

## Appendix 13.E. Wildlife Species and their Hydrologic Requirements

Several hydrologic constraints that affect wildlife are water depth, inundation rate, hydropattern (and return interval), and recession rate. Salinity is another constraint related to seasonal flow rates in the estuarine segments of the St. Johns River.

### WATER DEPTH

Many floodplain wildlife species are distributed by water depth depending on their foraging and nesting requirements, physical size, and morphological adaptations to water. General wildlife distribution related to water depth is shown in Figure 13.E-1. Water depth of less than 0.5 m (approximately 20 in.) is important to a number of wildlife (e.g., dabbling ducks, wading birds, shorebirds, and white ibis). Water depth greater than 5 m (16.4 ft) is important for the manatee (Campbell 1976), alligator (Mazzotti and Brandt 1994), and some turtle species (Carr 1940; Zappalorti and Iverson 2006).

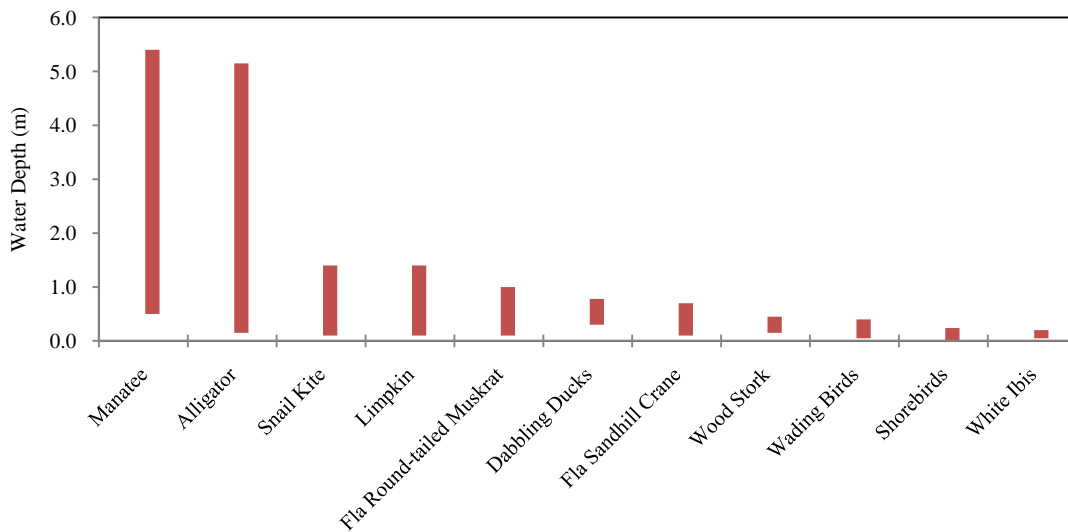


Figure 13.E-1. General distribution of some floodplain wildlife by water depth.

Some wildlife species use water depth to avoid competition or predation. For example, densely vegetated littoral zones are required by two-toed amphiuma, which prey on the greater siren and their juveniles. Greater siren juveniles occupy the vegetated shallows of littoral zones, while greater siren adults occupy deeper benthic habitats where they can avoid amphiuma predators (Snodgrass et al. 1999; Schalk et al. 2010).

Most turtles in the floodplain occur in water depths of less than 2 m (6.6 ft) when not basking on shorelines and embankments (Figure 13.E-2). The musk turtle (*Sternotherus* spp.) may inhabit water depths of 6 m or more. Water depth ranges for nine species of floodplain turtles are shown in Table .

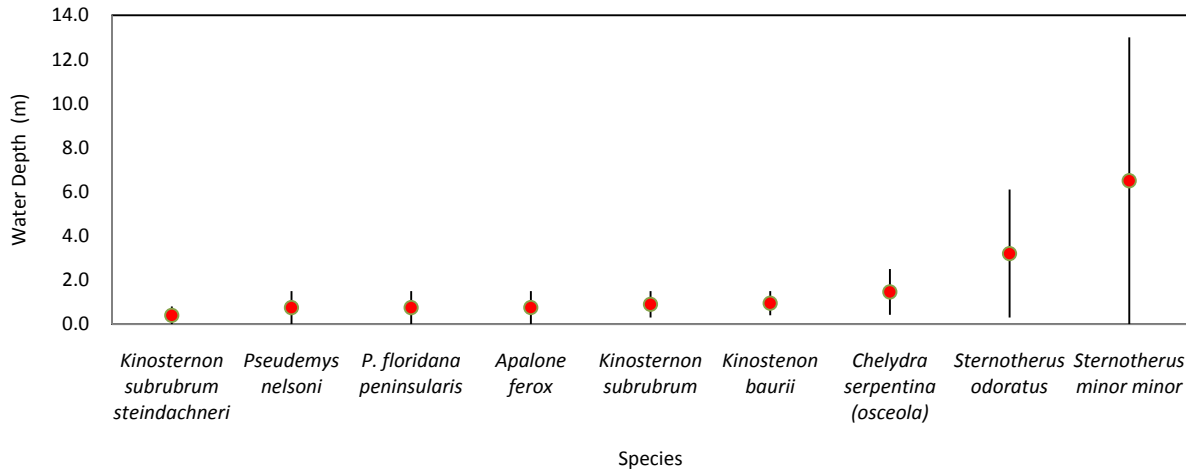


Figure 13.E-2. Water depth ranges for nine turtle species that occur in the St. Johns River floodplain.

Alligators generally occupy water depths from 15 to 120 cm (0.49 to 3.9 ft) and deeper. Female alligators and their juveniles use the shallows of marshes and shorelines, where water depth is typically 15 cm (5.9 in.) (Mazzotti and Brandt 1994). The habitat suitability indices by Palmer et al. (2000) and Rice et al. (2004) used a minimum depth of 15 cm for an 11-month period as an indication of reproductive conditions for alligators in the Everglades. Adult males occupy deeper waters, up to 5 m (16.4 ft) or more (Mazzotti and Brandt 1994).

Drought-related low water depth can aggregate alligator juveniles in gator holes, making them vulnerable to cannibalism by adults or predation by wading birds and raccoons (Craighead 1968; Mazzotti and Brandt 1994). Unsuitable water depth can delay sexual maturity and recruitment of juvenile alligators into the adult size class (Draugelis-Dale 2008).

Some snakes will forage in waters beyond their shoreline habitats. The brown water snake (*Nerodia taxispilota*) will bask on river shorelines with woody vegetation. Mills et al. (1995) observed individuals of this species diving in water depths > 2 m (6.6 ft) to capture juvenile ictalurid catfish (*Ictalurus* and *Ameiurus* spp.).

Kushlan (1979) observed white ibis in Everglades marsh and pond sites to estimate caloric consumption by prey selection. For both habitat types, he described an optimal foraging depth of 5 to 10 cm (2.0 to 3.9 in.) where the birds in his study captured mostly small fish (Figure 13.E-3). White ibis can forage in water up to 25 cm (9.8 in.) deep where Kushlan observed the highest crayfish densities (Kushlan 1979; Kushlan 1986). White ibis have a preference for the herbivorous freshwater crayfish (*Procambarus alleni*). This benthic macroinvertebrate occurs in the vegetated shallow waters of wet prairies and freshwater marshes (Hendrix et al. 1998; Hendrix and Loftus 2000). No crayfish were sampled in the pond sites by Kushlan (1979).

Table 13.E-1. Water depth ranges for nine turtle species that occur in the St. Johns River floodplain.

Species	Water Depth (m)	Water Depth (ft)	Sources
Florida Mud Turtle ( <i>Kinosternon subrubrum steindachneri</i> )	0 to 0.8	0 to 2.5	Ernst et al. (1972)
Florida Softshell ( <i>Apalone ferox</i> )	0 to >1.5	0 to > 4.9	Godley et al. (1981); Meylan and Moler (2006)
Peninsula Cooter ( <i>Pseudemys floridana peninsularis</i> )	0 to <1.5	0 to < 4.9	Godley et al. (1981)
Florida Red-bellied Turtle ( <i>P. nelsoni</i> )	0 to <1.5	0 to < 4.9	Godley et al. (1981)
Eastern Mud Turtle ( <i>K. subrubrum subrubrum</i> )	0.3 to 1.5	1.0 to 4.9	Mahmoud (1969)
Common Snapping Turtle ( <i>Chelydra serpentina osceola</i> )	0.42 to < 2.5	1.4 to < 8.2	Graves and Anderson (1987); Johnston et al. 2008
Striped Mud Turtle ( <i>K. baurii</i> )	0.4 < 3.15	1.4 to > 10.3	Ernst (1972); Wygoda (1979); Godley et al (1981)
Common Musk Turtle ( <i>Sternotherus odoratus</i> )	0.3 to 6.1	1.0 to 20	Carr (1940); Mahmoud (1969); Godley et al. (1981); Edmonds (2002)
Loggerhead Musk Turtle ( <i>S. minor minor</i> )	2 to 13	6.6 to 42.7	Zappalorti and Iverson (2006)

Water depth for charadriiform shorebirds ranges from 0 to 24 cm (0 to 9.4 in.) (Helmers 1992). Like wading birds, the physical size and leg length of shorebird species limits foraging opportunities based on water depth. Spring migratory shorebirds typically concentrate along shallow water edges on exposed mudflats (Breininger and Smith 1990).

Shorebird habitat use as a function of water depth is summarized in Figure 13.E-4. Long-legged shorebird species (e.g., American avocet (*Recurvirostra americana*), black-necked stilt (*Himantopus mexicanus*), greater yellowlegs (*Tringa melanoleuca*), and marbled godwit (*Limosa fedoa*) use flooded areas with at least a few centimeters of standing water. The black-necked stilt often forages in water depths of 8 to 24 cm (3.1 to 9.4 in.). The relatively short-legged Wilson's phalarope (*Phalaropus tricolor*) swims in water depths of 8 to 20 cm (3.1 to 7.9 in.) to catch invertebrates. Small sandpipers, like the sanderling (*Calidris alba*), forage in very shallow waters close to open shorelines.

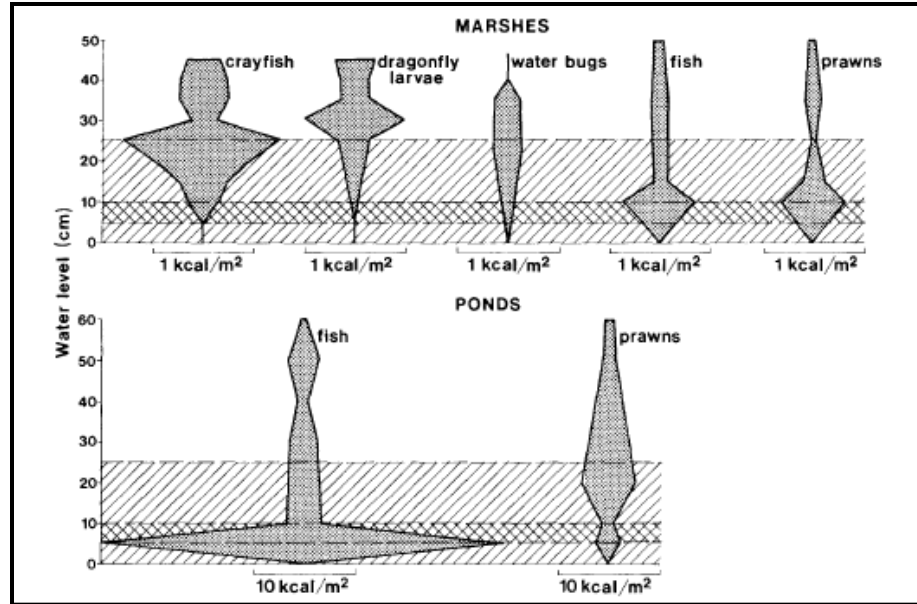


Figure 13.E-3. Prey consumption and caloric value for white ibis in two Everglades habitat types studied by Kushlan (1979). Single hatching indicates foraging depths by white ibis; double hatching indicates the most common foraging zone.

Kushlan et al. (1985) generalize water depth preferences by wading birds (Table 13.E-2). Water depths of about 15 cm (5.9 in.) or 30 cm (11.8 in.) are commonly used. Most small herons and white ibis forage in shallow water depths < 15 cm. Large birds with proportionally longer legs, such as great blue heron, great egret (*Ardea alba*), and wood stork, can exploit prey in water depths > 15 cm. The non-native cattle egret prefers dry or saturated conditions without standing water.

Frederick and Collopy (1989b) relate water depth to wading bird nest predation in the Everglades. Rookeries studied included great egrets, white ibis, tricolored herons (*Egretta tricolor*), little blue herons (*E. caerulea*), and snowy egrets (*E. thula*). The birds began nesting in willows when water depth was at least 30 cm (11.8 in.). Receding water and dry conditions exposed nests to predation by snakes, raccoons, foxes, and rats. Distances from dry land and the presence of alligators did not deter raccoons, but shallow water of only 5 to 10 cm (2.0 to 3.9 in.) seemed to reduce nest predation by this mammal.

Wood storks forage for small marsh fish in water depths < 30 cm (11.8 in.) (Kahl 1964; Kushlan et al. 1975). In his study, Kushlan (1980) reported that small marsh fish densities in his Everglades study areas were highest when water depths were about 30 cm (11.8 in.). Wood storks generally need a water depth range of 90 to 150 cm (3 to 5 ft) under nests to deter predation on eggs and young (Ogden 1990).

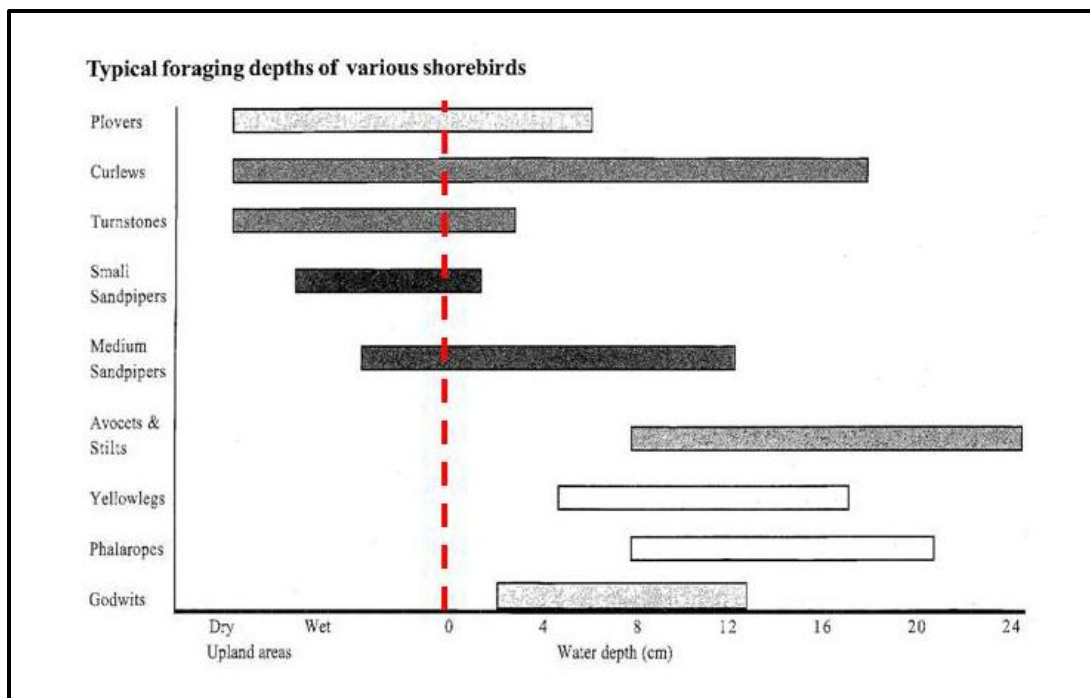


Figure 13.E-4. Shorebird foraging water depth (after Helmers (1992) and modified by the NRCS (2000). Dashed red line indicates a water depth of 0 cm.

Table 13.E-2. General water depth preferences by wading birds (adapted from Kushlan et al. (1985)). Shaded cells indicate preferred habitats and hatched cells refer to secondary habitats.

Species	General Water Depth	
	Shallow	Deep
American Bittern ( <i>Botarus lentiginosus</i> )		
Least Bittern ( <i>Ixobrychus exilis</i> )		
Great Blue Heron ( <i>Ardea herodias</i> )		
Great Egret ( <i>Ardea alba</i> )		
Snowy Egret ( <i>Egretta thula</i> )		
Little Blue Heron ( <i>Egretta caerulea</i> )		
Tricolor Heron ( <i>Egretta tricolor</i> )		
Cattle Egret ( <i>Bubulcus ibis</i> )		
Green Heron ( <i>Butorides virescens</i> )		
Black-crowned Night-Heron ( <i>Nycticorax nycticorax</i> )		
Yellow-crowned Night- Heron ( <i>Nyctanassa violacea</i> )		
White Ibis ( <i>Eudocimus albus</i> )		
Glossy Ibis ( <i>Plegadis falcinellus</i> )		
Roseate Spoonbill ( <i>Platalea ajaja</i> )		
Wood Stork ( <i>Mycteria americana</i> )		

Florida sandhill cranes (*Grus canadensis pratensis*) require broadleaf marsh vegetation and standing water to initiate nesting. Depkin et al. (1994) reported a water depth range of 36 to 100 cm (1.2 to 3.3 ft; n = 21) and an average maximum depth of 61 cm (2.0 ft). They observed that slough communities function as important drought refugia for Florida sandhill cranes.

Florida snail kites can capture apple snails to 16 cm (0.5 ft) below the water surface (Sykes 1987; USFWS 1999a). The maximum depth was derived from measured talon lengths (Sykes 1987). This depth overlaps the upper end of apple snail distribution in the water column. Apple snails require water depths that range from 10 to 115 cm (0.3 to 3.8 ft) (Hanning 1978). In Blue Cypress Lake, water depths under Florida snail kite nests observed by Toland (1994) varied from about 40 to 120 cm (1.3 to 3.9 ft). Sykes (1983b) described fluctuating water depth for Florida snail kite marshes. Limpkins, which also consume apple snails, use similar marsh habitats.

Foraging success by dabbling ducks is also limited by water depth. Florida mottled ducks forage for benthic macroinvertebrates and plant matter where water depths are < 30 cm (11.8 in.) (Rorabaugh and Swank 1983). Sincock (1957) reported tip-feeding by dabbling ducks where water depth is < 46 cm (18 in.).

At their study site in an isolated sandhill wetland, Smith and Franz (1994) found active Florida round-tailed muskrat houses in marshes with water depths of less than 1 m (3.3 ft). The bases of the houses were positioned 5 to 8 cm (2.0 to 3.2 in.) above the water surface.

Water depths are important to the river's manatees. The physical size of adults— up to 680 kg (approximately 1500 lbs) in weight and 6 m (approximately 20 ft) in length (Campbell 1976)— requires water depths sufficient for individual movement and passage, mating, and manatee cow-calf bonds. The USFWS (1999b) reported that manatees need access to waters of at least 2 m (6.6 ft) in depth. A minimum depth range of 1.5 to 2 m (approximately 5.0 to 6.6 ft) was recommended by Campbell (1976) and Langtimm et al. (2003) for manatee passage.

## **INUNDATION RATE**

Annual inundation rate, or the length of time an area is flooded, determines the presence of wetland and aquatic wildlife, either directly or through the influence of food web interactions. Shortened rates of inundation can affect floodplain productivity by lowering detritus abundance and microbial activity, and by reducing the production of macroinvertebrates and fish (Loftus et al. 1986) as well as other species.

The frogs and toads of the floodplain are examples of wildlife that depend on inundation rate. Annual inundation is an important determinant for tadpole survival, and will determine the anuran species composition and abundance of a site (Pechman et al. 1989). Metamorphosis times vary by species from less than 1 month to 1 yr or more depending on latitude (Table 13.E-3). For example, Donnelly (1997) determined that tadpoles of the little grass frog in south Florida wetlands can metamorphose in a few weeks after larval emergence, tolerating an annual inundation rate about 8%. Bullfrog tadpoles need longer durations of at least 250 to 365 days, or an annual inundation rate of 68.5% to 100% (Donnelly 1997; Casper and Hendricks 2005).

Compared to other frogs, the ranids (*Lithobates* spp.) require relatively long hydroperiods for tadpole metamorphosis. In their laboratory study, Ryan and Winne (2001) concluded that their

southern leopard frog (*L. sphenoccephala*) subjects had better metamorphosis and survival rates when the period for tadpole development was at least 90 days, an annual inundation rate of about 25%. As a group, the ranid frogs in the floodplain are the most aquatic of the frogs, although the southern leopard frog may forage terrestrially.

Table 13.E–3. Amphibian metamorphosis times.

Species	Metamorphosis Time (days)	Annual Inundation Rate (%)
Bullfrog ( <i>Lithobates catesbeiana</i> )	250 to 365	68.5 to 100
Pig Frog ( <i>Lithobates grylio</i> )	250	68.5
Southern Dwarf Siren ( <i>Pseudobranchis striatus axanthus</i> )	250	68.5
Two-toed Amphiuma ( <i>Amphiuma means</i> )	210	57.5
Peninsula Newt ( <i>Notophthalmus viridescens piaropicola</i> )	210	57.5
Southern Leopard Frog ( <i>Lithobates sphenoccephala</i> )	90	24.7
Southern Cricket Frog ( <i>Acris gryllus</i> )	90	24.7
Green Treefrog ( <i>Hyla cinerea</i> )	60	16.4
Cuban Treefrog ( <i>Osteopilus septentrionalis</i> )	60	16.4
Southern Toad ( <i>Bufo terrestris</i> )	60	16.4
Squirrel Treefrog ( <i>Hyla squirella</i> )	55	15.1
Eastern Narrow-mouthed Toad ( <i>Gastrophryne carolinensis</i> )	30	8.2
Little Grass Frog ( <i>Pseudacris ocularis</i> )	10	2.7

Source: Donnelly 1997; Casper and Hendricks 2005.

Adult and juvenile salamanders also depend on wetland hydroperiods. Vestigial limbs limit the ability of salamanders to disperse from drying wetlands unless wet corridors are available. One exception is the peninsula newt (*Notophthalmus viridescens piaropicola*). The juveniles may develop during an eft phase spent in the leaf litter of forested uplands.

Two aquatic salamanders—the two-toed amphiuma and the greater siren—need hydroperiods of at least 182 days, or an annual inundation rate  $\geq 50\%$  (Snodgrass et al. 1999). The amphiuma and greater siren respond to droughts by burrowing into muddy substrates. The strategy does not preclude starvation-related mortality that results from prolonged droughts or drying events in successive years (Snodgrass et al. 1999; Schalk et al. 2010).

Although alligators benefit from dry season conditions that concentrate prey into gator holes, prolonged droughts can have adverse effects. Reduced prey abundance means weak crocodylian body condition, reproduction, and survival rates (Craighead 1968; Percival et al. 2000). Draugelis-Dale (2008) reported slower juvenile alligator growth rates in marshes with shortened hydroperiods; the period for sexual maturation almost doubled from 10 to 18 years.

Turtle responses to inundation rates and drying conditions vary. Bodie et al. (2000), who studied the alligator-free waters of the lower Missouri and upper Mississippi rivers, concluded that long hydroperiod wetlands were important for turtle species richness.

Individuals of some turtle species in the floodplain typically migrate away from drying wetlands and water bodies. The chicken turtle (*Deirochelys reticularia*), the striped mud turtle

(*Kinosternon baurii*), and the eastern mud turtle (*K. subrubrum subrubrum*) aestivate in terrestrial locations during dry conditions, or find ponded areas in neighboring wetlands (Gibbons et al. 1983; Ernst and Lovich 2009). These turtles return to wetlands that refill with seasonal rains. Gibbons et al. (1983) found that drought had relatively no effect on egg laying by the eastern mud turtle.

In contrast, the common musk turtle (*Sternotherus odoratus*) requires permanently flooded conditions (Gibbons et al. 1983). Congdon and Gibbons (1996) reported that the common musk turtle avoided ephemeral wetlands. Females spend brief periods on land for egg laying (Gibbons et al. 1983). Desiccation is a problem for common musk turtle individuals that leave their aquatic habitats during droughts (Iverson and Meshaka, Jr. 2006). Congdon and Gibbons (1996) observed that common musk turtle individuals were subject to extermination or the need to emigrate when long hydroperiod marshes dried. Emigration distances to ponded areas must be short. For this reason, landscape linkages to suitable habitats are important to the common musk turtle. Gibbons et al. (1983) reported that common musk turtles burrowed into muddy substrates to wait out a drought; however, this species is sensitive to anoxic conditions (Jackson et al. 2007). Anoxia, which is common in the upper St. Johns River marshes (see Chapter 7. Biogeochemistry), may limit abundance and distribution of the common musk turtle in the floodplain.

Of the floodplain snakes, the Florida green water snake (*Nerodia floridana*) may be the most sensitive to dry conditions according to mark-and-recapture studies by Seigel et al. (1995) and Willson et al. (2006). The Florida green water snake responds to drying marshes by burrowing. However, this adaptive behavior only succeeds when the duration of drying events does not exceed the snake's ability to survive on body fat reserves. Seigel et al. (1995) reported that Florida green water snakes in their South Carolina study experienced high mortality rates during a 1-in-300-yr drought.

Seigel et al. (1995) observed that banded water snakes (*Nerodia fasciata*), brown water snakes (*N. taxispilota*), and black swamp snakes (*Seminatrix pygaea*) dispersed from drying wetlands. These three species re-established themselves when water conditions improved, but their abundance ratios changed from predrought conditions. Willson et al. (2006) observed responses to drying wetlands by banded water snakes and black swamp snakes. Banded water snakes were sensitive to low water; no reproduction occurred, and their population size decreased. By contrast, black swamp snakes were not as sensitive to drying. Willson et al. (2006) concluded that the black swamp snake responded not so much to drying as to the reduced abundance of small marsh fish that coincided with drought conditions.

Inundation rates affect marsh bird foraging conditions by determining prey production and recruitment (Kahl 1964; Smith et al. 1995; Frederick et al. 1996), including prey species composition, density, size, and availability (Bancroft et al. 2002; Beissinger and Snyder 2002; Gawlik 2002). Productive marshes have suitable annual and inter-annual inundation that support forage quality, and rookeries that are closely located to foraging sites (Kahl 1964; Kushlan 1974; Fleming et al. 1994).

Florida snail kites require long-hydroperiod marshes because of their full dependency on apple snails (*Pomacea paludosa*). Long periods of inundation support the reproduction and growth of



apple snails. Reduced hydroperiods affect the abundance of both species (Sykes 1983a; Sykes 1983b; Toland 1994). Beissinger (1995) modeled drought return intervals using stochastic simulations and concluded that Florida snail kites require  $\geq 4.3$  years between drying events.

## HYDROPATTERN

Hydropatterns are seasonal water conditions that fluctuate with rainfall and water levels. Wetland wildlife reproduction and food availability follow seasonal patterns. The reproductive timing of a number of wetland species (e.g., herpetofauna and wading birds) is dependent on hydropattern. The hydrograph of the St. Johns River at Lake Harney is an example of a hydropattern for the period of record from 1 January 1960 to 31 December 2008 (Figure 13.E-5).

Hydropatterns also include return intervals, meaning the frequency of occurrence of wet and dry cycles. Interannual return intervals can drive floodplain productivity of benthic macroinvertebrates and fish. High or low water level events that occur too frequently on a year-to-year basis can disrupt prey production and successful nesting by wading birds and Florida snail kites.

Decreasing water levels are normal for the winter and spring months. Rainfall and runoff from convective thunderstorms and tropical systems cause river water level conditions to peak in late summer and early fall, usually between September and October. Stage elevations decline again in the normally drier months of late fall and early winter. Changes to the typical pattern occur, such as when wet *El Niño* winters precede dry *La Niña* summers. Wildfires often accompany droughts.

For the frog species that occur in the floodplain, male calling phenologies indicate when water must be present for oviposition and external fertilization. Generally, the calling seasons for the floodplain correspond to the months of April to August although some species call for longer periods. Compared to the Lake Harney hydropattern, the common calling season occurs when water level conditions are increasing (solid red arrow, Figure 13.E-5).

Salamander adults mate in the cool weather months from winter to early spring when water levels are typically low (open red arrow, Figure 13.E-5). Female amphiuma burrow above the water line to create nest chambers for oviposition. The females incubate the eggs for about 5 months. Neonate emergence occurs in the summer and fall months. Seasonal rains increase water levels at this time, which shortens travel distances from the egg chambers to the waterline of wet habitats, such as littoral zones and marshes.

Nesting by freshwater turtles in central and north Florida occurs in the spring and early summer when water levels are normally receding (Iverson 1977). Nesting and oviposition occur on terrestrial sites having dry or moist substrates. Embryonic development depends on relatively dry conditions to allow oxygen and vapor exchange across the egg membrane. Hatchling emergence occurs within 8 to 10 weeks of nesting, depending on the species (Water depth and timing are critical to alligator reproduction (Draugelis-Dale 2008), which follows a seasonal pattern that is similar to turtle reproduction. Mating begins in the spring dry season, after which the female prepares a nest from emergent vegetation growing in her marsh and shoreline habitat. Egg laying and incubation typically begin in June during low water conditions. Hatchling emergence occurs from July to September as water levels peak (Mazotti and Brandt 1994).

Table 13.E-4). Emergence usually coincides with rainfall and increasing water levels from mid to late summer and early fall (Meylan 2006). After emergence, when water levels are normally increasing, hatchling turtles leave their nests and move toward vegetated shorelines.

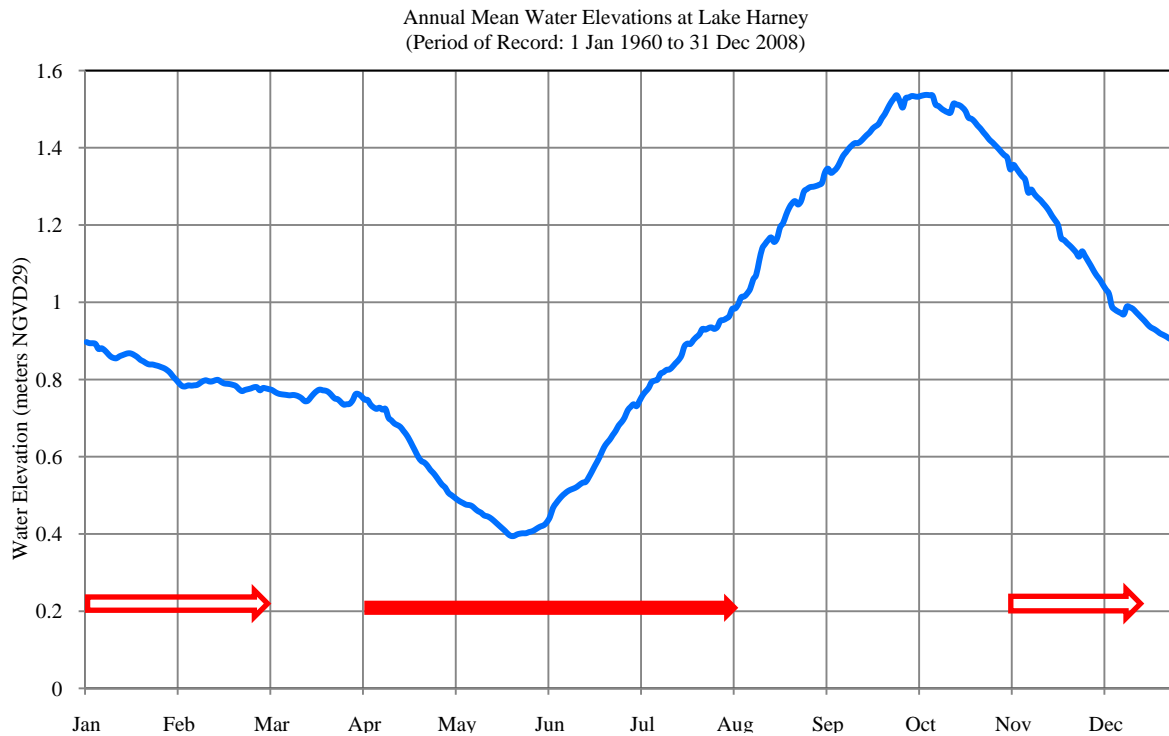


Figure 13.E-5. Amphibian reproduction times for the St. Johns River floodplain compared to a hydrograph for Lake Harney; solid red arrow = frogs (common calling season); open red arrow = salamanders (oviposition).

Water depth and timing are critical to alligator reproduction (Draugelis-Dale 2008), which follows a seasonal pattern that is similar to turtle reproduction. Mating begins in the spring dry season, after which the female prepares a nest from emergent vegetation growing in her marsh and shoreline habitat. Egg laying and incubation typically begin in June during low water conditions. Hatchling emergence occurs from July to September as water levels peak (Mazotti and Brandt 1994).

Table 13.E-4. Approximate dates for nesting and hatchling emergence for three turtle species that occur in the St. Johns River floodplain.

Species	Nesting Season	Nestling emergence
Florida Softshell	April to May	August
Common Snapping Turtle	May to June	August to October
Eastern Musk Turtle	May to June	July to August

Source: adapted from Iverson 1977.

Wading birds depend on hydropatterns that drive secondary productivity. Seasonal water levels determine prey size, density, and availability (Kahl 1964; Fleming et al. 1994). Beneficial hydropatterns grow small marsh fish and crustaceans in the summer (June to October) and concentrate them in drying pools in the winter and spring when wading birds are nesting (Kahl 1964; Browder 1978; Kushlan 1980; Bancroft et al. 1990; Bancroft et al. 1994; Fleming et al. 1994; Jordan et al. 1998; Gawlik 2002). Year-to-year seasonal water level fluctuations largely determine fish community composition (Loftus and Eklund 1994; Gawlik 2002) and predator to prey ratios for a marsh (Kushlan 1976; Loftus and Eklund 1994).

Ciconiiform wading birds and Florida snail kites require quality foraging and nesting habitats that are supported by suitable water depth fluctuations on an annual and interannual basis (Kushlan et al. 1985; Bancroft 1989; Frederick and Collopy 1989a, 1989b; David 1994; Beissinger 1995; Bennetts and Kitchens 1997; Comiskey et al. 1998a, 1998b). Annual surface water fluctuations create a mosaic of wet depressions that vary by depth and drying rate. Changing water level conditions support a succession of foraging locations across the floodplain if prey organisms are available (Kahl 1964; Frederick and Ogden 2001; Mooij et al. 2007). Adequate water depth supports nesting in locations where foraging distances are energetically efficient and terrestrial predators are excluded (Frederick and Collopy 1989b; Toland 1994).

Kahl (1964) described the ecological relationship of nesting wood storks to seasonal water fluctuations and fish densities in the Everglades (Figure 13.E-6). Although wood storks may nest 3 months later in the St. Johns River floodplain, the Kahl model indicates that successful reproduction and egg laying coincides with receding waters and high caloric consumption of small marsh fish. If too few calories are available for nesting adult birds, chick abandonment and mortality can occur.

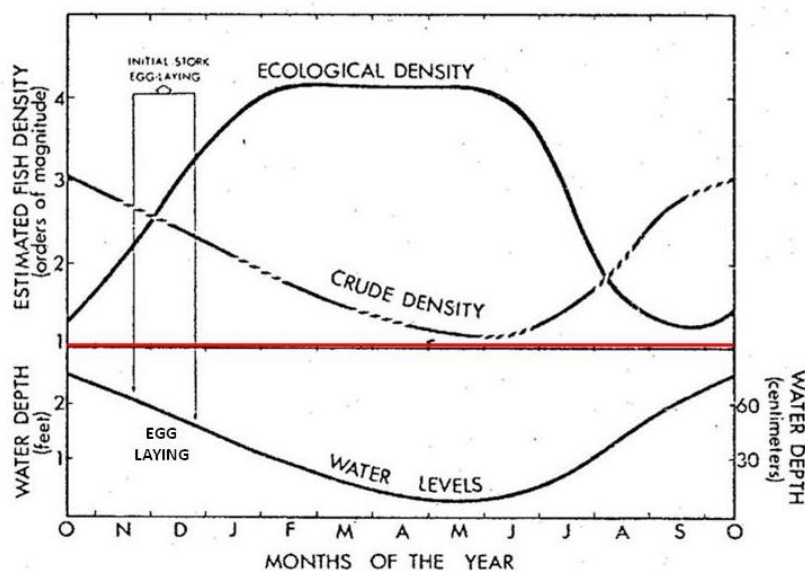


Figure 13.E-6. Relationship of wood stork reproduction relative to seasonal water levels and prey fish density (adapted from Kahl 1964). Ecological density = fish density per unit volume of water. Crude density = total number of fish per unit area of land-marsh surface. The red line separates fish density changes (top) and water level changes (bottom). Wood stork nesting is indicated by a rectangle.

Chamberlain (1960) reports a relationship between hydropattern and habitat values for wintering waterfowl on Lake Kissimmee. Good habitat values result when typical increases in water levels occur from late summer to mid-winter. This seasonal hydropattern supports relatively large populations of wintering ducks and coots (*Fulica americana*). By comparison, waterfowl numbers are low in years when water levels decrease for the same seasonal period.

### RECESSION RATE

Recession rates can represent an important constraint because they determine prey fish densities and foraging conditions for ciconiiform wading birds, particularly during the critical nesting period of April through May (Cook and Kobza 2010). Unsuitable recession rates combined with water level conditions and low prey availability can result in rookery abandonment for species such as white ibis and wood stork (Frederick and Collopy 1989a; Frederick and Spalding 1994).

### SALINITY

The freshwater reaches of the St. Johns River have an important relationship to estuarine populations of white ibis, which is a species of special concern. Salinity regimes affect white ibis that nest in estuarine rookeries. Coastal white ibis depend on crayfish and small marsh fish populations of nearby freshwater wetlands (Bildstein et al. 1990; Frederick et al. 1996). In a laboratory experiment, Johnston and Bildstein (1990) report that the high salt content of estuarine prey causes white ibis chick mortality. For this reason, white ibis chicks in coastal rookeries are often fed by the adults with regurgitated food collected from freshwater marshes (Bildstein et al. 1990).

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