Journal of Environmental Management (2001) **62**, 443–455
doi:10.1006/jema.2001.0454, available online at http://www.idealibrary.com on IDEAL®

Stream and riparian management for freshwater turtles

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The regulation and management of stream ecosystems worldwide have led to irreversible loss of wildlife species. Due to recent scrutiny of water policy and dam feasibility, there is an urgent need for fundamental research on the biotic integrity of streams and riparian zones. Although riverine turtles rely on stream and riparian zones to complete their life cycle, are vital producers and consumers, and are declining worldwide, they have received relatively little attention. I review the literature on the impacts of contemporary stream management on freshwater turtles. Specifically, I summarize and discuss 10 distinct practices that produce five potential biological repercussions. I then focus on the often-overlooked use of riparian zones by freshwater turtles, calculate a biologically determined riparian width, and offer recommendations for ecosystem management. Migration data were summarized on 10 species from eight US states and four countries. A riparian zone encompassing the majority of freshwater turtle migrations would need to span 150 m from the stream edge. Freshwater turtles primarily chose high, open, sandy habitats to nest. Nests in North America contained eggs and hatchlings during April through September and often through the winter. In addition, freshwater turtles utilized diverse riparian habitats for feeding, nesting, and overwintering. Additional documentation of stream and riparian habitat use by turtles is needed.

Keywords: conservation, riparian buffer, stream management, turtles, wildlife habitat.

Introduction

Stream management pervades not only aquatic but also terrestrial systems. For example, 19 300 km of United States rivers are actively modified for commercial navigation through the creation, operation and maintenance of 75 reservoirs, 276 navigation locks and 13 670 km of federally maintained levees (US Army Corps of Engineers, 2000). Management of these rivers directly and indirectly affects a combined drainage area of 6 954 150 km^2 or 87% of the total area of the coterminous US (US Department of Commerce, 1998). Although the social benefits of these actions include hundreds of billions of dollars in commerce, hydropower and estimated protection from flood damages, environmental costs are great (Sparks *et al.*, 1998). Worldwide, human regulation of 60% of total streamflow has led to irreversible loss of species and ecosystems (World Commission on Dams, 2000).

Recent scrutiny of water policy (e.g. Hirsch *et al.*, 2001) and dam feasibility (e.g. World Commission on Dams, 2000) have heightened interest in research and management of streams, from intermittent brooks to large rivers (Haeuber and Michener, 1998). Likewise, there is a global surge of research on riparian ecology and management (Naiman *et al.*, 2000). Although large-scale stream studies are yielding results (e.g. Molles *et al.*, 1998, Toth *et al.*, 1998), there remains an urgent need for fundamental research on the biotic integrity of streams and riparian zones (Haeuber and Michener, 1998).

Much of our current understanding of stream ecology has come from focused studies on fishes (e.g. Moyle and Vondracek, 1985; Schlosser, 1990). Freshwater turtles have received comparatively little attention, despite that 20 of 24 species listed under US law are associated with fluvial habitats (US Fish and Wildlife Service, 2000). Likewise, severe species reductions in Asia, India, North America, and South America signify a global decline of riverine turtles (Gibbons

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Received 23 November 1999; accepted 26 March 2001

0301–4797/01/080443+13 $35.00/0

et al., 2000). In many lotic ecosystems, high annual consumption of eggs and hatchlings by a wide range of predators (e.g. mammals, birds, other reptiles), and densities from 0·02 to 1·3 individuals per meter of shoreline indicate that freshwater turtles are vital producers and consumers (Tinkle, 1958; Plummer, 1977; Moll, 1990; Vogt and Villareal, 1993, Foscarini and Brooks, 1997). Moreover, because freshwater turtles require terrestrial habitats to complete their life cycle, they can provide more comprehensive information on riparian ecosystems. For instance, the importance of semi-aquatic organisms in buffer delineation has recently been recognized for isolated wetlands (e.g. Burke and Gibbons, 1995, Semlitsch, 1998), but to my knowledge has not been addressed for streams.

I review the literature on the impacts of contemporary stream management on freshwater turtles. Specifically, I summarize and discuss 10 distinct practices that produce five potential biological repercussions. I then focus on the often-overlooked use of riparian zones by freshwater turtles, calculate a biologically determined riparian buffer width, and offer recommendations for stream and riparian management.

Methods

Reliable data were obtained from published literature and unpublished dissertations for studies concerning stream-management practices or riparian use pertaining to freshwater turtles. Although the majority of streams worldwide are managed, the effects on freshwater turtles have been studied most frequently in the US.

Management practices

Contemporary practices of stream-management were summarized directly from the literature. Although each of these practices is distinct, their effects may be direct or indirect (e.g. human riparian uses may lead to siltation or pollution). Practices were classified, based on the literature accounts, as potentially causing one or more population or species-level consequences.

Riparian use

There were many anecdotal observations of approximate distances of nests and nesting habitats from streams, but only actual measurements of individual nest and overwinter sites from streams were used. Data were considered reliable if derived from direct examinations of terrestrial nest and overwinter sites adjacent to known sources of turtles. Researchers located these sites through direct observation, radiotelemetry, signs of depredation (i.e. eggshells), and by following turtle tracks originating at the water's edge. I also searched for data concerning the use of riparian habitats for reasons other than nesting and overwintering (e.g. feeding). Only actual measurements of seasonal migrations through the use of radiotelemetry and mark-recapture methods were included. For each reference, I recorded the specific timing (in months) and habitat association for the corresponding riparian use. I summarized data for each species on average migration distance from the stream edge for the purposes of nesting, overwintering, or feeding.

Results and discussion

Management practices

I categorized literature accounts of contemporary stream management into ten practices affecting freshwater turtles (Table 1). I discuss aspects of each management practice individually.

Reduction of snags and logjams

Systematic clearing of vegetative debris from many US streams began nearly two hundred years ago (Sedell and Froggatt, 1984). Moll (1980) reports that Illinois River turtle populations suffered drastic changes in composition and abundance of prey species (e.g. invertebrates, fishes) due to clearing of vegetation. Moll reports that woody debris remaining along the Illinois River is important for basking by species such as map turtles (*Graptemys* spp.) and sliders (*Trachemys scripta*). False map turtles (*Graptemys pseudogeographica*) collected from 186

Table 1. Direct and indirect stream-management practices (numbered left column) and their potential effects on freshwater turtles (lettered right column)

1. Reduction of snags and logjams—A, D, E	A. Change in historical food supply
2. Riparian draining—A, B, E	B. Change in population structure
3. Channelization—B, D, E	C. Nest inundation and failure
4. Impoundment—A, B, D, E	D. Population fragmentation
5. Flow regulation—B, C, E	E. Local reduction or elimination of species
6. Reduction of sandbars and beaches—C, D, E	
7. Human riparian use—A, D, E	
8. Pollution and siltation—B, D, E	
9. Management for monotypic conditions—B, E	
10. Unsustainable use—B, D, E	

The letters following each practice correspond to its biological effects in the right column.

study sites in Kansas preferred habitats with basking structures (Fuselier and Edds, 1994). Likewise, extensive surveys of basking map turtles in Kentucky, Louisiana, and Mississippi showed significant positive correlations between turtle density and deadwood density (Lindeman, 1999). Removal of snags within the Warrior River Basin in Alabama is in part responsible for fragmentation of preferred habitat and hence, populations of the US-listed flattened musk turtle (*Sternotherus depressus*; Dodd, 1990). Vandewalle and Christiansen (1996) sampled seven major streams and a reservoir in Iowa and found a significant negative relationship between river modification, including clearing and snagging, and turtle species richness. Reese and Welsh (1998b) recommended the natural or managed addition of woody debris in the Trinity River in California in order to provide greater habitat complexity for western pond turtles (*Clemmys marmorata*). In addition, the importance of vegetative debris as critical to lotic systems extends beyond turtles to include their prey (e.g. fishes and invertebrates; reviewed by Marzolf (1978), Simpson *et al*. (1982) and Benke *et al*. (1985)).

Riparian draining

Draining of floodplains through construction of canal and levee systems also has a long history in the US and abroad (Gore and Shields, 1995). Certain declines of Illinois mud turtles (*Kinosternon flavescens spooneri*), Blanding's turtles (*Emydoidea blandingi*), and map turtles can be blamed on draining of riparian wetlands in Illinois and Iowa (Moll, 1980, Vandewalle and Christiansen, 1996). False map turtles and sliders along the Missouri River spend a substantial portion of the year in flooded riparian wetlands, when these habitats are available (Bodie and Semlitsch, 2000a). Turtle population density as well as species diversity may be higher in floodplain wetlands than in all other lotic habitats (Timken, 1968; Tucker *et al*., 1999; Bodie *et al*., 2000). Jones (1996) touted the importance of riparian cypress ponds to foraging female yellow-blotched map turtles (*Graptemys flavimaculata*). Moreover, juvenile map turtles, sliders, and western pond turtles were more abundant in floodplain wetlands, presumably taking advantage of food productivity in these shallow, fertile habitats (Reese and Welsh, 1998a,b, Bodie and Semlitsch, 2000a). In this regard, floodplain wetlands are nursery habitats for many turtles just as they are for many fishes (Hesse and Mestl, 1993).

Channelization

Stream channelization is used worldwide to control flooding, increase agricultural acreage, improve navigability, or maintain an efficient flow of water. However, the direct and indirect effects of channelization include reduction of food resources, habitat loss, and concomitant shifts in species composition (Simpson *et al*., 1982). Three species in the US, Illinois mud turtles, Blanding's turtles, and smooth softshells (*Apalone mutica*), have been reduced or eliminated from the Illinois River due to channelization (Moll, 1980). The physical process of channel dredging may also directly disturb turtles overwintering in streambed sediments (Graham and Graham, 1997). Channelization has been shown to reduce habitat diversity, which also reduces populations of western pond turtles that prefer a system of pools and shallows (Reese and Welsh, 1998b). Extensive sampling of freshwater turtles in Iowa demonstrated a significant negative relationship between channelization and species richness (Vandewalle and Christiansen, 1996). Moreover, although most riverine turtles are highly mobile, some studies suggest that certain species and sexes may avoid crossing streams with high water velocities, possibly due to channelization (Plummer, 1977; Jones, 1996; Bodie and Semlitsch, 2000a). Therefore, channelization in some streams may isolate and fragment freshwater turtle populations, with potential demographic and evolutionary effects such as reduction of gene flow.

Impoundment

Many of the well-known effects of impounding streams on fishes and invertebrates [reviewed by Petts (1984)] apply to freshwater turtles. The most direct consequence of impoundment is fragmentation of habitat and consequently, populations. There is evidence of population insularization and decline for several species including ringed sawback (*Graptemys oculifera*), flattened musk, and western pond turtles (US Fish and Wildlife Service, 1987, Dodd, 1990, Reese and Welsh, 1998a). Impoundment reservoirs also reduce turtle diversity by homogenizing habitat and supporting more lentic species (Vandewalle and Christainsen, 1996; Reese and Welsh, 1998a,b; Tucker *et al*., 1999). These reservoirs may also have indirect effects on turtle populations including introduction of exotic competitors, predators and vectors for disease (Vannote *et al*., 1980). Asian species such as *Chitra chitra* and *Batagur baska*, which were already in danger due to overcollection, are now facing imminent extinction due to direct and indirect effects of enormous reservoirs (van Dijk and Thirakhupt, 1996; Moll, 1997). In addition, permanent inundation of floodplain wetlands by reservoirs has reduced adult and juvenile feeding habitats for species including Blanding's turtles, Illinois mud turtles, sliders, map turtles, and western pond turtles (Moll, 1980; Vandewalle and Christiansen, 1996; Reese and Welsh, 1998a,b).

Flow regulation

One of the central purposes of stream impoundment is flow regulation. Stream flows are typically regulated with respect to the needs of agriculture, hydropower, navigation, and recreation. These needs rarely correspond with those of native stream flora and fauna (Kushlan and Jacobsen, 1990; Sparks, 1995). Similar to fishes (see Figures 9 and 10 in Galat *et al*., 1998), freshwater turtles depend upon the proper coupling of natural riverine hydrology and nesting habitat accessibility. Turtles often nest during a point in the season when stream water levels were historically dropping, perhaps to avoid nest flooding (Tucker *et al*., 1997). Although turtle nests near stream shorelines doubtless suffered mortality from inundation prior to stream regulation, contemporary streamflow management may place turtle nests in greater jeopardy. Tucker *et al*. (1997) suggested that turtle embryos could suffer high mortality late in development when water levels are artificially elevated for summer navigation. Conversely, in winter, juveniles selecting shallow overwinter sites in the fall may suffer mortality due to artificial reductions in water level at the end of the navigation season that exposes turtles to freezing or desiccation (Bodie and Semlitsch, 2000a).

Reduction of sandbars and beaches

Sandbars and beaches have been virtually eliminated from many US rivers due to stream-management practices including channelization, impoundment, and flow regulation. For example, islands and sandbars along a 740-km portion of the Missouri River were reduced 98% from 1879 to 1954 (Funk and Robinson, 1974). Declines of map turtles and softshells in the lower Missouri River have been attributed to loss of these habitats (Johnson, 1992). Like threatened piping plovers (*Charadrius melodus*) and endangered least terns (*Sterna antillarum*), softshells nest almost exclusively on high sandbars, when these habitats are available. Fitch and Plummer, (1975) reported that for smooth softshells, nearly all activities including mating, feeding, and nesting occurred on or adjacent to sandbars. In Asia, sand mining along river banks poses enormous threats to available nesting habitats of species such as *Batagur baska*, which faces sand mining in every river it inhabits in at least five countries (Moll, 1997). In fact, nesting riverine turtles of most species prefer open, sandy beaches for oviposition (see Table 2) and may seek alternate artificial habitats such as levees if historic nesting habitats are unavailable.

Human riparian use

Humans have exerted a particularly strong pressure on habitats adjacent to streams. To use again the example of the 740-km portion of the Missouri River, from 1879 to 1972, water surface area was reduced by 24 654 ha or 50% of the 1879 surface area primarily to increase arable land (Funk and Robinson, 1974). Because most freshwater turtle species need the very habitats that have been reduced (e.g. sandbars, side channels; Vandewalle and Christiansen, 1996; Bodie *et al*., 2000; Tucker *et al*., 1999), it follows that turtle populations may have suffered greater habitat losses (i.e. >50% for the Missouri River example). Human uses of riparian areas principally include agriculture, cattle grazing, and urbanization. Urbanization can directly remove habitat and indirectly change stream hydrology, temperature, and

Table 2. Nest-site timing, habitat type, distance from the stream edge, and data source by freshwater turtle species and location

Species and location	Nest sites			
	Timing	Habitat	Average distance from stream	Data source
Flattened musk turtle (*Sternotherus depressus*)				
AL, USA	July–September	High, sandy shoreline	6·5 N=1	Dodd (1988)
Florida softshell (*Apalone ferox*)				
FL, USA	May–August	Hammock clearing	22·9 N=1	Goff and Goff (1935)
Map turtle (*Graptemys geographica*)				
Quebec, Canada	June–August	Backwater shoreline	2·3 (2–3) N=3	Gordon and MacCulloch (1980)
Slider turtle (*Trachemys scripta*)				
Panama, Panama	January–May	Open sand and grass	50 (2–320) N=139	Moll and Legler (1971)
Smooth softshell (*Apalone mutica*)				
KA, USA	June–September	Open sandbar	38·2 (4–90) N=104	Fitch and Plummer (1975)
Spiny softshell (*Apalone spinifera*)				
AR, USA	—	Open, sandy shoreline	2·5 (2–3) N=4	Plummer *et al*. (1997)
MN, USA	June–September	Open sandbar	0·3 N=1	Hedrick and Holmes (1956)
NB, USA	June–September	Open sandbar	4·5 N=1	Gehlbach and Collette (1959)
Terecay turtle (*Podocnemis unifilis*)				
Amazonas, Venezuela	—	High, open shoreline	38·3 (21–80) N=422	Escalona and Fa (1998)
Western pond turtle (*Clemmys marmorata*)				
CA, USA	June–August	Forest clearing	31 N=1	Reese (1996)
Mean (±1 SD)			19·7±18·6 m	

particulate loads (Dunne and Leopold, 1978). The effects of human riparian use on turtles are manifested in floodplain draining and flow regulation (discussed above), and pollution and siltation (discussed below). While occasional flooding of streamside agricultural fields may provide habitats functionally analogous to historical riparian wetlands (Reese and Welsh, 1998b; Bodie and Semlitsch, 2000a), it is clear that conversion of riparian habitats to human land uses is deleterious to turtle populations (Moll, 1980; Dodd, 1990; Reese and Welsh, 1998b; Bodie and Semlitsch, 2000a).

Pollution and siltation

Although studied far less than amphibians and fishes, freshwater turtles can be heavily impacted by pollution and siltation. Many freshwater turtles have environmental sex determination and are therefore particularly sensitive to endocrine-disrupting chemicals that can cause sex reversal or abnormal gonads (Bergeron *et al*., 1994; Guillette and Crain, 1996). Slider turtles are known to incur genetic damage from metal and radioisotope contaminants (Lamb *et al*., 1995). Ernst *et al*. (1989) sampled 68 stream sites in the Black Warrior River drainage in Alabama and determined that agricultural runoff, surface mining, municipal wastes, and industrial wastes all severely degraded habitats of threatened flattened musk turtles. Water pollution in Spain has nearly caused the disappearance of the European pond turtle (*Emys orbicularis*) from that country's rivers (Mascort, 1997). In addition to pollutants, Ernst *et al*. (1989) determined that streams lined with fine silt and clay supported significantly smaller populations of flattened musk turtles. From several years of sampling the Illinois River, Moll (1980) attributed the decline and possible extirpation of smooth softshells and Illinois mud turtles to continual deposits of silt. Similar reasons were given for declines of map turtles and softshells in Missouri (Johnson, 1992) as well as Kansas (Plummer, 1976). In California, siltation of deep pools in the Trinity River has reduced populations of western pond turtles (Reese and Welsh, 1998b).

Management for monotypic conditions

In many riparian wetlands in the US, management for suites of game species is common practice (Sparks, 1995). Although refuge managers agree that practices to encourage nongame species are also a target of management (Reid *et al*., 1989), attempts to mimic conditions for all species are unrealistic (Sparks, 1995). Riverine turtles are adapted to seasonally varying conditions and may require a multitude of habitats to achieve sufficient growth and reproduction. For mobile and long-lived species such as turtles, access to habitats with different and annually variable attributes may be especially important for long-term persistence of metapopulations (Burke *et al*., 1995). Plummer (1977) found that smooth softshells were very mobile, utilizing wide-ranging riverine habitats. Reese and Welsh (1998b) suggested that a single body of water was not a sufficient unit of management for western pond turtles, and that multiple habitats including streams, shallow marshes and riparian forests were all integral parts of their life histories. Similarly, Bodie and Semlitsch (2000a) found that riverine populations of sliders and false map turtles used at least six general habitats (i.e. agriculture, flooded field, flooded forest, river, flood-scoured wetland, slough) within a single year. Likewise, overall turtle species diversity is enhanced with diverse geomorphology within the stream proper (e.g. varied substrates, water velocity, water depth; Donner-Wright *et al*., 1999).

Unsustainable use

Freshwater turtles, prized as food, medicinal remedies, and pets, suffer from overuse in many parts of the world. Collection of adults and eggs for consumption poses a serious problem in North America, South America, India, and Asia (Polisar, 1997; Moll, 1997; Escalona and Fa, 1998; Gibbons *et al*., 2000). In fact, the commercial trade of riverine species such as softshells has reached crisis proportions in southern China and Vietnam, with extinction for some species expected within the next decade (Gibbons *et al*., 2000). Turtle life-history traits make them especially susceptible to changes in large juvenile and adult survival (Congdon *et al*., 1993, 1994). A modest harvest pressure (10% per year for 15 years) may result in a 50% reduction in population size (Congdon *et al.*, 1994). When overuse is combined with other stresses, it may become even more severe. Dodd (1988) and Ernst *et al.* (1989) report potential impacts of commercial collectors on US populations of threatened flattened musk turtles inhabiting separate river basins in Alabama. Close and Seigel (1997) found that selection by collectors of large individuals might have contributed to significantly larger turtles in sites protected from collection vs. sites with no protection. This sustained pressure could eventually cause population declines (see Congdon *et al.*, 1993, 1994). In a similar way, Tucker and Moll (1997) suggest that removal of large reproducing females, even when regulated, may place turtle populations in jeopardy of extinction.

Riparian-zone use

Data were summarized on 10 species from eight US states and four countries (Tables 2 and 3). Nests (N=677) of seven freshwater turtle species from North and South America were found an average of 19·7 m from the edge of streams (Table 2). Nests were found as close as 0·3 m and up to 320 m away from the shoreline. Overwinter sites (N=19) and seasonal migrations of individuals (N=36) were on average 224 m from the stream edge (Table 3). Overwinter sites for western pond turtles were found up to 423 m from the stream edge, and slider turtles migrated up to 1394 m from the edge during a single year. Under the assumption that the distances turtles migrated from the stream were normally distributed (test of normality for log-transformed data in Tables 2 and 3; W=0·956, P=0·670), then the mean for all species and movements combined (mean=78 m, N=14) represents a distance encompassing 50% of the migrations. A riparian zone encompassing the majority (95% confidence limits=mean±2·17[α=0·05, df=13]× standard deviation/$\sqrt{n}$) of freshwater turtle migrations would need to encompass a distance of 150·3 m from the stream edge.

The timing of riparian use for most North American freshwater turtles spanned from March through September, with a concentration of use for nest deposition and incubation during June through September (Table 2). However, many species have hatchlings that overwintered in the nest during the months of September through March, and adults of at least one species also overwinter terrestrially during this time (i.e. western pond turtles; Table 3). Freshwater turtles primarily chose high, open, sandy habitats for nesting (Table 2). The nesting habitats used included

Table 3. Overwinter-site and seasonal-migration timing, habitat type, average distance from the stream edge, and data source by freshwater turtle species and location

Species and location	Overwinter sites			
	Timing	Habitat	Average distance from stream	Data source
Western pond turtle (*Clemmys marmorata*)				
CA, USA	August–February	Forests	168 (39–423) N=19	Reese (1996)
	Seasonal migrations			
False map turtle (*Graptemys pseudogeographica*)				
MO, USA	March–August	Floodplain wetlands	353 (0–1133) N=15	Bodie and Semlitsch (2000a,b)
Slider turtle (*Trachemys scripta*)				
MO, USA	March–August	Floodplain wetlands	348 (0–1394) N=11	Bodie and Semlitsch (2000a,b)
Wood turtle (*Clemmys insculpta*)				
Ontario, Canada	May–August	Fields and forests	27 (0–500) N=10	Foscarini and Brooks (1993)
Mean (±1 SD)			224±157 m	

sandbars, open shorelines, hammock clearings, and levees, occasionally bordered by vegetation. Adult western pond turtles overwintered in riparian forests. Adult false map turtles and sliders used a variety of riparian wetlands throughout the year (see Bodie and Semlitsch, 2000a for details).

The results indicate freshwater turtles use large riparian zones to complete several aspects of their life cycle. Elimination or alteration of these riparian habitats would most likely reduce nest survival and, hence, juvenile recruitment into the breeding population. It would also reduce adult survival through lack of overwintering and feeding areas, and therefore increase the risk of extinction for freshwater turtle populations. The importance of riparian zones to other myriad fauna including invertebrates (e.g. Edwards and Huryn, 1996), fishes (e.g. Growns *et al*., 1998), amphibians (e.g. Rudolph and Dickson, 1990), birds (e.g. Machtans *et al*., 1996), and mammals (e.g. Thurmond and Miller, 1994) emphasizes the universal need for protection of these habitats (reviewed by Hall and Lambou, 1990; Gregory *et al*., 1991; Schaefer and Brown, 1992).

Although the extent of riparian area used by freshwater turtles varied due to the purpose of migration, species differences, and stream and riparian habitat characteristics, a generalized riparian zone cannot by definition encompass every stream and species. However, the suggested 150-m riparian zone encompassing 95% of population migrations, and based on data collected over several decades on 10 species, should be robust for management purposes. Furthermore, the majority of studies concerning turtle nests anecdotally mention estimates of migration distances from streams without direct measurement. In many of these cases, anecdotal estimates are much longer than the measured distances found in the literature (e.g. 400–1600 m, Cagle, 1950; 200 m, Ewert and Jackson, 1994; 30–1200 m, Tucker *et al*., 1997), suggesting that such data were not collected because of the inherent difficulty in measuring long distances across riparian habitats. In addition, to my knowledge, only two studies (i.e. Foscarini and Brooks, 1997; Bodie and Semlitsch, 2000a) have purposely measured the size of the riparian area used for seasonal migrations of riverine turtles. Therefore, my suggested 150-m riparian zone should be considered a minimum estimate pending additional data.

How applicable is this recommendation to riparian estimates derived from other sources? Brosofske *et al*. (1997) found that stream microclimate was well maintained by retaining 45-m buffer strips on either side of streams. A riparian buffer of 60 m may be adequate for removal of nonpoint-source pollutants such as nitrates (Phillips, 1989). In a similar way, Darveau *et al*. (1995) determined that 60-m riparian buffers provided habitat for many forest-dwelling birds. Hodges and Krementz, (1996) recommend a 100-m buffer to maintain diversity of the neotropical bird community. Likewise, Vander-Haegen and Degraaf (1996) suggest that 100-m buffers are necessary to reduce edge-related depredation on bird nests. Davies and Nelson (1994) suggested that a minimum of 30 m of riparian vegetation was required to maintain stream habitat characteristics, invertebrate community composition, and fish abundance. Rudolph and Dickson (1990) suggested a 30-m buffer for the maintenance of stream-dwelling amphibians, while McComb *et al*. (1993) suggested a 100-m buffer for amphibians and small mammals. Still others recommend that protected riparian zones should be proportional to stream width, adjacent land use, and slope (deMaynadier and Hunter, 1995). The above studies yielded mixed recommendations ranging from 30 to 100 m, all less than the biologically determined 150 m required for 95% of turtle migration distances.

Perhaps more important than the quantity of riparian zones is the quality. As mentioned above, freshwater turtle species such as softshells require habitats very similar to those of piping plovers and least terns, birds that have suffered severe declines due to reductions in sandbar nesting and feeding habitats (US Fish and Wildlife Service, 1985a,b). Stream-management techniques such as stabilizing shorelines with riprap and dramatically altering flow not only eliminate habitats spatially but also temporally. Although relatively few studies of riparian use by riverine turtles have been conducted, it is evident that these turtles are mobile and utilize several riparian habitats to complete their life cycle, even within a single year (Jones, 1996; Reese and Welsh, 1998b, Bodie and

Semlitsch, 2000a). It is clear that more comprehensive data for freshwater turtles are needed, especially on the timing and extent of riparian use, and in rapidly developing parts of the world.

Application to stream and riparian management

Contemporary managers are faced with the daunting task of ecosystem management—management driven by adaptability through monitoring, and based on sound knowledge of ecological processes that sustain ecosystem diversity and function (Christensen *et al.*, 1996). It is therefore essential that biologists emphasize the processes that sustain important, yet often neglected, faunal components of stream system diversity such as freshwater turtles. Based on the literature, I offer the following recommendations.

A key hydrological process is the connection of stream and riparian habitats through groundwater and over-bank flow. This connection provides riparian habitat complexity and woody debris through hydraulic erosion and deposition. For regulated streams, the timing of connection should be adapted to the historical hydroperiod, providing conditions that favor formation and maintenance of temporary wetlands and high, sandy beaches throughout the warm months. Likewise, it is crucial to reduce or eliminate artificial changes in streamflow throughout the cool months when hatchlings, juveniles, and adults overwinter. Mechanical and other disturbance of riparian nesting and overwintering habitats should be disallowed throughout the year. Monitoring, a tenet of ecosystem management, is especially critical for riverine turtle populations that experience collection or consumption, as effects of overuse of these long-lived species may take years to detect and overcome. Indeed, the overexploitation of Asian riverine turtles can only benefit from a moratorium on collection. To sustain species diversity, broad-scale management for conditions that promote permanent lentic habitats should be avoided in lotic systems. Finally, sources of pollutants and silt entering stream systems must be identified and eliminated or managed through, for example, incorporation of vegetative buffers.

Simple passive management (e.g. Galat *et al.*, 1998) may accomplish many of these goals. By allowing historical processes to pervade a portion or all of the stream system, the effects of negative management practices (Table 1) may be reduced or eliminated. Ultimately, the effectiveness of management for any given stream system is greatly affected by surrounding systems and should be adaptable to enlightened approaches (Christensen *et al.*, 1996). True to the ecosystem management approach, the goals of turtle population monitoring should ensure successful reproduction, juvenile recruitment, and a diverse riverine species assemblage. In addition, many single riverine species display strong genetic distinctiveness among drainages, signifying the drainage as the proper management unit for preserving genetic resources important for long-term species survival (Roman *et al.*, 1999).

I encourage these practices within a minimum 150-m riparian zone, an area that should be considered biologically critical to freshwater turtles. A buffer as originally intended (i.e. Schonewald-Cox, 1988) would extend farther than the 150-m core habitat to reduce potentially damaging edge effects (see Semlitsch, 1998). I also encourage additional documentation of turtle riparian habitat use, especially for species of federal or international conservation concern or with special habitat requirements (e.g. terrestrial overwintering).

Acknowledgements

I thank D. Galat, W. Gibbons and D. Moll for insightful manuscript criticisms. Much of the tenor of this paper was inspired by discussions with R. Semlitsch, who also critiqued the manuscript. This review was partially supported by cooperative research grant MCC 82-01-00-136 to R. Semlitsch between the University of Missouri and the Missouri Department of Conservation, and in part with Federal Aid in Wildlife Restoration Act funds under Missouri's Pittman-Robertson Project W-13-R.

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