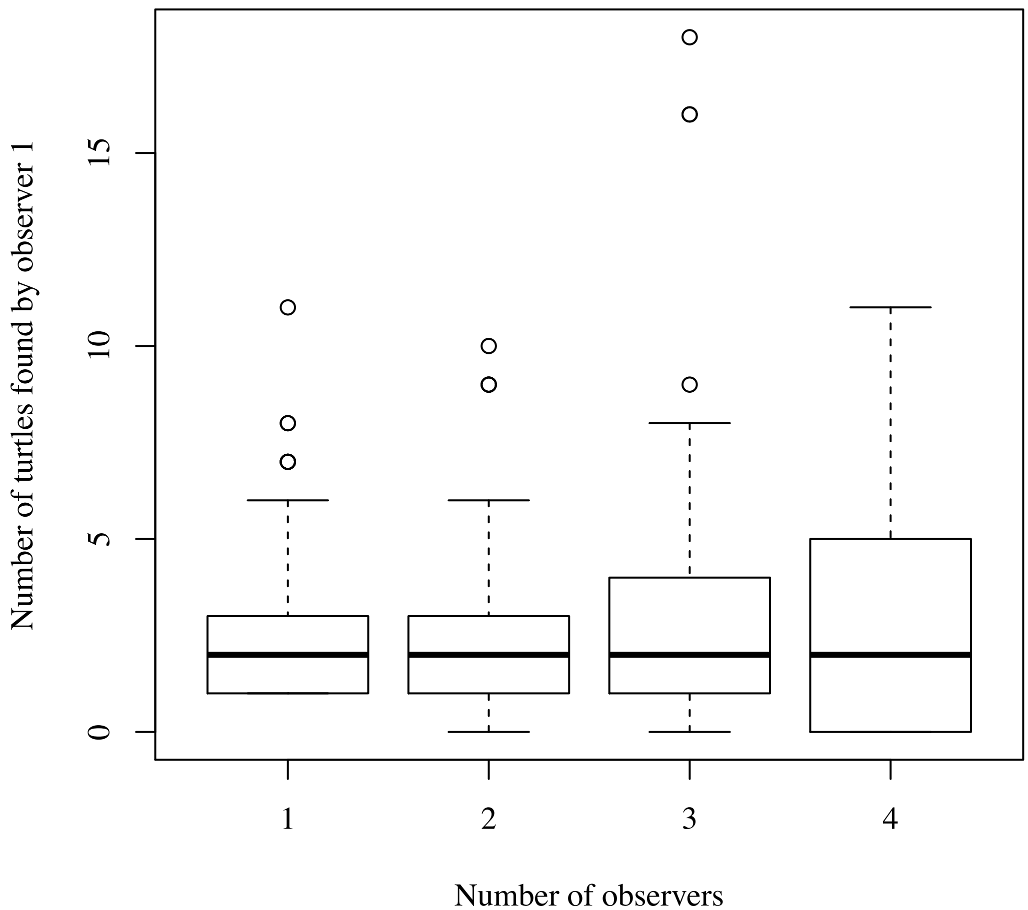

Figure 4. The effect of observer group size on the capture rates of Observer 1 (Lead Observer).

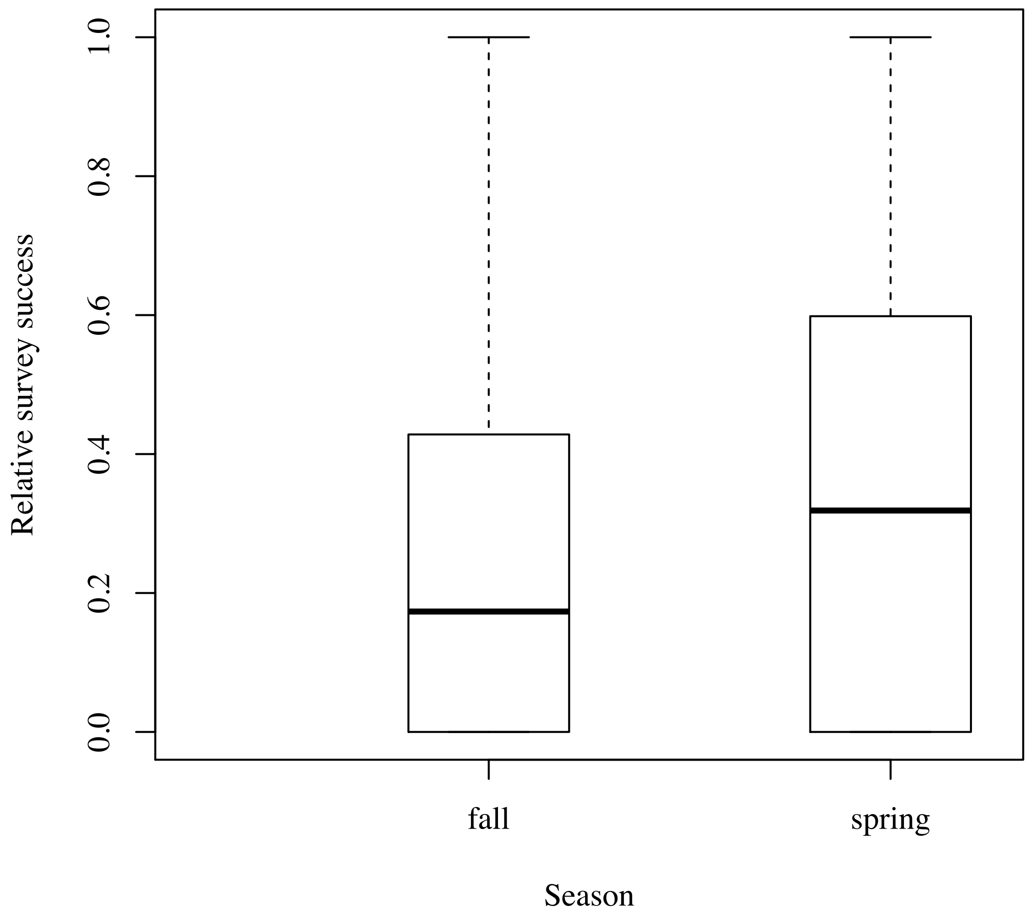

Figure 5. Although spring survey yield significantly higher detection rates than those in the fall, fall surveys perform about half as well as spring surveys and diversify the pool of captured and marked animals.

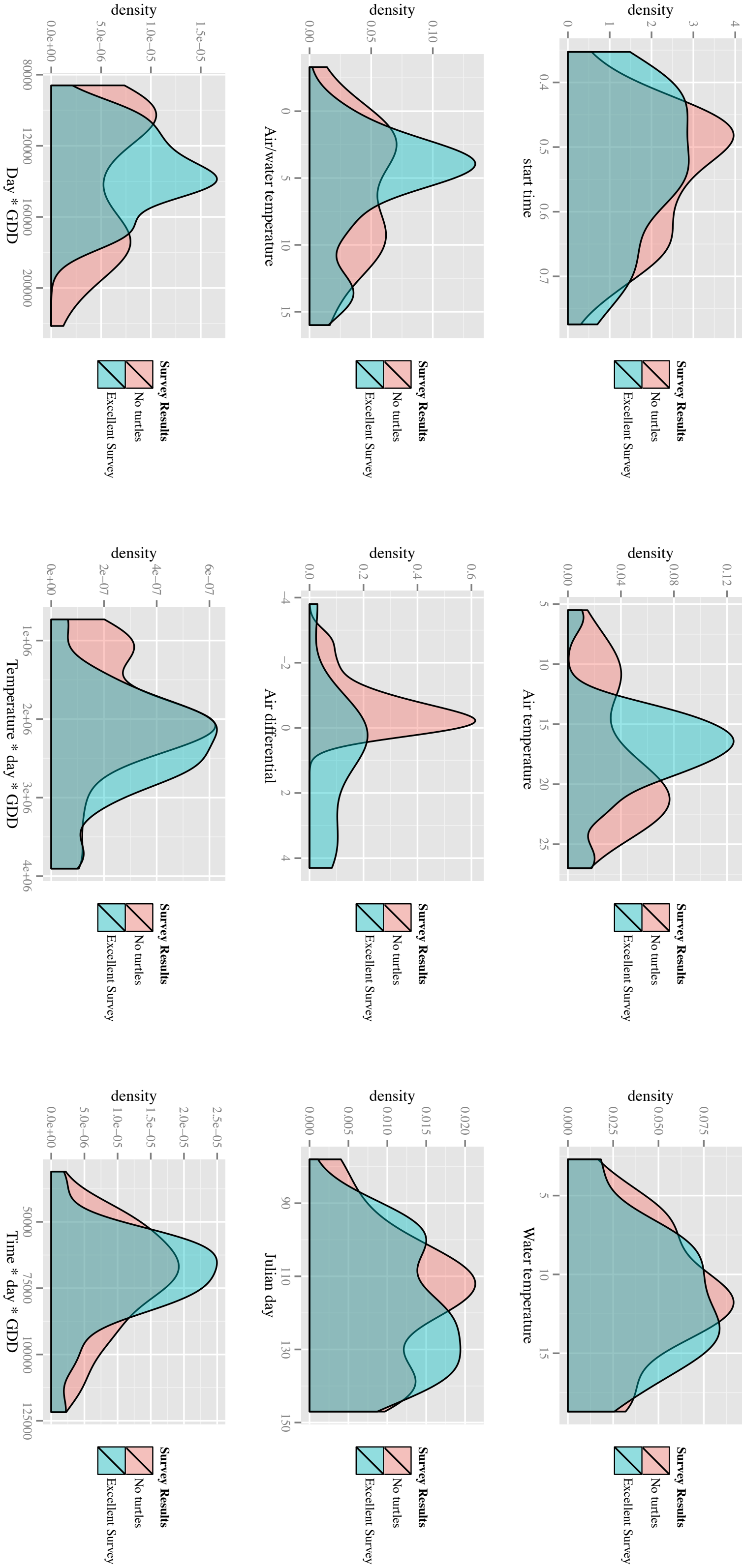

Figure 6. Effects of environmental parameters on the detection rates by Observer 1 (Lead Observer) in spring.

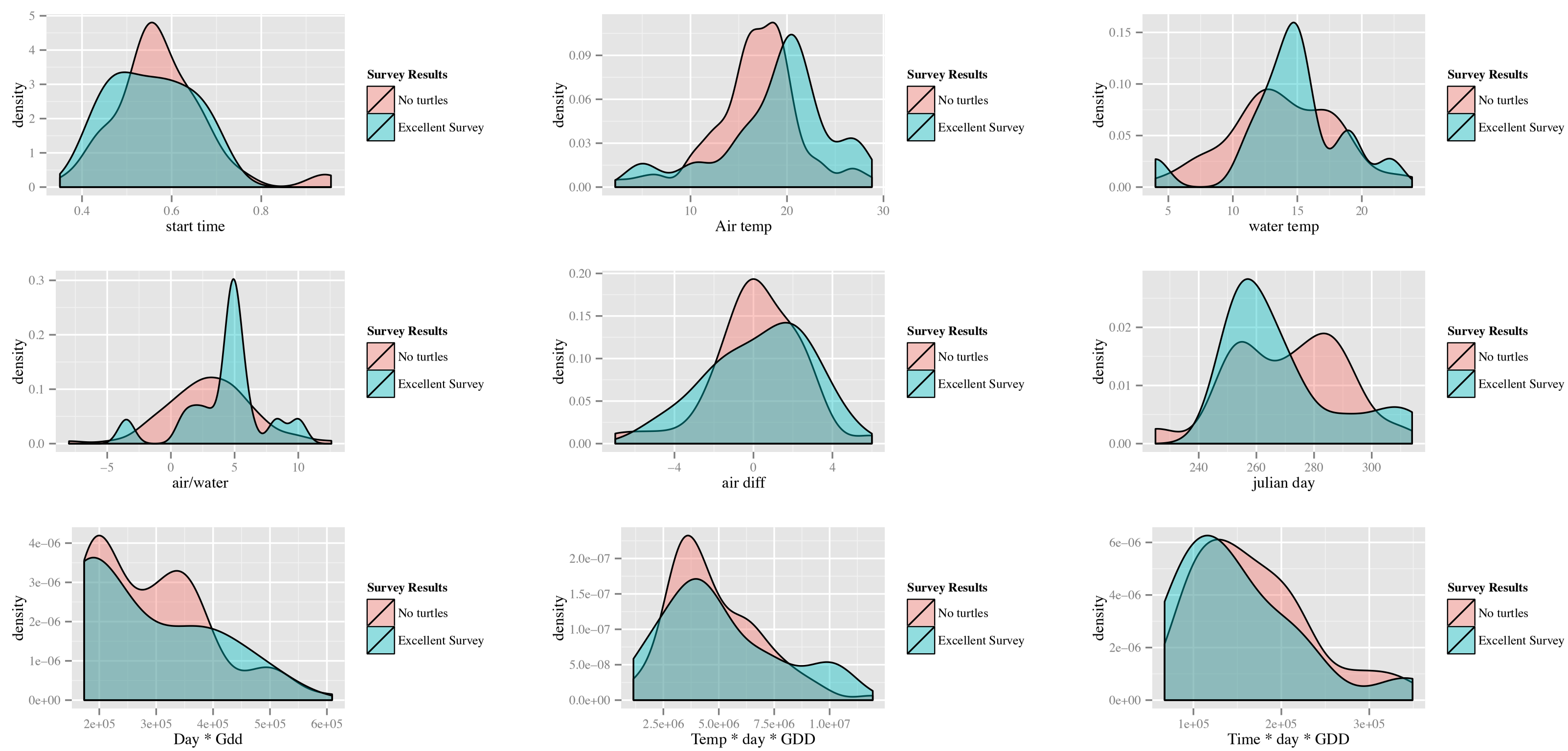

Figure 7. Effects of environmental parameters on fall detection rates by Observer 1 (Lead Observer).

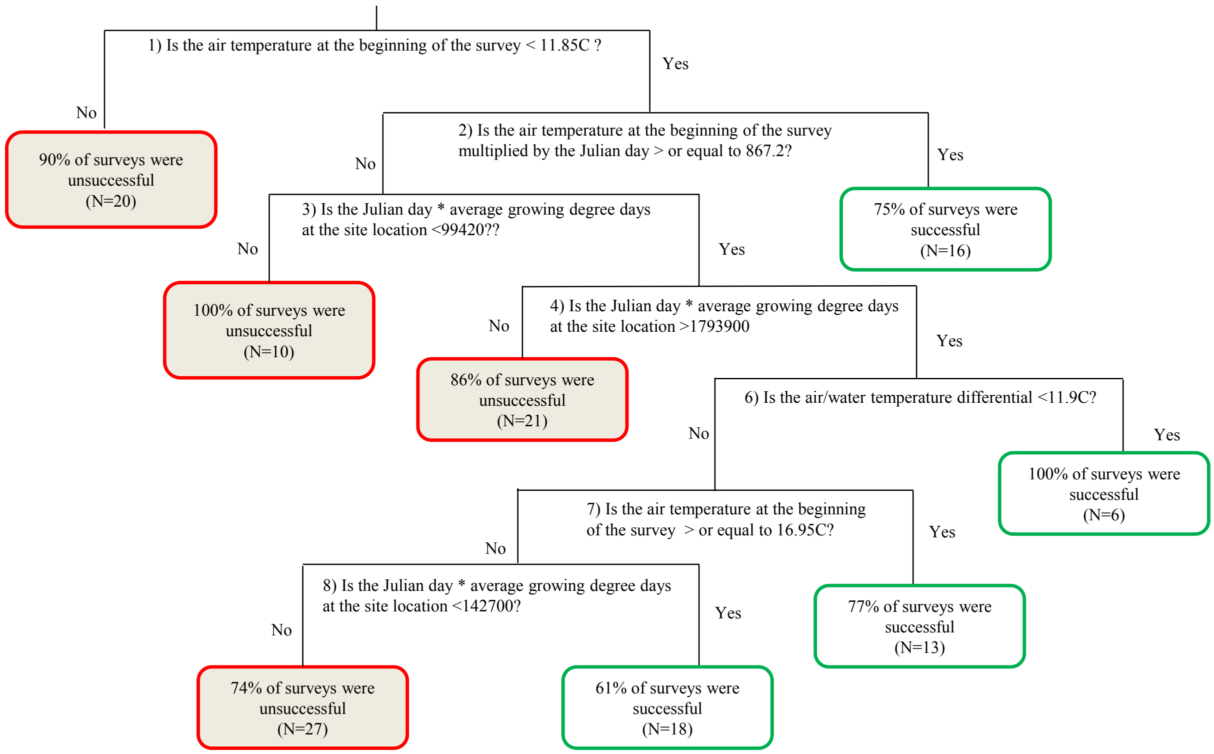

Figure 8. Classification and Regression Tree (CART) explaining positive detection for all sites with three or more surveys.

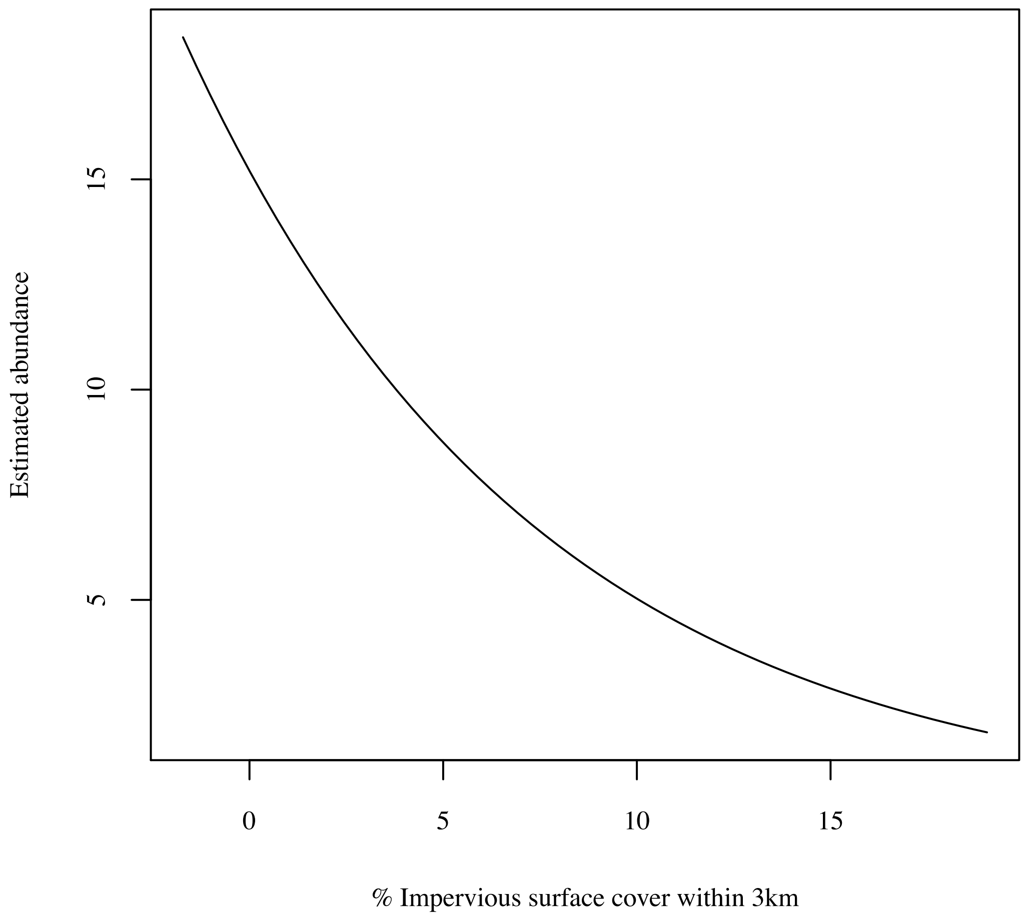

Figure 9. Relationship of estimated wood turtle abundance and % impervious surface cover within 3 km.

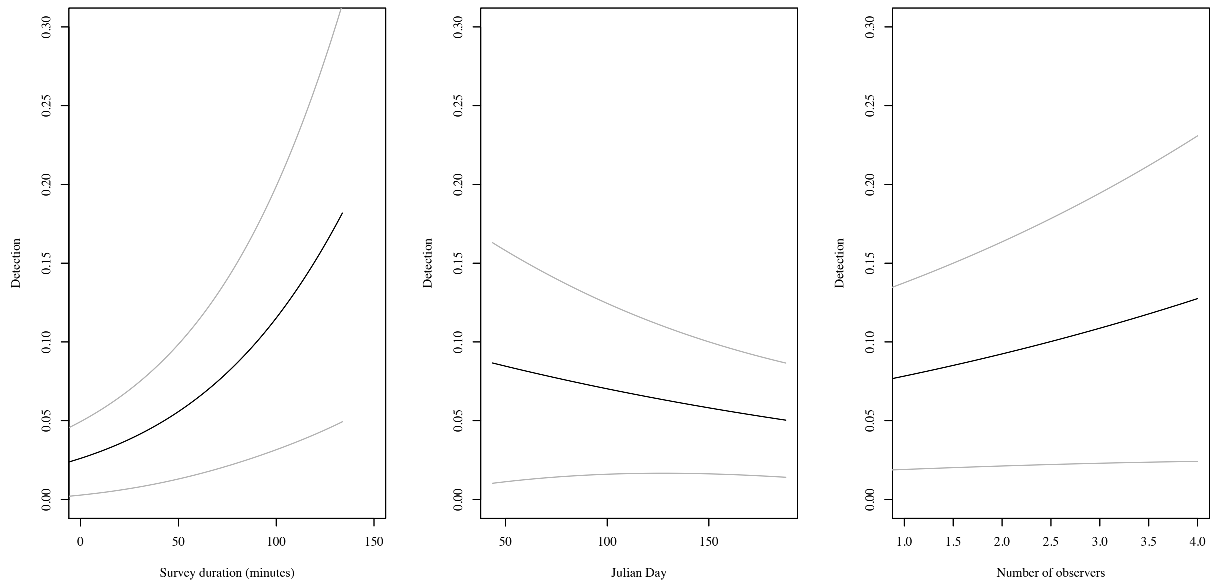

Figure 10. Effect of survey duration, Julian day, and number of observers on detection rates.

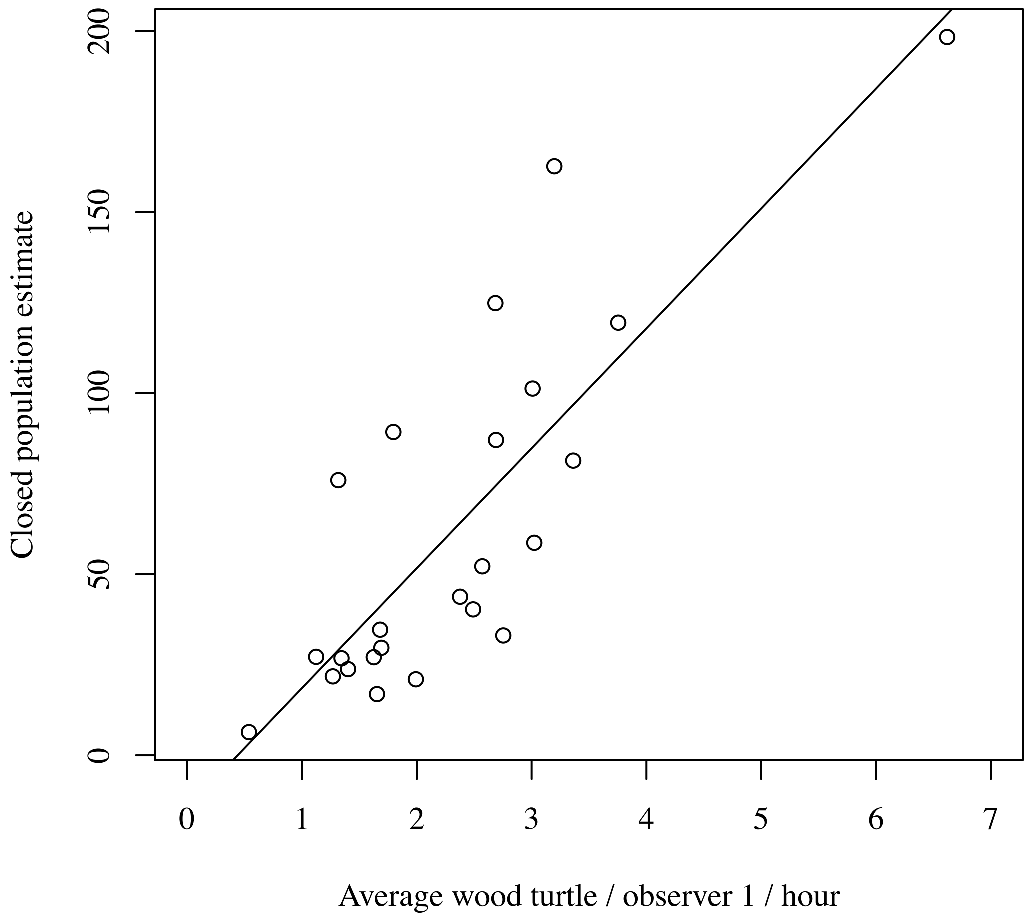

Figure 11. Relationship between closed population estimate and the average number of wood turtles detected by Observer 1 (Lead Observer) per hour.

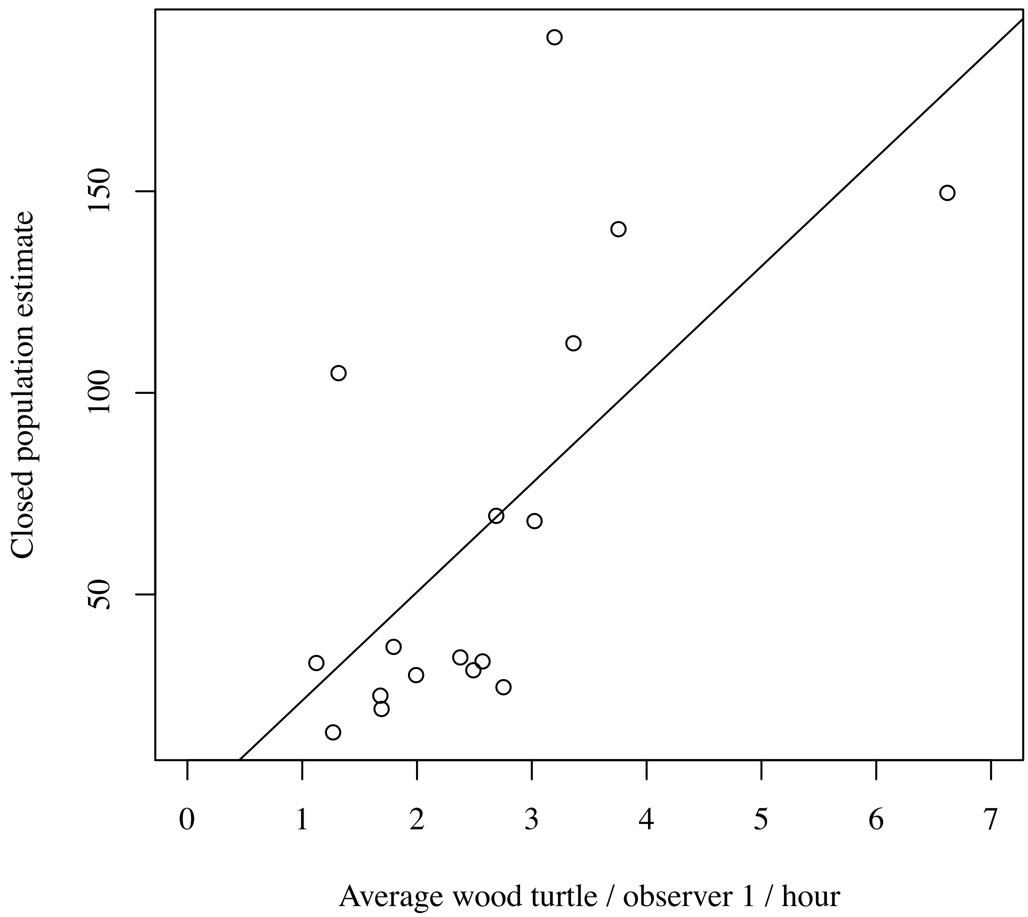

Figure 12. Relationship between open population estimate and the average number of wood turtles detected by Observer 1 (Lead Observer) per hour.

Figure 13. Wood turtles marked by previous researchers were detected at 13 LTR sites and several RA sites, including F2014 at Akre and Ernst's (2006) Site C, pictured ca. 2002 (A) and 2013 (B); M103 at Jones's (2009) Site F, pictured in 2004 (C), 2005 (D), and 2013 (E); and two turtles from Kaufmann's (1992) study, including an adult female that may be F3 (F) and an adult male that may be M24 (G and H). These sites are potentially critical sources of information about the long-term response of wood turtle populations to changing landuse and landcover, if the original data are accompanied with sufficient metadata and the databases are reconciled. Photographs © Kathy Gipe, Thomas Akre, and Michael T. Jones

Part 4. Evaluation of Recent Distributional Trends

Summary

There is compelling evidence that wood turtles have sustained widespread declines in most regions, and further evidence to suggest that declines are ongoing. Most previous long-term or repeat-interval studies have demonstrated quantifiable declines. Nearly all reviewers to closely examine certain geographic areas have concluded that wood turtles have experienced a range contraction or substantial reduction in numbers, especially in the vicinity of Boston, Worcester, New York, Havre de Grace, Baltimore, and Washington. Historical data suggest an eastward contraction away from the Great Lakes and Ohio-Pennsylvania border. A strong anecdotal link has been established between the decline of wood turtles associated with urbanization and loss of riparian and upland habitats or degraded stream quality. Preliminary analyses in Part 3 of this report indicated a strong negative relationship between impervious surface cover at the 3 km scale and the abundance of wood turtles at standardized survey plots. It is certainly the conclusion (and presumption) of most wood turtle researchers that the species has declined substantially and is continuing to decline—so it is essential that we be overly critical of our own methods to explore this phenomenon. In this section, we investigate the relationships between wood turtle abundance and land cover (broadly expressed as forested or urbanized) at multiple scales. We then extrapolate the modeled relationship to the stream-based Species Distribution Model (SDM) developed in Part 2. We quantify the extent of severe habitat alteration at multiple scales. Based on the original analysis, it appears that over 50% of suitable stream habitat in the Northeast Region has been potentially impaired by urbanization and deforestation. Further, our results strongly suggest that wood turtle abundance is influenced by urbanization and deforestation at relatively large scales, larger than the annual home ranges of wood turtles. Using these original datalayers and minimum numbers of turtles observed onsite, we identified 145 potentially significant populations in the Northeast region, 90 or which occur in potentially optimal landscape conditions.

Methods

We used results from the 2012-2013 regional sampling effort (Part 3), to evaluate the potential effects of land cover on wood turtle abundance. We then built models to describe the relationship between urbanization and abundance and applied those models to the SDM developed in Part 2 in order to evaluate the potential status of wood turtle habitat throughout the Northeast.

Model development

Results in Part 3 confirm that raw survey returns by the lead observer under repeated sampling is a good indicator of modeled wood turtle abundance at sites sampled frequently enough to develop open population models. We therefore attempted to use the larger database of average results from observer 1 to evaluate the effects of landscape factors on survey returns, as a surrogate for wood turtle abundance.

We first evaluated the best scale at which to build the models, following Charney (2012). We did this by calculating landscape characteristics in a series of buffers around each surveyed stream segment. The four landscape variables we calculated were:

Forest cover: Classes 41, 42, and 43 from the 2006 NLCD

Urban development: Classes 21, 22, 23, and 24 from the 2006 NLCD

Impervious surface cover from the 2006 NLCD

Agricultural cover: Classes 81 and 82 from the 2006 NLCD

For each of these four variables, we calculated average values in buffers surrounding each stream segment at 90 meter intervals from 90 to 2070m, and then every 500m to 10 km, in addition to a 300m buffer, which is often used for regulatory purposes. This resulted in 40 values for each variable.

Our objectives were to:

1. Predict landscape characters associated with excellent sites (i.e., those in the top 25th percentile of survey returns). All sites where more than 1.35 turtles were observed on an average survey by observer 1 were placed into this category and given a value of 1 (N=48), those with fewer than 1.35 turtles on average were given a value of 0 (N=144).
2. Predict landscape characteristics associated with sites not likely to support significant populations. To estimate this, all sites visited three times that returned 0 on all three surveys were placed in the 0 category (N=38), while those visited 3 times with at least 1 turtle observed were placed in the 1 category (N=89).

We then fit simple logistic regression models for each of the four variables at each of the 40 scales for each of the two response variables. For each model, we calculated AIC, P-values, D^2, and the parameter estimate, and created plots to evaluate how model strength varied with the scale of the variable. We evaluated the plots to determine the most influential scale for all four variables.

The forest and urban cover AIC plots (Figure 1) begin to reach a minimum at a scale of approximately 5,500 m while agriculture reaches a minimum at about 3,000 m. We therefore used these scales to move into the next phase of model selection. The AIC plots for impervious surface cover and urban cover have local minima at around 300 m, so we included this scale as well. We also included the 90m scale, because this is known to be biologically relevant for wood turtle (see Part 1).

We fit multiple logistic regression models for the two response variables (excellent sites and sites that returned 0 survey results) using 16 potential variables: forest cover, urban cover, impervious surface cover, and agricultural cover at 90, 300, 300, and 5500m scales. We used an all-subsets approach to determine which two-variable model performed the best for each of the two predictor variables. We evaluated the selected models using a Hosmer Lemeshow goodness of fit test (Hosmer and Lemeshow 2000).

Model Application

We applied these the “excellent site” and “zero return site” models to the Species Distribution Model (SDM) results from Part 2 in order to evaluate the percent of potential wood turtle habitat with similar landscape characteristics as those stream segments that produced excellent and poor survey results, and that may therefore have optimal landscape contexts or potentially impaired habitat conditions. For each of the stream segments identified as potential habitat in Part 2, we applied the two logistic regression models described above. We then classified each segment as potentially impaired if it fell below the selected cutpoint for the zero survey results model, or potentially optimal if it fell above the cutpoint for the top 25th percentile survey results model. We calculated the number of stream segments that fell into each of these classes in each state, county, watershed, and region as a whole.

We also evaluated the logistic regression scores of the stream segments known to have corroborated occurrences (Part 2). We then compared the relative impairment of historic (before 1983) and recent corroborated occurrences using a probability density function and a t-test.

Results

Model Fit

Stream segments in the top 25th percentile for survey returns (average of 1.35 turtles or more per Lead Observer per standardized survey) were best predicted by urban cover at 300 m and forest cover at 5500 m. Probability of high survey returns increase with increasing forest cover and decreasing urbanization at these scales (Figure 2). This model was significant ($D_{2,189}$=31.03, P<0.001), and a Hosmer Lemeshow test suggested no evidence for lack of fit (X^2_8=4.20, P=0.84). We used the PresenceAbsence package (Freeman and Moisen 2008) in R (R core team 2012) to select the threshold (threshold=0.35) for this model that maximized Kappa (K=0.34).

Zero survey results after three standardized surveys were best predicted by urban cover at 90 m and forest cover at 5500 m. Probability of survey returns greater than zero after three surveys increased significantly with forest cover at the broad scale and decreased significantly with urban cover at the fine scale (Figure 3). This model was also significant ($D_{2,124}$=37.53, P<0.001), explained 24.2% of the variation in survey results, and also showed no evidence for lack of fit using the Hosmer Lemeshow test (X^2_8=8.42, P=0.39). A threshold of 0.71 maximized Kappa (K=0.49) for this model.

Model application and estimate of impaired and optimal habitats

Of the 127,000 km of potentially suitable stream habitat in the Northeast, approximately 58% were scored as potentially impaired, that is, they share similar landscape characteristics (i.e., the percent urban cover at 300m and percent forest cover at 5500 m) to those stream segments that returned no wood turtles after three standardized surveys (Figure 5). Approximately 18% of potential stream habitat were scored as potentially optimal landscape context, that is, they share landscape characteristics with those survey sites that fell in the top 25th percentile of sites (i.e., >1.35 turtles were found by the first observer / survey on average) (Figure 6).

We evaluated the scores of segments known to have recent corroborated occurrences and those with only historic records, and plotted them using a probability density function (Figure 6). Historic occurrences, with no recent corroboration had significantly higher "impairment" scores (i.e., had landscape characteristics that made them significantly more likely to return no turtles after three standardized surveys ($t_{60.335}$=-3.263, P=0.0018) than those with recent occurrences.

Potentially Significant Populations

We used the corroborated occurrence database from Part 2 in conjunction with the potentially optimal landscape condition model, derived in Part 4, to identify potentially significant, known populations of wood turtle. Corroborated occurrences were considered potentially significant if they had either a known minimum population size of 20 animals (i.e., at least 20 wood turtles had been observed on site), or a known minimum population size of five turtles in potentially optimal landscape condition (as described above). Using this definition, there are 145 potentially significant populations in the Northeast region, 90 or which occur in potentially optimal landscape conditions. These are detailed by state and HUC4 in Table 4. Shapefiles delineating these populations were provided to the States.

Discussion

We were able to successfully model the results of standardized wood turtle surveys based on broad scale land cover characteristics, suggesting that there may, in fact, be a significant and predictable influence of landscape context on the ability of a stream segment to support a significant population of wood turtles. Regardless of the scale evaluated or the specific response predictor being evaluated, wood turtle survey results increased with forest abundance surrounding the site and decreased with urbanization, impervious surface cover, and agricultural cover. Of the variables measured, forest cover, particularly at the broad scale, tended to be the best predictor of survey results. Urban and impervious surface cover are highly correlated and both had local minima in AIC around 300 m, but had the best fit at broader scales as well. Agricultural cover was also a significant predictor of survey returns, and fit best at the 3000 m scale, but forest and urban cover were better predictors of survey returns and therefore agriculture was not included in the final models.

Although we were able to fit significant models, neither model had a large explanatory power, and though better than chance, kappas were relatively low for both models (0.34 and 0.49). This is not surprising given the many factors that affect survey results and the fact that only two variables were included in the models.

Because of our relatively limited sample size, we fit fairly simple (two variable) models. As more data become available from surveys and more sites have population estimates or more robust survey results available, these models should be revisited and improved upon. Future work could further explore these and other variables in the n-mixture model framework described in Part 3, or in another framework that makes use of the count nature of the data (survey results), rather than a binary response as we have done here.

In generalizing our survey results across the Species Distribution Model (SDM) described in Part 2, we can obtain a general sense of the relative likelihood of survey success under various conditions available on the landscape. The majority of stream segments that are geomorphically and climatically suitable for wood turtle in the Northeast have relatively high urban cover at the fine scale and relatively low forest cover at the broad scale, such that they are similar to those stream segments that returned zeroes after three standardized surveys. This metric may be indicative of the inability of these landscapes to support significant populations, though additional field and modeling work needs to be undertaken to validate this hypothesis. In any case, this exercise provides tools to preliminarily assess potential wood turtle habitat impairment at the state, watershed, and county level (or other scales as necessary or appropriate), and provides a basemap to guide part of a regional sampling strategy.

Further, the fact that historic wood turtle occurrences (see Part 2) that have not been corroborated in the past 30 years (pre-1983) occur on stream segments more likely to return zeroes during survey events based on landscape context suggests that many of these populations may have been extirpated or substantially reduced as a result of landscape change, or conversion of forested landscapes to urbanization. Although both datasets (the survey results and the corroborated occurrences) are limited in size and scope and biased in their locations, these two independent datasets both corroborate the pattern that abundance appears to be reduced in more urban contexts, and both suggest that a large portion of the Northeast may no longer be suitable to support large populations of wood turtles. Standardized, randomized field surveys should specifically test this hypothesis, and land managers should take note of predicted conditions in their states.

Tables

Table 1. Assessment of potential impaired habitat for wood turtles in the northeastern States.

State	Total stream habitat (km)	km of potentially impaired habitat	% of habitat that is potenitally impaired	km with optimal landscape condition	% of habitat with optimal landscape condition
Maine	18211	3790	21%	6087	33%
New Hampshire	4627	1666	36%	1540	33%
Vermont	2987	1318	44%	746	25%
Massachusetts	6172	4395	71%	569	9%
Rhode Island	650	423	65%	23	4%
Connecticut	3541	2363	67%	189	5%
New York	21470	13162	61%	3127	15%
New Jersey	8233	6945	84%	244	3%
Pennsylvania	46258	30178	65%	7890	17%
Delaware	437	437	100%	0	0%
Maryland	5739	4814	84%	461	8%
Virginia	6025	3876	64%	1118	19%
West Virginia	3182	979	31%	1395	44%
Total	127532	74344	58%	23389	18%

Table 2. Assessment of potential impaired habitat for wood turtles in the northeastern watersheds (HUC4).

Watershed	Total stream habitat (km)	km of potentially impaired habitat	% of habitat that is potenitally impaired	km with optimal landscape condition
101 St. John	3465	661	19%	1538
102 Penobscot	5026	597	12%	1989
103 Kennebec	2751	578	21%	702
104 Androscoggin	1769	366	21%	708
105 Maine Coastal	3077	698	23%	909
106 Saco	3281	1373	42%	552
107 Merrimack	3355	1878	56%	717
108 Connecticut	6233	2792	45%	1628
109 Massachusetts-Rhode Island Coastal.	2555	2240	88%	26
110 Connecticut Coastal	3463	2160	62%	204
111 St. Francois	196	100	51%	20
201 Richelieu	1270	683	54%	203
202 Upper Hudson	9811	6687	68%	1224
203 Lower Hudson-Long Island	5184	4480	86%	179
204 Delaware	16908	12547	74%	2066
205 Susquehanna	25571	15859	62%	4446
206 Upper Chesapeake	2030	1964	97%	0
207 Potomac	12919	7993	62%	2859
208 Lower Chesapeake	1227	408	33%	406
412 Eastern Lake Erie-Lake Erie	774	617	80%	1
413 Southwestern Lake Ontario	604	441	73%	24
414 Southeastern Lake Ontario	976	718	74%	81
415 Northeastern Lake Ontario-Lake Ontario-S	1509	646	43%	415
501 Allegheny	9004	4269	47%	2102
502 Monongahela	1915	1260	66%	374
503 Upper Ohio	2657	2327	88%	17

Table 3a. Assessment of potential impaired habitat for wood turtles in the counties of Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, and New Hampshire. The most recent occurrence data is the last observation from a corroborated occurrence site (Part 2) and may not reflect the last time a single turtle was observed in the county.

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
Connecticut	Fairfield	264	237	90%	1	0%	5.55	4	4	0	2011
Connecticut	Hartford	690	605	88%	12	2%	4.58	12	9	2	2012
Connecticut	Litchfield	717	379	53%	83	12%	0.77	12	10	0	2011
Connecticut	Middlesex	187	106	57%	19	10%	1.68	0			
Connecticut	New Haven	318	277	87%	2	1%	5.42	9	7	1	2009
Connecticut	New London	404	232	57%	13	3%	1.50	2	2	0	2006
Connecticut	Tolland	348	203	58%	23	7%	1.40	8	8	0	2009
Connecticut	Windham	501	256	51%	25	5%	0.87	6	6	0	2012
Delaware	Kent	61	61	100%	0	0%	0.98	0			
Delaware	New Castle	328	328	100%	0	0%	4.60	1	1	0	2011
District of Columbia	District of Columbi	2	2	100%	0	0%	33.74	0			
Maine	Androscoggin	442	191	43%	3	1%	0.83	0			
Maine	Aroostook	3310	687	21%	1521	46%	0.04	19	14	3	2013
Maine	Cumberland	704	383	54%	28	4%	1.18	5	4	1	2013
Maine	Franklin	689	109	16%	319	46%	0.06	5	5	0	2010
Maine	Hancock	667	95	14%	319	48%	0.12	1	0	0	
Maine	Kennebec	487	190	39%	17	4%	0.49	0			
Maine	Knox	212	71	34%	12	5%	0.42	0			
Maine	Lincoln	312	52	17%	61	20%	0.27	2	2	0	2004
Maine	Oxford	1308	157	12%	706	54%	0.10	8	7	1	2011
Maine	Penobscot	2452	387	16%	757	31%	0.16	6	6	0	2004
Maine	Piscataquis	1788	104	6%	905	51%	0.01	15	15	0	2013
Maine	Sagadahoc	135	64	48%	11	8%	0.49	0			
Maine	Somerset	1982	249	13%	593	30%	0.05	23	22	0	2013
Maine	Waldo	490	93	19%	112	23%	0.20	1	1	0	1999
Maine	Washington	1672	362	22%	518	31%	0.04	4	4	0	1998
Maine	York	973	429	44%	58	6%	0.79	9	9	0	2013
Maryland	Allegany	425	141	33%	220	52%	0.61	17	16	0	2011
Maryland	Anne Arundel	136	135	100%	0	0%	5.05	0			
Maryland	Baltimore	337	315	93%	0	0%	5.17	2	1	1	2011
Maryland	Baltimore City	34	34	100%	0	0%	30.26	0			
Maryland	Calvert	36	30	83%	0	0%	1.63	0			
Maryland	Caroline	1	1	100%	0	0%	0.38	0			
Maryland	Carroll	479	479	100%	0	0%	1.53	0			
Maryland	Cecil	185	185	100%	0	0%	1.11	1	0	1	1947
Maryland	Charles	205	111	54%	1	0%	0.92	1	1	0	1995
Maryland	Frederick	873	826	95%	16	2%	1.40	2	0	2	1972
Maryland	Garrett	246	48	19%	135	55%	0.16	5	4	1	2010
Maryland	Harford	373	371	100%	0	0%	2.23	5	2	2	2010
Maryland	Howard	173	173	100%	0	0%	4.69	0			
Maryland	Kent	83	83	100%	0	0%	0.25	0			
Maryland	Montgomery	526	521	99%	0	0%	7.53	5	2	1	2012
Maryland	Prince Georges	352	328	93%	0	0%	6.88	1	1	0	1995
Maryland	Queen Annes	78	78	100%	0	0%	0.49	0			
Maryland	St Marys	11	5	46%	0	0%	0.65	0			
Maryland	Washington	537	441	82%	25	5%	1.17	10	9	0	2012
Massachusetts	Barnstable	1	1	100%	0	0%	2.17	0			
Massachusetts	Berkshire	626	343	55%	94	15%	0.51	25	25	0	2010
Massachusetts	Bristol	302	296	98%	0	0%	3.72	3	3	0	2010
Massachusetts	Essex	357	352	99%	0	0%	5.63	7	7	0	2013
Massachusetts	Franklin	489	181	37%	155	32%	0.38	30	29	1	2013
Massachusetts	Hampden	465	297	64%	63	14%	2.85	18	18	0	2013
Massachusetts	Hampshire	508	300	59%	105	21%	1.12	23	21	1	2013
Massachusetts	Middlesex	801	712	89%	12	2%	6.76	21	13	8	2012
Massachusetts	Norfolk	308	308	100%	0	0%	6.21	1	1	0	2010
Massachusetts	Plymouth	454	444	98%	0	0%	2.83	1	1	0	1993
Massachusetts	Suffolk	2	2	100%	0	0%	47.34	0			
Massachusetts	Worcester	1592	966	61%	106	7%	1.96	34	33	1	2012
New Hampshire	Belknap	116	33	28%	39	34%	0.52	4	4	0	2010
New Hampshire	Carroll	454	99	22%	207	46%	0.19	0			
New Hampshire	Cheshire	492	125	25%	206	42%	0.41	14	13	1	2009
New Hampshire	Coos	354	67	19%	158	45%	0.06	15	11	0	2013
New Hampshire	Grafton	657	167	25%	296	45%	0.19	25	24	0	2013
New Hampshire	Hillsborough	741	356	48%	187	25%	1.87	18	15	0	2012
New Hampshire	Merrimack	585	171	29%	200	34%	0.62	15	14	1	2013
New Hampshire	Rockingham	489	361	74%	20	4%	1.68	5	5	0	2010
New Hampshire	Strafford	239	149	62%	16	7%	1.27	5	5	0	2010
New Hampshire	Sullivan	333	75	23%	145	44%	0.29	4	4	0	2006

Table 3b. Assessment of potential impaired habitat for wood turtles in the counties of New York and New Jersey.

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
New Jersey	Atlantic	40	36	92%	0	0%	2.07	0			
New Jersey	Bergen	337	325	96%	3	1%	15.25	4	4	0	2008
New Jersey	Burlington	391	252	64%	11	3%	2.22	1	1	0	2008
New Jersey	Camden	2	2	100%	0	0%	9.14	0			
New Jersey	Essex	142	142	100%	0	0%	25.22	2	0	2	1979
New Jersey	Gloucester	3	3	100%	0	0%	3.36	0			
New Jersey	Hunterdon	1122	1089	97%	0	0%	1.21	17	17	0	2011
New Jersey	Mercer	372	356	96%	0	0%	6.56	2	2	0	2010
New Jersey	Middlesex	269	269	100%	0	0%	10.63	2	1	1	2009
New Jersey	Monmouth	443	439	99%	0	0%	5.43	5	2	3	2001
New Jersey	Morris	937	746	80%	22	2%	4.13	14	14	0	2011
New Jersey	Ocean	576	394	68%	53	9%	3.55	3	1	2	2002
New Jersey	Passaic	320	198	62%	42	13%	10.52	2	2	0	2008
New Jersey	Salem	12	12	100%	0	0%	0.69	0			
New Jersey	Somerset	704	691	98%	0	0%	4.40	7	7	0	2012
New Jersey	Sussex	1154	763	66%	102	9%	1.13	34	30	4	2013
New Jersey	Union	56	56	100%	0	0%	20.64	2	2	0	1998
New Jersey	Warren	729	579	79%	9	1%	1.19	14	14	0	2012
New York	Albany	294	229	78%	8	3%	2.19	3	3	0	1998
New York	Allegany	316	136	43%	45	14%	0.18	0			
New York	Broome	546	317	58%	34	6%	1.02	0			
New York	Cattaraugus	719	259	36%	185	26%	0.23	1	0	1	1968
New York	Cayuga	89	88	99%	0	0%	0.41	0			
New York	Chautauqua	735	572	78%	0	0%	0.47	0			
New York	Chemung	232	138	60%	13	5%	0.79	1	1	0	1998
New York	Chenango	666	295	44%	70	11%	0.21	0			
New York	Clinton	103	61	59%	22	22%	0.28	4	4	0	1999
New York	Columbia	733	590	81%	8	1%	0.36	3	3	0	1999
New York	Cortland	321	211	66%	2	1%	0.36	0			
New York	Delaware	572	165	29%	220	38%	0.11	10	6	2	1999
New York	Dutchess	1180	884	75%	8	1%	1.45	9	8	0	2012
New York	Erie	191	156	82%	0	0%	3.45	1	1	0	1997
New York	Essex	230	23	10%	158	69%	0.07	10	9	0	2001
New York	Franklin	178	74	42%	78	44%	0.11	5	5	0	2009
New York	Fulton	312	200	64%	29	9%	0.38	0			
New York	Genesee	143	141	99%	0	0%	0.43	0			
New York	Greene	411	225	55%	46	11%	0.28	1	1	0	1994
New York	Hamilton	273	1	0%	243	89%	0.01	0			
New York	Herkimer	459	349	76%	14	3%	0.16	1	1	0	2011
New York	Jefferson	290	223	77%	6	2%	0.37	4	3	0	2009
New York	Lewis	435	161	37%	104	24%	0.07	0			
New York	Livingston	113	102	91%	0	0%	0.38	0			
New York	Madison	293	270	92%	0	0%	0.40	0			
New York	Monroe	20	20	100%	0	0%	4.50	0			
New York	Montgomery	251	249	99%	0	0%	0.42	1	1	0	1999
New York	Niagara	23	23	100%	0	0%	1.60	0			
New York	Oneida	682	473	69%	19	3%	0.74	2	2	0	2003
New York	Onondaga	117	114	98%	0	0%	2.32	0			
New York	Ontario	59	45	77%	0	0%	0.61	0			
New York	Orange	1234	974	79%	133	11%	1.91	16	14	2	2013
New York	Orleans	9	9	100%	0	0%	0.42	0			
New York	Oswego	144	67	47%	36	25%	0.48	7	7	0	2006
New York	Otsego	638	407	64%	2	0%	0.23	1	1	0	1999
New York	Putnam	394	247	63%	49	13%	1.67	2	1	0	2005
New York	Rensselaer	631	464	74%	74	12%	0.91	4	3	0	2013
New York	Richmond	2	2	100%	0	0%	36.29	0			
New York	Rockland	257	219	85%	21	8%	6.22	1	1	0	1999
New York	Saratoga	627	492	78%	54	9%	1.03	0			
New York	Schenectady	73	65	89%	0	0%	2.72	0			
New York	Schoharie	178	97	55%	28	16%	0.18	2	2	0	1996
New York	Schuyler	55	35	64%	7	12%	0.19	0			
New York	Seneca	3	3	100%	0	0%	0.32	1	0	1	1931
New York	St Lawrence	650	212	33%	261	40%	0.15	15	14	0	2013
New York	Steuben	309	176	57%	9	3%	0.26	1	1	0	1994
New York	Sullivan	1090	234	21%	627	58%	0.29	6	6	0	1998
New York	Tioga	401	251	62%	3	1%	0.35	0			
New York	Tompkins	121	94	78%	5	4%	0.85	4	1	3	1995
New York	Ulster	1218	580	48%	258	21%	0.62	15	8	7	1999
New York	Warren	381	73	19%	182	48%	0.27	7	6	0	2002
New York	Washington	455	417	92%	3	1%	0.28	2	1	0	1998
New York	Wayne	8	8	100%	0	0%	0.59	0			
New York	Westchester	341	291	85%	2	1%	8.08	2	2	0	2012
New York	Wyoming	230	221	96%	0	0%	0.26	0			
New York	Yates	90	70	78%	1	1%	0.24	0			

Table 3c. Assessment of potential impaired habitat for wood turtles in the counties of Pennsylvania and Rhode Island.

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
Pennsylvania	Adams	772	682	88%	54	7%	0.76	3	0	1	1944
Pennsylvania	Allegheny	603	593	98%	0	0%	6.39	1	0	0	#NAME?
Pennsylvania	Armstrong	646	382	59%	12	2%	0.38	6	4	0	2011
Pennsylvania	Beaver	338	290	86%	2	1%	1.46	1	1	0	2005
Pennsylvania	Bedford	1114	543	49%	290	26%	0.17	6	4	1	2011
Pennsylvania	Berks	1737	1660	96%	16	1%	1.88	7	4	2	2009
Pennsylvania	Blair	536	400	75%	35	7%	0.87	4	3	0	2010
Pennsylvania	Bradford	611	453	74%	27	4%	0.19	2	0	2	1912
Pennsylvania	Bucks	1200	1183	99%	0	0%	4.16	5	4	0	2011
Pennsylvania	Butler	688	469	68%	22	3%	0.89	4	3	1	2010
Pennsylvania	Cambria	265	113	43%	51	19%	0.77	1	0	1	1908
Pennsylvania	Cameron	260	9	4%	248	96%	0.05	4	1	1	2013
Pennsylvania	Carbon	646	291	45%	240	37%	0.58	2	1	0	2013
Pennsylvania	Centre	749	386	52%	237	32%	0.56	13	13	0	2012
Pennsylvania	Chester	1492	1475	99%	0	0%	2.68	5	3	0	2013
Pennsylvania	Clarion	594	275	46%	84	14%	0.23	1	1	0	2008
Pennsylvania	Clearfield	724	197	27%	264	36%	0.26	3	2	1	2010
Pennsylvania	Clinton	697	167	24%	445	64%	0.15	4	3	1	2010
Pennsylvania	Columbia	712	572	80%	61	9%	0.49	0			
Pennsylvania	Crawford	731	564	77%	1	0%	0.32	2	1	1	2010
Pennsylvania	Cumberlan	593	486	82%	51	9%	1.64	6	3	1	2013
Pennsylvania	Dauphin	799	555	70%	142	18%	1.84	2	0	1	1935
Pennsylvania	Delaware	87	87	100%	0	0%	11.79	1	0	0	#NAME?
Pennsylvania	Elk	517	55	11%	412	80%	0.13	1	0	1	1940
Pennsylvania	Erie	456	406	89%	0	0%	1.37	0			
Pennsylvania	Fayette	564	314	56%	176	31%	0.67	0			
Pennsylvania	Forest	351	5	1%	325	93%	0.06	2	2	0	2013
Pennsylvania	Franklin	945	724	77%	102	11%	0.68	10	7	1	2009
Pennsylvania	Fulton	595	208	35%	81	14%	0.11	1	1	0	2012
Pennsylvania	Greene	2	2	100%	0	0%	0.24	0			
Pennsylvania	Huntingdo	1043	325	31%	326	31%	0.18	14	13	1	2013
Pennsylvania	Indiana	778	450	58%	34	4%	0.40	5	2	1	2007
Pennsylvania	Jefferson	529	222	42%	82	15%	0.23	0			
Pennsylvania	Juniata	615	345	56%	136	22%	0.21	11	3	0	2008
Pennsylvania	Lackawann	243	194	80%	19	8%	1.67	1	1	0	2000
Pennsylvania	Lancaster	1444	1437	99%	0	0%	2.03	2	1	1	2002
Pennsylvania	Lawrence	359	346	96%	0	0%	0.90	0			
Pennsylvania	Lebanon	559	490	88%	47	8%	1.32	2	1	0	2013
Pennsylvania	Lehigh	800	792	99%	0	0%	3.74	1	0	0	#NAME?
Pennsylvania	Luzerne	1119	504	45%	272	24%	1.29	0			
Pennsylvania	Lycoming	1175	593	50%	414	35%	0.35	4	3	1	2010
Pennsylvania	McKean	532	77	15%	359	67%	0.15	0			
Pennsylvania	Mercer	540	493	91%	1	0%	0.64	0			
Pennsylvania	Mifflin	520	277	53%	104	20%	0.39	5	3	1	2010
Pennsylvania	Monroe	957	560	58%	145	15%	1.16	19	13	3	2013
Pennsylvania	Montgomer	851	848	100%	0	0%	6.28	3	0	1	1954
Pennsylvania	Montour	206	206	100%	0	0%	0.46	3	0	2	1978
Pennsylvania	Northampt	726	704	97%	0	0%	3.01	10	5	2	2012
Pennsylvania	Northumbe	731	655	90%	5	1%	0.69	0			
Pennsylvania	Perry	811	445	55%	124	15%	0.30	2	0	1	1982
Pennsylvania	Philadelphi	9	9	100%	0	0%	40.31	0			
Pennsylvania	Pike	654	179	27%	291	44%	0.46	3	1	1	2010
Pennsylvania	Potter	286	60	21%	144	50%	0.05	3	1	2	2012
Pennsylvania	Schuylkill	1394	698	50%	224	16%	0.68	10	7	1	2010
Pennsylvania	Snyder	582	412	71%	43	7%	0.41	1	0	0	#NAME?
Pennsylvania	Somerset	281	61	22%	136	48%	0.26	0			
Pennsylvania	Sullivan	329	40	12%	241	73%	0.05	0			
Pennsylvania	Susquehann	562	320	57%	34	6%	0.18	1	0	1	1963
Pennsylvania	Tioga	222	89	40%	77	34%	0.13	1	0	1	1955
Pennsylvania	Union	546	331	61%	163	30%	0.50	3	1	2	1991
Pennsylvania	Venango	576	119	21%	229	40%	0.28	7	4	2	2008
Pennsylvania	Warren	503	122	24%	254	51%	0.16	1	0	0	#NAME?
Pennsylvania	Washingtor	653	581	89%	6	1%	0.88	0			
Pennsylvania	Wayne	534	255	48%	72	14%	0.26	0			
Pennsylvania	Westmorela	923	701	76%	79	9%	1.32	4	2	2	2004
Pennsylvania	Wyoming	407	232	57%	79	19%	0.24	5	0	4	1982
Pennsylvania	York	1133	1109	98%	0	0%	1.78	5	4	0	2012
Rhode Island	Bristol	0	0	100%	0	0%	8.01	0			
Rhode Island	Kent	112	57	51%	10	9%	3.81	2	1	1	2009
Rhode Island	Newport	9	5	59%	0	0%	2.91	0			
Rhode Island	Providence	267	177	66%	8	3%	5.94	7	6	0	1998
Rhode Island	Washingtor	213	142	67%	4	2%	1.48	8	7	1	2010

Table 3d. Assessment of potential impaired habitat for wood turtles in the counties of Vermont, Virginia, and West Virginia.

State	County	Total estimated habitat (km)	Potentially impaired stream km	% of habitat potentially impaired	Stream km in optimal landscape condition	% of habitat in optimal landscape condition	Population Density (People / ha)	Corroborated occurrences in the county	Recent occurrences	Historic occurrences	Most recent occurrence
Vermont	Addison	202	161	80%	14	7%	0.17	7	7	0	2012
Vermont	Bennington	208	103	49%	52	25%	0.19	9	8	1	2009
Vermont	Caledonia	198	114	57%	23	12%	0.17	4	3	1	2010
Vermont	Chittenden	118	61	52%	24	20%	0.97	7	7	0	2012
Vermont	Essex	159	15	9%	106	67%	0.04	3	2	0	2006
Vermont	Franklin	213	130	61%	7	3%	0.27	4	4	0	2010
Vermont	Lamoille	135	41	31%	40	30%	0.20	4	1	2	2007
Vermont	Orange	269	107	40%	86	32%	0.15	10	8	0	2008
Vermont	Orleans	201	109	54%	17	9%	0.14	6	5	1	2008
Vermont	Rutland	200	98	49%	22	11%	0.25	8	7	0	2008
Vermont	Washington	145	58	40%	38	26%	0.32	14	13	1	2010
Vermont	Windham	257	56	22%	157	61%	0.20	9	9	0	2010
Vermont	Windsor	463	197	42%	136	29%	0.22	12	11	0	2008
Virginia	Albemarle	10	2	20%	9	90%	0.51	0			
Virginia	Alexandria	8	8	100%	0	0%	35.38	0			
Virginia	Arlington	5	5	100%	0	0%	30.72	0			
Virginia	Augusta	680	474	70%	191	28%	0.28	0			
Virginia	Bath	31	0	1%	31	100%	0.04	0			
Virginia	Clarke	121	92	76%	3	3%	0.28	0			
Virginia	Culpeper	86	37	43%	0	0%	0.45	0			
Virginia	Fairfax	142	138	97%	0	0%	12.38	5	2	0	2001
Virginia	Fauquier	445	329	74%	6	1%	0.41	0			
Virginia	Frederick	367	194	53%	109	30%	0.70	12	7	0	2013
Virginia	Greene	55	32	58%	7	12%	0.46	0			
Virginia	Harrisonbu	12	12	100%	0	0%	9.76	0			
Virginia	Highland	272	58	21%	167	61%	0.02	0			
Virginia	King Georg	6	2	37%	0	0%	0.45	0			
Virginia	Loudoun	430	419	97%	0	0%	2.40	6	4	0	2013
Virginia	Madison	123	80	65%	21	17%	0.14	0			
Virginia	Manassas C	1	1	100%	0	0%	17.80	0			
Virginia	Page	337	200	59%	42	12%	0.27	0			
Virginia	Prince Will	179	151	84%	6	3%	4.47	0			
Virginia	Rappahann	236	93	40%	26	11%	0.11	0			
Virginia	Rockinghar	1020	675	66%	267	26%	0.33	14	10	0	2011
Virginia	Shenandoal	658	394	60%	149	23%	0.28	19	16	0	2012
Virginia	Stafford	79	37	46%	1	1%	1.90	0			
Virginia	Staunton C	4	4	100%	0	0%	3.99	0			
Virginia	Warren	257	143	56%	24	9%	0.64	1	1	0	1996
Virginia	Winchester	5	5	100%	0	0%	11.28	0			
West Virginia	Berkeley	256	151	59%	38	15%	1.19	15	13	1	2011
West Virginia	Brooke	74	57	76%	1	1%	0.84	0			
West Virginia	Grant	289	83	29%	103	36%	0.08	4	4	0	2009
West Virginia	Hampshire	664	77	12%	430	65%	0.13	19	17	0	2012
West Virginia	Hancock	54	43	80%	1	1%	1.14	0			
West Virginia	Hardy	519	118	23%	313	60%	0.08	24	22	1	2012
West Virginia	Jefferson	102	99	97%	0	0%	0.91	0			
West Virginia	Mineral	243	78	32%	93	38%	0.28	1	1	0	2001
West Virginia	Morgan	224	34	15%	106	47%	0.25	4	4	0	2012
West Virginia	Ohio	17	16	97%	0	0%	1.37	0			
West Virginia	Pendleton	357	81	23%	166	47%	0.04	5	4	0	2010
West Virginia	Preston	122	30	24%	31	25%	0.16	0			
West Virginia	Randolph	11	2	18%	7	64%	0.09	0			
West Virginia	Tucker	28	1	3%	25	90%	0.06	0			

Table 4. Preliminary assessment of potentially significant populations presented by State and HUC4 Watershed.

State	Number of Potentially Significant Sites	Number in Good Landscape Context
Connecticut	6	0
Massachusetts	29	16
Maryland	8	7
Maine	15	11
New Hampshire	21	19
New Jersey	6	1
New York	7	2
Pennsylvania	13	5
Virginia	23	14
Vermont	4	3
West Virginia	13	12
Total	145	90

Watershed	Number of Potentially Significant Sites	Number in Good Landscape Context
101 St. John	6	4
102 Penobscot	1	1
103 Kennebec	7	5
104 Androscoggin	5	5
105 Maine Coastal	0	0
106 Saco	1	1
107 Merrimack	17	11
108 Connecticut	26	18
109 Massachusetts-Rhode Island Coastal.	0	0
110 Connecticut Coastal	10	3
111 St. Francois	0	0
201 Richelieu	2	1
202 Upper Hudson	7	2
203 Lower Hudson-Long Island	3	0
204 Delaware	5	1
205 Susquehanna	10	4
206 Upper Chesapeake	0	0
207 Potomac	44	33
208 Lower Chesapeake	0	0
412 Eastern Lake Erie-Lake Erie	0	0
413 Southwestern Lake Ontario	0	0
414 Southeastern Lake Ontario	0	0
415 Northeastern Lake Ontario-Lake Ontario-	0	0
501 Allegheny	1	1
502 Monongahela	0	0
503 Upper Ohio	0	0
Total	145	90

Figures

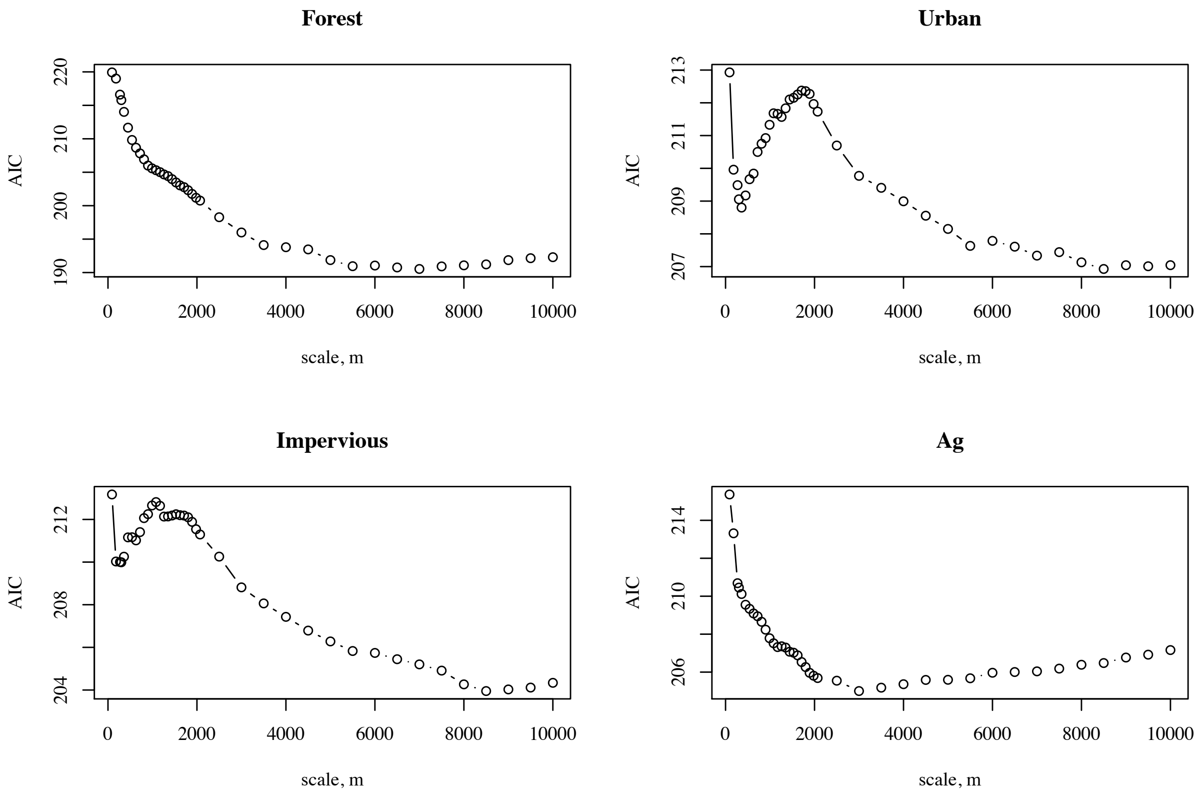

Figure 1. Scale analysis of four landscape variables (forest, urbanization, impervious surface, and agriculture) on the number of wood turtles detected during standardized surveys across the Northeast region (following Charney 2012).

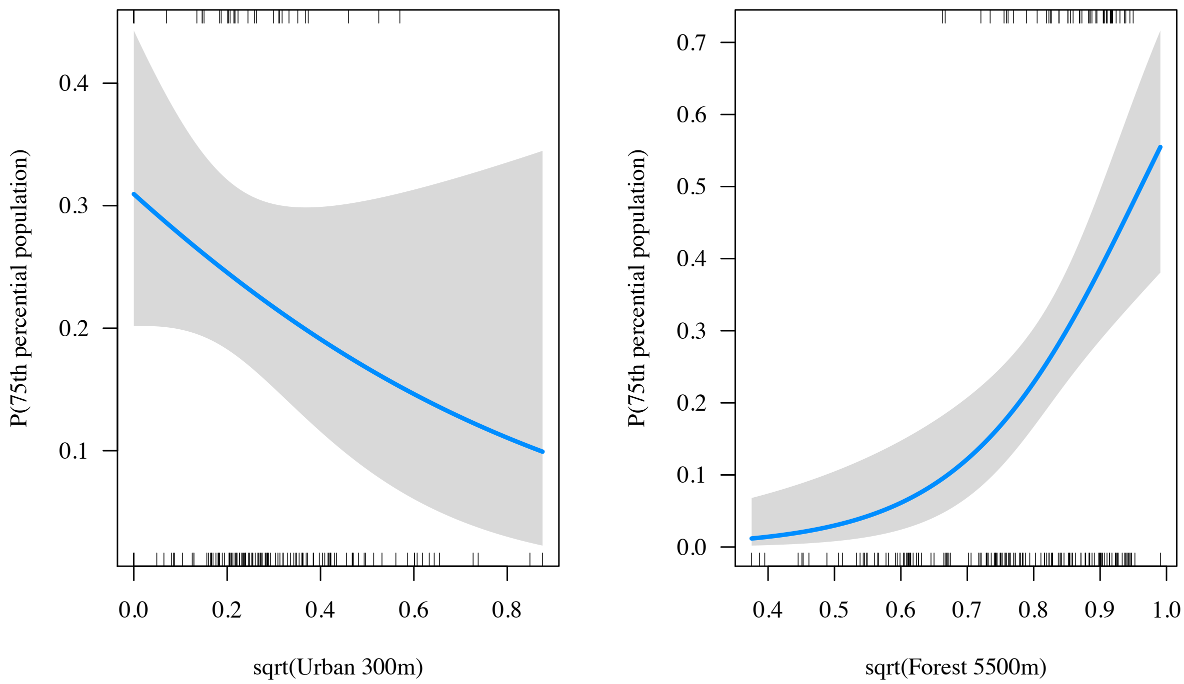

Figure 2. Partial regression plots for two landcover variables (urbanization at 300 m and forest cover at 5500 m, square root-transformed) against the probability that a site is within the 75th percentile of all standardized survey sites.

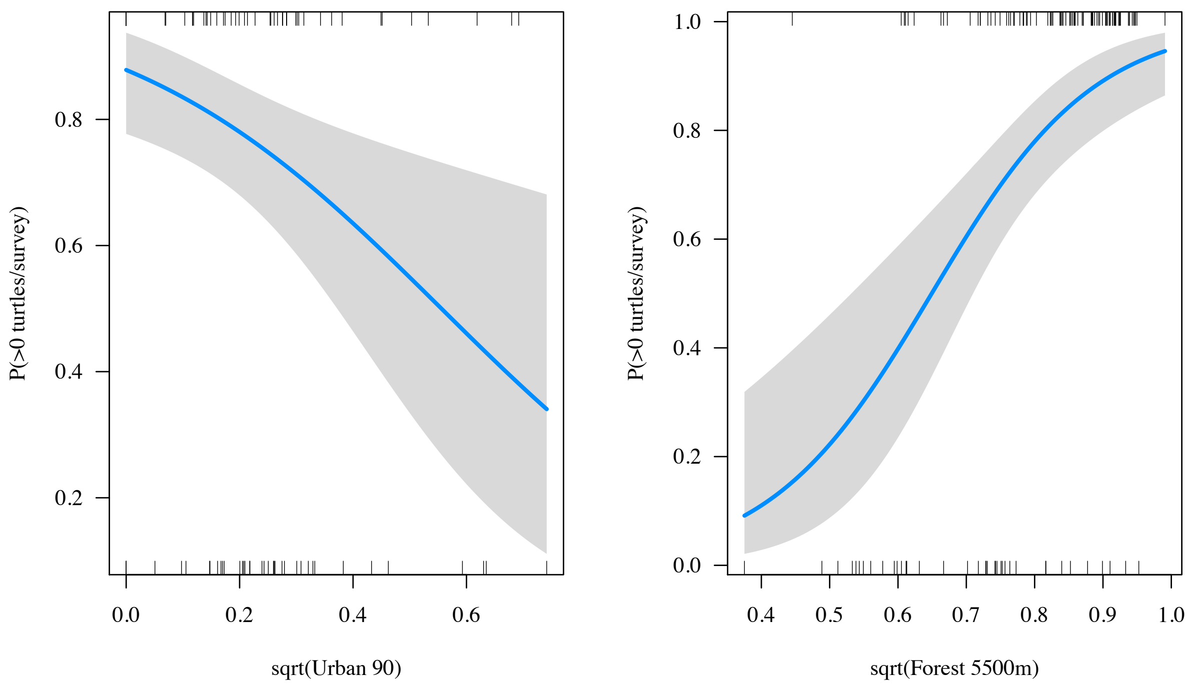

Figure 3. Partial regression plots for two landcover variables (urbanization at 90 m and forest cover at 5500 m, square root-transformed) against the probability that zero turtles would be detected during three standardized surveys.

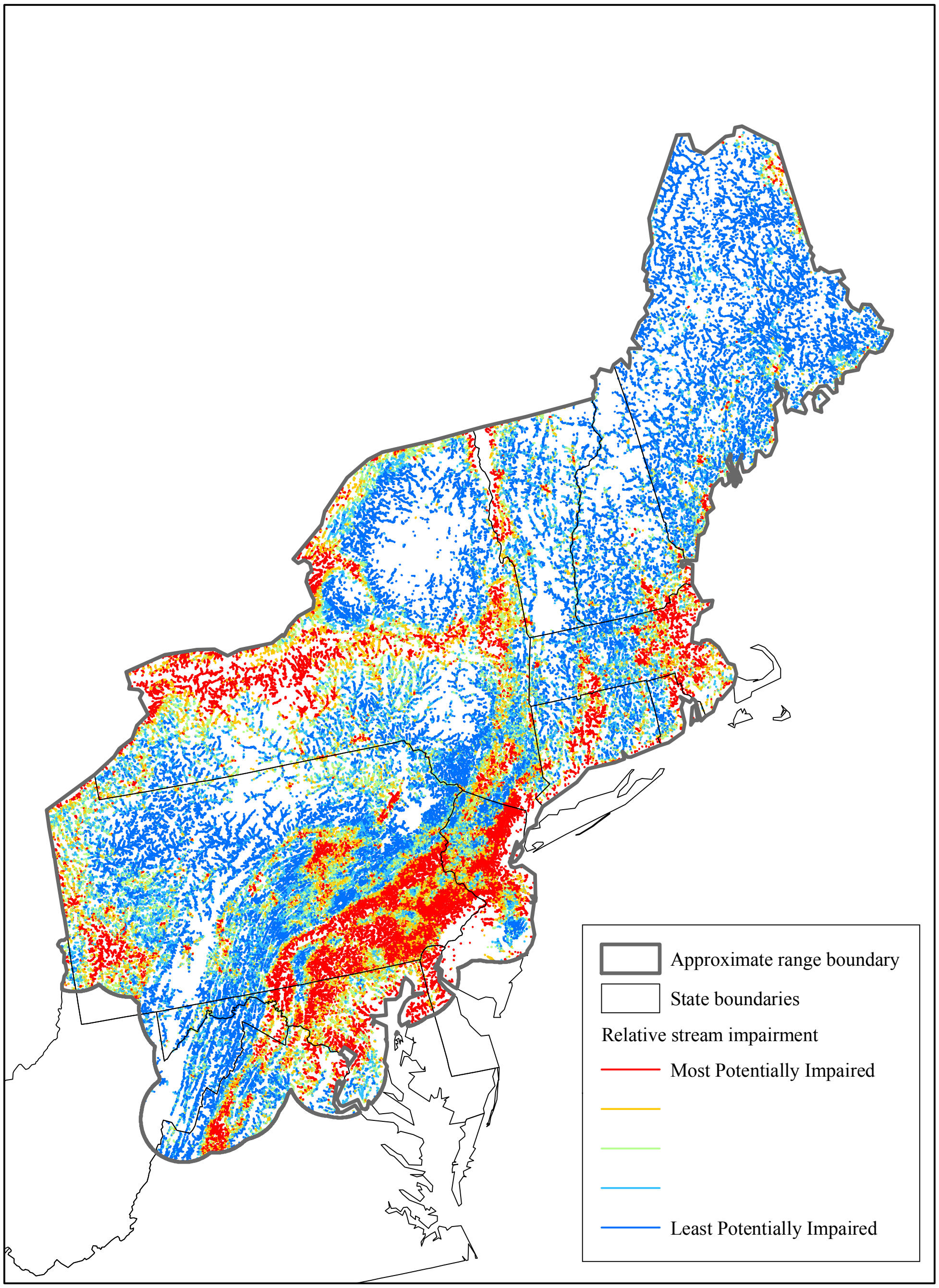

Figure 4. Relative impairment of modeled wood turtle streams in the Northeastern United States.

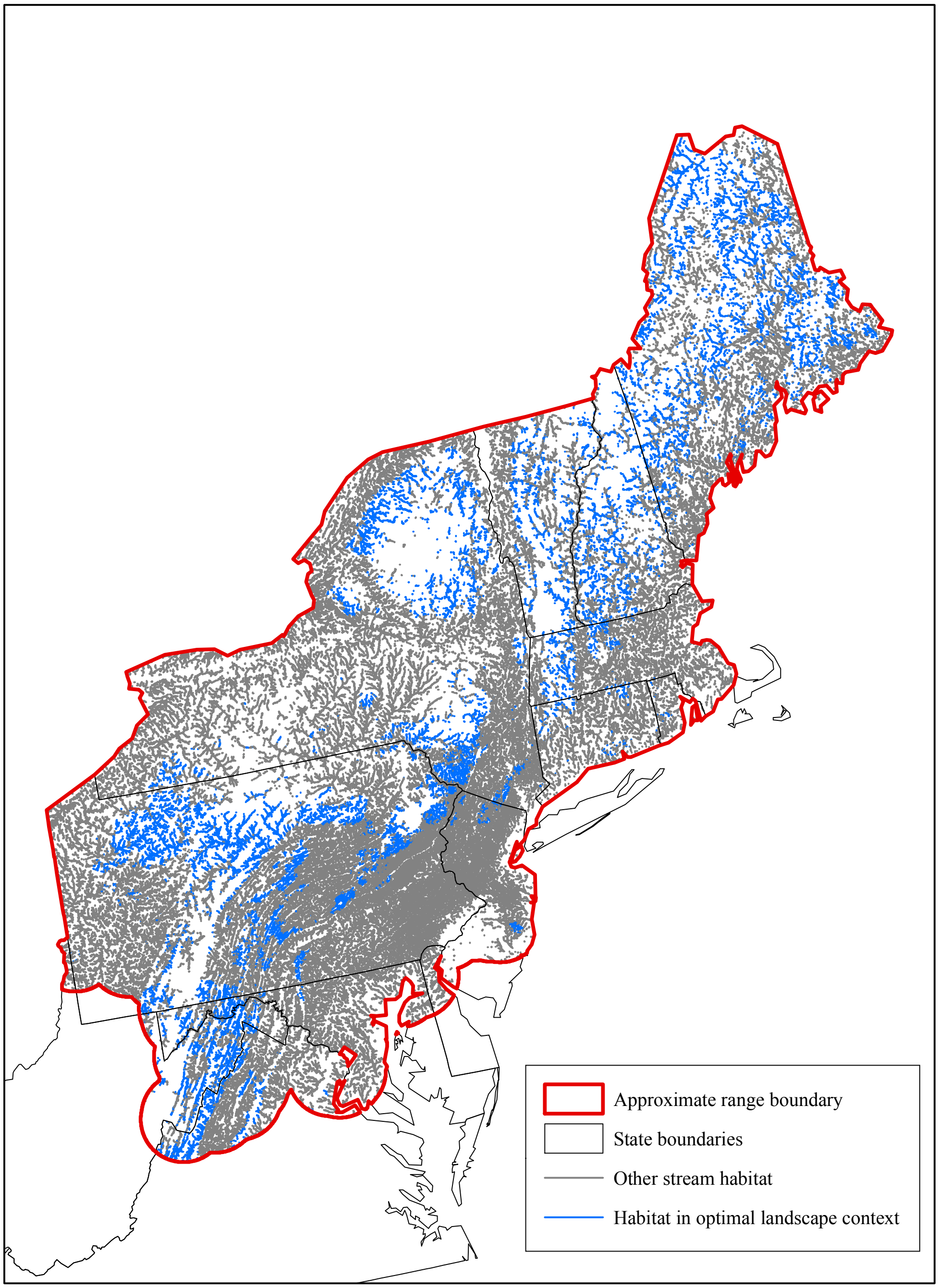

Figure 5. Distribution of wood turtle habitat in "optimal" landscape context is shown in blue. Potential wood turtle stream habitat (Part 2) not in an optimal landscape context. is shown in gray.

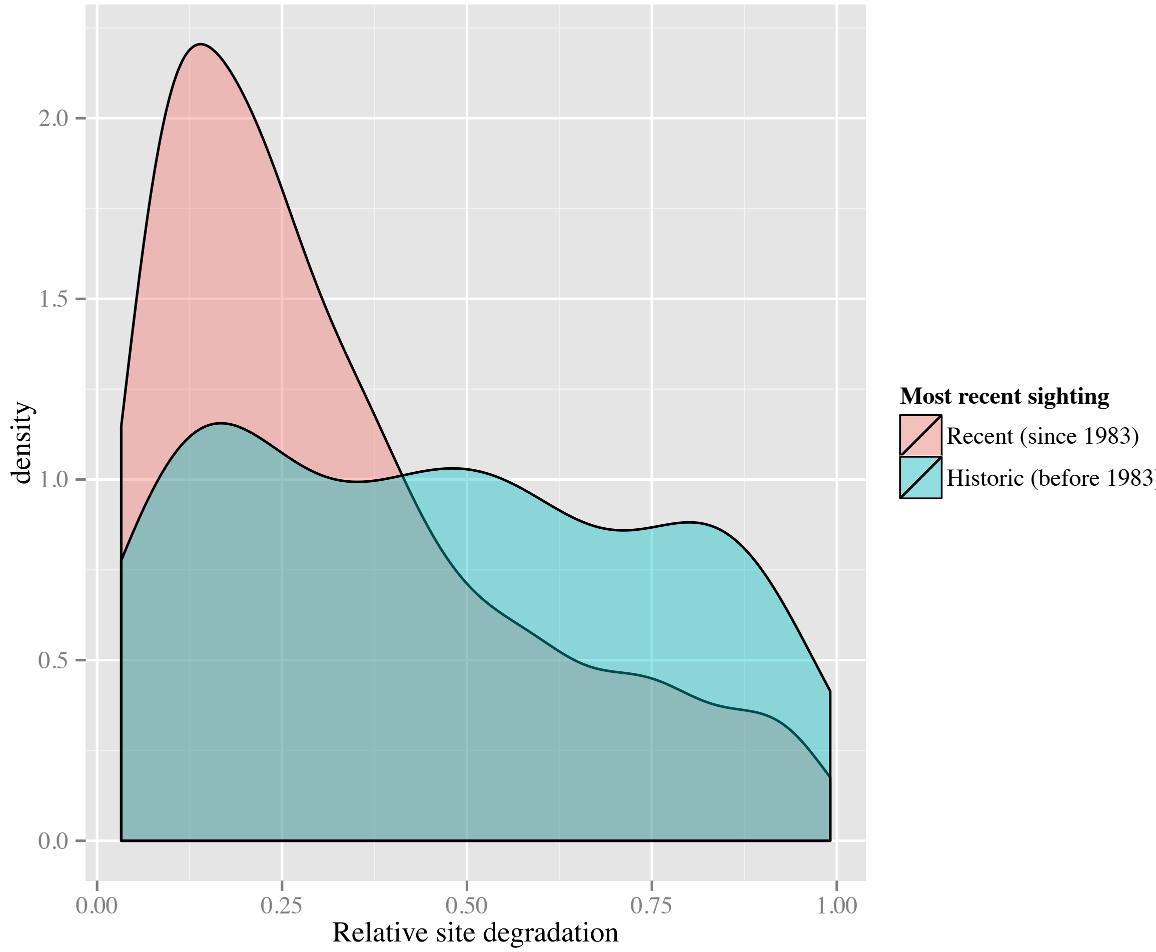

Figure 6. The distribution of "recent (last observation post-1983)" corroborated occurrences (see Part 2) against "historic" corroborated occurrences (last observation pre-1983) against relative site degradation, suggesting that historic corroborations of wood turtle occurrences are more likely to be associated with sites apparently impaired by urbanization.

Relative site impairment

Part 5. Conservation Strategy

State Summary

Maine

There are 83 corroborated (multiple individual wood turtles documented) occurrences in Maine, which has approximately 18,211 km of modeled stream habitat, which is equivalent to 14.3% of the suitable stream habitat in the Northeast Region (Part 2). However, despite containing a much smaller proportion of potentially suitable stream habitat than Pennsylvania or New York, Maine is the least potentially impaired of any state (21% of stream segments are potentially impaired; see Part 4). Maine also ranks high in optimal landscape configuration at 33%, behind West Virginia and equal to New Hampshire, although the total amount of stream habitat in optimal landscape condition is greater than any other state except Pennsylvania. This further supports anecdotal accounts that successful conservation and management in Maine is essential for the long-term persistence of wood turtles in the Northeast, and appears to warrant stronger regulatory protections for wood turtles and wood turtle habitat. Some of the most promising conservation opportunities for wood turtle exist in small areas of northern Maine, because of the remote landscape context. However, despite large-scale conservation actions in the area, we are aware of the protection of only two significant wood turtle population in the state, one of which is at risk from incidental collection by recreationists and the other (Compton 1999) is apparently aging and low-density.

New Hampshire

There are 88 corroborated occurrences in New Hampshire, which has 4,627 km of modeled stream habitat, or 3.6% of modeled suitable stream habitat in the Northeast Region. New Hampshire is relatively rural compared to more southern states; only 36% of the stream habitat is potentially impaired and 33% of the landscape is in optimal condition. Because of this, numerous opportunities for conservation and management of regionally significant sites exists. Surveys should target potentially significant sites and continue to assess long-term intensive sites at intervals.

Vermont

There are 87 corroborated occurrences in Vermont, which has 2,983 km of modeled stream habitat, or 2.3% of modeled suitable stream habitat in the Northeast Region. Vermont appears to have a higher proportion of potentially impaired stream habitat (44%). Also, a smaller proportion (25%) is in optimal landscape context. Only two sites in Vermont have been quantitatively assessed. Additional long-term work at new sites would shed light on regional trends. Focused surveys should target potentially significant sites throughout the State.

Massachusetts

There are 168 corroborated occurrences in Massachusetts, which has 6,172 km of modeled stream habitat, or 4.8% of modeled suitable stream habitat in the Northeast Region. Massachusetts is a heavily urbanized state and a large proportion of potentially suitable wood turtle stream habitat appears likely to be impaired (71%). Only 9% of stream segments are in optimal landscape context.

Connecticut

There are 52 corroborated occurrences in Connecticut, which has 3,537 km of modeled stream habitat, or 2.8% of modeled suitable stream habitat in the Northeast Region. Similar to Massachusetts, nearly 67% of Connecticut's streams appear to be potentially impaired, and only 5% are in optimal landscape context.

Rhode Island

There are 10 corroborated occurrences in Rhode Island, which has only 650 km of modeled stream habitat, or 0.5% of modeled suitable stream habitat in the Northeast Region. Sixty-five percent of Rhode Island's potentially suitable stream habitat is potentially impaired, and only 4% is in optimal landscape condition (the lowest of any state except New Jersey).

New York

One of the largest and most significant states for wood turtles anywhere in their range, there are 131 corroborated occurrences in New York, which has 21,414 km of modeled stream habitat, or 16.8% of all modeled suitable stream habitat in the Northeast Region. Due in part to the extensive urbanization and agriculture of the Lake Plains, Mohawk and Hudson Valleys, 61% New York's potentially suitable wood turtle habitat is potentially impaired. However, 15% of stream segments are in optimal landscape condition, an average proportion in the Northeast Region but significant because of the total area involved. Much of the optimal landscape streams are located in the Adirondack and Catskill regions.

New Jersey

There are 116 corroborated occurrences in New Jersey, which has 8,197 km of modeled stream habitat, or 6.4% of modeled suitable stream habitat in the Northeast Region. Eighty-four percent of potentially suitable stream segments in New Jersey appear potentially impaired, and only 3% of stream segments are in optimal landscape context. This suggests that the long-term conservation outlook for wood turtles in this state will ultimately rely on intensive habitat and population management efforts. However, remaining populations in optimal habitat context should be protected using landscape-scale planning.

Pennsylvania

One of the largest wood turtle states anywhere in the range, there are 161 corroborated occurrences in Pennsylvania. Pennsylvania has 46,169 km of modeled stream habitat, or 36.2% of all modeled suitable stream habitat in the Northeast Region. Sixty-five percent of Pennsylvania's suitable stream habitat is potentially impaired, which is average for the region. Seventeen percent are located in potentially optimal habitat context.

Because Pennsylvania has more than one third of potential wood turtle habitat in the Northeast it is clearly the most critical state for long-term conservation of wood turtle populations.

Delaware

There are no corroborated occurrences in Delaware, but 438 km of stream model as potentially suitable habitat, or 0.3% of all modeled suitable stream habitat in the Northeast Region. One hundred percent of Delaware's potentially suitable stream habitat is also potentially impaired. None of the modeled habitat in Delaware is in a potentially optimal landscape context.

Maryland

There are 43 corroborated occurrences in Maryland, most of which are in the western part of the state. Maryland has 5,762 km of modeled stream habitat, or 4.5% of the entire Northeast Region. With New Jersey, Maryland is, proportionately, the state with the most potentially impaired habitat (84%). Only 8% of Maryland streams are situated in an optimal landscape context.

Virginia

There are 68 corroborated occurrences in Virginia, most of which are west of the Shenandoah River and Blue Ridge. Virginia has 6,037 km of modeled suitable stream habitat, or 4.7% of the entire Northeast Region. Sixty-four percent of Virginia's potentially suitable stream habitat is potentially impaired, and 19% is in an optimal landscape context. Landscape metrics aside, the populations in Virginia and West Virginia are ecologically significant because they are located at the extreme southern edge of the species range.

West Virginia

There are 69 corroborated occurrences in West Virginia. West Virginia has only 3,182 km of modeled suitable stream habitat, or 2.5% of the entire Northeast Region. West Virginia has a relatively small amount of potentially impaired habitat (31%, less than every State except Maine), and has the highest proportion of potentially optimal landscape context (44%). For the same reasons outlined for Maine, West Virginia is a critical component of regional wood turtle persistence. Together with Virginia, West Virginia is ecologically significant because it supports the absolute southernmost corroborated occurrences in the region.

Watershed (HUC 4) Summary

St. John and Penobscot

The St. John and Penobscot Watersheds lie primarily in Maine but share portions of the St. John watershed with Québec and New Brunswick. There are 38 corroborated occurrences in this watershed. Combined, these watersheds support 8,491 km of potentially suitable stream habitat as modeled in Part 2, equivalent to 2.7% and 3.9% of the entire Northeast Region, respectively. Both watersheds are relatively unimpaired (19% and 12%, respectively). Both watersheds are considered priorities for additional field survey work to identify regionally significant populations.

Kennebec and Androscoggin

The Kennebec and Androscoggin watersheds (combined) drain western Maine and a small portion eastern New Hampshire. There are 27 corroborated occurrences in this watershed. Combined, these watersheds support 4,520 km of potentially suitable stream habitat as modeled in Part 2, equivalent to 2.2% and 1.4% of the entire Northeast Region, respectively. Approximately one-fifth (21%) of the stream segments in both watersheds are potentially impaired. Both watersheds are considered priorities for additional field survey work to identify regionally significant populations.

Saco

The Saco River watershed drains eastern New Hampshire and portions of western Maine. There are 24 corroborated occurrences in this watershed. The Saco watershed supports 3,281 km of potentially suitable stream habitat, of 2.6% of the entire Northeast Region, but 42% of suitable stream habitat in the watershed is potentially impaired. The Saco watershed encompasses a large portion of coastal Maine, which is generally depauperate in wood turtle occurrences. Corroborated occurrences in the coastal portion of the basin are ecologically noteworthy.

Merrimack

The Merrimack watershed drains central New Hampshire and northeastern Massachusetts. There are 82 corroborated occurrences in this watershed. Several studies were conducted in this basin, including Tuttle and Carroll (1997) and Jones (2009). The Merrimack watershed supports 3,355 km of potentially suitable stream habitat, of 2.6% of the entire Northeast Region, and 56% of suitable stream habitat in the watershed is potentially impaired.

Connecticut

There are 165 corroborated occurrences in this watershed. The Connecticut watershed supports 6,233 km of potentially suitable stream habitat, of 4.9% of the entire Northeast Region, and 45% of suitable stream habitat in the watershed is potentially impaired.

Massachusetts-Rhode Island Coastal

The Massachusetts and Rhode Island coastal watershed encompasses the Boston Basin and Narragansett Bay. There are 25 corroborated occurrences in this watershed. The Massachusetts-Rhode Island coastal watershed supports 2,555 km of potentially suitable stream habitat, of 2.0% of the entire Northeast Region. This is one of the most heavily altered watersheds in the region, 88% of suitable stream habitat in the watershed is potentially impaired, contributing the wood turtle's tenuous status in this region. Long-term persistence may require active management of habitats and populations.

Connecticut Coastal

The Connecticut Coastal watershed drains western Massachusetts and western Connecticut via the Housatonic River. There are 72 corroborated occurrences in this watershed. The Connecticut coastal watershed supports 3,450 km of potentially suitable stream habitat, of 2.7% of the entire Northeast Region. Sixty-two percent of suitable stream habitat in the watershed is potentially impaired.

St. Francois and Richelieu

The St. Francois-Richelieu combined watersheds drain portions of New York and Vermont, including the Champlain Valley. There are 49 corroborated occurrences in this watershed. Combined, these two watershed (primarily in the Richelieu) supports 1,466 km of potentially suitable stream habitat, equivalent to 0.2 and 1.0% of the entire Northeast Region. Fifty-one percent of suitable stream habitat in the St. Francois watershed and 54% of stream habitat in the Richelieu watershed is potentially impaired.

Upper Hudson

The Upper Hudson is contiguous with the Lower Hudson and drains portions of New York, Vermont, and Massachusetts. There are 77 corroborated occurrences in this watershed. The Upper Hudson watershed supports 9,802 km of potentially suitable stream habitat, of 7.7% of the entire Northeast Region, one of the largest and most significant basins. Sixty-eight percent of suitable stream habitat in the watershed is potentially impaired.

Lower Hudson-Long Island

The Lower Hudson is contiguous with the Upper Hudson and drains portions of New Jersey and New York. There are 67 corroborated occurrences in this watershed. The Lower Huson watershed supports 5,177 km of potentially suitable stream habitat, of 4.1% of the entire Northeast Region. This region is one of the more heavily altered landscapes in the region, and 86% of suitable stream habitat in the watershed is potentially impaired. The long-term persistence of wood turtles in this region is uncertain and will possibly require active management of populations and habitat.

Delaware

The Delaware drains portions of New York, Pennsylvania, and New Jersey. There are 101 corroborated occurrences in this watershed. The Delaware watershed supports 16,770 km of potentially suitable stream habitat, of 13.2% of the entire Northeast Region, the largest and possibly the most significant basin from a conservation standpoint; however, 74% percent of suitable stream habitat in the watershed is potentially impaired. Portions of the lower Delaware encompass most of the Atlantic Coastal Pine Barrens of southern New Jersey, an area considered data deficient because of the relative scarcity of Coastal Plain records between Virginia and Massachusetts. The Lower Delaware watershed also encompasses northern Delaware, which is considered data deficient because the native (and extirpated) status of wood turtles has not been clearly resolved.

Susquehanna

The Susquehanna drains portions of New York and Pennsylvania and reaches the ocean at Chesapeake Bay. There are 104 corroborated occurrences in this watershed. The Susquehanna watershed supports 25,551 km of potentially suitable stream habitat, of 20.1% of the entire Northeast Region, a major portion. Despite encompassing a significant portion of the region, 62% of potentially suitable stream segments in the Susquehanna are potentially impaired.

Potomac

The Potomac River drains portions of West Virginia, Virginia, Maryland, and Pennsylvania including the Cacapon and Shenandoah Rivers. There are 173 corroborated occurrences in this watershed. The Potomac is the site of numerous long-term and intensive studies including Niederberger and Seidel (1999); Breisch (2006); Akre and Ernst (2006); Spradling et al. (2010). The Potomac watershed supports 12,951 km of modeled suitable stream habitat, or 10.2%. Sixty-two percent of suitable stream habitat in the watershed is potentially impaired.

Northeastern/Southeastern Lake Ontario-St. Lawrence

There are 36 corroborated occurrences in this watershed. Although it is well within the extent of occurrence of the wood turtle, the Southwestern Lake Ontario and Lake Erie watersheds does not have any corroborated occurrences and should be considered data deficient. This combined watershed supports 2,484 km of potentially suitable stream habitat, equivalent to 1.2% and 0.8%% of the entire Northeast Region. The entire Lake Plain region of Lakes Ontario and Erie should be considered data deficient and worthy of additional study or collaboration to understand the current distribution and abundance of populations. Forty-three percent of the potentially suitable stream segments in the Northeastern Lake Ontario watershed are potentially impaired, compared to 74% of the Southeastern Lake Ontario watershed.

Allegheny and Monongahela

The Allegheny watershed drains portions of Pennsylvania and New York, and the Monongahela drains portions of western Pennsylvania, Maryland, and West Virginia. There are only 15 corroborated occurrences in this watershed, the only Mississippi tributary south of the Great Lakes. For this reason, the Allegheny watersheds are considered to be of high ecological significance. In this area, the wood turtle potentially co-occurs with numerous vertebrate taxa (including fish, amphibians, and turtles) that are uncommon or absent from other northeastern drainages. Further, this region encompasses the western Allegheny Plateau, an ecoregion with relatively few corroborated occurrences. The entire area appears to be data deficient. Although corroborated occurrences are rare in this basin, the watershed supports 10,919 km of modeled suitable stream habitat, equivalent to 7.1% and 1.5% of the entire region. Both watersheds have average potential impairment estimates of 66% and 44%, respectively.

Summary of Conservation Strategy

Based on the review of available information provided in Part 1 and the original analyses presented in Parts 2–4, as well as a Delphi poll of wood turtle experts in the northeastern United States (following Compton 2007), we present a summary overview a Conservation Strategy for wood turtles in the

Northeast Region. Recommendations are provided at the state or watershed level, where appropriate, but most recommendations are proposed as coordinated regional actions to improve effectiveness and efficiency. A range of proactive and applied measures are proposed. We place heavy emphasis on site prioritization as a technique to facilitate greater regulatory protection. We anticipate that if these actions are achieved in the near-term and sustained, the ongoing decline of wood turtles may be slowed or mitigated in some areas.

These major projects and action items fall broadly into eight programs or categories:

1) Formal organization to coordinate monitoring and conservation (Wood Turtle Council); 2) Develop a Conservation Plan; 3) Increase habitat protection and management efforts; 4) Improve effectiveness of regulation; 5) Implement a regional research strategy; 6) Undertake a regional genetic analysis; 7) Reduce trade of wild-caught adults; 8.) Develop and implement a coordinated technical assistance and outreach program.

1. Launch a Formal Coordinating Organization

We propose that a small organization be convened with regional representation, bylaws and an organizational structure to: 1) facilitate and develop the recommended conservation actions outlined in this section; 2) manage and expand the regional monitoring site network; 3) manage, protect, and analyze data gathered by team members; 4) pursue funding (e.g., Competitive SWG) for major conservation projects; 5) promote data-sharing and collaborations through meetings and symposia. The organization is here referred to as "Wood Turtle Council" but it is essentially a formalized continuation of the Northeast Wood Turtle Working Group. In the bulleted items that follow, we presume that most conservation actions will occur at the state level and that the Wood Turtle Council will be a secondary, coordinating authority.

In addition to the typical officers of a small, focused, non-governmental organization (president, vice president, treasurer, and clerk), the Council should include the liaisons to other programs listed below (North Atlantic Landscape Conservation Cooperative, Priority Areas for Amphibian and Reptile Conservation, Trout Unlimited). The Council should include as many state agency leads as can afford time to participate, as well as LTR site leaders (Part 3) or others designated by state agency leads. Last, the Council should include a database manager responsible for stewarding, augmenting, and protecting sensitive site location data until reassessment.

The Council should meet annually or at intervals established by the group. We propose that the initial meeting be held in conjunction with field training and a research symposium in 2014.

2. Implement Conservation Strategy

Maintain and expand the Corroborated Occurrence Database (from Part 2) and maintain and expand the Coordinated Monitoring Database (from Part 3)

Update species distribution models (SDMs) from the NEAFWA RCN and Refine the Ability to ID Key Features and Excellent Stream Habitat in GIS

This distribution model was partly built on results from sampling undertaken as part of the RCN effort. Incorporate continuous-sampling abundance data from coordinated monitoring effort to refine models of stream habitat and the effect of landscape on abundance. Use both GIS and leaf-off aerial photographs to identify key features such as nesting sites to aid in site prioritization measures.

Prioritize Potentially Significant Populations

In Part 4 we defined and identified Significant Populations. Using results from Project 2 and Project 3, in conjunction with the Significant Populations layer and additional sampling, we recommend prioritizing these sites throughout the Northeast Region where they are available and appropriate conservation targets. Sites should be prioritized by implementing site ranking metrics outlined throughout the RCN report (percentiles of minimum number of animals; percentile of survey results; biogeographic considerations; landscape configuration) so that limited resources may be allocated to proportionally fewer sites. Ranks resulting from this proposed analysis should prioritize sites at the state scale, and spatial outputs provided to the states.

Develop Conservation Plans for X sites at regional and state scale

Develop X Conservation Plans. Within states, designate "site leaders" (in some cases, state agency lead) for Conservation Plan Sites that meet "priority" criteria based on biogeography, estimated population size, landscape context, or genetic distinctiveness. It is this person's (or group's) responsibility to facilitate or maintain Long-Term Reference (LTR) Site sampling, identify conservation and management opportunities, and maintain dialogues with landowners and land managers. Through a formal network of site leaders (Wood Turtle Council), formally track progress toward site protection in a spatially explicit GIS. We will prioritize road crossings issues within "High Priority" sites and present proposed upgrades to State DOTs.

Ensure Wood Turtle's Inclusion in Regional Planning Efforts

There are multiple, active, landscape-scale conservation planning efforts underway, including the USFWS North Atlantic Landscape Conservation Cooperative (NALCC), the Priority Amphibian and Reptile Conservation Areas (PARCAs), and other regional planning efforts. The Wood Turtle Council should designate a liaison to these groups to identify potential overlap opportunities that benefit wood turtles and to build complementary predictive models. This could provide a context to discuss sensitive details about priority sites. Further, the State Wildlife Action Plan revisions are due in the fall of 2015 and revisions should reflect the recommendations of the RCN and outline implementation measures.

Develop Strategic Partnerships with Conservation Organizations

Designate liaisons to conservation organizations such as the Open Space Institute, Cacapon Institute, Nature Conservancy, and other groups. Designate a liaison to Trout Unlimited and/or other coldwater fisheries interest groups to explore areas of potential interest overlap. Co-publish outreach materials on stream conservation and management.

3. Habitat Protection and Management

Assign Site Leaders for Priority Sites and Track Progress

Within states, designate "site leaders" (in some cases, state agency lead) for sites that meet "priority" criteria based on biogeography, estimated population size, landscape context, or genetic distinctiveness. It is this person's responsibility to facilitate or maintain Long-Term Reference (LTR) Site sampling, identify conservation and management opportunities, and maintain dialogues with land owners and land managers. Through a formal network of site leaders (Wood Turtle Council), formally track progress toward site protection in a spatially explicit GIS.

Implement and Update Best Management Practices

In conjunction with an effort to prioritize conservation actions for wood turtles at sites that are deemed potentially significant, implement Best Management Practices and refine them at intervals based on feedback from the Wood Turtle Council.

Expand or Improve Nesting Habitat at Significant Sites

In coordination with local landowners and NGOs, protect nesting areas from common threats such as recreational boating and swimming, nest predators, succession, and invasive plants.

Reduce or Eliminate Active Season Mowing at Significant Sites

In coordination with state wildlife agencies and the NRCS, implement grazing, burning, or off-season mowing at priority sites across the Northeast Region.

4. Improve Effectiveness of Regulation

Recommended Regulatory Framework

As outlined and discussed in Part 1, wood turtle upland habitat and surrounding watershed area is provided relatively little regulatory protection in most northeastern States except Massachusetts (beyond prohibition of possession, capture, and trade). Effective conservation of the wood turtle will probably require a higher level of upland habitat protection in all twelve northeastern States with extant populations, even if upland protections are afforded only at regionally significant or high-priority sites (see Strategic Prioritization, later).

A new model for wood turtle conservation could hinge upon higher listing status in all twelve northeastern States with extant populations, with regulatory protections afforded only to those sites demonstrated to be significant through regionally appropriate combinations of the above-listed methods.

Massachusetts essentially employs this method now and has done so effectively for more than a decade using a combination of 1) stringent EO screening; 2) corroborative data; 3) meaningful site ranking and prioritization; 4) standardized habitat mapping; 5) consistent environmental review (see Part 1, Regulatory Measures), and 6) recently undertaken a standardized sampling plan following the regional sampling protocol to track status and progress.

Regulatory Data Deficiencies

Delaware.—Multiple lines of evidence indicate that wood turtles were native to Delaware (Part 1; Part 2), but are now extirpated. The species is currently listed as "reported" (SR) with no current status. Three lines of evidence suggest that wood turtles were native to Delaware in recent times: extensive areas of potentially suitable stream habitat identified by Species Distribution Models generated at multiple scales (Part 2); corroborated occurrences in the upper portion of a major Delaware watershed and in nearby areas in the lower Susquehanna watershed and Elk Neck, Cecil County, Maryland; and archeological remains near Dover. Together, these indicate probable native status, and a status of "extirpated" is probably warranted.

Maine.—Because the wood turtle is listed as G3, the Maine S-rank should be updated from S4 to S3. Further, Maine has one of the lowest densities of corroborated occurrences in the Northeast, meaning that the assessment has been made with comparatively little data, and its S4 (Secure) listing for wood turtle has relatively little scientific basis in terms of distributional data. Prior to this study, only one thorough population study had been conducted in Maine (Compton 1999; Compton et al 2002), which showed an aged population with little or no recruitment and numerous primary threats to recruitment. Further, regulations should be updated as soon as possible to prohibit the noncommercial collection of wood turtles in the state, as the biological basis for prohibition of all harvest has been well-established for over 30 years and Maine is the last state to implement this small measure of protection.

Maryland.—Because the wood turtle is listed as G3, the Maryland S-rank should be updated from S4 to S3. Beyond the technicality of this change, it is important to note that no available evidence suggests that the wood turtle is secure in Maryland. Original analyses of landuse (Part 4) indicate that Maryland is in fact the state with the greatest proportion of potentially impaired originally suitable habitat (84%), suggesting that most populations in the eastern part of the state may be very low density and possibly nonviable. Unless new information from randomized, standardized surveys and long-term monitoring indicate otherwise, the status of wood turtles in Maryland should be considered tenuous.

New Jersey.—With Maryland, New Jersey has likely seen the greatest proportion of potentially suitable habitat potentially impaired by urbanization (84%). Based on the stepwise analyses in Parts 2 through 4, it appears that most historic occurrences of wood turtle in New Jersey may be impaired. The status of wood turtles in New Jersey, with the exception of several populations with recent population data, should be considered tenuous.

Massachusetts, Rhode Island, Connecticut.—Because of evidence of widespread range contraction (Part 1, 2) and extensive habitat degradation (Part 4), and/or lack of evidence of significant populations geographically representative of the species' original range in these states, the wood turtle may warrant Threatened status in the southern New England states. On a state scale and with the exception of a few well-documented large populations, the overall status of wood turtles in the southern New England states should be considered tenuous.

Strategic Prioritization of Basins and Populations (Triage)

Klemens (1997) suggested that triage be employed to allocate minimal resources to the most important populations of the *"Clemmys"* complex of turtles, including wood turtles. In this assessment, we provide the preliminary basis of tools for population assessment and prioritization. By implementing site ranking metrics outlined in this report (percentiles of minimum number of animals [Part 2]; percentile of survey results [Part 3]; biogeographic considerations [Part 2]; landscape configuration [Part 4]) limited resources may be allocated to proportionally fewer sites. For example, populations above the 75th percentile in standardized survey returns or estimated/minimum population size should be prioritized for greater regulatory oversight in all cases, as these appear to represent significant populations. Populations in underrepresented Level III ecoregions, such as the coastal plain populations in New Jersey, the Central Appalachians, and the Western Allegheny Plateau (as described in Part 2), are of regional ecological significance. Populations should be prioritized at the state scale, so that the full extent of the wood turtle's range may be maintained. For example, Rhode Island and Delaware do not currently appear to support dense populations of regional significance or demonstrated viability, but are critical for their role in maintaining the recent extent of occurrence of wood turtles.

5. Implement Regional Research Strategy

Standardized Element Tracking in All States

Our collaborative analysis suggests that wood turtle populations may be negatively influenced by urbanization over a majority of their range in the northeastern States. Conducting more robust analyses in the future will require a standardized database of element occurrence data. We recommend that all states initiate or continue, as appropriate, formal data collection by the state Natural Heritage Program, wildlife agency, or a suitable partner such as The Nature Conservancy. This is especially important in Vermont, New York, and Maryland, but standardized EO tracking in Rhode Island, Delaware, and the District of Columbia, as well as Ohio (outside the Northeast Region but biogeographically connected, as noted in Part 1) is essential. We recommended continuing to track and aggregate occurrence records in Maine, New Hampshire, Massachusetts, Connecticut, New Jersey, Virginia, and West Virginia where records are currently tracked in relatively consistent fashion. Border states should coordinate periodically with Ohio, Ontario, Québec, and New Brunswick to share information in border areas. States with low density of corroborated occurrences, or georeferenced occurrences, should seek funds (possibly as part of a regional plan) to have text records georeferenced.

Maintain, expand, protect the Corroborated Occurrences and Monitoring Databases

The corroborated occurrences database in Part 1 will be maintained by the Massachusetts Cooperative Fish and Wildlife Research Unit in cooperation with the Wood Turtle Council's database manager. The database will be password protected and stored on encrypted drives at the University of Massachusetts, Amherst, MA or on secure servers. The Corroborated Occurrences Database should be updated and re-analyzed at 5 to 10 year intervals. Individual data release agreements will be submitted to state Natural Heritage Programs to cover element occurrence data used as corroborative material in the database. The results of coordinated monitoring in the Northeast Region will be maintained by the Massachusetts Cooperative Fish and Wildlife Research Unit in cooperation with the Wood Turtle Council's database manager. Due to the sensitivity of the information, as with the corroborated occurrences database, the coordinated monitoring results database will be password protected and stored on encrypted drives at the University of Massachusetts, Amherst, MA or on other secure servers. No stream names or sites with extant wood turtle populations will be revealed in public documents or public meetings. The data will be used only for analyses approved by the Wood Turtle Council's executive committee.

Formalize decontamination protocols

Decontamination protocols are in effect for bog turtle, desert tortoise, and other turtle species of greatest conservation need, an example is outlined by Miller and Gray (2009). We recommend adapting existing protocols (e.g., Miller and Gray 2009; NEPARC in prep.) for the regional wood turtle project. Once developed, all researchers are encouraged to follow the decontamination protocols and use common sense.

Formalize Network of Long-Term Reference (=Index) Sites

Continue standardized sampling at LTR sites that were initiated during the RCN project in 2012 and 2013. Continue to build this network of LTR "index" sites by initiating new LTR sites, where feasible, with primary emphasis on western New York, western Pennsylvania, Rhode Island, Connecticut, Delaware, and Maryland and other areas. Expand the RA sites in West Virginia into LTR sites. Initiate LTR sites in the Allegheny basins west of the Appalachians, where possible. Initiate a stable LTR at high-density sites in New Jersey, Maryland, and West Virginia. Continue LTR sampling until robust open population models are generated.

Initiate Randomized Sampling from SDM (Part 2)

Initiate a rolling, continuous, stratified sampling effort in 2015 and 2016. Design a sampling strategy to include randomized "potentially impaired," "intermediate", and "optimal" 1 km segments and ensure that these site stratifications are mixed with other relevant strata such as ecoregional breaks or major climatic thresholds.

Conduct Standardized Surveys in Data-deficient Regions (Part 2)

Initiate standardized surveys (as LTRs or RAs) in regions identified as data deficient in the RCN report because of potential conservation significance or ecological significance. Broadly, these include most of Maine, northern New Hampshire, western New York and the Mohawk Valley, western Pennsylvania and the Lake Erie plain, and southwestern Pennsylvania and adjacent Ohio and West Virginia. Further, standardized sampling should continue in the District of Columbia and Delaware. Identify regional liaisons on the Wood Turtle Council to build partnerships in data deficient regions to encourage additional standardized surveys.

Implement two-stage eDNA sampling at regional scale

Analysis of environmental DNA (eDNA) is a promising approach for assessing the distribution and occurrence of wide-ranging aquatic organisms. Where implementation is feasible, eDNA techniques may ultimately be refined to the point that the expense of regional biodiversity monitoring programs may be substantially reduced, and duplicative sampling efforts minimized. Concurrent with the emergence of eDNA as a promising new tool, the evident decline of once-common vertebrate wetland fauna is of increasing concern nationwide. A continued regional wood turtle project would provide a cost-effective and timely opportunity to launch a regional eDNA sampling component. Preliminary work has demonstrated proof of concept at the landscape level (Lemmon and Akre, pers. comm.). An eDNA sampling strategy that allows for robust calculation of Type I and Type II error should be implemented concurrently with regional sampling in 2014 and beyond.

Implement and Evaluate Minimum Qualifications for Wood Turtle Observers

Because of the large effect of observer on detection rates reported in Part 3, a system of qualifying observers should be implemented. Roughly, this should be equivalent, but less stringent than the requirements for bog turtle surveyors. As part of continued regional wood turtle coordination and planning, the Wood Turtle Council will develop and evaluate qualification guidelines. As part of the regional monitoring effort, observer qualifications should be examined statistically to determine if this standard is appropriate or needs to be modified. As part of the regional effort, a training day for key personnel will be established in conjunction with the Northeast PARC meetings.

Targeted Research

Where feasible, fund and support targeted, hypothesis-driven research, in specific categories:

Urbanization

Using the modeled outputs from Part 4, conduct randomized, standardized field surveys throughout the Northeast to assess the threshold of urbanization on population viability. This should be undertaken as part of a regional effort to assess abundance.

Dispersal

Using a combination of tools and methods, investigate the relative importance of effective dispersal in fragmented and unfragmented systems, and how dispersal varies among different age-classes.

Genetics

See (5) Region-wide Genetic Analysis, later.

Resource-dependent life history models

Using demographic data and other parameters measured at LTR sites, develop resource dependent life-history models. Build models to explain variation in age-based survivorship, maturity, recruitment, dispersal, reproductive output, effective population size, and longevity. This will allow the site prioritization process to be optimized.

Disease

Where appropriate, implement targeted monitoring for pathogens at LTR sites as recommended above.

Lake and reservoir-based demes

Support multi-scale (fine scale and landscape scale) research into the use of lakes and reservoirs by self-sustaining wood turtle populations throughout the region.

Hydraulic fracturing

Conduct before-after control-impact (BACI) studies in streams subjected to effects of hydraulic fracturing and develop best management practices.

6. Conduct a Region/Range-wide Genetic Analysis

Collect blood samples for regional genetic analysis

At LTR sites sampled on an ongoing basis, blood samples should be drawn from the caudal vein of ~ 20 adult turtles. These should be refrigerated and shipped on ice to a lead geneticist for regional analysis. Protocols for the collection, storage, and analysis of blood from around the region will be formalized by a lead geneticist or genetics working group.

Identify highly distinct and diverse populations and assess extent of recent declines

From the bank of regional blood samples outlined above, population distinctiveness and diversity should be assessed.

Identify population units and develop a stream network model for connectivity

Develop a stream network model for gene flow that identifies the relative degree of overland, headwater, and main stem flow that contributes to connectivity among populations. Relate this to real and predicted future barriers.

7. Reduce Trade of Wild-Caught Adults

Launch an anti-poaching task force with federal cooperation

An interagency, interdisciplinary anti-poaching task force should be launched to effectively counter the commercial collection of wood turtles. Ideally, this group would have representation from the USFWS and northeastern state wildlife agencies, and a cooperating geneticist.

Renewed effort to support multijurisdictional sting operations

Environmental law enforcement officials and state herpetologists will coordinate interstate plans to conduct additional sting operations targeting rare turtles illegally offered for sale.

Genetic fingerprinting of significant and representative populations

A database of genetic material should be maintained by the Wood Turtle Council on secure servers in coordination with a lead geneticist. The database should be used to identify the origin of confiscated specimens to aid in enforcement actions. See Region-wide Genetic Analysis, above.

Coordination with Customs and Border Patrol

The anti-poaching task force should designate a liaison to the U.S. Customs and Border Patrol to maintain communication regarding wood turtles. In particular, the USCBP could be a strong partner not only at the actual border, but on forest roads in Maine and other locations where priority wood turtle populations occur in close proximity to the border. Similar overtures should be made to the Wildlife Enforcement Directorate of Environment Canada.

Increase use of PIT/RFID at border crossings and LTR reference sites

Most researchers in the Northeast currently mark their research subjects with marginal scute notches or drill holes and do not heavily use PIT tags. Increased use of PIT tags, especially in a regionally coordinated framework, could aid enforcement actions and improve detectability at border crossing checkpoints, if most researchers used the same equipment.

8. Coordinated Technical Assistance and Outreach Campaign

Several authors have concluded that technical assistance campaigns within priority wood turtle sites are essential components of a long-term conservation strategy (e.g., Compton 1999; Akre and Ernst 2006). We strongly repeat this recommendation, and further suggest that the cost-benefit ratio would be substantially improved through regional coordination.

Cards and Brochures

Akre and Ernst (2006, p. 200) suggested brochure campaigns with three emphases: (1) the connection between wood turtles, healthy riverine ecosystems, and the conservation of brook trout and smallmouth bass (geared toward fishermen); (2) the overlap in habitat requirements between wood turtle and popular game species such as deer and turkey (geared toward hunters); (3) general overview of wood turtle life history (geared toward recreationists and local residents).

As an interim step and a priority action item, we propose to develop, refine, print, and distribute an educational card or brochure that conveys the four simple messages: (1) key identification characteristics of the wood turtles; (2) its rarity, longevity, and intolerance for captivity; (3) that the collection of wood turtles is prohibited; (4) a centralized website which routes interested citizens to the individual state wildlife agency reporting programs (see example in Figure 1).

Once developed and printed, cards can be distributed through fish and wildlife agencies, federal and state properties, Northeast PARC, boat and ATV registration offices, major outfitters, and other outlets. Weatherproof versions should be revised for display at boat landings and popular fishing sites, following a similar model to the "artificial bait only" and Atlantic salmon information placards posted along Wild and Scenic Rivers and Atlantic salmon streams.

Symposium

In order to share information, provide technical assistance to agencies, and reach out to partner organizations and the public, we recommend and annual symposium on wood turtle conservation and biology. Similar meetings have been effective for the Desert Tortoise Council (Kristin Berry, pers. comm.), the New England Cottontail (Anthony Tur, USFWS, pers. comm.), and the Diamondback Terrapin (Russ Burke, pers. comm.). The proceedings will be published as a standalone document.

Monitoring Implementation and Re-evaluation Schedule

The Coordinated Monitoring Strategy should be launched and fully implemented as soon as possible. Random site evaluations and surveys in data deficient areas should continue on a rolling basis as resources are available. Return surveys at Long-Term Reference Sites should be undertaken on five year intervals in coordinated fashion.

Figure 1. Sample educational card for general distribution.

6. Best Management Practices for the Wood Turtle in the Northeastern United States: Seven Land-use Scenarios

Abstract

This document provides an overview of Best Management Practices (BMPs) for wood turtles (*Glyptemys insculpta*) in the northeastern United States, based on literature, technical reports, and unpublished data of the Northeast Wood Turtle Working Group (NEWTWG). The primary goal of this document is to seek a convergence in the recommended management guidelines from across the Northeast Region, and to outline BMPs for a number of representative land-management scenarios. Although there is abundant descriptive literature on wood turtle behavior and ecology, management recommendations are sometimes contradictory and in all cases should be tailored to a particular site as much as possible. Because resources for wood turtle conservation are generally scarce, more stringent management standards and greater management resources should be applied at higher-priority or "significant" populations in optimal landscape contexts (see Part 4) that will require relatively little management in subsequent years. However, in many areas populations have been reduced and surrounding landscapes fragmented. In these cases, or to support the persistence of ecologically significant populations, intensive habitat or population management may be necessary. As a manager, it is appropriate to determine whether a site is functioning without management and whether it has received the protection it requires. If not, the site may warrant intensive management to reduce adult mortality and increase recruitment. In these cases, it is important to ensure that intensive population management does not detract from efforts to protect highly functional sites. We propose management practices for a variety of land-use scenarios, but they all bear one thing in common: preserve the integrity of highly functional sites by stringently limiting disturbance, except as targeted management actions, and improve the function of potentially impaired sites by reducing threats to adult survival and improving recruitment.

Introduction

The biological parameters of the wood turtle are well established (see Part 1). The wood turtle occurs primarily in clear, clean, cold streams in both forested and agricultural areas from Maine to Virginia. Remaining populations appear to range in density of adults and subadults from ~1 to nearly 200 turtles per kilometer of stream (Part 3). In order to meet minimum probabilities of persistence, populations will ideally encompass a wide range of age classes of turtles and occur in large mosaics of diverse riparian and upland habitats unfragmented by roads. Although the largest populations remaining are associated with large, unfragmented tracts of forest with minimal urbanization and impervious surface area, wood turtles are well-known to seek out early successional habitats whether they are natural or anthropogenic.

All age classes use a variety of riparian and upland habitats during the warm season, which may range from March to October in the southern states and low elevations to May to September in the northern states and high elevations. During the annual terrestrial period, wood turtles are exposed to increased risk of mortality caused primarily by machinery associated with agriculture, forestry, and land development. Although the primary risk associated with these activities is the direct mortality of adult turtles due to crushing injuries from machines such as mowers, tractors, plows, and trucks, development and agriculture may indirectly harm wood turtle populations in a number of ways. Nest and hatchling predators such as raccoons, skunks, foxes, and chipmunks may be more common in suburban or developed landscapes.

Inappropriately sited recreational access areas may place long-term stress on the population by facilitating incidental and commercial collection. Roads constructed for timber operations may subsequently facilitate residential development or elevate roadkill rates over long periods. Improper sediment control systems in logging and agricultural areas may increase sedimentation of rivers, degrading stream quality. Undersized bridges or culverts may exacerbate downstream erosion. New disturbance along the river and in riparian areas may provide corridors for the colonization of invasive plant species such as Japanese knotweed (*Fallopia japonica*), which may compromise nesting areas, or multiflora rose (*Rosa multiflora*) and bittersweet (*Celastrus orbicularis*).

Thus, BMPs should be flexible but restrictive and geared toward "significant populations" or sites for which intensive management is feasible and a relatively high priority, as on some federal and state wildlife refuges. Application of BMPs should be determined by the relative significance and probability of persistence, as well as cost-benefit considerations, of the wood turtle populations present at a given scale (e.g., Town, State, Wildlife Refuge Complex, National Forest, etc.). These may be assessed either from 1) standardized survey data; 2) population estimates from long-term monitoring data; or 3) aerial photo interpretation, GIS analysis, or habitat assessment combined with (1) and (2). If no population data are available, effort should be made to assess the population on the ground using standardized protocols (see Part 3) before requiring or enforcing stringent restrictions.

We present a synthesis of recommended protections for wood turtles and propose that the most stringent and restrictive protections be reserved for sites with a higher probability of persistence without intensive management unless the resources necessary for intensive management have been pledged by a managing authority and actions are being taken to mitigate sources of mortality or causes of population decline. Wood turtle populations in more urbanized or heavily agricultural landscapes may require intensive management to persist.

Although every site is different and wood turtles at two nearby sites can have strikingly different movement patterns, two different land protection scales are proposed based on movement data from the literature and unpublished sources: 90 m (general protection for supporting populations) and 300 m (maximum protection for significant populations). As an example, where possible, new agricultural activities should be prohibited within the 90 m boundary from all corroborated wood turtle streams or supporting populations and prohibited within 300 m of significant wood turtle streams because the necessary mowing and harvest regimes will present severe long-term conservation challenges. In all cases where feasible, agriculture should be minimized within 300 m of the stream. Where agriculture already exists near priority streams, buffer zones should be implemented based on site-specific information or the buffer guidelines presented here.

Forestry activities should occur primarily in the winter, and should not result in new road construction within 300 m of significant overwintering streams. Further, forestry activities, where already occurring, should capitalize on opportunities to create **nesting areas** and early successional clearings between 30–90 m from the stream *if these features are lacking,* and if conducted in the off-season (October to March, inclusive). Forestry activities solely to improve habitat should be very carefully considered, as the potential increase in adult mortality, recreation, and nest predation may outweigh any benefit from the management action. However, if open canopy habitats are not rejuvenated by natural stream processes, then they may require anthropogenic augmentation.

Residential development should be prohibited within 300 m of significant streams and key features such as communal nesting areas, and within 90 m of low-quality streams. Further, although clearly impossible and impractical to regulate using existing rare species regulations, our analyses indicate that it may be beneficial to minimize development at much larger scales of up to 5500 m surrounding significant stream systems (Part 4). This is clearly not feasible in most cases, but underscores the apparent sensitivity of wood turtles to landscape change and associated effects.

Influence of Landscape on Abundance and Mortality

As noted, the wood turtle occupies a wide range of riverine and riparian habitats and associated uplands, including both forested and open/early-successional areas, where agricultural machinery and automobiles present some of the most important proximate causes of adult mortality. In many cases, adult mortality from machinery appears to be high enough to result in population declines or skewed demographic structure. Protection standards have been proposed for two of the most common land-uses in wood turtle habitat: agriculture and mowing (Saumure 2004; Sweeten 2008; NHESP 2009; Tingley et al. 2009; Erb and Jones 2011) and forestry (Compton 1999; Bol 2005; Tingley and Hermann 2008), as well as nest site management (Buhlmann and Osborn 2011) and dam management (Compton 1999). Wood turtles rely on a variety of upland cover types during the course of the warm months. At landscape or watershed scales, wood turtles are associated with forested landscapes along streams or rivers (Compton et al. 2002), while at finer scales wood turtles are associated with nonforested locations such as clearings in Maine (Compton et al. 2002), hayfields in Québec (Saumure 2004), pastures in Massachusetts (Erb and Jones 2011) and New Jersey (Buhlmann and Osborn 2011) and seepage areas in Virginia (Akre and Ernst 2006).

Population Prioritization

We propose two designations of wood turtle site prioritization: Significant and Supporting. The level of recommended protections and landuse restrictions should reflect the status of the population according to its (1) statewide and regional significance; (2) landscape context; (3) potential viability, as described below.

Significant Populations

Significant populations are generally those with excellent probabilities of persistence without intensive management, or those that are ecologically or biogeographically (or genetically) unique. Wood turtle streams may be deemed to be of regional significance by one of several criteria (see Part 4 for greater elaboration). In one case, potentially significant sites have demonstrated presence of multiple (≥5) turtles and are situated in potentially optimal landscape context (see Part 4 and Part 5). Site assessments in these areas will generally reveal key supporting landscape features such as instream or nearstream nesting areas, large logjams, known overwintering or nesting sites, and early successional clearings near the stream. In unfragmented contexts along larger streams, these features may be associated with recurring hydrological processes and keystone species such as beaver, but may be entirely anthropogenically driven in more fragmented or urbanized systems. Other potentially significant sites are those with demonstrated presence of individuals (≥2 turtles, as in Part 2), and are in either data deficient regions or ecologically significant areas, as noted in Parts 2 and 5. For example, regionally significant populations also encompass all corroborated occurrences in ecologically significant ecoregions and watersheds with few known populations such as the Atlantic Coastal Pine Plain, the Allegheny/Monongahela drainages, the Lake Plain of Lake Erie and Lake Ontario, as well as extreme peripheral populations that may be adapted to distinct climate patterns such as those in western Pennsylvania, West Virginia and Virginia, and northern Maine and New Hampshire. Significant populations also include those identified as in the upper percentile (>75th) of regional populations in density or abundance.

Supporting Populations

Because of the major threats facing wood turtles throughout the Northeast, all populations with some chance of persistence should be managed for recovery. “Supporting” populations are those that may not meet “significant” criteria but are apparently recoverable with intensive management. However, these may rise to the level of state or local priorities if there are relatively few significant sites and/or they have been successfully protected. These sites may warrant nest-site creation, predator control, nest protection, and/or a structured headstarting program. Often these sites have fragmented riparian environments, and/or lack of suitable nesting areas within contiguous habitat core, and/or relatively low standardized survey returns (<25% percentile), or a lack of population data.

Management Zones

1. Riverine (Instream; variable width)

2. High Priority Buffer Habitat (0 to 90 m)—should approximate the floodplain area

3. Best Management/Precautionary (90 m to 300 m)—should encompass potential habitat in upland areas.

			Conservative protection		Maximum protection	
Source	**State**	**Site**	**Distance (m)**	**Comments**	**Distance (m)**	**Comments**
Arvisais et al. 2002	QC	-	-	-	300	100% locations
Tingley & Herman 2008	NS	-	-	-	182	95% locations
Tingley & Herman 2008	NS	-	43	95% male locations	235	95% female locations
Tingley & Herman 2008	NS	-	-	-	400	100% female locations
Compton 1999	ME	-	-	-	300	99% locations
Jones, unpubl. data	NH/ MA	-	136	75% female summer locations	321	95% female summer locations
Jones, unpubl. data	NH/ MA	-	76	75% all August locations	775	99% female August locations
Erb 2006	MA	-	90	1 Nov.–31 Mar.	180–300	1 Apr.–31 Oct.
Akre and Ernst 2006	VA	A	-	-	250	90%
Akre and Ernst 2006	VA	B	-	-	300	95%
Akre and Ernst 2006	VA	C	-	-	200	95%
Akre and Ernst 2006	VA	D&E	-	-	300	100%
Sweeten 2008	VA	1	30	54% locations	90	94% locations
Sweeten 2008	VA	1	30	65% locations	90	96% locations
Sweeten 2008	VA	n/a	30	1 Apr–15 May; 1 Oct–15 Nov.	90	15 May–30 Sept.

Other Management Considerations

Nest and hatchling predators and impediments to recruitment

As noted by Buhlmann and Osborn (2011), NatureServe (2013), and many others (e.g., Klemens 2000; Ernst and Lovich 2009), mid-sized and small predators can present a major threat to successful recruitment in many wood turtle populations. At sites where adult mortality (from cars, mowers, and collection) have been successfully minimized, depressed recruitment rates may be the greatest threat to wood turtle populations. In these cases, managers should consider creative options ranging from predator (e.g., raccoon) control, new nesting area creation (to disperse nesting behavior), and nest protection (especially at sites that are already intensively managed). These are essential tools to manage wood turtle populations in suburban and urban environments. Because of the long-term costs of these programs, the only caveat to implementing these is that these efforts should not detract from efforts to protect and manage significant populations in optimal contexts that are unlikely to require sustained management. Buhlmann (pers. comm.) and Buhlmann and Osborn (2011) also note the necessity of nursery habitat as a critical component of successful and significant recruitment.

Road Construction

Roads are a clearly established threat to wood turtles by facilitating roadkill of all age classes. In many cases, roads probably reduce the probability of persistence of wood turtle populations. Roads that parallel wood turtle streams, especially within 90 m high-use areas, present major conservation challenges. Perpendicular road crossings may exert proportionately similar effects on adult survival in the areas where they cross streams if there are attractive early successional or nesting features near the road, or if the culvert is undersized or perched (see Threats to Population Stability in Part 1). To date, no cost-effective (or effective) measures to reduce wood turtle roadkill have been evaluated. To effectively conserve wood turtles, it is important that new roads be prohibited near important wood turtle streams. All road construction should be prohibited within 90 m of significant and supporting populations. New road construction should be prohibited, where feasible, within 300 m of significant streams. New roads are not only a potential threat to population viability in and of themselves, but the facilitate additional risks such as new development, recreational use, subsidized predation, and mowing along roadsides. Further, to minimize the necessity of long-term population management, roads should be minimized up to 5.5 kilometers from the regionally significant sites. State officials or site managers should capitalize on opportunities to close or seasonally gate existing roads within 300 m of significant wood turtle streams. Numerous roads on federal properties that serve hunters during the cold season could potentially be closed to protect wood turtles at all other times.

Culverts and crossings—New stream crossings can exert stress or negative influence for decades after installation on the local population, and should be avoided in all possible cases near regionally significant streams. When it is necessary for roads to cross wood turtle streams, it is critical (A) that the culvert or bridge allow turtles to pass underneath (i.e., it is not perched) and (B) the road surface and side slopes not become an attractive nuisance to nesting females, unless the road will be gated. However, designing road crossing structures for wood turtles has not been experimentally tested, and many examples exist of repeat roadkills at perpendicular crossings, especially in New England (Jones and Willey, unpublished data).

Agriculture and Mowing

Wood turtles are negatively affected by intensive agriculture because adults may be placed at higher risk of crushing injuries from mowers, combines, tractors, plows, harrows, and other farm machinery (Saumure and Bider 1998; Saumure 2004; Saumure et al. 2007; Jones 2009; Tingley et al. 2009; Erb and Jones 2011).

Under certain landscape configurations and timing, mass mortality events or repeated mortalities in the same field occur (Tingley et al. 2009; Jones 2009). Certain landscape configurations probably result in higher mortality rates, although these have not been well-studied. Saumure (2004) noted that mortality rates in fields have probably increased since the 1970s because of the advent of disc and rotary mowers, which are more efficient than sickle-bar cutters but inflict greater damage to turtles. Although Saumure et al. (2007) and Tingley et al. (2009) suggested raising mower heads above 100 mm, Erb and Jones (2011) tested this hypothesis and found that sickle-bar mowers **do result in significantly lower** mortality rates. Further, they tested whether raising the mower head of disc and rotary mowers reduced mortality rates, but found **no significant reduction in mortality by raising the blades.** Raising mower blades saves some turtles and is certainly worth the effort where no other option exists, but it is important to note that even with blades set high, both blades and tires kill wood turtles at relatively high rates. This suggests that other, more effective alternatives to raising mower heads should be considered whenever possible, and these are discussed below.

Several authors have proposed riparian buffers are the strongest mechanism to reduce agricultural mortality (Tingley et al. 2009). Jones (2009; unpublished data) noted the tendency for wood turtles to congregate in certain shrub habitats along the edges of fields. These typically had good solar exposure (facing south) and were often close to ditches or damp areas or the river itself. In some cases, it may be possible to delineate high-activity areas through standardized surveys or radiotelemetry. However, at any given site, absence of sightings in fields should not be construed to reflect low use if densities are otherwise high in the river. Wood turtles are well-documented to heavily use both forb and graminoid-dominated meadows and hayfields, so their presence should be assumed wherever hayfields, pastures, or abandoned farmland comes in close proximity to a high-density overwintering stream.

Other authors have proposed other means of land-clearing, such as grazing, off-season burning, or off-season mowing (Erb and Jones 2011). These seem to be the most compatible with wood turtles. Where the primary risk to turtles comes from row-crop agriculture such as corn, Castellano et al. (2008) suggested using late-season varieties that require harvest in October rather than August or September.

All available data support the following Best Management Practices for agriculture in wood turtle habitat:

1. Establish unfragmented riparian buffers of ≥90 m at supporting sites;
2. Establish unfragmented riparian and upland buffers ≥300 m at regionally significant sites with no mowed or mechanically cleared areas, where feasible, provided that early successional habitats are available along the river;
3. Mow or clear existing fields, if necessary, during the cold months of 15 November to 15 March (south) or 15 October to 15 April (north). If warm season mowing or management is necessary leave a buffer at the edge of fields that are only maintained in winter;
4. Implement off-season burning or year-round grazing if areas must be kept open for other competing interests;
5. Use late-season crop varieties that require harvest in October rather than August;
6. Use radiotelemetry on a large sample of adults (>10), or systematic surveys, to identify heavily used areas within the fields and avoid these areas at a bare minimum.

Forestry

Forestry is likely to negatively affect wood turtles if adults are crushed by tractors, skidders, or other heavy equipment. Some forms of broadscale, intensive forestry such as clearcutting likely degrades habitat quality by facilitating numerous long-term management concerns. Removal of large wood from the system also decreases the availability of logjams and other overwintering structure in the streams. There are several types of forestry including clear cuts, shelterwood cuts, group selection, patch cuts, and salvage (Sweeten 2008; Martin 2010) and some of these may provide an opportunity to enhance wood turtle habitat if conducted when turtles are overwintering. For instance, most northern studies indicate that open, patch cuts near the river (in an otherwise forested landscape) may be beneficial (Compton 1999; Saumure 2004; Tingley and Herman 2008), but it is possible or likely that the relationship to landuse varies with latitude and elevation.

Several authors from disparate regions have proposed best management practices for forestry, and they are in general agreement (Compton 1999; Bol 2005; Tingley and Herman 2008). Harvesting within 300 m of high-quality riparian areas known to be occupied by wood turtles should occur only in the cold season when wood turtles are inactive (variable by region, but safely late October–late February).

Our recommendations for forestry are:

1. Minimize or prohibit forestry activities during the active season within 90 m of wood turtle streams.
2. Minimize forest manipulations within ≥90 m at supporting sites;
3. Minimize forest manipulations within ≥300 m at regionally significant and significant sites;
4. *If early successional habitats or nesting habitats near the stream are lacking*, small group selection cuts may enhance riparian habitat quality if conducted during the inactive season;
5. Logging roads should be discontinued after logging operations are complete so they do not provide multiple new access points to the river or provide for driving access parallel to streams.

Development

Development affects wood turtles in a variety of ways ranging from habitat and stream degradation to the facilitation of mortality due to roadkill, collection, and other sources. Parren (2013) noted the tendency of land developers to suggest recreational trails as a component of mitigation; this is counterproductive and probably worsens the outcome for wood turtles because of increased collection.

We recommend:

1. Minimize development activities within 90 m of documented wood turtle streams containing "corroborated" occurrences (two or more individuals in close proximity);
2. Minimize all development within 300 m of designated "priority" wood turtle streams though regulation, deed restriction, and fee acquisition;
3. Use strategic partnerships and landscape-scale planning to minimize future development within 5.5 km of priority wood turtle streams.

Nesting Area Management

Where possible, nesting area management should focus on instream features generated by the stream itself, such as point bars, sand and gravel bars, beaches, and cutbanks. In most cases where they are available, these instream features are probably preferable to anthropogenic nest sites away from the stream. These areas appear to be more abundant in eastern Canada, Maine, and New Hampshire than at the southern edge of the range. At significant sites where instream nesting is not available, management should focus on maintaining and monitoring existing nest sites, expanding and augmenting existing nest sites, and creating new nesting areas, as appropriate during the off-season from 1 November to 31 March.

New, anthropogenic nesting areas should avoid creating landscape configurations that result in attractive nuisances or ecological traps, in which females are attracted to nesting areas that either result in decreased adult survival rates, decreased nest success, or decreased hatchling survivorship. For example, it is not ideal to have suitable or attractive nesting habitat located across a road from the overwintering stream, even if the road is infrequently traveled. Further, it is not ideal for nesting to be heavily concentrated at a single location because this may result in elevated nest depredation rates (Buhlmann and Osborn 2011; Buhlmann, pers. comm.).

Researchers and managers have successfully created wood turtle nesting habitat by constructing piles of soil in open fields (Buhlmann and Osborn 2011). At one site in Morris County, New Jersey, the nesting mound was 18 m long, 8 m wide, and 1.5 m tall (see Part 1, Plate 9).

A summary of considerations for managing nesting habitats follows:

1. Survey and map potential nesting areas within the stream segment of interest using aerial photographs and ground surveys;
2. Secure and manage natural occurrences of instream nesting habitat by clearing vegetation (during the inactive season) as necessary;
3. If instream nesting habitat is not available, evaluate the availability and condition of anthropogenic nesting habitat, and protect, manage or augment it as necessary and as resources allow;
4. If no nesting habitat is available but the population is otherwise assessed to be a potentially significant population without need of intensive management, construct new nesting areas by clearing land to expose mixed poorly-graded sand and gravel, or build mound(s) of sand in an open field near (≤50 m) the stream.

Dam Management

Dams influence wood turtles in two major ways, by flooding upstream areas and turning low-gradient stream habitat into deep reservoirs, and by altering the downstream flow regime, which degrades nesting habitat or and/or flood nests near the river.

Compton (1999) provided the most detailed recommendations for dam management in wood turtle habitat, focusing mostly on the suitability of nesting habitat. These recommendations probably apply throughout the range: 1) minimize large water releases between late May and the estimated date of nest emergence (generally in August) on rivers with wood turtles and known or suspected low-lying nesting areas; 2) allow high flows during early spring, before nesting, to encourage natural scouring of vegetation and redistribution of sand and gravel sediments. We recommend adhering to these recommendations throughout the range.

During dam re-permitting near regionally significant and supporting populations, managers should go so far as to map essential resource areas and key features and determine whether nest-site creation or management is necessary as a result of the dam-induced flow regime.

Recreational Access

Wood turtles co-occur with brook trout and are often found on high-quality coldwater trout streams, which may be frequently traveled by fishermen. Furthermore, wood turtles often occur on scenic waterways with high value to canoeists and boaters. Even infrequent collection poses a long-term conservation challenge, and so it is critical to re-site recreational access points away from significant wood turtle stream segments (preferably downstream, so that boaters don't frequently access priority stream sections incidentally). Where possible, recreational access points for fishing and boating should be installed >300 m downstream of the lower reach of a regionally significant occurrence and >300 m from key features such as nesting areas, logjams, and potential or documented overwintering areas.

Table 1. Overview of recommended management practices within supporting and regionally significant wood turtle streams.

Activity	Supporting Sites	Regionally Significant or "Priority" Sites
Roads	Minimize road construction within 90 m.	Minimize road construction within 300 m. Seek opportunities to gate or close existing roads near streams.
Agriculture	Minimize agricultural fields within 90 m of stream.	Minimize or prohibit new agricultural fields within 300 m of significant stream segments. Reduce the extent of active agriculture by developing riparian buffers and implementing off-season clearing techniques.
Forestry	Minimize active-season forestry activities within 90 m of the stream unless habitat management is necessary to create critical features that are absent; retire roads after job is complete.	Minimize active-season forestry activities within 300 m of the stream unless habitat management is necessary to create critical features that are absent; retire roads after project.
Development	Minimize construction of new buildings and major land conversion within 90 m.	Minimize construction of new buildings and major land conversion within 300 m; minimize construction within 5.5 km through landscape-scale planning.
Nesting Area Management	Augment or create nesting areas as necessary; avoid ecological traps.	Protect and manage existing instream and "natural" nesting areas; create new nesting habitat if necessary; avoid ecological traps. Monitor nesting areas for relative use and monitor recruitment rates in population.
Dam Management	Minimize large water releases between May and August; allow high flows during early spring to encourage natural scouring of vegetation and redistribution of sand and gravel sediments.	Minimize large water releases between May and August; allow high flows during early spring to encourage natural scouring of vegetation and redistribution of sand and gravel sediments. Develop a base map of nesting resources and potential downstream dam conflicts. Monitor recruitment rates as proportion of juveniles in marked annual sample.
Recreational Access	Place recreational access points downstream (for boating) of all documented key features such as nesting areas, logjams, and overwintering locations.	Minimize recreational access during active season. If necessary, place access points downstream (for boating) of all documented key features such as nesting areas, logjams, and overwintering locations.

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Appendix I. Decontamination and Sterile Work Protocols

SEPARC
Information Sheet #10

Southeastern PARTNERS IN AMPHIBIAN AND REPTILE CONSERVATION

DISINFECTION OF FIELD EQUIPMENT AND PERSONAL GEAR

By: Debra L. Miller and Matthew J. Gray

Importance of Disinfection:

Anthropogenic spread of pathogens (commonly called pathogen pollution) has been identified as a threat to the health of amphibians and reptiles worldwide (Converse and Green 2005, Picco and Collins 2008, Picco et al. 2007, St-Amour et al. 2008). In some cases, field researchers have been suspected as contributing to pathogen pollution. As we continue to combat the spread of pathogens such as *Batrachochytrium dendrobatidis* (*Bd*) and ranaviruses, it becomes imperative for biologists and researchers to employ basic disinfecting procedures that prevent the spread of pathogens during normal field activities. We also encourage water recreationists to disinfect gear whenever feasible. Our discussion below focuses on ranaviruses and *Bd*, but the procedures and disinfectants are effective at preventing pathogen pollution for multiple disease agents.

Our understanding of the environmental persistence of ranaviruses and *Bd* is limited but it is likely these pathogens may survive months outside the host in aquatic environments (Langdon 1989, Johnson and Speare 2003). Langdon (1989) reported that a fish iridovirus (EHNV) remained viable for about 3 months in water. Similarly, Johnson and Speare (2003) found that *Bd* can survive for about 2 months in water. These studies emphasize the potential persistence of amphibian pathogens in aquatic environments and highlight the risk of transporting them when footwear or equipment comes in contact with water at sites inhabited by amphibians.

Procedures:

Once sampling at an aquatic site is completed and before moving to a new site or returning from the field, all field equipment (e.g., nets, buckets, water quality meters) and personal gear (e.g., boots, waders) should be rinsed with water (either from the site or a municipal source), and all debris and mud removed. Exterior surfaces of boats or canoes should be rinsed also. If the tires of a vehicle or boat trailer contact water with amphibians, they should be cleaned. The next step is applying an effective disinfectant. It is imperative that all debris and mud is removed prior to disinfectant application, because organic matter and soil can reduce its effectiveness.

Bryan et al (2009) reported that a 3% household bleach (active ingredient [AI]: sodium hypochlorite), 0.75% Nolvasan® (Fort Dodge Animal Health; AI = chlorhexidine diacetate) or 1% Virkon® S (DuPont Animal Health Solutions; AI = potassium peroxymonosulfate) solutions are effective for inactivating ranaviruses. Generally, a 10% solution of household bleach is recommended for inactivating *Bd* (Brem et al 2007); however, Johnson et al. (2003) reported that 1 – 4% household bleach is sufficient to kill *Bd*. Thus, 4% household bleach is effective at inactivating both pathogens. Ethanol (70%) also inactivates both pathogens (Langdon 1989, Johnson et al. 2003). Bleach, ethanol, and Virkon® can be toxic to amphibians and other aquatic organisms, hence Bryan et al. (2009) recommended to use Nolvasan®, although the effectiveness of this chemical at inactivating *Bd* has not been tested. The disinfectant must remain in contact with equipment or personal gear for at least 5 minutes to ensure complete inactivation of pathogens. This duration could occur when traveling between field sites. Equipment and footwear should be rinsed with municipal water after the minimum disinfecting time to remove residual chemical, which can damage equipment and be toxic to aquatic life. We found that handheld spray bottles and pump sprayers are practical at distributing disinfectants and rinse water (Figure 1).

After returning from a field site, we recommend that equipment and personal gear be thoroughly washed and disinfected again. Equipment and gear should be hung and allowed to completely dry. In many cases, drying serves as a means of inactivating pathogens. Although limited information exists, ranaviruses and *Bd* probably are inactivated after two weeks of complete desiccation. If bleach is used as a disinfectant, it breaks down with exposure to air, sunlight and organic material, thus solutions should be discarded after 5 days following mixing (Green et al. 2009).

Figure 1. Applying the disinfectant can be accomplished by immersion and spraying.

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Appendix II. NatureServe Element Occurrence Mapping Criteria

Population/Occurrence Mapping Delineation

Use Class: Not applicable

Subtype(s): Hibernaculum, Nesting Area.

Minimum Criteria for an Occurrence: Occurrences are based on evidence of historical presence, or current and likely recurring presence, at a given location. Such evidence minimally includes collection or reliable observation and documentation of one or more individuals (including eggs) in or near appropriate habitat where the species is presumed to be established and breeding.

Separation Barriers: Busy highway or highway with obstructions such that turtles rarely if ever cross successfully; untraversable topography (e.g., cliff); urbanized area lacking aquatic or wetland habitat; large impoundment or lake.

Alternate Separation Procedure: Separation distance across continuous upland habitat: 1 km. Separation distance for locations along riverine corridors: 5 km. Separation distance for intermediate (e.g., mixed upland-riverine wetland) situations: 3 km.

A riverine corridor is measured along the river, not as a straight line distance. It includes areas that have stream-influenced conditions (geomorphology, vegetation, hydrology). Upland habitat lacks hydric soils and stream-influenced conditions.

Separation Justification: Available data (see Migration/Mobility comments) indicate that home ranges tend be be elongate (usually less than 2 km long) and follow streams, extending out from streams up to 300 m. These data suggest a separation distance of the nominal minimum of 1 km for expanses of upland habitat and at least 5 km for riverine corridors. The latter distance is roughly 2.5 times the maximum known home range length (Quinn and Tate 1991) and more than four times the maximum recorded home range length in most other studies, which, due to small sample sizes and minimal radio-tracking effort, likely underestimated movements.

Inferred Minimum Extent of Habitat Use (when actual extent is unknown): .5 km

Date: 12Feb2003

Author: Hammerson, G.

Ranking Criteria

See NatureServe's (2008) Generic Occurrence Rank Guidelines for current recommended element ranking criteria.

Appendix III. Long-Term Monitoring Protocol: Step by Step

1.) Identify reach of stream occupied by wood turtles. These may be priority conservation sites, long-term research sites, or data-deficient areas. Select 1 kilometer of meandering stream habitat in GoogleEarth or a similar program (e.g., ArcView, ArcMap, USGS topos). If possible, choose a homogenous section of stream (e.g., mostly agricultural, or mostly forested, etc.). If surveys were completed in the spring or fall of 2012 or 2013, prioritize these sites for surveys in 2014. New sites in 2014 are also OK.

2.) Record the upper and lower bounds (decimal degrees) of the LT segment using a GPS or GIS (e.g., Arc10; GoogleEarth).

3.) Identify one or more survey partners (all surveys should ideally be conducted by two observers). Each observer is numbered 1, 2, 3, etc. Observer #1 is the **lead observer** (this is important). Single observers are OK, but they are called "Observer #1".

4.) Identify different seasons over two years in which surveys are to take place. For example, spring and fall of 2013, or fall 2012 and spring and fall of 2013. Ideally, LT surveys will take place in the following seasons, but more or less are OK. Two to four seasons are ideal for LT sites.

5.) In each of your survey seasons, 1 or more observers will conduct **3** surveys of the LT reach, following these protocols:

a.) Surveys should be undertaken in a clearly defined season, as described in 5.), above;

b.) Observers should maintain an approximate pace of **1 hr per km.**

c.) During each survey, record the start time, end time, weather, and temperature using the provided survey field form. Surveys should ideally be completed during daylight hours between air temperatures of 9° and 24°C and water temperatures of 7° to 20°C, but any temperatures are acceptable.

d.) Both (or all) observers should maintain independent tracks (turtles observed by one should not be visible to the other observer). The **lead observer** has the right of way and must survey in front, so that the other observers cannot scare turtles into the water.

e.) All observers should remain within 10 m of the stream bank if possible, but may follow riparian features such as oxbows or pools into the floodplain more than 10 m from the riverbank.

f.) Record the identity of wood turtles observed. Follow the turtle processing guidelines outlined in this document in Part 3.

g.) Record the location of each turtle observed in decimal degrees using a hand-held GPS.

h.) Record survey dates, observers, weather conditions, and survey results online field form provided on http://northeastturtles.org.

i.) submit an .xls or .csv file with all GLIN observations detected during LT surveys at the end of each biological season, or submit individual turtle forms.

7.) After three surveys in each season, report your results using the data-entry portal on http://northeastturtles.org.

Appendix IV. Rapid Assessment Survey Protocol: Step by Step

1.) Rapid assessment sites may be either "known" (non-random) or randomly selected. Ideally, we will have a sample of greater than 20 random rapid assessment sites (this is an update from 2012).

2.) For random rapid assessment sites, select twenty segments from the layer provided by UMass, and go through them in random order.

3.) Record the upper and lower bounds of each RA reach using a GPS or GIS (e.g., Arc10; GoogleEarth).

4.) If possible, identify one or more survey partners.

5.) With one partner, conduct three visual surveys of the study reach. Follow these protocols:

a.) All three surveys should be undertaken in either pre-nesting (spring) season (before 28 May) or fall;

b.) The 1-km RA reach should be surveyed over the course of 1 hour;

c.) A "lead observer" (observer #1) must be identified; this person has right of way to walk the stream in front of other observers;

d.) During each survey, record the start time, end time, weather, and temperature using the provided survey field form (Appendix V). Surveys should ideally be completed during daylight hours between air temperatures of 9° and 24°C and water temperatures of 7° to 20°C, but any temperatures are acceptable;

e.) Both observers should maintain independent tracks (turtles observed by one observer should not be visible to the other observer). Observer #1 (lead observer) takes precedence and surveys where s/he wants to. Observer 2, 3 et al. survey independently of observer 1. One way to do this may be to stay on opposite banks of the stream.

f.) Both observers should try to stay within 10 m of the stream bank, but may explore farther afield in association with riparian features such as oxbows, pools, etc.

g.) Record all wood turtles observed. Turtles do not need to be handled or captured, only counted. However, identifying the turtles is ideal, especially if there is potential for the site to become an LTR site.

h.) Record all required information on the RA field form provided on http://northeastturtles.org. Submit copies of the forms to Mike Jones (mtjones@bio.umass.edu) or enter data on the online forms provided, whichever is more convenient.

6.) After three surveys are complete in a single season, report your results using the data-entry portal on http://northeastturtles.org.

Appendix V. Field Forms

Our coordinated research and monitoring programs were based on identifying common denominators that could be reported and analyzed centrally. We used two simple field forms: one for each survey event (below, left) and one foreach individual turtle (below, right). Data were submitted electronically using a secure web-based online database and form.

Original field forms may be downloaded at http://northeastturtles.org.

Wood Turtle Rapid Assessment Form - 1 km (4/18/13)

Stream name: Site code: State: Survey #:

Part I. Stream Characteristics

Segment upstream end (GPS coords)	*enter on first form only*	Survey direction: ☐ upstream ☐ downstream
Segment dstream end (GPS coords)	*enter on first form only*	

Average stream width (m):

Stream substrates present in >1/3 of reach: ☐ silt ☐ sand ☐ gravel ☐ cobble ☐ rock

Stream features (check all present):
☐ braided channels ☐ sinuous meanders ☐ beaches suitable for nesting
☐ anthropogenic straightening ☐ bank hardening/stabilization ☐ >1 m deep pools

Forested riparian buffer present: ☐ yes ☐ no | Public access: ☐ yes ☐ no

Dominant landuse along river segment (guideline: w/in 50 m of banks; >1/3 length):
☐ upland forest ☐ forested floodplain ☐ scrub floodplain ☐ emergent wetland
☐ hay ☐ crop ☐ abandoned agriculture ☐ sand & gravel extraction
☐ residential ☐ commercial ☐ industrial ☐ other (specify):

Part II. Survey Results

Survey constraints: ☐ property access ☐ deep H20 ☐ H20 visibility ☐ scrub ☐ flood

Date:		Start time:		End time:		Stopped:	
Weather (start):		AirT (start):		H20T (start):			
Weather (end):		AirT (end):		H20T (end):			

Number of observers:	
Obs #1 name:	
Obs #2 name:	
Obs #3 name:	

Total number of wood turtles observed[1]:

Males:		Females:		Juv:		Unk:	
Obs. #1:		Obs. #2:		Obs. #3:			
# Turtles on land:		# Turtles in water:					
# sets							

Comments[2]:

IMPORTANT! Please list the sex and ID numbers of all wood turtles detected during this survey, e.g.: M1, M4, F12, F22, J101. A juvenile turtle is 14 years old or less. List turtles found dead, or outside of survey event while accessing the site, separately. List any deviations from protocol and other comments.

Wood Turtle Individual Form (4/18/13)

Observer(s): Site Name: Site Code:

Turtle ID #		Date:		Time:	

Survey method: ☐ RA ☐ LT ☐ Inc. | GPS point:

Sex: ☐ M ☐ F ☐ J (≤14 yr) | Coordinates (dd.dddd):

☐ measured ☐ notched ☐ bled ☐ photos ☐ PIT

SCLmin (mm):		PIT number:	
SPLmin (mm):		Photo file names:	
CW (optional):		Visible annuli:	
PW (optional):		General health: ☐ URT distress ☐ lethargy ☐ sores ☐ other:	
Mass (g):			

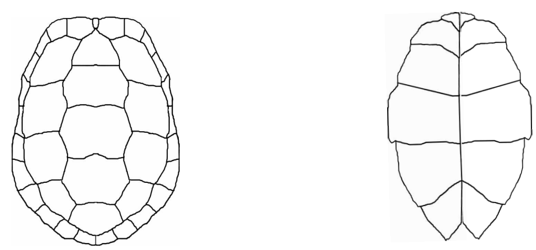
Wear class: ☐ not worn ☐ ≤50 % worn ☐ >50 % worn ☐ ≥90 % worn

Scute morphology: ☐ normal ☐ irregular (specify or mark below)

Injuries: ☐ tail ☐ eye ☐ limb (specify in comments)

☐ initial capture ☐ recapture ☐ gravid

Indicate notches and record marks or injuries:



Comments:

List any important comments here. Remember to list all turtle IDs on your survey form!

Appendix VI. Summarized Responses to Expert and Manager Questionnaire

Overview

A questionnaire was distributed by email to the members of the Northeast Wood Turtle Working Group (NEWTWG) in December 2012 to establish priorities for the Status Assessment coordination process. Thirty people responded to the survey, including representatives of eleven state agencies, provincial wildlife agencies, the U.S. Forest Service, the U.S. Geological Survey Cooperative Fish and Wildlife Units, as well as several academic or nongovernmental organizations, and the Canadian Department of National Defence, and private wildlife consultants. The average number of years experience working with wood turtles was 11.7. Responses are outlined below. Where numbered questions are skipped, the question was removed because it was relevant to a decision at hand that has already been addressed in this document.

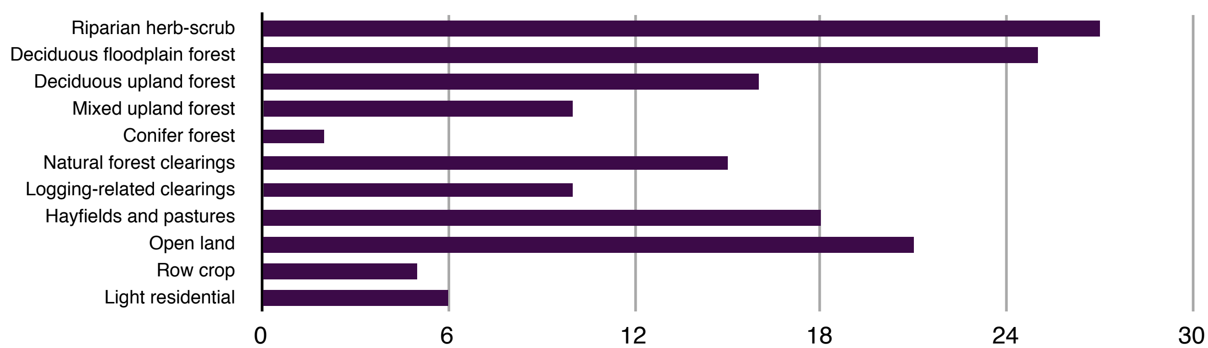
A link to the original poll may be found here: http://form.jotformpro.com/form/23395212761957

Questionnaire Part 1. Basic Ecology

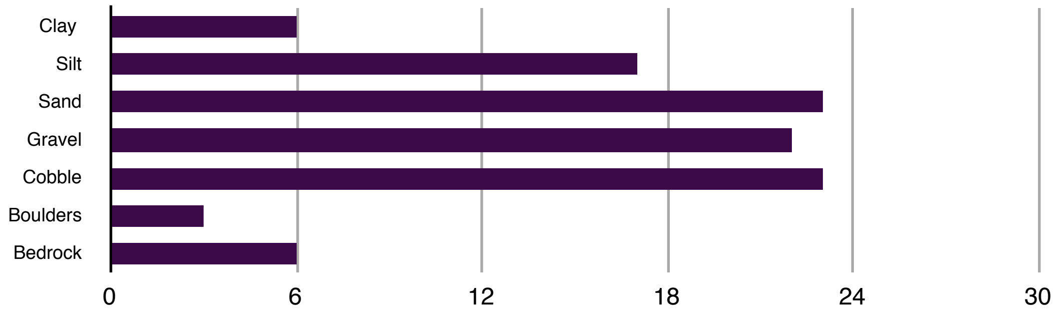
1b. Approximately how many wood turtle populations in your state are estimated to exceed 50 individuals?
Twenty-three respondents said "not enough information" or "not sure" or left the question blank. Of the remaining respondents, one reported "zero", two reported "five", one reported 10, one reported 16–20, one reported 21–25, and one reported 36–40.

1c. Approximately how many wood turtle populations in your state are estimated to exceed 500 individuals?
Sixteen respondents said "not enough information" or "not sure" or left the question blank. Eight respondents said "zero". Of the remainder, two reported "one", one reported "3", one reported "4", and two reported "10".

2a. What upland land cover provides preferred habitats for wood turtles in your state/province? (sum of responses):

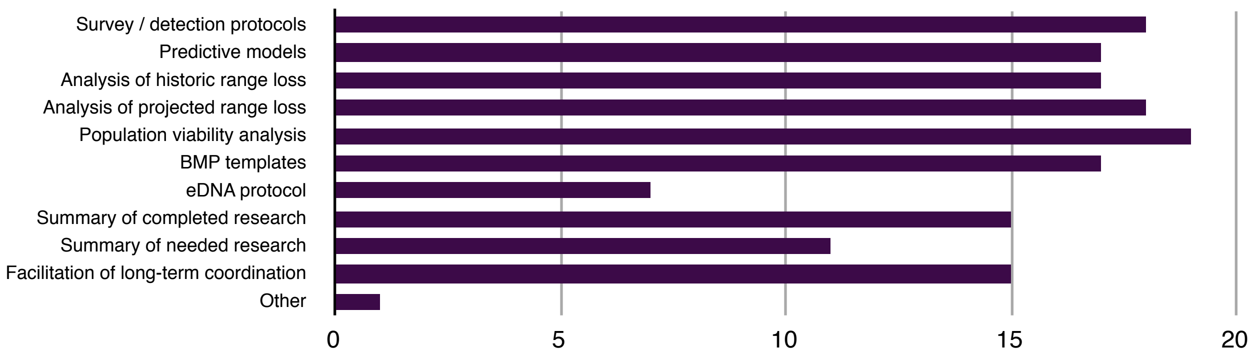


2b. What substrate typically forms the bed of stream segments occupied by wood turtles in your state/province (sum of responses)?

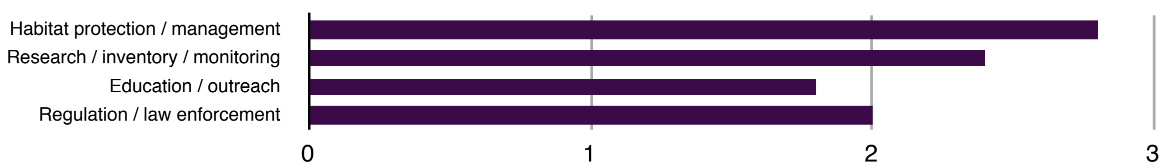


Questionnaire Part 2. Conservation Status of Wood Turtles in the Northeast

3a. What would be the most useful products from the regional wood turtle status assessment (sum of responses)?

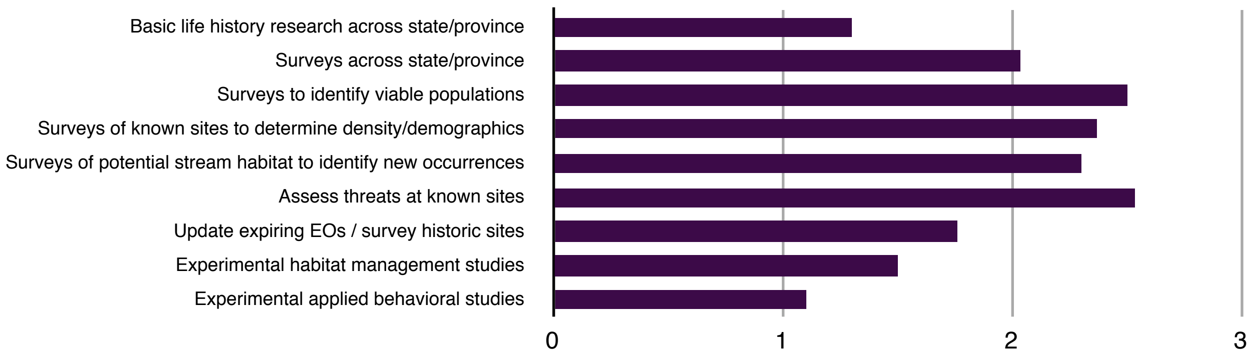


4a. How would you prioritize conservation needs for wood turtles in your state (average of responses from 0 to 3)?

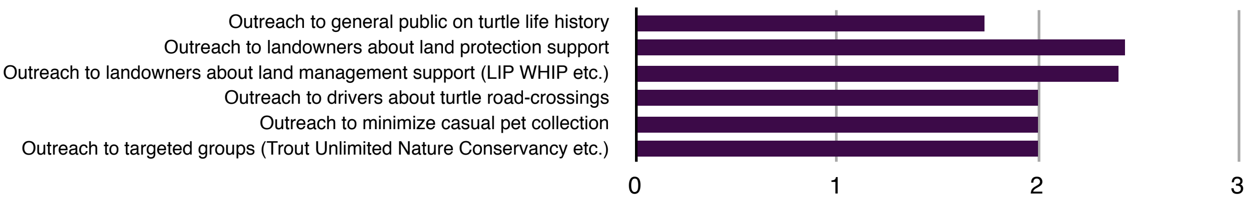


4b. Habitat protection and management priorities (average of responses from 0 to 3):

4c. Research, inventory, and monitoring priorities (average of responses from 0 to 3):

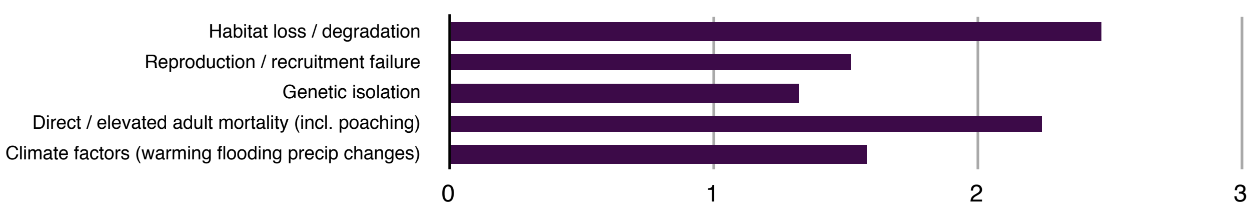


4d. Education and Outreach Priorities (average of responses from 0 to 3):

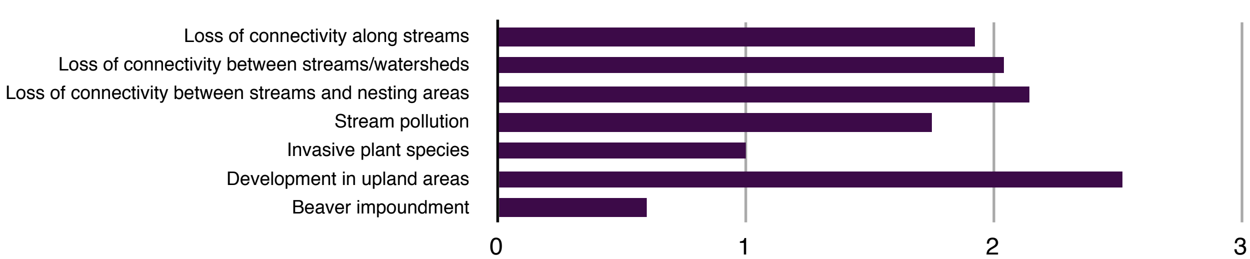


4e. Law enforcement and regulatory priorities (average of responses from 0 to 3):

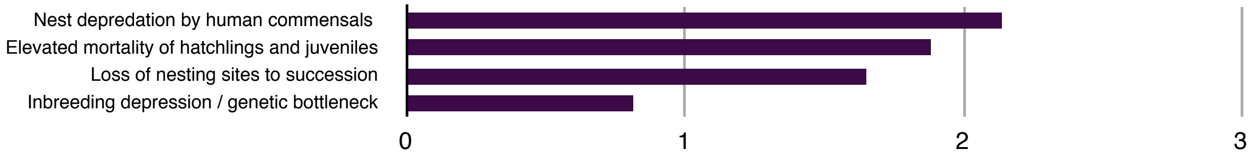
5a. What are the primary threats to wood turtle populations in your state (average of responses from 0 to 3)?



5b. Habitat loss/degradation categories (average of responses from 0 to 3)?



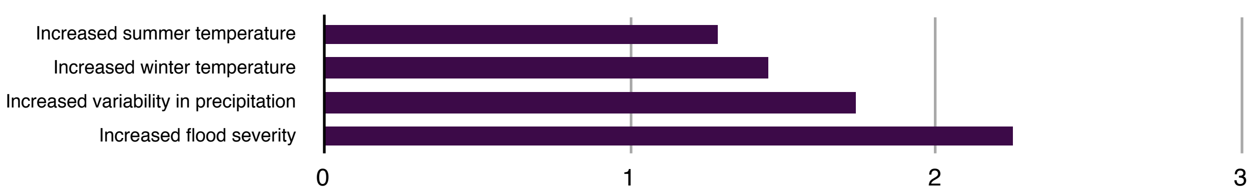
5c. Reproduction / recruitment failure categories (average of responses from 0 to 3)?



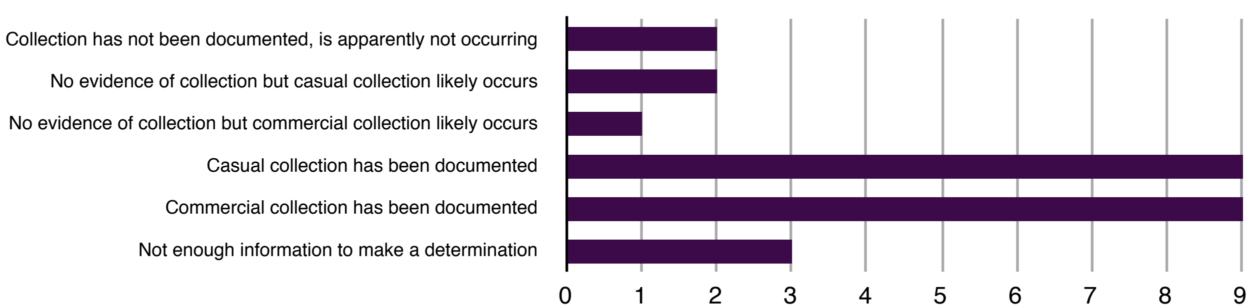
5d. Genetic isolation categories (average of responses from 0 to 3)?

5e. Adult mortality threat categories (average of responses from 0 to 3)?

5f. Climate-related threat categories (average of responses from 0 to 3)?

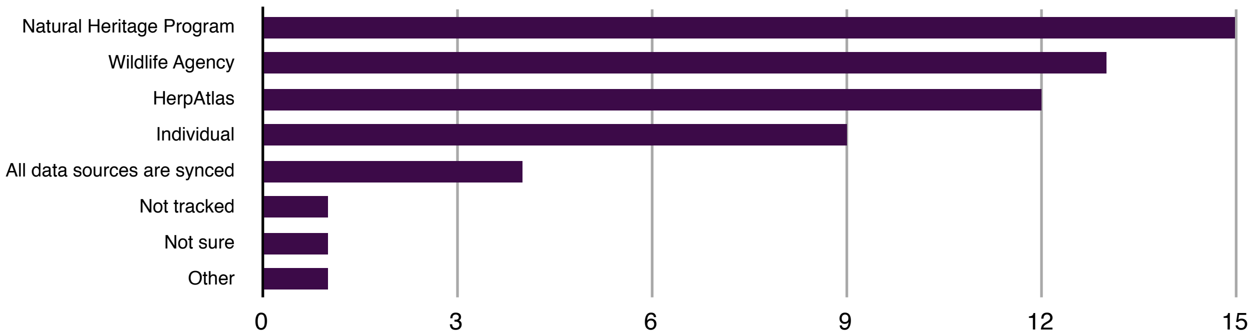


6a. Have there been documented instances of illegal wood turtle collection in your state (sum of responses)?



Questionnaire Part 3. Element occurrence tracking and populations

7a. How are wood turtle occurrences tracked in your state/province? (sum of responses)

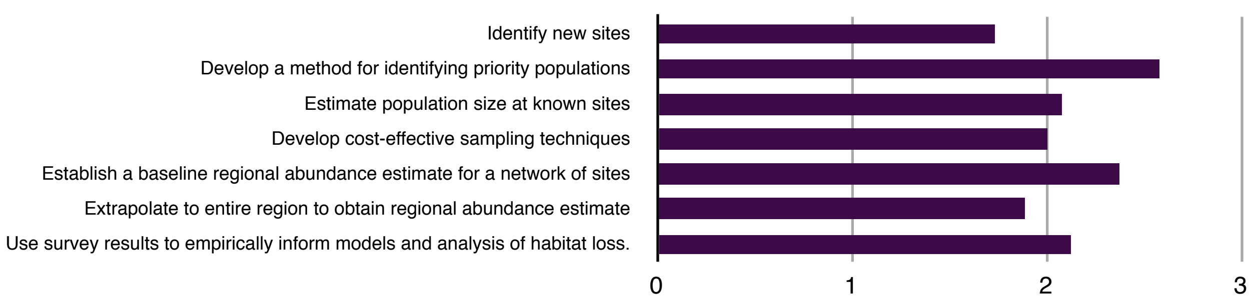


7b. Has your state/province developed its own system for ranking element occurrences? (sum of responses from Northeast state biologists only)

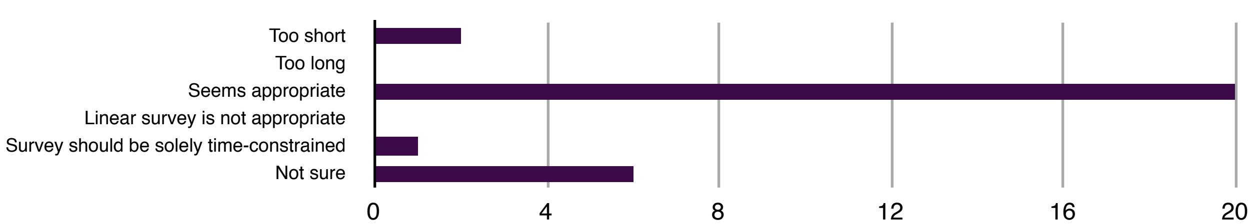
Questions 8–11, including Parts IV and V, are excluded from this summary because they were contributed in narrative form, or are related specifically to data availability.

Questionnaire Part 4. Coordinated Monitoring Strategy

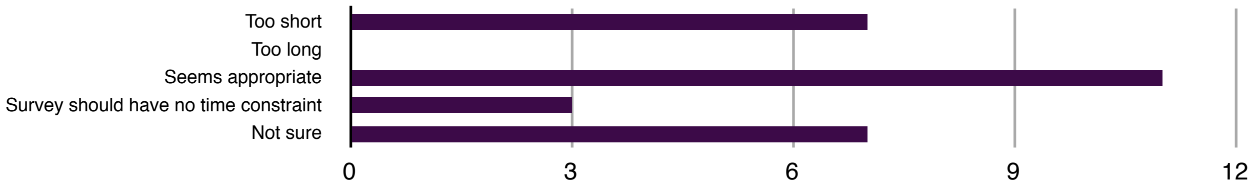
13b. What are the most essential components of a Coordinated Monitoring Strategy for wood turtles in the Northeast? (average of responses ranging from 0 to 3)



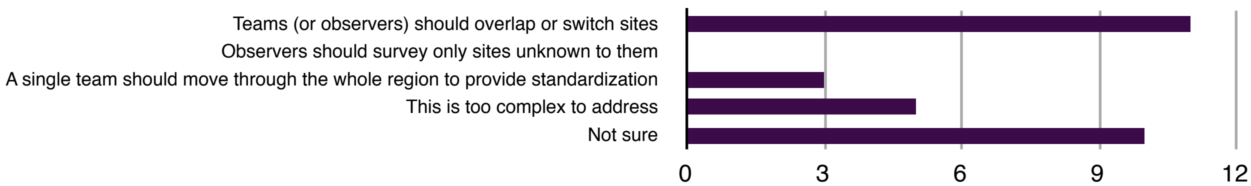
13c. What is your opinion of the space-constrained linear survey of 1 km of riparian habitat? (sum of responses out of 24 respondents)



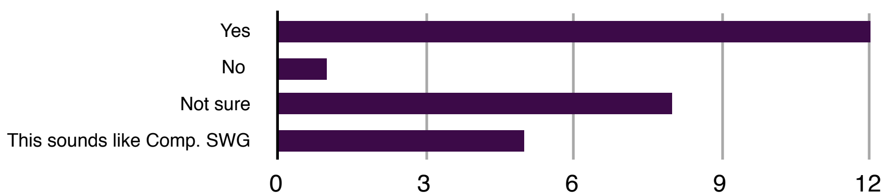
13c. What is your opinion of the time-constrained 1 hr survey of riparian habitat? (sum of responses out of 24 respondents)



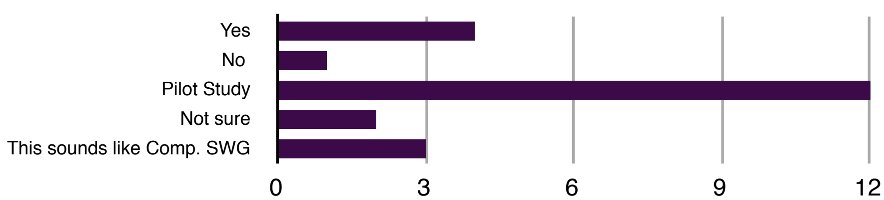
13d. Which of the following methods to reduce observer bias would you most support? (sum of responses out of 24 respondents):



13e. Should we strive to incorporate randomized site selection into the CMS 2013? (sum of responses out of 24 respondents):

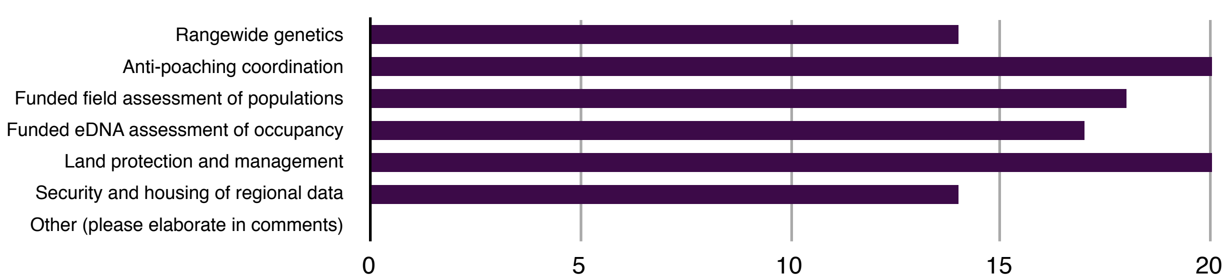


13f. Should we strive to incorporate environmental DNA (eDNA) sampling in 2013? (sum of responses out of 24 respondents):



Questionnaire Part 5. Implementation of Conservation Strategy and Coordinated Monitoring

14a. Check all of the components that may warrant further coordination beyond the scope of the RCN (sum of responses out of 24 respondents):



14c. Under what organizational structure should this group pursue long-term conservation objectives? (sum of responses out of 24 respondents):

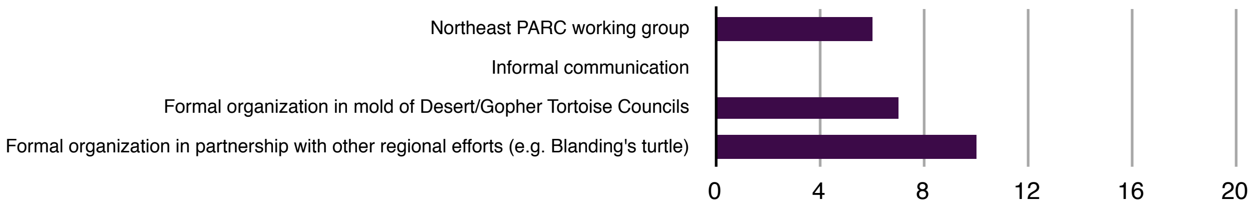


Table 1. List of respondents to questionnaire on wood turtle ecology and conservation in the Northeast. The "Primary State" field denotes the region in which the respondent has primarily worked with wood turtles.

Name	Primary State(s)	Title	Affiliation
Thomas Akre	VA	Assoc. Prof. of Biology	Longwood University; Smithsonian Cons. Biology Inst.
Scott Angus	PA	Consultant	Private
Alvin Breisch	NY	Retired herp specialist	NYS Department of Environmental Conservation
Christina Castellano	NJ	General Curator	Hogle Zoo
Phillip deMaynadier	ME	Wildlife Biologist	Maine Department of Inland Fisheries and Wildlife
Jenny Dickson	CT	Supervising Wildlife Biologist	CT DEEP Wildlife Division
Jeffrey Dragon	VA	Graduate student	George mason university
James Drasher	PA	Manager of Env. Services	Aqua-Terra Environmental Ltd.
Yohann Dubois	QC	Herp coordinator, Biologist	Ministère Ressources naturelles et faune du Québec
Lori Erb	MA	Turtle Conservation Biologist	MA Division of Fisheries and Wildlife
Jennifer Feese	VA	Environmental Scientist	Wetland Studies and Solutions, Inc.
Kathy Gipe	PA	Herpetologist	PA Fish and Boat Commission
Hank Gruner	CT	Vice President of Programs	Connecticut Science Center
William Hoffman	NY	Fish and Wildlife Tech	NYS Department of Environmental Conservation
Fred Huber	VA-WV	Biologist	U.S. Forest Service
Michael Jones	MA, NH, ME	Postdoc	MA Cooperative Fish and Wildlife Research Unit
JD Kleopfer	VA	Herpetologist	VA Department of Game and Inland Fish
Mike Marchand	NH	Wildlife Biologist	NH Fish & Game
Deanna McCullum	NB	Range Biologist	Department of National Defence
Kieran O'Malley	WV	Wildlife Diversity Biologist	WV Division of Natural Resources
Steve Parren	VT	Dir., Wildlife Diversity Prog.	VT Fish & Wildlife
Leighlan Prout	NH-ME	Wildlife Program Leader	U.S. Forest Service
Alison Robinson	VA	Environmental Scientist	Wetland Studies and Solutions, Inc.
Ben Rosner	VA	Assoc. Environmental Scientist	Wetland Studies and Solutions, Inc.
Angelena Ross	NY	Biologist	NYS Department of Environmental Conservation
Ed Thompson	MD	Forest Ecologist	MD Department of Natural Resources-Natural Heritage
Barry Wicklow	NH	Professor of Biology	Saint Anselm College
Liz Willey	MA, NH, ME	Postdoc biologist	MA Cooperative Fish and Wildlife Research Unit
Derek Yorks	MA	Biologist	ME Department of Inland Fisheries and Wildlife
Brian Zarate	NJ	Senior Zoologist	NJ Division of Fish and Wildlife