9. Restoration and Management

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An adult Wood Turtle rests in a New Brunswick hayfield. Shaylyn Wallace

9.1—Wood Turtle populations may be classified along gradients of habitat impairment that should be considered when deciding where, how, and when to manage for the species. This site is heavily used by farm machinery. It is bordered on one side by a railroad line and on the other by a busy commuter road. Mike Jones

Introduction

Wood Turtle habitat has been fundamentally altered by human beings throughout the species' range. No streams remain uninfluenced by anthropogenic change; even the most remote watersheds are experiencing interacting effects of climate change, invasive plant species, large carnivore collapse, or mesocarnivore release. Wood Turtles are highly sensitive to human activities including development, road construction, and recreation; therefore the most robust and stable populations persist in landscapes where there is minimal human presence (Garber and Burger 1995; Saumure et al. 2007; Jones et al. 2018; Willey et al. 2021). Although habitat impairment is widespread and even pervasive in many areas, landscapes with minimal degradation still remain. Functional populations could persist in these areas for the foreseeable future without immediate human intervention, provided the landscapes are adequately buffered from human activity (Jones et al. 2018; Willey et al. 2021). A combination of land protection and strategic monitoring of populations and habitat would benefit these noteworthy populations more than active, on-the-ground management. In these (relatively) intact systems, particularly those large and undisturbed enough to maintain regimes of moderate disturbance from flooding and beavers, habitat protection that allows the systems to function as naturally as possible is the most urgent path forward.

However, meaningful land protection for Wood Turtles—at sufficient levels to ensure the species' persistence in a given watershed for any evolutionarily significant timeframe—is often riddled with challenges and practical problems that reduce the long-term feasibility of adequate preservation (e.g., Browne and Hecnar 2007; Carroll 2018). Some of these challenges include disclosures of site-specific details as a necessary component of publicly funded real estate transactions, the prohibitive cost of preserving landscapes of sufficient size, and the societal pressure to promote and facilitate public access, which can lead to rapid attrition of turtles through collection (Garber and Burger 1995). It follows, then, that managers should strategically pursue opportunities to restore and manage Wood Turtle habitat as a realistic hedge against some failures on the land protection front, especially where it is possible to leverage local or specialized resources for projects. Strategic restoration geared toward restoring fluvial disturbance processes may also help to offset the immeasurable loss of Wood Turtle nesting habitat and overwintering habitat in streams associated with development, dams, and hydrologic alterations.

Gradients of Impairment.—Wood Turtle populations may be classified along gradients of habitat impairment that should be considered when deciding where, how, and when to manage for the species (9.1).[1] Within a management jurisdiction such as a state or a federal land agency, restoration activities should generally be directed toward sites that appear to have some reasonable chance of continued persistence without continuous management. Severely impaired populations may not be a priority to organizations and entities whose scope of work has a regional or range-wide focus, but may be the most noteworthy natural resource in a town, county, or state park. In these cases, it often makes sense to attempt interventionist management. Ultimately, habitat management initiatives geared toward restoring function to ecosystem processes will maximize the cost-benefit ratio of Wood Turtle restoration, while also benefiting other species in the system. In any case, some level of strategic planning is helpful in order to identify restoration activities that restore the greatest function within the focal site.

Delayed Population Response.—Habitat restoration for Wood Turtles is further complicated by the species' low annual reproductive output, late maturity, slow life history, and long generation time, generally meaning that population responses to any management actions will be slow (Klemens 2000; Mullin et al. 2020). Determining the real effect of restoration for any emydine turtle species will usually require years—if not decades—before detectable changes can be measured.[2] Partly for this reason, there is a notable dearth of peer-reviewed, empirical studies quantifying population-level responses of freshwater turtles to prescribed management actions (Mullin et al. 2020). This lack of direct evidence should not deter management for Wood Turtles and post-management monitoring, but rather serve as point of caution that, given the unique context and myriad factors influencing any given population, managers should take care when considering when, where, and how to manage for Wood Turtles. Monitoring frameworks should consider the practical limitations associated with a delayed population response (i.e., a necessity for long-term studies).

In this chapter we summarize the available research on restoration and management prescriptions for Wood Turtle populations. We also discuss some general considerations for planning management actions or a restoration program. We put some additional emphasis on those management actions most likely to effectively promote Wood Turtle population persistence by restoring ecosystem function such as natural stream-channel processes. We attempt to seek some congruence between the many documents already available at the state and regional level. However, we underscore two additional notes of caution: (1) without a meaningful evaluation of

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1 The precise seasonal timing—as well as distances most appropriate for management—vary across the species range, as well as from site to site, so we intentionally generalize that discussion here.

2 Note that relatively fast population response to strategic management was reported in a European Pond Turtle (*Emys orbicularis*) in southern France (Ficheux et al. 2014).

the needs of the target population, as well as the broader landscape context, improper habitat management can undermine population recovery or even promote further population decline; and (2) effective restoration will require sustained support over time, and can require immense investment of monetary resources and human effort. If management actions are supported primarily with funds that would otherwise support landscape conservation at large scales (relative to the spatial needs of Wood Turtle populations), they can easily misdirect valuable conservation resources and undermine a larger vision for regional Wood Turtle conservation.

9.2—Nesting habitats often provide some of the clearest opportunities for management, ranging from light scarification to tree removal. Here, volunteers work to scarify plots within a concentrated Wood Turtle nesting area in Massachusetts. Mike Jones

Nest Area Management

Nesting habitats often provide some of the most straightforward opportunities for Wood Turtle management, ranging from light scarification to tree removal (9.2), but are probably most effective when they are part of a management strategy geared toward increasing adult survival. Wood Turtles generally require well-drained, elevated, and exposed areas of sand and/or gravel (or other, primarily inorganic substrates) for nesting (Buech et al. 1997; see Chapter 5), but the acceptable range of nesting conditions seems to vary somewhat throughout the species' range. In relatively natural and unmanaged systems, Wood Turtles often select nesting sites that are generated and maintained by natural stream dynamics and seasonal flooding, such as instream point bars. In more cases than not, however, hydrologically altered stream systems characterized by dams, bank stabilization, and river channel alteration have disrupted the dynamism and depositional patterns of the stream such that natural nesting conditions are rare or non-existent.

9.3—In some cases, especially in areas where natural nesting features are lacking, Wood Turtle nesting areas can be improved upon by depositing piles of sand and gravel, as pictured here in New Jersey. Colin Osborn

Wood Turtle nesting areas can, in some cases, be restored, augmented, or created by clearing land to expose underlying deposits of poorly graded sand and gravel, or by depositing piles from offsite (Buhlmann and Osborn 2011) (9.3). Nesting mounds have also been constructed for other freshwater turtle species (Dowling et al. 2010; Paterson et al. 2013). Paterson et al. (2013) found that nesting mounds built for

Snapping (*Chelydra serpentina*) and Painted Turtles (*Chrysemys picta*) experienced higher use than expected—and higher nest success—compared to more natural nesting areas. Optimal artificial nesting mound dimensions have not been identified; however, a utilized nesting mound created for Wood Turtles in New Jersey by Buhlmann and Osborn (2011) was 18.2 m long, 7.6 m wide, and 1.5 m tall. Artificial nesting areas should be situated in open-canopy areas with ample sun exposure (e.g., a field or scrub/shrub mosaic) and provide a direct, unfragmented path (no intervening roads or structures) to suitable stream habitat. Spatial replication of nesting features at a site will provide turtles with a range of environmental conditions to choose from, and may reduce depredation rates, which have been shown to be higher when nests are spatially concentrated (Marchand and Litvaitis 2004).

9.4—Instream features such as point bars, sand and gravel bars, beaches, and cutbanks can be improved by proactively attempting to eradicate invasive plant species such as Japanese Knotweed (*Reynoutria* [*Fallopia*] *japonica*), or clearing openings to allow nesting at sites where invasive species are already well established. Mike Jones

Instream nesting features such as point bars, sand and gravel bars, beaches, and cutbanks in more fragmented habitats are frequently invaded by introduced plant species such as Japanense Knotweed (*Reynoutria* [=*Fallopia*] *japonica*) (Colleran and Goodall 2014; 2015), Spotted Knapweed (*Centaurea stoebe*), Multiflora Rose (*Rosa multiflora*), Autumn and Russian Olive (*Elaeagnus umbellata* and *E. angustifolia*), and Glossy Buckthorn (*Frangula alnus*), which can degrade otherwise suitable nesting areas as a result of shading, lack of open substrates, and root invasion of Wood Turtle nest cavities (9.4). Each of these species requires a specific management approach, and some eradication efforts may be impractical. In all cases, invasive and introduced plant removal efforts involving machinery, heavy equipment, or vehicles should occur outside of the Wood Turtle activity window.[3]

Managers should avoid landscape configurations that result in attractive nuisances or ecological traps, in which female Wood Turtles are attracted to nesting areas that either result in decreased adult survival rates (because of predation, road mortality, or collection), decreased nest success, or decreased hatchling survivorship. For example, it is not ideal to have suitable or attractive nesting habitat located across the road from the primary watercourse, even if the road is infrequently traveled. Nest area restoration efforts may be monitored via remote sensing cameras, providing immediate feedback about the effectiveness of management and guiding the improvement of future actions (Buhlmann and Osborn 2011; Jones, unpubl. data).

Predator Deterrents and Control.—In landscapes that support exceptionally high densities of mammalian and avian predators, rates of predation on nests, hatchlings, and/or adult Wood Turtles are known to be unsustainably high (9.5). Several management strategies have been

3 For additional discussion of the Wood Turtle activity season, see Chapter 6.

employed across the species range to reduce mammalian predation rates on turtle nests. For example, individual Wood Turtle nests can be protected with a physical transparent structure such as hardware cloth or chicken wire to reduce mammalian predation rates, often by researchers attempting to measure demographic parameters such as clutch size (Compton 1999; Jones 2009) (9.6). These protective exclosures can cause hatchling mortality if not monitored daily beginning well prior to the expected emergence of hatchlings. These exclosures are generally only permitted to be installed in coordination with state or provincial wildlife agencies. More recently, larger-scale, electric fence exclosures have been utilized to surround entire nesting areas in order to exclude mammalian predators (Wisconsin: Lapin et al. 2015; Vraniak et al. 2017; Minnesota: Markle et al. 2019). Electric fences require substantial effort to set up, might attract unwanted attention by recreationists, and have proven to be only moderately effective in some locations for protecting nests of related turtle species. In their evaluation of a long-term headstarting program, Mullin et al. (2020) noted that predator control would likely result in greater positive impact on population growth rates than headstarting young turtles. The effectiveness of predator control on the nest-success rate of wild Wood Turtles has not been specifically tested, but should be targeted for future experimental research.

9.5—In landscapes that support high densities of mammalian predators such as Red Fox, rates of predation on nests, hatchlings, and/or adult Wood Turtles are known to be unsustainably high. Mike Jones

9.6—Several management strategies have been employed to reduce mammalian predation rates on turtle nests, including individual nest protection with exclosures. Here, a Virginia Wood Turtle nest protected by a hardware cloth exclosure is shown with the lid open. Generally, the use of nest exclosures is closely regulated by wildlife agencies because some designs can easily result in hatchling mortality. John D. Kleopfer

Agricultural Land Management

Upland habitats used by Wood Turtles vary geographically and seasonally, but most Wood Turtles annually utilize land-cover mosaics that include forested and early-successional cover types, including agricultural fields. Vegetation ecotones, or edge habitats, that support structural diversity appear to play an important role for Wood Turtles by providing opportunities to balance both thermoregulation and food requirements (Compton 1999; Saumure 2004; Jones 2009). Before the intensification of agricultural machinery, agricultural lands were sources of early-successional habitat that provided areas for foraging, thermoregulation, and localized nesting opportunities.

Wherever agricultural fields are situated near Wood Turtle watercourses, machinery such as mowers, combines, tractors, plows, and harrows can pose a significant threat to Wood Turtle populations by elevating rates of adult and juvenile mortality and injury throughout the species range (Saumure and Bider 1998; Saumure 2004; Jones et al. 2018). Mortality events have been regularly documented within mowed fields (e.g., Saumure and Bider 1998; Saumure et al. 2007; Tingley et al. 2009; Jones 2009) and plowed fields (Saumure 2004; Sweeten 2008; Jones 2009). Under certain landscape configurations and times of year, relatively large mortality events can occur. Below we summarize the available research geared toward minimizing Wood Turtle mortality within active agricultural landscapes. Management of Wood Turtles in agricultural sites is particularly challenging, as resource managers must reconcile their necessity for societal means of food production.

9.7—Research in New Brunswick, Québec, and Massachusetts indicates that sickle-bar mowers result in lower rates of expected Wood Turtle mortality when compared to disc and rotary mowers, but they are less efficient and have largely fallen out of use. Hayfield mowing is pictured at Wallace et al. (2020)'s research site in New Brunswick. Shaylyn Wallace

Mowing Reduction.—Increasing the width of unmowed riparian buffers will likely benefit resident Wood Turtle populations, though these buffers need to be managed/mowed periodically during the Wood Turtle inactive season to maintain the site as early successional habitat (Tingley et al. 2009; Wallace et al. 2020). Further reducing machinery use around the margins of fields near rivers may be an effective method for reducing agricultural mortality. Wood Turtles have been observed congregating along the edges of field and shrub habitats with good solar exposure (i.e., facing south and southwest; Jones, unpubl. data). These congregation areas are often close to abandoned river meanders, ditches, damp areas, or the river itself. Wood Turtles are well-documented to heavily use both forb- and graminoid-dominated meadows and hayfields (see Chapter 5), so turtle presence should be assumed wherever hayfields, pastures, or abandoned farmland provides the most accessible early-successional habitats within a few hundred meters of the margin of a watercourse with high densities of overwintering Wood Turtles. Once fallow, fields should be mowed every one to two years during the Wood Turtle inactive season.

Type of Machinery.—Although less efficient than disc and rotary mowers (Saumure 2004), sickle-bar mowers have been shown to significantly lower expected mortality rates in proxy studies (Erb and Jones 2011; Wallace et al. 2020) (9.7). Raising mower blades above 20 cm when mowing in fields occupied by Wood Turtles may slightly reduce the overall mortality and injury rate, although there is some variability in the exact recommended mowing height. Erb and Jones

(2011) found no further reduction in expected injury rates (to proxies for real turtles) when mower heads were set below 15 cm. Wallace et al. (2020) estimated that raising the mower head to ≥17 cm might reduce mower-caused mortality by 50% (15 cm for smaller turtles). Mitchell et al. (2006) suggested 20 cm as a rough target. Even with blades set high, tractor tires may result in crushing mortality up to 46% (Erb and Jones 2011). Saumure (2004) inferred from carapace fractures that Wood Turtles head for rivers when they detect vibrations from a mower and postulated that mowing progressively from the edge of the field farthest from the river could allow some turtles to move toward the river and out of harm's way. However, the only study to specifically test this assumption found that Wood Turtles did not move from fields during mowing trials (Wallace et al. 2020). As with other methods of agricultural land management, mowing trials (and behavioral studies) would be helpful.

Grazing.—Livestock grazing has the potential to maintain upland, non-riparian areas as diverse, open-canopy, early-successional habitats, and may have value in some areas as an alternative management method to heavy machinery. Grazing areas should be located away from streams to avoid water quality degradation (9.8). The effects of large animal grazing on Wood Turtle habitat use or recruitment have not been specifically evaluated, but there is evidence that low- to intermediate-density livestock grazing is associated with an improved demographic response in Bog Turtle (*Glyptemys muhlenbergii*) populations (Tesauro and Ehrenfeld 2007). However, livestock trampling is associated with reduced recruitment rates in the European Pond Turtle (*Emys orbicularis*) in France (Olivier et al. 2010; Ficheux et al. 2014), suggesting that livestock should be excluded from nesting areas. This suite of effects—including the effects of river, stream, and brook degradation—should be specifically evaluated where feasible.

9.8—Livestock grazing has the potential to maintain large areas as diverse, open-canopy habitats, and for Bog Turtles (*Glyptemys muhlenbergii*) has been a practical management alternative to heavy machinery, but needs further study as a management technique for Wood Turtles. A dairy farm that supports a relatively large Wood Turtle population in New England is pictured. Mike Jones

9.9—Row crop agriculture can result in Wood Turtle mortality depending on the harvest date and other machinery use during the season. Rotation of a given field from corn or potatoes to a late-season crop such as pumpkins could result in annual variation in Wood Turtle mortality rates. Two radio-equipped female Wood Turtles were killed in this Massachusetts potato field in midsummer. Mike Jones

Row Crop Harvest.—Many authors have noted that the potential for row crop agriculture to result in Wood Turtle mortality is partly a function of the harvest date (Saumure and Bider 1998; Castellano et al. 2008) (9.9). Late-season crop varieties that require harvest in fall (rather than summer) may result in lower risk to Wood Turtles because many turtles will have already returned to their overwintering habitat. For this reason, the annual rotation sequence of crops with different harvest schedules (e.g., corn vs. pumpkins) will influence mortality rates in unpredictable and complex ways. Castellano et al. (2008) recommended a harvest schedule that would minimize mortality to nests and hatchlings. In the Ontario system studied by Mullin et al. (2020), the watercourse was bordered by rotational crops of soy, corn, and hay (Mullin, unpubl. data). Of these crops, hay probably posed the greatest risk to the local Wood Turtle population because of its near-monthly harvest, while corn and soy were harvested relatively late in the season.

9.10—Roads near rivers occupied by Wood Turtles seem to be associated with increased probability of extinction of local Wood Turtle populations. This New England juvenile was killed on a state highway where the road parallels the suitable stream habitat for several kilometers—a long-term management challenge for this particular population. Mike Jones

Timber Management

Logging operations near occupied Wood Turtle rivers pose several threats to Wood Turtle populations, the most significant of which is direct adult mortality resulting from the use of heavy machinery (tractors, skidders, or other equipment) during the active season (deMaynadier, unpubl. data). However, we note that the heavy machinery associated with logging operations is likely less of a potential threat than agricultural machinery, given that forests are harvested on the order of multiple decades and hayfields (for example) are harvested multiple times per year. Intensive forest management can also degrade aquatic and terrestrial habitat quality by promoting soil erosion, altering conditions in the watercourse, and introducing invasive species. Intensive forestry can alter the thermal landscape available to Wood Turtles, increasing their exposure to extreme temperatures (Hughes and Litzgus 2019). In addition, centuries of forestry have changed the structural configuration of rivers and streams (Dolloff and Warren, Jr. 2003). In some cases the extensive removal of large wood from riparian areas immediately adjacent to streams through logging has likely decreased the total availability of large wood in the form of instream logjams and other structural features such as debris dams (Silsbee and Larson 1983), a phenomenon discussed in more detail later in this chapter (see River and Stream Management).

Creation of new logging roads can increase direct mortality by vehicle strikes, while also allowing access to otherwise remote unfragmented habitat, which can facilitate the intrusion of poachers or invasive plants into the site. However, smaller-scale forestry operations such as shelterwood cuts, group selection, and patch cuts may provide opportunities to enhance Wood Turtle habitat if conducted during late fall and winter (i.e., while Wood Turtles are underwater, see Ch. 6). The indirect benefits of forest harvest may be variable across the species' range, as northern turtles may benefit more from the creation of early successional habitat. At the present moment, intensive forestry is relatively commonplace within northern Wood Turtle habitats from Minnesota to Nova Scotia, including very large areas of Ontario, Québec, and Maine. Carefully planned research should examine the spatial response of individual Wood Turtles to newly cleared habitats and the population-level response to forestry near Wood Turtle streams.

Roadway Management

Although rates of road mortality in Wood Turtles have not often been examined, roads near occupied rivers seem to be associated with increased probability of extinction of local Wood Turtle populations (Willey et al. 2021). Roads that parallel Wood Turtle streams are particularly detrimental (9.10), especially if there are attractive early-successional habitats or nesting features on the opposite side of the road from the watercourse.

Perpendicular road crossings can also result in elevated rates of road mortality near stream and river crossing points if suitable habitat is located near the road shoulder, or if the culvert is undersized or "perched" (i.e., elevated above the low-flow waterline on the downstream end). In these cases, Wood Turtles traveling along the stream may be forced to cross existing road surfaces in order to access key resources, risking collision with cars. Numerous road-killed Wood Turtles have been found on state highways associated with perched culverts in New England (Jones, unpubl. data) (9.11). In those cases where a road already crosses a Wood Turtle stream, it is important to consider practices and redesigns of road features, including culverts or bridges, to accommodate the movements of Wood Turtles. In addition to replacing perched culvert in order to facilitate turtle passage, it is important to avoid situations where the road surface, shoulder, and/or side slopes attracts nesting females.

9.11—Perched culverts, such as these two sites in New England, interfere with instream Wood Turtle movements and appear to prompt turtles to move onto the roadway surface. Wood Turtles have been killed at these culvert crossings on several occasions. Mike Jones

9.12—Full span bridges that approximate natural stream habitats, with high amounts of available light, will best accommodate Wood Turtle passage under roadways, such as this site in New England. Mike Jones

Wherever feasible, natural bank habitats will best accommodate turtle passage under roadways (9.12). In some site-specific instances, fencing or a similar barrier may be installed off the road shoulder to minimize Wood Turtle intrusion onto the roadway and encourage the use of existing culverts or bridges to travel under the road. However, subsequent monitoring of fence integrity is important because any gaps that allow passage of turtles may substantially reduce the effectiveness of the entire effort (Markle et al. 2017). In a study of related species, Yorks (2015) found evidence that opaque fencing is more effective at getting turtles to move along the fence; turtles tend to keep trying to get to the other side if the fencing is transparent and seem to take longer to move along the fencing to a passageway. This may be important for predation and desiccation/overheating risk. One study of Painted Turtles, Spotted Turtles (*Clemmys guttata*), and Blanding's Turtles (*Emydoidea blandingii*) found that turtles are more likely to use tunnels that are larger and well lit (Yorks 2015). There is a growing trend of using turtle crossing signs at road mortality hot spots, though the effectiveness of these signs has not been thoroughly evaluated (Seburn and McCurdy-Adams 2019). In some cases, these signs may facilitate the detection of Wood Turtle sites by poachers.

Roads increase the ease of human access into otherwise unfragmented habitats, allowing poachers to more easily reach population centers and potentially facilitating the spread of invasive plants. New road and stream crossings should be avoided in all possible cases near extant Wood Turtle populations.

Recreational Access Management

Wood Turtles occur on numerous scenic waterways with high value to canoeists and boaters, and are often found along coldwater trout streams that are frequently traveled by anglers. Collection of Wood Turtles for pets, even at infrequent intervals, can cause population decline and pose a long-term conservation challenge for the species (Congdon et al. 1993; Garber and Burger 1995; Compton 1999). Further, Wood Turtles are occasionally hooked by anglers (Jones and Yorks, unpubl. data; Saumure, unpubl. data in the Canadian Museum of Nature). In order to minimize encounters between recreationists, recreational access points should be relocated away from regionally significant Wood Turtle watercourses.

River and Stream Management

Wood Turtles require moderately dynamic fluvial and adjacent terrestrial habitats in order to maintain viable populations. The most important fluvial characteristics are also those that are not easily re-engineered in a restoration context: flow volume, channel slope, flooding propensity, substrate, sinuosity, and depositional tendencies.

Dam Removal.—Dams have eliminated Wood Turtle habitat by turning low-gradient stream habitat into unsuitable reservoirs and altering the downstream flow regime, which degrades nesting habitat and/or floods nests near rivers (Compton 1999; Lenhart et al. 2013). Dam managers should consider minimizing large water releases between late May and the estimated date of nest emergence (generally throughout August) on rivers with Wood Turtles and known or suspected low-lying nesting areas in order to prevent nest inundation. High flows should be allowed during early spring, before nesting, to encourage natural scouring of vegetation and redistribution of sand and gravel sediments. During dam re-permitting near Wood Turtle streams, managers should 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.

Over 1,000 dams have been removed in the United States since 1970 (O'Connor et al. 2015), most within the range of the Wood Turtle in the northeastern states and upper Midwest (Foley et al. 2017), and that number is growing every year. As historic and defunct dams are removed from throughout the Wood Turtle's range, there may be rare opportunities to restore the integrity of some river systems. In these cases, returning the stream or river to its natural flow and dynamic hydrological regime will support the persistence of the natural nesting and overwintering features (9.13). Removing hardened banks and restoring sinuosity are some actions that might reduce extreme flooding and restore natural nesting features. Though such actions are expensive and difficult to undertake logistically, as part of a larger restoration effort they may be feasible. Managers and conservationists should engage in conversation with collaborative stream restoration projects throughout the species range to ensure that Wood Turtle habitat and management needs are considered as part of broader ecological restoration efforts.

9.13—In some cases, dam removal provides opportunities to restore the natural flow of Wood Turtle rivers, returning the stream to a dynamic hydrological regime (top). However, some dams counter-intuitively provide habitat in their upstream delta channels, such as this site in New England (bottom). Mike Jones

Large Wood.—The importance of woody material—including large wood and coarse, woody debris—in stream systems has been a focal point of research in fisheries science for decades (Gregory and Davis 1992; Roni and Beechie 2012; Roni et al. 2014). Large wood in the form of fallen trees can dramatically alter the channel dynamics of small- to midsize streams, increasing the availability of deeper instream pools. However, its influence on the distribution of stream-dwelling turtles has only been suggested and not critically examined (Dolloff and Warren 2003). Nevertheless, the role of large wood in Wood Turtle streams can be inferred—at least so far as to inform a research study and some preliminary management—from decades of research on salmonids and other coldwater fish (Dolloff and Warren 2003; Floyd et al. 2008) (9.14). Floyd et al. (2008) found that the addition of large woody structures (digger logs and deflectors) improved salmonid habitat by narrowing the stream channel, scouring pools, and creating bank undercuts. By diversifying the substrates, flow patterns, and habitats within the stream channel it is likely that the addition of woody debris benefits Wood Turtles. Further, Wood Turtles will actively bask on logjams (9.15). In general, as noted by Gregory and Davis (1992) for more general applications of river restoration, management of Wood Turtle streams should maximize the diversity of instream conditions while minimizing disturbance to natural channel dynamics. Streams with extensive riparian areas devoid of mature forest are more likely to have depauperate accumulations of large wood in the stream channel, and may benefit from the direct addition of large trees (Floyd et al. 2008), though all wood should be locally sourced to limit the spread of invasive pests and diseases. Researchers should consider evaluating the association of Wood Turtles with large wood and/or accumulations of coarse, woody debris, as well as the response of Wood Turtles to experimental and controlled additions of large wood.

Beaver Control.—As ecosystem engineers, Beavers (*Castor canadensis*) can dramatically alter Wood Turtle streams in ways that are both positive and negative. Overall, the presence of beavers in large and unfragmented landscapes should be considered neutral or positive unless specifically assessed otherwise. Within landscapes that are anthropogenically unaltered, and contain ample fluvial (i.e., river or stream) habitats, beavers likely benefit Wood Turtles by generating open, early-successional conditions ideal for thermoregulation, foraging, and potentially even nesting (under certain circumstances) via tree removal, flooding, and vegetation removal. However, in relatively fragmented landscapes and/or isolated patches of Wood Turtle stream habitat where suitable nearby conditions do not exist, beavers may negatively affect Wood Turtles by degrading local fluvial habitat quality through associated increases in organic material, water temperature, and hypoxic conditions. However, the influence of beaver impoundments on the instream distribution and habitat selection of Wood Turtles has not been directly examined. Anecdotally, Wood Turtles seemed to avoid a 0.5-ha beaver impoundment in Massachusetts, but overwintered within small (<0.1 ha) beaver impoundments at several sites in New England (9.16).

9.14—Large wood can diversify substrates, flow patterns, and habitats within the stream channel, and likely benefits Wood Turtles. The role of large wood in Wood Turtle streams warrants further research as a restoration technique. Mike Jones

9.15—In addition to general instream habitat improvements associated with large wood, Wood Turtles likely benefit from the addition of large wood by actively bask on logjams and seeking shelter in the accumulated logjam. Basking Wood Turtles are pictured in northern New England. Mike Jones

In areas where beavers are not actively controlled, large areas of free-flowing stream may become impeded and sluggish with organic substrate deposition. Outright dam removal may be appropriate in some cases, or installation of flow control structures (beaver deceivers). However, managers should take into account local stream and flood dynamics before implementing dam removal or beaver management. Strong annual or interannual spring floods may naturally remove dams that impound free-flowing stream habitat. The negative impact of beaver residency on local Wood Turtle populations should be gauged as a function of impoundment duration and proportion of available, connected Wood Turtle habitat that is flooded. If Wood Turtle habitat is typically only flooded sporadically (with intervening periods of beaver inactivity), and free-flowing, instream overwintering habitat is still available, the net effects for the local turtle population are likely positive. If flooded conditions are maintained for extended periods (e.g., >2 years) and impounded areas represent the majority of available Wood Turtle habitat, managers should consider active management. For example, a population decline in the related Bog Turtle was caused by sustained beaver flooding of nesting and overwintering habitat (Sirois et al. 2014).

In heavily altered but otherwise unfragmented (e.g., by roads) stream systems, restoring natural flow regimes through dam removal and/or stream channel restoration will likely promote the availability of important habitat features within Wood Turtle streams. Most applied research involving Wood Turtles has been directed toward some manipulation of the upland environment to support nesting or foraging, but we lack rigorous evaluations of Wood Turtle response (at the individual or population level) to stream restoration efforts.

9.16—Anecdotally, Wood Turtles in Massachusetts seemed to avoid relatively large (0.5 ha) beaver impoundments, but elsewhere in New England Wood Turtles occasionally overwintered within small (<0.1 ha) beaver impoundments. The influence of beavers is probably net positive for Wood Turtles in large areas of continuous habitats, but may pose local management challenges where habitats have been severely fragmented. Here, a small beaver dam impedes a New England Wood Turtle stream. Mike Jones

9.17—In cases where confiscated Wood Turtles appear to be of wild origin, they can be genotyped to their approximate watershed basin of origin and returned to the jurisdictional state wildlife agency to determine the best possible conservation outcome. Mike Jones

Captive Management

The overarching, guiding philosophy of this book—indeed, the whole reason to write it—is the apparent fact that Wood Turtles can still be managed and conserved as wholly functional populations upon dynamic natural landscapes throughout representative portions of their native range in Canada and the United States. From this perspective, it is important to ensure adequate protections for remaining stream systems that are relatively remote from human influence and frequent human traffic. However, as a part of landscape-scale restoration activities, to restore connectivity between important Wood Turtle populations, or to "buy time" to achieve long-term management or conservation actions, it is sometimes feasible to headstart young Wood Turtles. Mullin et al. (2020)—in the only study to critically evaluate this method for Wood Turtles—found that even with headstarting, an Ontario Wood Turtle population would likely continue to decline without predator control. We recommend caution when beginning headstarting initiatives, as their real costs are immense when compounded over multiple decades. Here we essentially pass the discussion over to others who are more invested in this particular management strategy.

Regrettably, it is also the case that Wood Turtles are confiscated from illegal trade networks with some regularity by state and federal law enforcement (see Chapter 8). In our experience, the origin of these turtles is often not immediately clear (Jones and Willey, unpubl. data; Weigel and Whitely 2018). Also from our experience, it is clear that the costs of handling large confiscations can be high (Akre, Jones, and Willey, unpubl. data). Despite the high cost of captive care and uncertain outcomes or conservation value of these animals, some new tools are emerging that will improve our ability to confidently genotype animals of wild origin (Weigel and Whiteley 2018). For the time being, we recommend that seized or confiscated Wood Turtles are maintained in large outdoor enclosures separated by confiscation event and by sex to prevent uncoordinated breeding events and drowning of females by males. In cases where animals appear to be of wild origin, they should be genotyped to basin of origin and returned to the jurisdictional state wildlife agency to determine the best possible conservation outcome (9.17).

Summary

Across their range, important Wood Turtle populations have not yet been afforded sufficient protection from development, fragmentation, or human traffic. For Wood Turtle populations to persist as evolutionarily functional components of the North American landscape without decades of expensive intervention, protecting these exceptional landscapes should be the paramount priority. At present, it is not clear that this is feasible. Given the vast extent of Wood Turtle habitat lost to (or degraded by) habitat fragmentation and hydrological alterations, it follows that restoration activities should be pursued aggressively where the potential benefit outweighs various risks to the local or regional population. Some methods of managing upland habitat—such as minimizing machinery use in fields, or rejuvenating nesting areas—are likely to work in the short term. Management costs over longer durations will remain high in the long term, however, since these strategies do little to restore ecosystem function. Long-term restorative management actions, such as stream channel restoration, large wood additions, and—where practical and with some awareness of larger food supply chains—strategic retirement of agricultural fields near important Wood Turtle streams are generally cost-prohibitive, but are likely to improve the long-term viability of local Wood Turtle populations without the need for constant management. Where these actions are feasible—even if they are principally geared toward landscape restoration and not Wood Turtle conservation—researchers should endeavor to study, monitor, and evaluate Wood Turtles' individual- and population-level response to management, as well as the response of associated species of conservation concern.

BIOLOGY & CONSERVATION *of the* WOOD TURTLE

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Published by Northeast Association of Fish and Wildlife Agencies, Inc., 2021

Printed in USA on FSC certified paper

Designed and typeset by Matthew R. Burne

ISBN: 978-0-9883535-2-7 (Paperback)
ISBN: 978-0-9883535-3-4 (eBook)
Library of Congress Control Number: 2021904217

This publication was supported by State Wildlife Grants, including the Northeast Association of Fish and Wildlife Agencies, Inc. (NEAFWA) Regional Conservation Need (RCN) program and the Competitive State Wildlife Grant program. This project was also made possible by key contributions from American Turtle Observatory (www.americanturtles.org), the Wood Turtle Working Group (www.northeastturtles.org), and Northeast Partners for Amphibian and Reptile Conservation (www.northeastparc.org). Early drafts of portions of this book appeared in Part I of *Status and Conservation of Wood Turtle* (2015).

Publisher's Cataloging-in-Publication data

Names: Jones, Michael T., editor. | Willey, Lisabeth L., editor.

Title: Biology and Conservation of the Wood Turtle / Michael T. Jones ; Lisabeth L. Willey, editors.

Description: Includes bibliographical references. | Petersburgh, NY: Northeast Association of Fish & Wildlife Agencies, Inc., 2021.

Identifiers: LCCN: 2021904217 | ISBN: 978-0-9883535-2-7 (paperback) | 978-0-9883535-3-4 (ebook)

Subjects: LCSH Wood turtle. | Turtles--North America. | Forest animals. | Animals--Habits and behavior. | Reptiles--North America. | Natural history--North America. | Wildlife conservation--North America. | BISAC NATURE / Animals / Reptiles & Amphibians

Classification: LCC QL651 .B56 2021 | DDC 597.9/097--dc23

Biology & Conservation of the Wood Turtle