

# Effects of Turbidity on the Foraging Success of the Eastern Painted Turtle

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**The effect of increased turbidity levels on aquatic organisms is an increasing concern for aquatic biologists. Recent studies show reduced foraging efficiency of drift-feeding fish species, which are highly visual predators, with increasing water turbidity. Similar to fish, many aquatic turtle species are highly visual aquatic predators that may be negatively affected by increasing water turbidity. We used Eastern Painted Turtles (*Chrysemys picta*) to test the hypothesis that increasing water turbidity would decrease prey capture efficiency. We classically conditioned eight *C. picta* to search for a food item when presented with a novel stimulus, and then measured the time it took each turtle to find a prey item under a range of 26 turbidity levels ( $\leq 40$  nephelometric turbidity units, NTUs) presented in a random order. All turtles were successfully trained within 29 days to search for the food item when presented with the stimulus. Turbidity had no effect on the probability of successful prey capture. Turtles located the prey item in 97% of trials regardless of turbidity level. Turbidity had a minor effect on time to prey capture, increasing from an average of 30 seconds at a turbidity level of 2 NTUs to 55 seconds at 40 NTUs. Overall, turbidity level explained approximately 2% of the variation in the time it took a turtle to locate a prey item. These results contrast sharply with a nearly identical study, which showed that turbidity explained 70% and 90% of the variation in drift-feeding fish reactive distance and prey capture success respectively, and that a turbidity of only 9–10 NTUs reduced fish foraging performance by 50%. We suggest that resilience to turbidity effects on foraging proficiency among generalist species may be important to understanding their persistence in more degraded aquatic environments compared to more specialized species.**

**I**NCREASED turbidity levels in aquatic ecosystems have become a growing concern for aquatic biologists (Barrett et al., 1992; Reid et al., 1999; Sweka and Hartman, 2001a). A range of aquatic animals including unionid mussels, macroinvertebrates, and fishes have been negatively influenced by increased sediment loads as a result of riparian land use (Brim Box and Mossa, 1999; Muenz et al., 2006; Zamor and Grossman, 2007). For example, Houpp (1993) found that during an 11-year period, the mussel fauna in a Kentucky river shifted to species more tolerant of increased sedimentation associated with land use. In Missouri, increases in stream siltation were responsible for declines in the abundance and diversity of stream fishes (Berkman and Rabeni, 1987). Though these studies implicate increased sediments in the declines of certain taxa, the mechanisms that generate the effect are unknown, or proposed but untested.

Some aquatic organisms depend on water clarity to forage efficiently (Gregory and Northcote, 1993; Miner and Stein, 1993; Utne, 1997; Sweka and Hartman, 2003). Prior studies examining the effects of turbid water on foraging success have focused on fishes (Vogel and Beauchamp, 1999; Sweka and Hartman, 2001b; Meager et al., 2005). Most fish species are visual predators; therefore, increased turbidity can obscure prey detection, resulting in reduced feeding efficiency (Cezilly, 1992). For example, Zamor and Grossman (2007) found that turbidity levels as low as nine nephelometric turbidity units (NTUs) can reduce the reactive distance and prey capture success of Rosyside Dace (*Clinostomus funduloides*) by 50%. Whether turbidity has similar effects on other aquatic fauna has not been addressed.

Aquatic turtles are also visual predators (Parmenter and Avery, 1990), and can be found in both lentic and lotic ecosystems in the southeastern United States. Freshwater ecosystems of the southeastern U.S. are a global hotspot of freshwater turtle diversity, and declining water quality is attributed to the declines and imperilment of many species.

Turbidity levels in many rivers are known to exceed 100 NTUs (USGS, unpubl.). It is known that turtles have acute vision and rely heavily on visual detection of prey (Sexton, 1959; Parmenter and Avery, 1990; Ernst and Lovich, 2009); however, whether turbidity reduces turtle foraging efficiency has not been addressed.

In this study, we examined the foraging efficiency of wild-caught, classically conditioned Eastern Painted Turtles (*Chrysemys picta picta*). Specifically, we predicted that (1) the amount of time required to locate prey is negatively correlated with water turbidity, and (2) the probability of successful prey capture is negatively correlated with water turbidity.

## MATERIALS AND METHODS

**Study species.**—The Eastern Painted Turtle (*Chrysemys picta*) ranges from southern Canada, throughout the northeastern U.S. and Atlantic coastal states to Georgia, then west to Alabama (Ernst and Lovich, 2009). *Chrysemys picta* is considered a habitat generalist and has been observed in a variety of aquatic habitats including ponds, swamps, wetlands, lakes, sloughs, oxbows, creeks, and brackish waters (Ernst and Lovich, 2009). In addition to being a habitat generalist, *C. picta* is an omnivorous generalist and is known to consume a variety of plant and animal prey species, including algae, numerous vascular plants, insects, amphibians, and carrion (Ernst and Lovich, 2009).

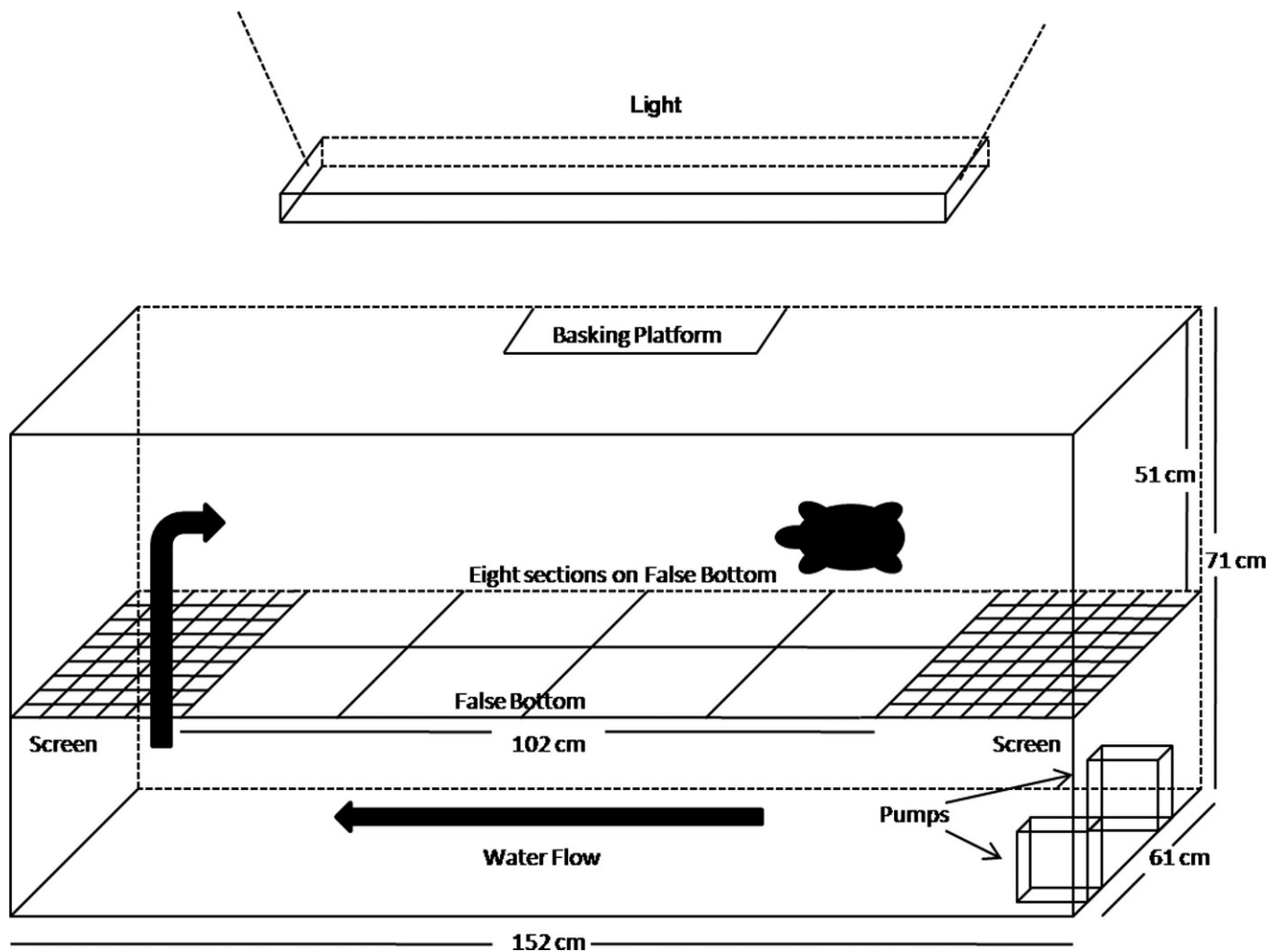
**Turtle trapping.**—During the summer and early fall, hoop traps were set in a manmade pond within the Whitehall Forest, Athens, Georgia. Traps were baited with sardines and checked daily for turtles (Lagler, 1943). Because adult *C. picta* tend to be more herbivorous (Ernst and Lovich, 2009), we only collected subadult *C. picta* (62–94 mm plastron length) for this study. Subadult *C. picta* were taken directly to holding tanks in a climate controlled field laboratory on

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**Fig. 1.** Diagram of artificial stream system used to test Eastern Painted Turtle (*Chrysemys picta*) foraging performance under varying levels of turbidity.

the site. Turtles were held in groups of four in 57 L aquaria containing 45 L of tap water and provided a basking surface, heat lamp, and water heater. In total, individuals were housed for 15 weeks, during which a constant water temperature of 26°C and a 14/10 h light/dark cycle was maintained. At the conclusion of this experiment, all turtles were released at their individual capture locations.

**Training.**—After some preliminary trials in an artificial stream system (Zamor and Grossman, 2007), we observed that turtles, particularly those basking, would not forage reliably when a small prey (a piece of liver) was introduced to the test aquaria. We concluded that the turtles were not always aware that a prey item had been released, and delays in the onset of prey searching would affect our results. Thus, we decided to first condition turtles to search for prey when presented with an independent stimulus. Aquatic turtles have been trained in a laboratory setting to discriminate stimuli and complete simple tasks (Burghardt, 1977; Lopez et al., 2001). Lopez et al. (2001) showed that *Trachemys scripta* (authors referred to species as *Pseudemys scripta*) were capable of using visual cues to solve spatial problems. Burghardt (1977) reported that turtles, including *C. picta*, showed an increasing ability to perform simple tasks with each repetition, demonstrating that aquatic turtles are capable of learning tasks.

Over a 15-week period, eight *C. picta* were fed beef liver in their holding aquaria similar to those used by Davis and Burghardt (2007). We used a standard classical condition approach to train turtles to forage during trials. Every other day the turtles were provided a stimulus (a white ping pong ball painted with black dots floating on the water surface) associated with the introduction of a piece of liver. After ten minutes, the stimulus and liver were removed from the aquaria. This procedure was repeated until all turtles were successfully trained to show prey seeking behaviors when presented with the conditioned stimulus for seven consecutive feedings. After two or three consecutive feedings, individuals would consistently feed when provided a stimulus; however, we wanted to ensure all individuals were sufficiently conditioned before beginning trials; therefore, seven consecutive feedings was used as a conservative cutoff point.

**Artificial stream system.**—Foraging trials were conducted using a modified artificial stream system (Fig. 1) following the design of Zamor and Grossman (2007). The artificial stream system was constructed using a 152 × 61 × 71 cm (658 L) aquarium. A false bottom placed approximately 20 cm above the actual bottom of the tank extended 102 cm of the entire length of the artificial stream system. At each end of the false bottom, a screen bottom extending the

remaining 25 cm to the aquarium's end was installed to prevent any test subjects from leaving the experimental area. Thus, the experimental area measured a total of  $152 \times 61 \times 51$  cm (473 L). To allow for a constant flow throughout the system, water was pushed under the false bottom and circulated around the experimental area using two electric pond pumps (Maxi-jet 1200 power heads). The artificial stream system provided enough flow to keep suspended sediment from settling during trials, did not impede turtle movements throughout the system, and thus did not affect their foraging ability. The entire artificial stream system was surrounded by a large black tarp with viewing windows on each side, attached from the ceiling to the floor, to ensure the turtles were not disturbed during a trial. Also, consistent lighting was maintained by using a power compact light system with two 65-watt fluorescent bulbs. Standard aquarium heaters were used to maintain a constant water temperature of 26°C, which is the reported optimum foraging temperature for *C. picta* (Cagle, 1954).

**Creation of turbidity levels.**—Although natural turbidity levels of aquatic systems in the southeastern U.S. can exceed 100 NTUs (USGS, unpubl.), we only tested levels of turbidity between zero and 40 NTUs. Turbidity levels above 40 NTUs made it impossible to observe and accurately record turtle foraging behaviors. Turbidity levels were altered using red clay, which is a common dominant constituent of sediments in ponds and rivers of the southeastern U.S. (Zamor and Grossman, 2007). Red clay sediment was collected from the area immediately surrounding the site where the turtles were collected. Clay was oven dried and sifted using a screen mesh to separate large and small clay particles. Depending on the desired turbidity level, a selected amount of dried clay sediment was added to 1.9 L of water, mixed thoroughly, and added to the artificial stream system. Once the sediment was thoroughly mixed throughout the artificial river system, the turbidity level was measured using a turbidity meter (HACH Model 2100P). Turbidity was taken before and after each trial, and the average of the two was reported as the mean turbidity level for a particular trial.

**Trials.**—In total, each turtle's foraging ability was evaluated at 26 randomly chosen turbidity levels that ranged from zero to 40 NTUs. Each individual was observed at a minimum turbidity of 2 NTUs and a maximum of at least 30 NTUs, and no individuals were tested at the same turbidity level twice. During each test day, one randomly selected turtle was tested at a randomly selected turbidity level, and all turbidity levels were represented evenly across all trial days but in a random order for any individual turtle. For a specific trial, a single turtle was placed into the artificial stream system and allowed to habituate for one minute. Generally, turtles would rest on a basking platform or swim slowly at the water surface by the end of the habituation period. After the habituation period, the conditioned stimulus was added to the water surface concurrent with the release of a standard sized 2 g piece of liver. To avoid turtles habituating to a food release point, we randomly selected one of eight prey release areas on the false bottom of the artificial stream system to place the liver (Fig. 1). To ensure that turtles were not using our presence as a secondary cue, we placed the liver into its corresponding prey release area from above, while remaining behind the large tarp which encircled the artificial stream system. In

order to ensure that the liver was stationary throughout the experiment, we tethered the liver to a split shot weight using monofilament. We recorded the time between the release of stimulus and piece of liver until the turtle made contact with the liver. Trials in which a turtle did not contact the liver within 30 minutes were considered unsuccessful.

**Statistical analysis.**—To examine the effects of turbidity on the feeding efficiency of *C. picta*, we used a general linear model with the time it took *C. picta* to locate the liver as the dependent variable, turtle ID as a blocking variable, and turbidity as a continuous variable. We used logistic regression to determine whether the probability of successful prey capture declined with increasing turbidity. Analyses were conducted using STATISTICA 6.0 (StatSoft, Inc., Tulsa, OK).

## RESULTS

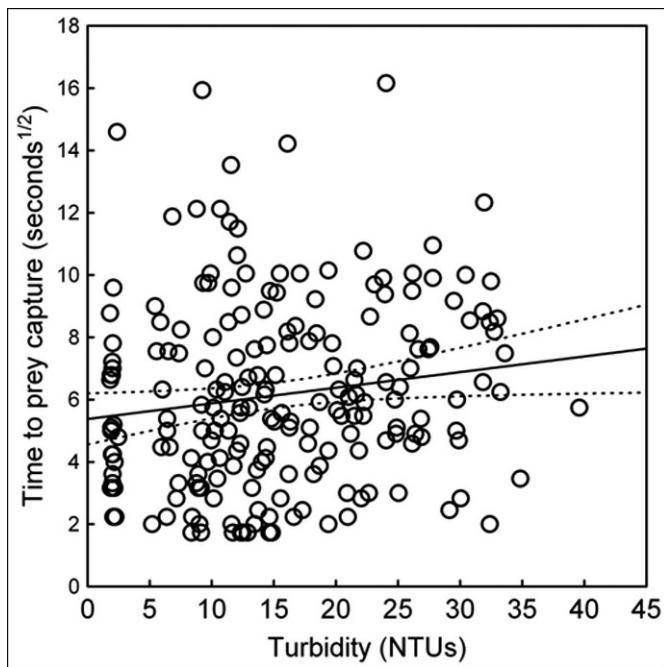
The time required to condition all individual turtles to the stimulus ranged from one to 29 days. The behavior of conditioned turtles was obvious; they would consistently swim along the bottom of their tank, noses to the bottom, when the conditioned stimulus was offered. Once an individual exhibited a conditioned response, they would consistently forage during subsequent reinforcement trials. We did not observe any signs of habituation to the conditioned stimulus.

Turtles failed to find the liver in only six of the 208 trials. Overall, we observed no measureable effect of turbidity between 2 and 40 NTUs on the probability that a turtle would successfully find the prey item ( $\chi^2 = 0.04$ ,  $df = 1$ ,  $P = 0.85$ ). Time to capture for all trials ranged from 3–862 seconds across all turbidity levels (mean capture time  $\pm 1$  SE = 46 sec  $\pm$  44.2 sec). Our trial of 862 seconds, occurring at 26 NTUs, was an extreme outlier, as the second longest time to capture was 261 seconds; therefore, we excluded this trial from subsequent analyses. We found no significant variation among turtles in time to capture prey ( $MS = 11.24$ ,  $F_{7,187} = 1.30$ ,  $P = 0.30$ ) and a statistically significant effect of increasing turbidity between 2 and 40 NTUs and time to capture prey ( $MS = 33.77$ ,  $F_{1,187} = 3.90$ ,  $P = 0.05$ ). There was no measurable difference among turtles in their response to turbidity (turtle  $\times$  turbidity interaction:  $MS = 9.00$ ,  $F_{7,187} = 1.04$ ,  $P = 0.41$ ). As is conventional, when a blocking variable is not significant, we dropped turtle ID as a blocking variable and the associated interaction term, and observed a statistically significant effect of turbidity on time to capture prey ( $MS = 40.27$ ,  $F_{1,201} = 4.61$ ,  $P = 0.03$ ). As predicted, time to capture prey increased with increasing turbidity (Fig. 2); however, turbidity explained only a minor proportion of the variation in time to capture among trials ( $R^2 = 0.02$ ).

## DISCUSSION

We found that increasing turbidity levels between 2 and 40 NTUs did not negatively affect the probability that *C. picta* would find prey, and had only a minor effect on increasing the time it took the turtles to locate a prey item. This result contrasts with the strong negative effect of similar turbidity levels on a Rosyside Dace (*Clinostomus funduloides*), a drift feeding fish, tested using a similar design (Zamor and Grossman, 2007). That study found that turbidity levels as low as 9 NTUs can reduce the reactive distance and prey capture success of Rosyside Dace by 50%. While Rosyside





**Fig. 2.** Effect of turbidity on Eastern Painted Turtle (*Chrysemys picta*) time (in seconds) to capture prey. Time to capture prey is square root transformed. Turbidity is expressed as NTUs (nephelometric turbidity units). The solid line shows the linear regression of time to capture (square root transformed) on NTUs. Dashed lines show 95% confidence bands. Turbidity had a significant effect on time to capture ( $MS = 40.27$ ,  $F_{1,201} = 4.61$ ,  $P = 0.03$ ); however, it explained only a minor proportion of the variation in time to capture among trials ( $R^2 = 0.02$ ).

Dace reactive distance and prey capture success were reduced by 80% at 40 NTUs, we found that Painted Turtle prey capture success remained unchanged at 97% and success rate and mean time to prey capture increased by only 25 seconds at 40 NTUs. While mean time to prey capture increased by 83% between 2 and 40 NTUs, this was an insignificant increase relative to the overall variation in time to capture. That is, between 2 and 40 NTUs, the mean time to locate a prey item only increased by 2 seconds. These results indicate that despite their visual acuity and use of visual cues to find prey, *C. picta* is capable of efficient location of prey with significantly degraded water clarity. We do not know whether the ability to maintain efficient prey location was the result of the turtles' physical ability to search the artificial system quickly or the ability to use other sensory modes such as olfaction or touch (Constantino and Salmon, 2003; Swimmer et al., 2005). We caution that we were only able to study turbidity levels up to 40 NTUs. Levels in natural water systems can routinely be 2–3 times greater. It is possible that at these levels, turtle foraging efficiency would be affected. Nonetheless, at 40 NTUs it was nearly impossible for us to see the turtles forage at close range; therefore, *C. picta* foraging efficiency was relatively robust to poor visibility.

The degree to which turbidity affects the foraging efficiency of a species may determine in part how a species will respond to degraded water quality. *Chrysemys picta* is considered a habitat generalist due to its tolerance of multiple habitat types and degraded water quality (Ernst and Lovich, 2009). Their broad habitat use and tolerance to degraded conditions may in part be a function of their more generalized diet (Ernst and Lovich, 2009) and in part to their

ability to forage effectively across a range of water clarity conditions. We expect that other cosmopolitan turtle species that show similar broad habitat associations and more generalized diets such as Sliders (*Trachemys scripta* spp.) would show similar abilities to forage in degraded water clarity. Similarly, Largemouth Bass (*Micropterus salmoides*) show resilience in foraging efficiency with decreased water clarity and commonly inhabit both clear and turbid waters (Reid et al., 1999). By contrast, the Rosyside Dace (*Clinostomus funduloides*), a drift feeding fish species typically found in clear, cool mountain streams, showed a marked reduction in prey capture success with relatively small increases in turbidity (Zamor and Grossman, 2007). It is speculated that the current distribution of the Rosyside Dace may be the result of unfavorable changes in turbidity within the streams they inhabit (Zamor and Grossman, 2007).

Shifts in prey abundance in combination with species-specific differences in the ability to forage efficiently with declining water clarity may be important for understanding both declines in freshwater turtle abundance and shifts in community composition. In the southeastern U.S., land use practices have increased sedimentation in river systems, negatively impacting unionid mussels (Brim Box and Mossa, 1999) and aquatic invertebrates (Sponseller et al., 2001; Muenz et al., 2006). These organisms make up the majority of the diet for many turtle species, particularly juvenile turtles or species with more specialized diets (e.g., *Graptemys* spp.; Vogt, 1980; Lindeman, 2000), and reduced prey availability is likely a proximate mechanism negatively affecting turtles and other predators in degraded waters (Moll and Moll, 2004). Dodd (1977) suggested that beyond being more vulnerable and susceptible to declines in specific prey, dietary specialists such as Map Turtles (*Graptemys* spp.) may be at a competitive disadvantage with more tolerant cosmopolitan turtle species with more generalized diets and a greater tolerance to degraded river conditions. Our research provides evidence that the ability of a generalist turtle species to forage efficiently despite significant declines in water clarity may contribute to their persistence in degraded habitats and replacement of more specialized species. It will be valuable if future studies compare the effects of turbidity on the relative foraging efficiency of generalists (e.g., *Chrysemys*, *Trachemys*, and *Pseudemys*) and specialist turtle species (e.g., *Graptemys*, *Apalone*). Identifying the relative importance of other sensory modes to foraging may also be informative in determining the relative sensitivity of different species to declining water clarity.

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#### LITERATURE CITED

- Barrett, J. D., G. D. Grossman, and J. Rosenfield. 1992. Turbidity induced changes in reactive distance in rainbow trout (*Oncorhynchus mykiss*). Transactions of the American Fisheries Society 121:437–443.

- Berkman, H. E., and C. F. Rabeni.** 1987. Effect of siltation on stream fish communities. *Environmental Biology of Fishes* 18:285–294.
- Brim Box, J., and J. Mossa.** 1999. Sediment, land use, and freshwater mussels: prospects and problems. *Journal of the North American Benthological Society* 18:99–117.
- Burghardt, G. M.** 1977. Learning processes in reptiles, p. 555–681. *In: Biology of the Reptilia*. Vol. 7. Ecology and Behavior. A. C. Gans and D. Tinkle (eds.). Academic Press, New York.
- Cagle, F. R.** 1954. Observations on the life cycles of painted turtles (genus *Chrysemys*). *American Midland Naturalist* 52:225–235.
- Cezilly, F.** 1992. Turbidity as an ecological solution to reduce the impact of fish-eating colonial waterbirds on fish farms. *Colonial Waterbirds* 15:249–252.
- Constantino, M. A., and M. Salmon.** 2003. Role of visual and chemical cues in food recognition by leatherback posthatchlings (*Dermochelys coriacea* L.). *Zoology* 106:173–181.
- Davis, K. M., and G. M. Burghardt.** 2007. Training and long-term memory of a novel food acquisition task in a turtle (*Pseudemys nelsoni*). *Behavioral Processes* 75:225–230.
- Dodd, C. K.** 1977. Amphibians and reptiles: the declining species. *Water Spectrum* 10:24–32.
- Ernst, C. H., and J. E. Lovich.** 2009. Turtles of the United States and Canada. Second edition. Johns Hopkins University Press, Baltimore, Maryland.
- Gregory, R. S., and T. G. Northcote.** 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences* 50:233–240.
- Houp, R. E.** 1993. Observations of long-term effects of sedimentation on freshwater mussels (Mollusca: Unionidae) in the North Fork of Red River, Kentucky. *Transactions of the Kentucky Academy of Science* 54:93–97.
- Lagler, K. F.** 1943. Methods of collecting freshwater turtles. *Copeia* 1943:21–25.
- Lindeman, P. V.** 2000. Evolution of the relative width of the head and alveolar surfaces in map turtles (Testudines: Emydidae: *Graptemys*). *Biological Journal of the Linnean Society* 69:549–576.
- Lopez, J. C., Y. Gomez, F. Rodriguez, C. Broglio, J. P. Vargas, and C. Salas.** 2001. Spatial learning in turtles. *Animal Cognition* 4:49–59.
- Meager, J. J., T. Solbakken, A. C. Utne-Palm, and T. Oen.** 2005. Effects of turbidity on the reactive distance, search time, and foraging success of juvenile Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences* 62:1978–1984.
- Miner, J. G., and R. A. Stein.** 1993. Interactive influence of turbidity and light on larval bluegill (*Lepomis macrochirus*) foraging. *Canadian Journal of Fisheries and Aquatic Sciences* 50:781–788.
- Moll, D., and E. O. Moll.** 2004. The Ecology, Exploitation, and Conservation of River Turtles. Oxford University Press, New York.
- Muenz, T. K., S. W. Golladay, G. Vellidis, and L. L. Smith.** 2006. Stream buffer effectiveness in an agriculturally influenced area, southwestern Georgia: responses of water quality, macroinvertebrates, and amphibians. *Journal of Environmental Quality* 35:1924–1938.
- Parmenter, R. R., and H. W. Avery.** 1990. The feeding ecology of the slider turtle, p. 257–266. *In: Life History and Ecology of the Slider Turtle*. J. W. Gibbons (ed.). Smithsonian Institution Press, Washington, D.C.
- Reid, S. M., M. G. Fox, and T. H. Whillans.** 1999. Influence of turbidity on piscivory in largemouth bass (*Micropterus salmoides*). *Canadian Journal of Fisheries and Aquatic Sciences* 56:1362–1369.
- Sexton, O. J.** 1959. Spatial and temporal movements of a population of the painted turtle, *Chrysemys picta marginata* (Agassiz). *Ecological Monographs* 29:113–140.
- Sponseller, R. A., E. F. Benfield, and H. M. Valett.** 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. *Freshwater Biology* 46:1409–1424.
- Sweka, J. A., and K. J. Hartman.** 2001a. Influence of turbidity on brook trout reactive distance and foraging success. *Transactions of the American Fisheries Society* 130:138–146.
- Sweka, J. A., and K. J. Hartman.** 2001b. Effects of turbidity on prey consumption and growth in brook trout and implications for bioenergetics modeling. *Canadian Journal of Fisheries and Aquatic Sciences* 58:386–393.
- Sweka, J. A., and K. J. Hartman.** 2003. Reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to elevated turbidity levels. *Environmental Biology of Fishes* 67:341–347.
- Swimmer, Y., R. Arauz, B. Higgins, L. McNaughton, M. McCracken, J. Ballester, and R. Brill.** 2005. Food color and marine turtle feeding behavior: Can blue bait reduce turtle bycatch in commercial fisheries? *Marine Ecology Progress Series* 295:273–378.
- Utne, A. C. W.** 1997. The effect of turbidity and illumination on the reaction distance and search time of the marine planktivore *Gobiusculus flavescens*. *Journal of Fish Biology* 50:926–938.
- Vogel, J. L., and D. A. Beauchamp.** 1999. Effects of light, prey size, and turbidity on reaction distances of lake trout (*Salvelinus namaycush*) to salmonid prey. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1293–1297.
- Vogt, R. C.** 1980. Natural history of the map turtles *Graptemys pseudogeographica* and *G. ouachitensis* in Wisconsin. *Tulane Studies in Zoology and Botany* 22:17–48.
- Zamor, R. M., and G. D. Grossman.** 2007. Turbidity affects foraging success on drift-feeding rosyside dace (*Clinostomus funduloides*). *Transactions of the American Fisheries Society* 136:167–176.