

of the moon, but only after the water temperature has risen to 17 °C (62.6 °F). Other researchers however, have found little evidence of spawning associated with lunar cycles (Slack *et al.*, 1999; and Fox *et al.*, 2000). Spawning in the Suwannee River occurs during the general period of spring high water, when ionic conductivity and calcium ion concentration are most favorable for egg development and adhesion (Sulak and Clugston, 1999). Fox *et al.* (2002) found no clear pattern between timing of Gulf sturgeon entering the river and flow patterns on the Choctawhatchee River. Ross *et al.* (2001b) surmised that the high flows in early March were a cue for sturgeon to begin their upstream movement in the Pascagoula River.

Atlantic sturgeon (*A. oxyrinchus*) exhibit a long inter-spawning period, with females spawning at intervals ranging from every 3 to 5 years, and males every 1 to 5 years (Smith, 1985). It is believed that Gulf sturgeon exhibit similar spawning periodicity, as male Gulf sturgeon are capable of annual spawning, and females require more than one year between spawning events (Huff, 1975; and Fox *et al.*, 2000).

Freshwater Habitat

In the spring (March to May), most adult and subadult Gulf sturgeon return to their natal river, where sexually mature sturgeon spawn, and the population spends until October or November (6 to 8 months) in freshwater (Odenkirk, 1989; Foster, 1993; Clugston *et al.*, 1995; and Fox *et al.*, 2000). Fox *et al.* (2000) found that some individuals of the Choctawhatchee River subpopulation do not enter the river until the summer months. Gulf sturgeon migration is further discussed in the "Migration" section of this rule. During their early life history stages, sturgeon require bedrock and clean gravel or cobble substrate for eggs to adhere to and for shelter for developing larvae (Sulak and Clugston, 1998). Young-of-the-year appear to disperse widely, using extensive portions of the river as nursery habitat. They are typically found on sandbars and sand shoals over rippled bottom and in shallow, relatively open, unstructured areas. Given that the river is generally nutrient poor with low levels of total phosphorus and organic carbon, suggesting low productivity, this dispersal may be an adaptation to exploit scarce food resources (Randall and Sulak, 1999). Clugston *et al.* (1995) reported that young Gulf sturgeon in the Suwannee River, weighing between 0.3 and 2.4 kg (0.7 and 5.3 lb), remain in the vicinity of the river mouth and estuary during the winter and spring.

Adult Gulf sturgeon spawn in upper river reaches. On some river systems such as the Pascagoula River and Apalachicola River, some adult and subadult Gulf sturgeon remain near the spawning grounds throughout the summer months (Wooley and Crateau, 1985; and Ross *et al.*, 2001b), but the majority move downstream to areas referred to as summer resting or holding areas. In other rivers, most Gulf sturgeon spawn and move downstream to aggregation areas also referred to as summer resting or holding areas. A few Gulf sturgeon have been documented remaining at or near their spawning grounds throughout the winter (Wooley and Crateau, 1985; Slack *et al.*, 1999; and Heise *et al.*, 1999a). Adults and subadults are not distributed uniformly throughout the river, but show a preference for these discrete areas usually located in lower and middle river reaches (Hightower *et al.*, in press). Often, these resting areas are located in close proximity to natural springs throughout the warmest months of the year, but are not located within a spring or thermal plume emanating from a spring (Clugston *et al.*, 1995; Foster and Clugston, 1997; and Hightower *et al.*, in press). These resting areas are also often located in deep holes or shallow areas along straight-aways ranging from 2 to 19 m (6.6 to 62.3 ft) deep (Wooley and Crateau, 1985; Morrow *et al.*, 1998a; Ross *et al.*, 2001a and b; Craft *et al.*, 2001; and Hightower *et al.*, in press). The substrates consisted of mixtures of limestone and sand (Clugston *et al.*, 1995), sand and gravel (Wooley and Crateau, 1985; and Morrow *et al.*, 1998a), or just sandy substrate (Hightower *et al.*, in press).

River flow may serve as an environmental cue that governs both sturgeon migration and spawning (Chapman and Carr, 1995; and Ross *et al.*, 2001b). If the flow rate is too high, sturgeon in several life-history stages can be adversely affected. Data describing the sturgeon's swimming ability in the Suwannee River strongly indicates that they cannot continually swim against prevailing currents of greater than 1 to 2 m per second (3.2 to 6.6 ft per second) (K. Sulak, USGS, pers. comm. cited in Wakeford, 2001). If the flow is too strong, eggs might not be able to settle on and adhere to suitable substrate (Wooley and Crateau *et al.*, 1985). Flows that are too low can cause clumping of eggs, which leads to increased mortality from asphyxiation and fungal infection (Wooley and Crateau *et al.*, 1985). Flow velocity requirements for age 0 sturgeon may vary depending on substrate type. Chan

et al. (1997) found that age 0 Gulf sturgeon under laboratory conditions exposed to water velocities over 12 centimeters per second (cm/s) (4.7 inches per second (in/s)) preferred a cobble substrate, but favored water velocities under 12 cm/s (4.7 in/s) and then used a variety of substrates (sand, gravel, and cobble).

Gulf sturgeon require large areas of diverse habitat that have natural variations in water flow, velocity, temperature, and turbidity (FWS *et al.*, 1995; and Wakeford, 2001). Natural surface and groundwater discharges influence a river's characteristic fluctuations in volume, depth, and velocity (Leitman *et al.*, 1993; and Albertson and Torak, 2002). Change in temperature is thought to be an important factor in initiating sturgeon migration (Wooley and Crateau, 1985; Chapman and Carr, 1995; and Foster and Clugston, 1997) (see "Migration" section for temperature ranges). Laboratory experiments indicate that Gulf sturgeon eggs, embryos, and larvae have the highest survival rates when temperatures are between 15 and 20 °C (59 and 68 °F). Mortality rates of Gulf sturgeon gametes and embryos are highest when temperatures are 25 °C (77 °F) and above (Chapman and Carr, 1995) (see "Reproduction" section for more detail). Researchers have documented temperature ranges at Gulf sturgeon resting areas between 15.3 and 33.7 °C (59.5 and 92.7 °F) with dissolved oxygen levels between 5.6 and 9.1 milligrams per liter (mg/l) (Morrow *et al.*, 1998a; and Hightower *et al.*, in press).

In comparison to other fish species, sturgeon have a limited behavioral and physiological capacity to respond to hypoxia (insufficient oxygen levels) (Secor and Niklitschek, 2001). Basal metabolism, growth, consumption, and survival are sensitive to changes in oxygen levels (Secor and Niklitschek, 2001). In laboratory experiments, young shortnose sturgeon (*A. brevirostrum*) (less than 77 days old) died at oxygen levels of 3.0 mg/l and all sturgeon died at oxygen levels of 2.0 mg/l (Jenkins *et al.*, 1993). Data concerning the temperature, oxygen, and current velocity requirements of cultured sturgeon are being collected. Researchers plan to use information gained from these laboratory experiments on hatchery-reared sturgeon to develop detailed information on water flow requirements of wild sturgeon throughout different phases of their freshwater residence (Wakeford, 2001).