Appendix 6-1: Herpetofauna (Animals), Rhizotrons (Plants) and Habitat Suitability Indices (Models)

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DETAILED INFORMATION ON HERPETOFAUNA OF TREE ISLANDS

Table 1. Turtles, which have a probability of utilizing Everglades tree islands. Known primary habitats, along with the known origin of the herpetofauna, are listed. Probability of tree island use is listed as follows: Low = most likely no use of the tree island; Medium = a possibility of tree island use; High = a good possibility of tree island use. Probable frequencies are listed as follows: Very Rare (extremely rare use of tree islands); Rare (rare or short, seasonal use of tree islands); Common (common or seasonal use of tree islands); Very Common (daily use of tree islands)

	THE TURTLES						
Genus/Species	Common Name	Known Primary Habitat	Probability of Tree Island Use	Probable Activities on Tree Island: Nesting	Probable Activities on Tree Island: Foraging	Origin	Probable Frequency
TRIONYX FEROX	Florida Softshell Turtle	P, Aq, T*	Medium	Yes**	Yes****	Native	Common
CHELYDRA SERPENTINA	Florida Snapping Turtle	P, Aq, T*	Medium	No***	Yes****	Native	Common
DEIROCHELYS RETICULARIA	Chicken Turtle	P, Aq, T	High	Yes	Yes****	Native	Common
KINOSTERNON BAURII	Striped Mud Turtle	P, Aq, T*	High	Yes	Yes****	Native	Common
KINOSTERNON SUBRUBRUM	Mud Turtle	P, Aq, T*	Low	Yes**	Yes****	Native	Very Rare
PSEUDEMYS FLORIDANA	Peninsular Cooter	P, Aq, T	High	Yes	Yes****	Native	Common
PSEUDEMYS NELSONI	Redbellied Turtle	P, Aq, T	High	Yes**	Yes****	Native	Common
STERNOTHERUS ODORATUS	Stinkpot	P, Aq, T*	Low	Yes	Yes****	Native	Very Rare
TERRAPENE CAROLINA	Box Turtle	P, Aq, T***	Low	No	Yes	Native	Rare
TRACHEMYS SCRIPTA ELEGANS	Red-eared Slider	P, Aq, T	Medium	Yes	Yes****	Exotic	Rare

ABBREVIATIONS FOR PRIMARY HABITATS

P = Wet Prairie (sawgrass/cattail/grasses)

Aq = Aquatic (open water)

T = Terrestrial (dry land)

* = Rarely leaves aquatic habitat, except for nesting or drought situations

** = May nest within alligator nest

*** = Would nest only on large higher elevation islands

**** = May forage within solution holes on islands or within alligator holes

***** = May cross shallow open water

Turtle table created from information found in the following:

Ashton, R.E. Jr. and P. Sawyer Ashton. 1991. *Handbook of Reptiles and Amphibians of Florida Part II: Lizards, Turtles, and Crocodilians*. Windward Publishing, Inc., Miami.

Bartlett, R.D. and P.P. Bartlett. 1999. *A Field Guide to Florida Reptiles and Amphibians*. Gulf Publishing Company, Houston.

Conant, R., J.T. Collins and I. Hunt Conant. 1998. *A Field Guide to the Reptiles and Amphibians of Eastern and Central North America, 4th ed*. Houghton Mifflin, Boston.

Dalrymple, G.H. 1988. *The Herpetofauna of Long Pine Key, Everglades National Park, in Relation to Vegetation and Hydrology*. Pp. 72-86 in Szoro, R.C., K.E. Severson, and D.R. Patton, (tech coords.). Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM. 166.

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Iverson, John B. and C.R. Etchberger. 1989. The distributions of the turtles of Florida. *Florida Scientist*, 52:119-144.

Meshaka, W.E., R. Snow, O.L. Bass and W.B. Robertson. 2002. Occurrence of Wildlife on Tree Islands in the Southern Everglades. Eds: A. van der Valk, F.H. Sklar. *Tree Islands of the Everglades*. In preparation.

Meshaka, W.E., W.F. Loftus and T. Steiner. 2000. The Herpetofauna of Everglades National Park. *Florida Scientist*, 63(2):84-103.

Towles, T. 1993. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Towles, T. 1995. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Table 2. Lizards that have a probability of utilizing Everglades tree islands. Known primary habitats, along with the known origin of the herpetofauna, are listed. Probability of tree island use is listed as follows: Low = most likely no use of the tree island; Medium = a possibility of tree island use; High = a good possibility of tree island use. Probable frequencies are listed as follows: Very Rare = extremely rare use of tree islands; Rare = rare or short, seasonal use of tree islands; Common = common or seasonal use of tree islands; Very Common = daily use of tree islands

	THE LIZARDS						
Genus/Species	Common Name	Known Primary Habitat	Probability of Tree Island Use	Probable Activities on Tree Island		Origin	Probable Frequency
				Nesting	Foraging		
ANOLIS CAROLINENSIS	Green Anole	P, T, Ar	High	Yes	Yes	Native	Common
ANOLIS SAGREI	Brown Anole	T, Ar	Medium	Yes	Yes	Exotic	Rare**
EUMECES INEXPECTATUS	Southeastern Five-lined Skink	P, T	High	Yes	Yes	Native	Very Common
IGUANA IGUANA	Green Iguana	T, Ar	Low	No	Yes	Exotic	Very Rare***
OPHISAURUS VENTRALIS	Common Glass Lizard	P, T	Low		Yes	Native	Very Rare
SCINCELLA LATERALIS	Ground Skink	P, Aq*, T	High	Yes	Yes	Native	Common

ABBREVIATIONS FOR PRIMARY HABITATS

P = Wet Prairie (sawgrass/cattail/grasses)

Aq = Aquatic (open water)

T = Terrestrial (dry land)

Ar = Arboreal (in trees and bushes)

* = Usually uses water as an escape route

** = More common on disturbed tree islands

*** = Most likely escaped/released pets

? = unable to determine

Lizard table created from information found in the following:

Ashton, R.E., Jr. and P. Sawyer Ashton. 1991. *Handbook of Reptiles and Amphibians of Florida Part II: Lizards, Turtles, and Crocodilians*. Windward Publishing, Inc., Miami.

Bartlett, R.D. and P.P. Bartlett. 1999. *A Field Guide to Florida Reptliles and Amphibians*. Gulf Publishing Company. Houston.

Conant, R., J.T. Collins and I. Hunt Conant. 1998. *A Field Guide to the Reptiles and Amphibians of Eastern and Central North America, 4th ed*. Houghton Mifflin. Boston.

Dalrymple, G.H. 1988. *The Herpetofauna of Long Pine Key, Everglades National Park, in Relation to Vegetation and Hydrology*. Pp. 72-86 in Szoro, R.C., K.E. Severson and D.R. Patton, (tech coords.). Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM. 166.

Duellman, W.E. and A. Schwartz. 1958. *Amphibians and Reptiles of Southern Florida*. Bulletin of the Florida State Museum, 3:181-324.

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Lodge, Thomas E. 1994. *The Everglades Handbook: Understanding the Ecosystem*. St. Lucie Press. Delray Beach, FL.

Meshaka, W.E., R. Snow, O.L. Bass and W.B. Robertson. 2002. Occurrence of Wildlife on Tree Islands in the Southern Everglades. A. van der Valk and F.H. Sklar, eds. *Tree Islands of the Everglades*. In preparation.

Meshaka, W.E., W.F. Loftus and T. Steiner. 2000. The Herpetofauna of Everglades National Park. *Florida Scientist*, 63(2):84-103.

Towles, T. 1993. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Towles, T. 1995. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Wilson, L.D. and L. Porras. 1983. *The Ecological Impact of Man on the South Florida Herpetofauna*. The University of Kansas Museum of Natural History. Allen Press, Lawrence, KS.

Table 3. Snakes that have a probability of utilizing Everglades tree islands. Known primary habitats have been listed, along with the known origin of the herpetofauna. Probability of tree island use is listed as in the above tables

	THE SNAKES						
Genus/Species	Common Name	Known Primary Habitat	Probability of Tree Island Use	Probable Activities on Tree Island		Origin	Probable Frequency
				Nesting	Foraging		
AGKISTRODON PISCIVORUS	Cottonmouth	P, Aq, T	High	No**	Yes	Native	Very Common
COLUBER CONSTRICTOR	Everglades Racer	T*, P	Medium	Yes	Yes	Native	Rare
CONSTRICTOR	Boa Constrictor	T, Ar	Low	No	Yes	Exotic	Very Rare****
CROTALUS ADAMANTEUS	Eastern Diamondback Rattlesnake	P, T	Low	No**	Yes	Native	Rare
DIADOPHIS PUNCTATUS	Ringneck Snake	P, T	High	Yes	Yes	Native	Common
DRYMARCHON CORAIS	Indigo Snake	P, T	Low	No	Yes	Native	Very Rare
ELAPHE GUTTATA	Corn Snake	P, T, Ar	Medium	Yes	Yes	Native	Rare
ELAPHE OBSOLETA	Everglades Rat Snake	P, T, Ar	High	Yes	Yes	Native	Common
FARANCIA ABACURA	Mudsnake	P, Aq	High	Yes	No***	Native	Common
LAMPROPELTIS GETULUS	Kingsnake	P, T	Medium	?	Yes	Native	Rare
LAMPROPELTIS TRIANGULUM	Scarlet Kingsnake	P, T	Low	?	Yes	Native	Very Rare
NERODIA FASCIATA	Southern Water Snake	P, Aq, T	High	No**	No***	Native	Common
NERODIA FLORIDANA	Florida Green Water Snake	P, Aq, T	High	No**	No***	Native	Common
NERODIA TAXISPILOTA	Brown Water Snake	P, Aq, T	High	No**	No***	Native	Common
OPHEODRYS AESTIVUS	Rough Green Snake	P, T, Ar	High	Yes	Yes	Native	Common

REGINA ALLENI	Striped Crayfish Snake	P, Aq	Medium	No**	No***	Native	Very Common
SEMINATRIX PYGAEA	Black Swamp Snake	P, Aq	Medium	No**	No	Native	Common
SISTRURUS MILIARIUS	Dusky Pigmy Rattlesnake	P, T	High	No**	Yes	Native	Common
THAMNOPHIS SAURITUS	Ribbon Snake	P, Aq, T	High	No**	Yes	Native	Very Common
THAMNOPHIS SIRTALIS	Garter Snake	P, Aq, T	High	No**	Yes	Native	Very Common

ABBREVIATIONS FOR PRIMARY HABITATS

P = Wet Prairie (sawgrass/cattail/grasses)

Aq = Aquatic (open water)

T = Terrestrial (dry land)

Ar = Arboreal (in trees and bushes)

* = Near truly dry areas such as levees

** = Live bearing snakes

*** = May forage within solution holes on islands or with alligator holes just off of islands

**** = Most likely escaped/released pets

? = unable to determine

Snake table created from information found in the following:

Anderson, R. 1989. *The Great Outdoors Book of Florida Snakes*. Great Outdoors Publishing Company. St. Petersburg, FL.

Ashton, R.E., Jr. and P.S. Ashton. 1988. *Handbook of Reptiles and Amphibians of Florida Part I: The Snakes*. Windward Publishing, Inc., Miami.

Conant, R., J.T. Collins and I.H. Conant. 1998. *A Field Guide to the Reptiles and Amphibians of Eastern and Central North America, 4th ed*. Houghton Mifflin, Boston.

Dalrymple, G.H. 1988. *The Herpetofauna of Long Pine Key, Everglades National Park, in Relation to Vegetation and Hydrology*. Pp. 72-86 in Szoro, R.C., K.E. Severson and D.R. Patton (tech coords.). Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM. 166.

Duellman, W.E. and A. Schwartz. 1958. *Amphibians and reptiles of southern Florida*. Bulletin of the Florida State Museum, 3:181-324.

Gunderson, L.H. and W. Loftus. 1993. The Everglades. Pp. 199-225. In Martin, W.H., S.G. Boyce and A.C. Echternacht, eds. *Biodiversity of the Southeastern United States*. John Wiley & Sons, New York.

Meshaka, W.E., R. Snow, O.L. Bass and W.B. Robertson. 2002. Occurrence of Wildlife on Tree Island in the Southern Everglades. A. van der Valk and F.H. Sklar, eds. *Tree Islands of the Everglades*. In preparation.

Meshaka, W.E., W.F. Loftus and T. Steiner. 2000. The Herpetofauna of Everglades National Park. *Florida Scientist*, 63(2):84-103.

Tennant, A. 1997. *A Field Guide to Snakes of Florida*. Gulf Publishing Company, Houston.

Towles, T. 1993. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Towles, T. 1995. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Wilson, L.D. and L. Porras. 1983. *The Ecological Impact of Man on the South Florida Herpetofauna*. The University of Kansas Museum of Natural History. Allen Press, Lawrence, KS.

Table 4. Salamanders that have a probability of utilizing Everglades tree islands. Known primary habitats are listed, along with the known origin of the herpetofauna. Probability of tree island use is listed as in the above tables

	THE SALAMANDERS						
Species	Common Name	Known Primary Habitat	Probability of Tree Island Use	Probable Activities on Tree Island		Origin	Probable Frequency
				Nesting	Foraging		
AMPHIUMA MEANS	Two-toed Amphiuma	Aq, P*	Low**	Yes**	Yes**	Native	Common
NOTOPHTHALMUS VIRIDENSCENS	Peninsula Newt	Aq, P, T*	High	Yes	Yes***	Native	Very Common
PSEUDOBRANCHUS AXANTHUS BELLI	Everglades Dwarf Siren	Aq, P*	Low**	Yes**	Yes**	Native	Rare
SIREN INTERMEDIA	Lesser Siren	Aq, P*	Low**	?	?	Native	Very Rare
SIREN LACERTINA	Greater Siren	Aq, P*	Low**	Yes**	Yes**	Native	Common

ABBREVIATIONS FOR PRIMARY HABITATS

P = Wet Prairie (sawgrass/cattail/grasses)

Aq = Aquatic (open water)

T = Terrestrial (dry land)

* = Rarely leaves aquatic environment

** = Most likely located around the tails of tree islands

*** = May forage within solution holes on islands or with alligator holes just off of islands

Salamander table created from information found in the following:

Ashton, R.E., Jr. and P. Sawyer Ashton. 1988. *Handbook of Reptiles and Amphibians of Florida Part III: The Amphibians*. Windward Publishing, Inc., Miami.

Bartlett, R.D. and P.P. Bartlett. 1999. *A Field Guide to Florida Reptliles and Amphibians*. Gulf Publishing Company, Houston.

Conant, R., J.T. Collins and I.H. Conant. 1998. *A Field Guide to the Reptiles and Amphibians of Eastern and Central North America, 4th ed*. Houghton Mifflin, Boston.

Dalrymple, G.H. 1988. *The Herpetofauna of Long Pine Key, Everglades National Park in Relation to Vegetation and Hydrology*. Pp. 72-86. In Szoro, R.C., K.E. Severson and D.R. Patton (tech coords.). Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM-166.

Duellman, W.E. and A. Schwartz. 1958. *Amphibians and reptiles of southern Florida*. Bulletin of the Florida State Muesum, 3:181-324.

Gunderson, L.H. and W. Loftus. 1993. The Everglades. Pp. 199-225. In Martin, W.H., S.G. Boyce and A.C. Echternacht (eds.). *Biodiversity of the southeastern United States*. John Wiley & Sons, New York.

Meshaka, W.E., R. Snow, O.L. Bass and W.B. Robertson. 2002. Occurrence of Wildlife on Tree Island in the Southern Everglades. A. van der Valk and F.H. Sklar, eds. *Tree Islands of the Everglades*. In preparation.

Meshaka, W.E., W.F. Loftus and T. Steiner. 2000. The herpetofauna of Everglades National Park. *Florida Scientist*, 63(2):84-103.

Towles, T. 1993. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Towles, T. 1995. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Table 5. Anurans, which have a probability of utilizing Everglades tree islands. Known primary habitats have been listed, along with the known origin of the herpetofauna. Probability of tree island use is listed as in the above tables

	THE ANURANS (FROGS & TOADS)						
Species	Common Name	Known Primary Habitat	Probability of Tree Island Use	Probable Activities on Tree Island		Origin	Probable Frequency
				Nesting	Foraging		
ACRIS GRYLLUS	Southern Cricket Frog	P, Aq, T	Medium*	yes	yes	Native	Very Rare
BUFO TERRESTRIS	Southern Toad	P, T	Medium	yes	yes	Native	Rare
ELEUTHERODACTYLUS PLANIROSTRIS	Greenhouse Frog	P, T	Medium	yes	yes	Exotic	Rare
GASTROPHRYNE CAROLINENSIS	Eastern Narrow-mouthed Toad	P, T	High	yes	yes	Native	Common
HYLA CINEREA	Green Tree Frog	P, T, Ar	Low*	yes	yes	Native	Rare
HYLA SQUIRELLA	Squirrel Tree Frog	P, T, Ar	Medium	yes	yes	Native	Common
OSTEOPILUS SEPTENTRIONALIS	Cuban Tree Frog	P, T, Ar	Medium	yes	yes	Exotic	Common
PSEUDACRIS NIGRITA	Florida Chorus Frog	P, Aq, T	Medium*	yes	yes	Native	Rare
PSEUDACRIS OCULARIS	Little Grass Frog	P, Aq, T	Medium*	yes	yes	Native	Common**
RANA GRYLIO	Pig Frog	P, Aq, T	High*	yes	yes	Native	Rare
RANA UTRICULARIA	Southern Leopard Frog	P, Aq, T	High*	yes	yes	Native	Rare

ABBREVIATIONS FOR PRIMARY HABITATS

P = Wet Prairie (sawgrass/cattail/grasses)

Aq = Aquatic (open water)

T = Terrestrial (dry land)

Ar = Arboreal (in trees and bushes)

* = Most likely found in the tree island tails

** = Often very difficult to locate

Anuran table created from information found in the following:

Ashton, Ray E. Jr. and P.S. Ashton. 1988. *Handbook of Reptiles and Amphibians of Florida Part III: The Amphibians*. Windward Publishing, Inc., Miami.

Bartlett, R. D & Patricia P. Bartlett. 1999. *A Field Guide to Florida Reptliles and Amphibians*. Gulf Publishing Company, Houston, TX.

Conant, R., J.T. Collins and I.H. Conant. 1998. *A Field Guide to the Reptiles and Amphibians of Eastern and Central North America, 4th ed*. Houghton Mifflin, Boston.

Dalrymple, G.H. 1988. *The Herpetofauna of Long Pine Key, Everglades National Park, in Relation to Vegetation and Hydrology*. Pp. 72-86 In Szoro, R.C., K.E. Severson and D.R. Patton (tech coords.). Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM-166.

Duellman, W.E. and A. Schwartz. 1958. *Amphibians and reptiles of southern Florida*. Bulletin of the Florida State Muesum, 3:181-324.

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Meshaka, W.E., R. Snow, O.L. Bass and W.B. Robertson. 2002. Occurrence of Wildlife on Tree Island in the Southern Everglades. A. van der Valk and F.H. Sklar, eds. *Tree Islands of the Everglades*. In preparation.

Meshaka, W.E., W.F. Loftus and T. Steiner. 2000. The herpetofauna of Everglades National Park. *Florida Scientist*, 63(2):84-103.

Towles, T. 1993. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Towles, T. 1995. Florida Fish and Wildlife Conservation Commission. Unpublished data.

Wilson, L.D. and L. Porras. 1983. *The Ecological Impact of Man on the South Florida Herpetofauna*. The University of Kansas Museum of Natural History. Allen Press, Lawrence, KS.

SUMMARY OF RHIZOTRON METHODS USED TO EVALUATE MARSH GRASS RESPONSE TO HYDROLOGIC TREATMENTS

Water levels were adjusted to the three different treatment levels. Rhizotrons receiving the drained treatment (D) were flooded daily to allow saturation of the soil, and then were drained into their respective reservoirs. Reservoir solutions were used to reflood the rhizotrons the following day. The water level in the other two water level treatments, waterlogged (W) and flooded (F), were initially increased to 10 cm above soil surface. In the rhizotrons receiving the highest water level (45 cm), the water level was later increased at a rate following plant growth until the final water level was reached (F). Water loss through evapotranspiration (ET) was replaced daily by addition of deionized water.

Peat, collected at 10 cm below sediment surface (the periphyton surface was excluded) from an oligotrophic area of Water Conservation Area 3A (WCA-3A) in the central Everglades, was transported in plastic-lined drums to Louisiana State University and stored in a cold room (0 to 10° C) until use. The peat was mixed and sorted by hand to remove live roots and shoots to yield a homogenous mixture. Half the peat was loaded with phosphorus (KH_2PO_4) by several flooding and draining cycles with a 50-mgl^{-1} phosphorus (P) solution, followed by flooding and draining cycles with deionized water to adjust the P content in the interstitial water close to high treatment level (500 µgl^{-1}). The other half of the peat not loaded by P was used as low-P treatment.

Twenty-four plants each of *R. tracyi* and *E. cellulosa* were selected. Half were planted in the rhizotrons with high-P treatment, and the other half were planted in the low-P treatment. Approximately 24 hours prior to planting, the plants were depotted and were rinsed in tap and deionized water to remove as much of the planting soil as possible from the roots without damaging them. The fresh weight and shoot length of each plant were obtained prior to transplantation. A separate set of plants was used to obtain wet:dry weight ratios. After the plants showed initial growth of new shoots or leaves, the first root tracking was measured 19 days after experiment initiation to provide data for the starting condition. Subsequently, root tracking was measured every three weeks to follow the growth and development of the roots and the root system.

The rhizotrons were harvested by block, which was randomly chosen, after 3.5 months of growth. The surface water in the rhizotrons receiving the two higher water levels (W and F) were drained, and afterwards, about one hour before harvest, the interstitial water of all the rhizotrons was drained into their specific reservoirs. The rhizotrons were dismantled by first removing the backside of the rhizotron. Then a piece of acrylic was placed onto the rhizotron, and the rhizotron was flipped over so the viewing side was upright. The viewing side of the rhizotron was then removed. The peat block with the intact root system was then cut into four blocks: soil surface to –10 cm, −10 to –20 cm, −20 to –30 cm, and deeper than –30 cm (**Figure 1**).

Figure 1. The four soil blocks of a rhizotron during harvest

HABITAT SUITABILITY INDICES

1. PERIPHYTON HABITAT SUITABILITY INDEX

Periphyton is a ubiquitous feature of Everglades marshes and has been shown to respond strongly in structure and function to alterations in both hydrologic conditions and water quality (Browder 1982; Swift and Nicholas, 1987; Grimshaw et al., 1993; Raschke, 1993; Vymazal and Richardson, 1995; McCormick et al., 1996; McCormick and O'Dell, 1996; McCormick et al., 1997; Cooper et al., 1999; Pan et al., 2000; McCormick et al., 1998). Periphyton is therefore not only a sensitive indicator of environmental change, it can also serve as an early warning signal of impending change in other ecosystem components. As a result, the suitability indices can be based on relationships that have the most empirical support, and we explicitly state the certainty and range of applicability of resulting models.

The periphyton-based hydrologic suitability index was partitioned into three separate models because three structurally different communities occur across the Everglades hydroscape (Browder et al., 1994). Structural and functional responses to hydroperiod alterations vary depending on the hydroperiod range to which the mat has been historically exposed. Periphyton in short-hydroperiod marshes (flooded 0 to 6 months) is typically consolidated into either sediment-associated mats or "sweaters," the thick, spongy coatings on submersed stems of emergent macrophytes. Because they are associated with a limestone substrate and are regularly exposed to oxidation, these mats are typically highly calcareous. Persistent flooding in longer-hydroperiod marshes (flooded 6 to 30 months) encourages production of submerged macrophytes, which become an important floating substrate for periphyton. Floating calcareous mats, often termed "metaphyton," predominate in these systems. Finally, the longer-hydroperiod marshes of WCA-1 contain a peat-forming plant community that supports a very different, acid-loving, epiphytic periphyton assemblage.

The parameters used to measure suitability of a particular hydroperiod range differ according to community type. The responses of periphyton to hydrologic changes can be related to features such as proportion of mat existing in the optimal growth form for the hydroperiod range, aerial cover of the mat, proportion of non blue-green algae, proportion of organic content, and presence of preferred attachment substrate. The form of the final suitability function for each hydroperiod range is a composite of the responses of the selected parameters, and the three models can be mathematically combined into a composite function that encompasses the entire gradient. Three features contribute to the suitability index for the benthic, floating and Epiphytic periphyton: (1) percent biomass of a specific periphyton comparing to the total periphyton biomass, (2) percent organic content of mat, and (3) proportion of the community comprised of non-blue-green algae.

Benthic Periphyton

Benthic, or sediment-associated, periphyton mats are an important component of shallow, short-hydroperiod Everglades marshes (Browder et al., 1994). Floating macrophytes are typically absent from these marshes; consequently, metaphytic periphyton mats are rare. However, often associated with benthic mats in these systems are thick growths of epiphytes, or sweaters, on the submersed stems of the emergent macrophytes (typically either *Eleocharis* spp. or *Cladium jamaicense*). For the purposes of the models, benthic and sweater-forming mats were combined into a single category. Benthic mat models should be applicable to areas with an average hydroperiod of less than eight months, which includes eastern Shark River Slough, Taylor Slough (the rocky glades), northwestern Shark River Slough and portions of WCA-3A (to the north) and WCA-2A (central).

Benthic periphyton mats are usually absent from marshes that are only flooded for a few days. Once formed, these mats form a fairly uniform cover across large areas and only disappear when water depths increase above 60 cm (when carbonate dynamics and light attenuation limit production) and when hydroperiod exceeds the point that limits the production of metaphyton-supporting submersed plants (ie., *Utricularia purpurea*, which becomes important when hydroperiods exceed eight months). The percent organic material in benthic mats increases with increasing hydroperiod. Data from limited surveys and ongoing experimental work suggest that the best community-based index of hydroperiod for benthic mats will come from the ratio of filamentous blue-green algae to other elements in the mat. This ratio increases with the duration of drought (Browder et al., 1981; E. Gaiser, unpublished data; A. Gottleib, unpublished data). This ratio shows strong promise in providing an early indication of ecological effects of altered hydroperiod. Based on the above, a suitability index as a function of hydroperiod is defined for benthic periphyton:

$$BPSI = 1 - \exp[-(t/2)^3], \text{ for } t \leq 4 \text{ months}$$

$$BPSI = \exp[-(t/14)^7], \text{ for } t > 4 \text{ months}$$

where “t” is the average hydroperiod (in months) over the period of simulation.

Floating Periphyton

In deeper, longer-hydroperiod Everglades marshes, periphyton occurs either in benthic aggregations, as sweaters on submersed stems of emergent macrophytes, or as floating metaphyton on submersed macrophytes. The formation of floating mats appears to be dependent on the availability of floating substrate, most often the purple bladderwort (*U. purpurea*), which is poorly adapted to desiccation and is therefore excluded from shorter-hydroperiod sites. Thick floating periphyton mats substantially reduce light penetration to sediments and therefore prohibit the co-existence of productive benthic periphyton mats. The upper hydroperiod limit for floating mats appears to be determined by carbonate dynamics. Floating mats do not occur in acidic wetlands with peat soils that have formed during episodes of prolonged flooding (i.e., WCA-1). Floating mats are presently the predominant form of periphyton in ridge and slough wetlands with hydroperiods ranging from eight to 30 months. These include central Shark River Slough and most of WCA-3A and WCA-2A. Therefore, two models that relate floating periphyton mat cover to hydroperiod, one for the dry season and one for the wet season, can be defined and expressed as one function of hydroperiod; however, mat cover varies.

The organic content of floating periphyton mats is correlated with hydroperiod and water depth. Periphyton in shallow, short-hydroperiod wetlands typically have greater access to bicarbonate, which is removed by filamentous blue-green algae and is precipitated into calcite crystals that maintain the mat's structural integrity. In peat-based, longer-hydroperiod wetlands, the pH is typically lower, and periphyton is predominantly comprised of highly organic, non-calcareous algae that do not form floating conglomerates. The suitability index as a function of hydroperiod is defined for floating periphyton as follows:

$$FPSI = 1 - \exp[-(t/8)^9], \qquad \text{for } t \leq 10.5 \text{ months}$$

$$FPSI = \exp[-(t/50)^{15}], \qquad \text{for } t \geq 10.5 \text{ months}$$

where "t" is the average hydroperiod (in months) over the period of simulation.

Epiphytic Periphyton

In peat-based wetlands with deeper water and longer hydroperiods, periphyton is abundant but does not form calcareous conglomerated mats (Gleason and Spackman, 1974; Swift and Nicholas, 1987). Rather, the periphyton is a flocculent algae and bacteria-rich matrix that grows attached to the submersed stems of aquatic plants. This is the predominant form of periphyton in the A.R.M. Loxahatchee National Wildlife Refuge (Refuge or WCA-1). This type of epiphytic periphyton should not be confused with "sweaters," which are calcareous aggregations that form in short-hydroperiod wetlands.

The organic matter content of periphyton is highly correlated with hydroperiod, particularly at the upper end of the hydroperiod spectrum. Epiphytic periphyton aggregations, occurring in the longest-hydroperiod marshes, are nearly 100 percent organic, being incapable at the resident pH of precipitating calcite crystals. A decrease in hydroperiod in WCA-1, however, may not induce the production of calcitic floating mats as would be predicted with the hydroperiod model alone. Because WCA-1 is situated on a silica sand substrate rather than limerock, the pH may remain low enough to prohibit the formation of a calcite-precipitating periphyton flora.

Recent studies across the Everglades system suggest that as hydroperiod and water depth increase, the abundance of filamentous blue-green algae that thrive in shallow, calcareous wetlands decreases. Communities in WCA-1 are dominated by an entirely different assemblage of acid-loving taxa, including an abundance of desmid algae and diatoms (Gleason and Spackman, 1974; Swift and Nicholas, 1987). This flora may have been important in large areas of the northern Everglades before modern canal construction increased the pH and decreased the water levels in adjacent marshes (Slate and Stevenson, 2000). It would be expected to reappear in these areas if hydroperiod was lengthened, but the return may happen slowly only after peat accumulations deepen and pH is reduced below ~6 to 7. As for benthic mats, a model that directly explains the relationship between non-blue-green algae and hydroperiod and/or water depth should be a major research aim because of its potential applicability in providing a reliable index of changing water availability.

Epiphytic periphyton predominates in acidic wetlands with an abundance of submersed macrophytes. It may be excluded when vegetation becomes too dense to permit light penetration to stems, but also when water depth exceeds the limits that support the growth of macrophytes. At this upper end, epiphytic algal assemblages are replaced by phytoplankton. This depends on limits to the depth of the growth of macrophytes, which exceeds depths currently represented in the Everglades system. The suitability index as a function of hydroperiod is defined for epiphytic periphyton as follows:

$$EPSI = 1 - \exp[-(t/15)^3]$$

where t is the average hydroperiod (in months) over the period of simulation.

2. RIDGE AND SLOUGH HABITAT SUITABILITY INDEX

Several hydrological attributes are considered influential in maintaining the ridge and slough landscape features. These attributes are based on the assumption that the continuous directional and patterned peatland, called the ridge and slough region, originally formed under natural pre-drainage conditions. Under these conditions the vegetation pattern was the direct result of water-depth differences that in turn are created by microtopographic variations in the peat surface. This microtopography was inherently unstable and required a directional process to maintain the original characteristic pattern. The type of pattern degradation observed today cannot be explained on the basis of altered water depths or hydroperiods alone. A change in a directional, flow-related process must also be implicated (McVoy and Crisfield, 2001).

The configuration of deeper sloughs adjacent to shallower, higher-elevation ridges is a nonequilibrium condition. Under equilibrium, the peat surface would become flat across the whole landscape. The ridge and slough configuration implies the presence of some process that maintained the nonequilibrium condition – processes that counterbalanced the natural tendency for the sloughs to fill in and to become the elevation of the ridges. These processes were both hydrological and biological.

Optimum conditions for sawgrass, as well as pre-drainage historical evidence, suggest that hydroperiods on sawgrass ridges were typically less than 12 months. For one or two months of the year, the water depth would drop somewhat below surface elevations, exposing the peat soil to oxidative decomposition, which lowered the elevation of the peat surface. Peat accumulating from annual sawgrass growth would act in the opposite direction and tended to raise the peat surface. Ridges grew only up to some height above the long-term average water depth, with the height determined by the balance of accumulation and decomposition. Net downstream transport of organic material might have played an additional role, but this seems unlikely given the density of sawgrass stems, along with substantial stabilization of the peat soil by root networks.

The directionality of the ridge and slough region clearly suggests water flow had something to do with the maintenance of the characteristic landscape pattern. Where flows have been blocked or interrupted, directionality has nearly disappeared.

The ridge and slough landscape suitability index consists of four components relating the ridge and slough landscape to hydrology. The first component is the long-term average depth of water in the ridge and slough region. The second component is the seasonal difference in average depths from the end of the wet season (October) to the end of the dry season (May). The third component is the difference between the flow velocity in a cell of the South Florida Water Management Model (SFWMM) simulation compared to the average velocity in the row of cells in the Natural Systems Model (NSM) simulation. The attempt here is to capture local velocity changes compared to the average velocity one might expect in the natural system. The fourth hydrologic attribute considered influential is the angular deviation of the flow from the direction of the ridge and slough landscape shown on pictures taken in the 1940s.

Water Depth

A sensitivity analysis was performed on the optimal long-term average water depth in the sloughs of the ridge and slough landscape. Changes in the suitability of a region under pre-drainage conditions (represented by the NSM simulation) and drainage conditions (represented by the 1995 Base SFWMM simulation) due to changes in the optimal water depth were analyzed and compared with historical and current conditions. From this analysis, an optimal long-term average water depth of 2.0 ft was determined, which corresponds to an average water depth of approximately 1.5 ft in a SFWMM cell. Lower water depths in the sloughs could result in sawgrass colonization and filling-in of the sloughs. The water depth index is defined as follows:

$$SI_{depth} = 1.089 \exp[-0.5((x - 1.252)/0.3579)^2], \qquad \text{for } d \leq 1.0 \text{ ft}$$

$$SI_{depth} = -0.9375\,(x - 1.4)^2 + 1, \qquad \text{for } 1.0 < d \leq 1.4 \text{ ft}$$

$$SI_{depth} = -0.6\,(x - 1.4)^2 + 1, \qquad \text{for } 1.4 < d \leq 1.9 \text{ ft}$$

$$SI_{depth} = 1.094 \exp[-0.5((x - 1.588)/0.4437)^2], \text{ for } d > 1.9 \text{ ft}$$

where “d” is the long-term (31-year) average water depth in a SFWMM cell.

Seasonal Difference in Water Depth

The seasonal difference in water depth index is defined as follows:

$$SI_{seasonal} = 1.018 \exp[-0.5((\Delta_{seasonal} - 2)/0.6362)^2], \qquad \text{for all } \Delta_{seasonal} \text{ ft}$$

where $\Delta_{seasonal}$ is the 31-year average October ponding depth minus the 31-year average May ponding depth + 0.3 ft

Flow Velocity

Based on the assumption that flow velocities under pre-drainage conditions were optimal for the maintenance of the ridge and slough landscape, large changes in flow velocity from the average row velocity predicted by the NSM could result in landscape degradation. For example, decreased velocities could result in decreased downstream transport of organic material and the filling in of the sloughs. The flow velocity index is defined as follows:

$$SI_{velocity} = 0.0, \qquad \text{for } v \leq 30\% \text{ or } v > 200\%$$

$$SI_{velocity} = (v - 30) / 50, \qquad \text{for } 30\% < v \leq 80\%$$

$$SI_{velocity} = 1.0, \qquad \text{for } 80\% < v \leq 120\%$$

$$SI_{velocity} = (200 - v) / 80, \qquad \text{for } 120\% < v \leq 200\%$$

where v is the fraction of modeled individual cell velocity relative to the mean NSM flow velocity for the model row where the cell is located.

Flow Direction

The uniformity (strong spatial autocorrelation) of the landscape and flow directionality observed in aerial photographs of the pre-drainage ridge and slough landscape is most likely the result of peat having accumulated in equilibrium with a regional water surface that was very level in the cross-flow (approximately east-west) direction. Consequently, significant departures from the pre-drainage flow direction based on 1940s aerial photos are expected to result in a loss of directionality and a degradation of the ridge and slough landscape. The flow direction index is defined as follows:

$$SI_{flow\ direction} = \exp(-\theta/22), \qquad \text{for all } \theta$$

where θ is the angular deviation of flow direction from flow direction estimated from 1940s photos.

3. TREE ISLAND HABITAT SUITABILITY INDEX

The Everglades is not just a "river of grass"; it is also a "river of tree islands." With a land elevation slope of less than 5 cm per km, hydrological regimes could be different with a small change in topography. Tree island topographical highs are usually from 2 to 3 ft in elevation above the surrounding wetlands (Loveless, 1959) and maintain a unique vegetation type different from the surrounding marsh. The total area of all tree islands combined may be about 5 to 10 percent of the wetland (Schneider, 1966). Tree islands in certain sections of the Everglades have experienced altered hydroperiods due to water management practices (Dineen, 1974; Zaffke, 1983; Guerra, 1996; Gawlik and Rocque, 1998; Heisler et al., 2001). This altered hydroperiod has at times caused tree island vegetation to die. Three habitat suitability indices (HSIs) were proposed for tree island habitat: the Species Richness Suitability Index, the Tree Island Flooding Index and the Tree Island Drought Index.

Species Richness Suitability Index

The Species Richness Suitability Index (SRSI) is based on a statistical relationship between estimated hydrologic conditions during 1979 through 1995, and also on field data from 1997 through 1999 on tree island vegetation on hammocks and elevated bayheads in WCA-3A. The empirical data are used to identify a measure that appears to be appropriate for evaluating tree island impacts; the Natural System Model is used to establish planning targets for this measure. Linear multiple regression of tree and shrub species richness yielded the following equation:

EQ (1) Number of tree and shrub species = 13.4 –0.75(percent of time depths < −1.0 ft) –0.10(percent of time depths ≥ 1.0 ft below island maximum)

This regression equation explains 68 percent of the variance in species richness. A depth of 2.0 ft was selected as a criterion for assessing high-water stress to tree islands. Consistent with equation 1, this depth would correspond to conditions under which a hypothetical 3.0 ft-high tree island was flooded within 1.0 ft of its top. It would also identify the depth at which most of the tree island vegetation within a grid cell would be flooded or was experiencing complete soil saturation. Substituting the hydroperiod at 2.0 ft into equation 1, a score for Predicted Species Richness (PSR) is defined as follows:

EQ (2) $\text{PSR} = 13.4 - 0.75 \cdot \text{LO\%} - 0.10 \cdot \text{HI\%}$, where

EQ (3) LO% = percent of weeks with mean weekly depth < −1.0 ft, and

EQ (4) HI% = percent of weeks with mean weekly depth > 2.0 ft

PSR provides a measure of the decrease in the number of tree and shrub species relative to a maximum of 13.4 that would be predicted by equation 1 to occur on a hypothetical 3.0 ft-high tree island in the model cell in question. Note that PSR should be constrained to a minimum value of 0; however, negative values for equation 2 have not yet been obtained using SFWMM or NSM model output for ridge and slough model cells.

Hence, the next step in developing the HSI was to re-scale the PSR with reference to a target value. A standardized value of PSR, denoted PSR*(c,x), as the deviation of the score for grid cell *c* of model *x* from the value predicted by NSM for the same grid cell is defined as follows:

EQ (5) $\text{PSR}^*(c,x) = [\text{PSR}(c,x) - \text{PSR}(c,\text{NSM})] / \sigma_{\text{NSM}}$

The parameter σ_{NSM} is the standard deviation of PSR(c, NSM) calculated over all N cells in the ridge and slough landscape:

EQ (6) $$\sigma_{\text{NSM}} = \sqrt{\left[\frac{1}{N}\sum_{c=1}^{N}[\text{PSR}(c,\text{NSM})]^2 - \frac{1}{N^2}\left(\sum_{c=1}^{N}\text{PSR}(c,\text{NSM})\right)^2\right]}$$

Re-scaling of PSR to standard deviation units creates a relative measure that avoids potential misinterpretation of PSR as a literal prediction of future species richness. It also creates a scale of measurement that allows differences in PSR to be related to the landscape pattern of variation in predicted species richness under NSM. Standardization relative to NSM underscores the fact that species richness is serving as an ecological response variable that identifies relevant variation in hydrology and is not being set as the restoration goal for tree islands per se.

The last step in developing the HSI is to define an index function that maps PSR* to the interval (0,1). A Species Richness Suitability Index (SRSI) is defined as follows:

$$\text{SRSI}(c,x) = 1.0 \qquad \text{if } \text{PSR}^*(c,x) \geq 0;$$

EQ (7)
$$\text{SRSI}(c,x) = 1.0 + \text{PSR}^*(c,x)/2 \qquad \text{if } -2 < \text{PSR}^*(c,x) < 0; \text{ and}$$

$$\text{SRSI}(c,x) = 0.0 \qquad \text{if } \text{PSR}^*(c,x) \leq -2.0$$

Using this definition, a grid cell receives the maximum score of SRSI = 1.0 if PSR(c,x) equals or exceeds PSR(c,NSM). If PSR(c,x) falls below the value predicted by NSM, then SRSI decreases linearly to a minimum of 0 when PSR(c,x) is two or more standard deviation units lower than the NSM value for the grid cell.

Tree Island Flooding Index

Using information from landscape vegetation models that aims to provide realistic, dynamic models of vegetation change (Wu et al., 1996, 1997, 2002), a time series of scores, called the Daily Flood Index (DFI), was generated. The DFI represents increasing and decreasing flood stress to tree islands as a function of the duration of periods during which depths either exceeded or fell below a criterion. Based on Loveless' (1959) report that tree islands range from 1.0 to 3.0 ft in elevation relative to the surrounding marsh, along with more recent data on tree island elevations, a criterion depth of 2.0 ft was chosen for evaluating flooding stress to tree islands. Duever (1984) has suggested that flooding durations of 300 days are unsuitable even for willow islands. Given these assumptions, a Daily Flood Index (DFI(t)) is defined as the score for day "t" of the time series, as follows:

EQ (8)
$$\text{DFI}(t) = 1.0 / \{1.0 + 0.0023 \cdot \exp[0.039 \cdot \text{CFD}(t)]\}$$

where t = 1, . . . , 365·N, for simulation of N years and CFD(t) provides a measure of the cumulative number of days of flood stress as of day t:

$$\text{CFD}(t) = \text{CFD}(t-1) + 1.0 \qquad \text{if water depth} > 2.0 \text{ ft}$$

EQ (9)
$$\text{CFD}(t) = \text{CFD}(t-1) - 0.5 \qquad \text{if water depth is} \leq 2.0 \text{ ft and CFD}(t-1) > 0.5$$

$$\text{CFD}(t) = 0, \text{ if water depth is} \leq 2.0 \text{ ft and CFD}(t-1) \leq 0.5$$

Tree Island Drought Index

Fire is a natural process in the Everglades. However, drainage and impoundment of the Everglades by humans during the past century has increased the duration of dry periods and the frequency, intensity and spatial extent of wildfires. This has led to extensive loss of peat soils, both in the marshes and on tree islands, as well as the destruction of tree island vegetation by fire (Loveless, 1959; Schortemeyer, 1980). In addition to the impact of intense fires on soils and tree island vegetation, soil loss has altered the Everglades topography.

South Florida Water Management District (SFWMD or District) scientific staff proposed a depth of 1.0 ft below ground surface as the best current estimate of the depth of groundwater recession in peat marshes below which the risk of peat-consuming wildfires becomes excessive. This value has been used to define a minimum groundwater level for the Everglades below which significant harm is considered likely (SFWMD, 2000).

The Drought Index proposed here is a dual-purpose tool because it can serve as both an index for assessing potential tree island impacts from drought and as a stand-alone performance measure for evaluating the risk of peat-consuming wildfires in the overall ridge and slough. The Daily Drought Index (DDI(t)) is defined as a time-dependent function of two variables: water depth (WD(t)) and cumulative drought duration (CDD(t)). CDD(t) is the number of sequential days up to and including day "t" during which depths were below the ground surface, calculated as follows:

EQ (10) $CDD(t) = 0, \quad \text{if } WD(t) > 0.0 \text{ ft; and}$

EQ (11) $CDD(t) = CDD(t-1) + 1, \quad \text{if } WD(t) < 0.0 \text{ ft}$

The Daily Drought Index is then defined as follows:

EQ (12) $DDI(t) = 1.0, \quad \text{if } WD(t) > 0.0 \text{ ft, and}$

EQ (13) $DDI(t) = [1.0 - 0.0035CDD(t)]/[1.0 + 0.010\exp\{-4.6WD(t)\}],$

$\text{if } WD(t) < 0$

Note that a single day with WD(t) > 0.0 ft is assumed to "break" the drought by resetting CDD(t) to 0 and DDI(t) to unity. The numerator of DDI(t) decreases from a maximum of 1.0 when surface water is present, to a minimum of 0 when CDD(t) reaches 285 days. The coefficient 0.0035 is an approximate measure of the daily increase in the risk that a cell will be included in a wildfire (Wu et al., 1996). The denominator of equation (12) serves to decrease the value DDI(t) as groundwater recedes further below the surface; this feature of the index is intended to mimic the increased risk of intense and damaging muck fires when the soil has dried to greater depths.

4. ALLIGATOR HABITAT SUITABILITY INDEX

The American alligator (*Alligator mississippiensis*) is not only a top food web consumer in South Florida, but it also physically influences the system through construction and maintenance of alligator holes and trails (Mazzotti and Brandt, 1994). The existence of this species is important to the faunal and floral character of the Everglades. The Everglades is believed to be a harsh environment for alligators. Everglades alligators weigh less than alligators of the same length from other parts of their range (Jacobson and Kushlan, 1989; Barr, 1997). Further, the maximum length of Everglades alligators is decreased and their sexual maturity is delayed (Kushlan and Jacobsen, 1990; Dalrymple, 1996a). Jacobsen and Kushlan's (1989) model for growth in the Everglades of southern Florida predicted the existence of alligators reaching a mere 1.26 meters in 10 years and requiring at least 18 years to reach sexual maturity. It is currently suspected that the reason for this poor condition is a combination of low food availability due to hydrological factors and high temperatures (Jacobson and Kushlan, 1989; Dalrymple, 1996a; Barr, 1997; Percival et al., 2000).

Current water management practices have resulted in a high and unpredictable rate of alligator nest flooding. Historically, maximum summer water levels were positively correlated with water levels during alligator nest construction. This natural predictability has been lost (Kushlan and Jacobsen, 1990; Dalrymple, 1996b). Historically, alligators were abundant in prairie habitats of the eastern floodplain, along the edges of habitats of the central sloughs. Pre-drainage occupancy of the deep-water central sloughs was relatively low. Marsh alligator densities are now highest in the central sloughs and canals and are relatively low in the edge habitats. Canal habitats contain high concentrations of adult alligators. Nest densities also are relatively high on levees and associated spoil islands. Less flooding of nests occurs on these higher elevations. However, survival of young alligators may be extremely low due to a decrease in the number of alligator holes or possible brood habitat proximal to canals. Modified hydrological conditions might be expected to increase nesting effort, nesting success and abundance of alligators in the aforementioned edge habitats. There also may be a corresponding increase in the number and occupancy of alligator holes to serve as drought refugia for alligators and other species.

The alligator suitability index consists of four components estimated annually that relate alligator life history to hydrology and include suitability for breeding and nest construction, nest flooding potential within a cell, and an estimate of the impact of hydrological condition on early age/class survival and body condition of all size classes. Many of the relationships contained in the index are based on the ATLSS American Alligator Production Index Model. Notably, the index discussed herein is based on a much larger scale and does not include components relating habitat and elevation to alligator population conditions. For calibration of the breeding, nesting and flooding components, gross nest estimates and counts from 2 sources were used: Systematic Reconnaissance Flights of Everglades National Park (S. Snow, USNPS, personal communication) and Florida Fish and Wildlife Conservation Commission (FWC) nest counts (L. Hord, FWC, personal communication).

Breeding

Fleming (1989) developed relationships between annual water stage duration and the proportion of adult alligator females that could be expected to nest in a given year in Shark River Slough in Everglades National Park. This regression relationship was modified to reflect index values for ponding depths throughout the Everglades system. This component addresses several aspects of alligator life history: the ability of adult males to disperse for mating, physiological stress associated with drought conditions, and the prolonged follicular development in the adult female. An index value for the suitability of an indicator region for alligator breeding was assigned based on the number of days with < 0.5-ft ponding depth from May 16 of the previous year to April 15 of the current breeding year. The index value was assigned as 1.0 through 50 days, and then decreased linearly to 0.0 at 125 days (**Figure 1**):

$SI_{breeding} = 1.0,$ for $t \leq 50$ days

$SI_{breeding} = (125 - t)/75,$ for $50 < t \leq 125$ days

$SI_{breeding} = 0.0,$ for $t > 125$ days

where t is the number of days with < 0.5-ft ponding depth from May 16 of the previous year to April 15 of the current breeding year.

Nest Construction

In Everglades National Park a significant relationship has been noted between alligator nesting effort and average water depth during the peak mating season (April to May; Fleming 1989, 1990). Regression analysis was used to examine the relationship between nest estimates from the Systematic Reconnaissance Flights of Everglades National Park (S. Snow, USNPS, personal communication) and water depth in Shark River Slough. These relationships were then used to develop the following component index by modification to reflect deeper water depths elsewhere in the system. The suitability of an area for alligator nest construction was defined by using the mean water depth from April 15 to May 15. Minimum index values (0) were assigned at a mean depth of 0.0 and 4.0 ft. and maximum (1) at depths of 1.3 to 1.6 ft. (**Figure 2**):

$SI_{nest\ construction} = 0.0,$ for $d \leq 0.0$ or $d > 4.0$ ft

$SI_{nest\ construction} = d/1.3,$ for $0.0 < d \leq 1.3$ ft

$SI_{nest\ construction} = 1.0,$ for $1.3 < d \leq 1.6$ ft

$SI_{nest\ construction} = (4.0 - d)/2.4,$ for $1.6 < d \leq 4.0$ ft

where d is the mean water depth from April 15 to May 15.

Nest Flooding

Alligators generally construct nests during late June to early July in South Florida (Kushlan and Jacobsen, 1990). Once the nest has been constructed, any rise in water level can result in both flooding of the clutch cavity and in egg mortality. The lowest eggs in the clutch cavity rest from 6 to 12 in. from the water surface during nest construction (WCA-2 and WCA-3, Rice, K.G., USGS, unpublished data, ENP, Kushlan and Jacobsen, 1990). The total clutch cavity also is from 6 to 12 in. deep. Therefore, after nest construction a rise in water level of around 6 in. will begin to result in egg mortality, with total mortality of the clutch occurring after a rise of 12 to 18 in. A notable exception exists in central WCA-1, where many nests are constructed on tree islands and little or no flooding occurs (Brandt and Mazzotti, 2000). Consequently, a nest-flooding component was established by subtracting the mean water depth during nest construction (June 15 through July 1) from the maximum water depth during egg incubation (July 1 through August 31). Differences of up to 6 in. were assigned an index value of 1, and the index decreased linearly to 0 at 18 in.:

$$SI_{\text{nest flooding}} = 1.0, \qquad \text{for } \Delta_{max} \leq 0.5 \text{ ft}$$

$$SI_{\text{nest flooding}} = 1.5 - \Delta_{max}, \qquad \text{for } 0.5 < \Delta_{max} \leq 1.5 \text{ ft}$$

$$SI_{\text{nest flooding}} = 0.0, \qquad \text{for } \Delta_{max} > 1.5 \text{ ft}$$

where Δ_{max} is the maximum water-depth difference between the average for June 15 to July 1 and the water depths from July 1 to August 31.

During calibration, it was observed that this component was not performing during certain low-water periods. It was also discovered that during nest construction, several regions would have water depths below ground surface, and thus when water levels rose just to the ground surface the index would predict flooding. Therefore, the component was adjusted to reflect that flooding would begin in these situations only when water depths increased to 6 in. above the ground surface.

Survival and Condition

Cannibalism by larger alligators, and predation by other species on early age-class alligators, is well established (Dalrymple, 1996a; Delany and Abercrombie, 1986). As water depths decrease to surface levels during extremely dry periods, alligators are concentrated in alligator holes and other depressions. In general, alligator holes are occupied by large adult animals (100 percent occupancy by adult alligators in holes > 5.0m in diameter, F. Mazzotti, Univ. of Florida, unpubl. data; Percival et al., 2000). Therefore, as water levels decrease below the surface, cannibalism by large adults on smaller age/size classes must increase. Survival of early age-class animals is therefore affected by hydrology. In this index component, this idea has been incorporated by assigning an index survival of 1 above surface water levels (see below for description of water level metric) and allowing the index to decrease linearly to 0 at –2.0 ft. These values were developed through repeated model runs and consultation with a group of crocodilian experts in South Florida (**Figure 4**).

Body condition of all size classes is known to decrease with an increase in water depth (Barr 1997; Dalrymple, 1996a, 1996b). An index using observed condition values (K. Rice, USGS, and F. Mazzotti, Univ. of Florida, unpubl. data) and expert opinion using the same water level metric as survival was established (see below). Also, an index value of 1.0 at water depths below 0.75 ft.

was assigned. The index was allowed to decrease linearly to 0.2 at 3.0 ft water depth (**Figure 4**):

$SI_{\text{survival and condition}} = 0.0,$ for $d \leq -2.0$ ft

$SI_{\text{survival and condition}} = (d + 2.0)/1.5,$ for $-2.0 < d \leq -0.5$ ft

$SI_{\text{survival and condition}} = 1.0,$ for $-0.5 < d \leq 0.75$ ft

$SI_{\text{survival and condition}} = (2.85 - 0.8d)/2.25,$ for $0.75 < d \leq 3.0$ ft

$SI_{\text{survival and condition}} = 0.2,$ for $d > 3.0$ ft

where d is the minimum monthly average water depth.

A weighted arithmetic mean of the above components is used to calculate the composite annual index value. Each of the component values is weighted based on the quantity and quality of data and expert opinion on each component. In general, components for which there are more data and less uncertainty were given higher weights. The breeding and nesting components appear to more adequately describe these stages in alligator life throughout the Everglades ecosystem. Therefore, this component was assigned the highest weight of 3.0 in compilation of the composite index value. Due to the influence of local habitat factors and elevation, it was felt that the nest-flooding component contained more uncertainty and was therefore assigned a weight of 2.0. It was also felt that the survival and condition index component contained the greatest amount of uncertainty and it was therefore assigned a weight of 1.

$$ASI = (3*SI_{\text{breeding}} + 3*SI_{\text{nest construction}} + 2*SI_{\text{nest flooding}} + SI_{\text{survival and condition}})/9$$

Due to the data used in construction, the composite index would be most appropriate for use in the Everglades central slough regions. Peripheral marl prairie or rocky glades regions may have index values that are skewed due to differences in the relationships between alligator population ecology and hydrology. The flooding component should not be used in the central A.R.M. Loxahatchee National Wildlife Refuge (Refuge or WCA-1), since many alligators nest on tree islands, which lessens the probability of nest flooding. Therefore, cells in this region are given a value of 1.0 for the nest-flooding component.

5. WADING BIRD HABITAT SUITABILITY INDEX

The sustainability of healthy wading bird populations is a primary goal of Everglades restoration. The understanding of the response of wading birds to hydrologic conditions has also been used to establish hydrologic targets for restoration. Over time, the response by wading birds will play a prominent role in assessing the progress of Everglades restoration. Both empirical data and simulation models were used to evaluate restoration scenarios. The modeling approaches include a complex, individual-based behavior model (i.e., ATLSS; Fleming et al., 1994; DeAngelis et al., 1998) and a simpler index model (Curnutt et al., 2000).

Observations show that fish populations are much higher in marshes that are inundated than in areas that regularly dry out (Loftus and Eklund, 1994; Frederick and Spalding, 1994). Therefore, in these models, fish population size increases as a function of time since the drying of the marsh. However, there is a distinction between processes that increase overall fish population size and those that produce high densities of fish in small patches at the scale at which wading birds are feeding. During much of the year, at those times when fish are being produced, the water is too deep to allow birds access to food. Ideal feeding conditions for wading birds occur when the marsh surface is almost dry and fish are experiencing high mortality (W. Loftus, personal communication). From a bird's perspective, conditions that contribute to high fish mortality are more important than conditions that allow for high fish production. Fish populations rebound quickly following a drydown, but most importantly, receding water levels overlaid on small depressions in the marsh surface during the dry season produce small patches of shallow water that have exceedingly high concentrations of fish many times greater than densities due to a prolonged hydroperiod. During a seasonal drydown, fish concentrations increased by a factor of 20 to 150 in the Everglades and in Big Cypress National Preserve (Carter et al., 1973; Loftus and Eklund, 1994; Howard et al., 1995). Thus, the density of fish within food patches is overwhelmingly affected by the physical process of drying.

Patches having concentrated prey are typically shallow and are without vegetation, making individual fish more vulnerable to capture, which increases wading bird feeding success (Kushlan, 1976a). Hydrologic patterns that produce the maximum number of these patches with high prey availability (i.e., high water levels at the end of the wet season and low water levels at the end of the dry season) tend to produce good nesting effort for these species (Smith and Collopy, 1995) and are consistent with predictions from experimental studies (Gawlik, in press; Kushlan, 1976b, 1981).

Wading Bird Suitability Index

The wading bird suitability index (SI_{WB}) is based solely on the physical processes that concentrate aquatic prey and make them vulnerable to capture by wading birds. The (SI_{WB}) is calculated for each two-mile-by-two-mile South Florida Water Management Model (SFWMD, 1999) grid cell in the remnant Everglades (**Figure 1**), and is then aggregated up to the landscape scale for each weekly time step. Two annual summary variables are used to characterize weekly patterns for a given year. Summary variables were validated against 10 years of observed wading bird nesting data for the Everglades. For each grid cell, the wading bird suitability index has one function for water depth (SI_{depth}) and one function for water recession rate ($SI_{recession}$).

Water Depth

Based on field studies and experiments (Kushlan 1976a, 1986; Hoffman et al., 1994; Gawlik, in review), it is clear that the number of wading birds at feeding sites is a quadratic function with water depth. At either very low or very high water depths, bird abundance is low. The ideal water level differs among species. For wood stork, white ibis and snowy egret feeding sites, the index for a grid cell is highest when water depths are between 0 cm and 15.0 cm (0.5 ft). The index drops to 0 when water depths are greater than 25.0 cm (0.8 ft), or less than 10.0 cm (0.3 ft) below marsh surface (**Figure 1**):

$SI_{depth} = 0.0,$ for $d \leq -0.3$ ft or $d > 0.8$ ft

$SI_{depth} = (d/0.3) + 1,$ for $-0.3 < d \leq 0.0$ ft

$SI_{depth} = 1.0,$ for $0.0 < d \leq 0.5$ ft

$SI_{depth} = (0.8 - d)/0.3,$ for $0.5 < d \leq 0.8$ ft

where "d" is the weekly average water depth from November to April.

Water Recession Rate

A rapid rate of receding water seems to produce good nesting effort (Kahl, 1964; Frederick and Spalding, 1994). Nest abandonment can occur when water level change is less than −0.11 ft per week, or particularly when it is a positive value (Kushlan 1976b, Frederick and Collopy 1989a, 1989b). Some degree of uncertainty around the ideal recession rate was accounted for in the index by keeping the suitability of a grid cell at 1.0 when water level change is anywhere between −0.16 and −0.05 ft per week (negative = receding water, positive = rising water). There is strong evidence that reversals in water level recession cause abandonment, so the index drops sharply from 1.0 to 0 when water level change is between −0.05 ft per week and 0.05 ft per week. There is less evidence to substantiate the ideal recession rate of −0.11 ft per week, so accordingly the index drops to 0 only when water level change is greater than −0.6 ft per week (**Figure 2**):

$SI_{recession} = 0.0,$ for $\Delta_{avg.\ weekly} \leq -0.6$ ft or $\Delta_{avg.\ weekly} > 0.05$ ft

$SI_{recession} = (\Delta_{avg.\ weekly} + 0.6)/0.44,$ for $-0.6 < \Delta_{avg.\ weekly} \leq -0.16$ ft

$SI_{recession} = 1.0,$ for $-0.16 < \Delta_{avg.\ weekly} \leq -0.05$ ft

$SI_{recession} = (0.5 - 10*\Delta_{avg.\ weekly}),$ for $-0.05 < \Delta_{avg.\ weekly} \leq 0.05$ ft

Where $\Delta_{ave\ weekly}$ is the average weekly change in water depth from November through April

The combined wading bird suitability index of each cell at each weekly time step is calculated as the minimum of either the recession rate or water depth scores [$SI_{WB} = \min(SI_{depth}, SI_{recession})$]. The scale of an individual cell, however, is not appropriate for assessing habitat quality for wading birds because they follow suitable habitat as it moves across the landscape during the dry season. To have a successful nesting year, wading birds must have access to suitable habitat throughout the dry season, but the location of suitable habitat can vary across the landscape. Thus, at any given time a highly suitable landscape will likely consist of individual cells that have not yet reached peak suitability for the year, cells that have already passed peak suitability, and cells that are at their highest suitability. To capture the landscape-level habitat suitability (SI_{land}), the mean suitability score for the top 23 percent of cells is calculated each week. Twenty-three percent was chosen because approximately one-quarter of the cells are occupied by feeding wading birds at any given time during a good nesting year (Gawlik, unpublished data). For the remnant Everglades, consisting of 666 cells, this amounts to 150 cells having the highest values of SI_{WB}. For the coastal zone of 217 cells, the highest SI_{WB} values of 50 cells are used to compute the average. For the interior zone of 449 cells, the highest-valued 100 cells are used to compute the average. These weekly SI_{land} values in each of the three regions of the Everglades are used to assess the impact on wading bird habitat associated with alternative water management policies.

The suitability index model, described above, was validated at two levels. Individual cell values (SI_{WB}) were correlated with the observed abundance of wood storks, white ibises, and small herons on 41 monthly (November through April) systematic aerial wading bird surveys conducted from 1985 through 1995 (Bancroft and Sawicki, 1995). Pearson correlation coefficients were low (wood stork, $r = 0.06$; white ibis, $r = 0.26$; small heron, $r = 0.13$), yet highly significant (all tests, $P < 0.001$) because of large sample sizes ($n = 34,861$).

The model was validated annually by comparing the weekly landscape index (SI_{land}) with the following:

1. The number of nests in the water conservation areas from 1986 through 1995 (Crozier et al., 2000)
2. The number of nests in both the water conservation areas and Everglades National Park during the same period

The reason for the separate analyses is that the most appropriate scale at which to compare foraging and nesting is as yet unclear. SI_{land} in its current form is for the entire Everglades landscape, whereas most wading birds (> 90 percent) nest in the water conservation areas. Thus, it is possible that processes in the model affect birds in one region more than birds in another region. The final version of SI_{land} will be calculated separately for the coastal and interior zones to evaluate this response.

This model validation exercise served both to validate the current model (SI_{land}) and identify an annual summary variable(s) that was most strongly associated with nesting effort. This summary variable will be used to evaluate hydrologic simulations.

Correlations between SI_{land} and the number of nests in the water conservation areas indicated there were two variables associated with nest numbers. The number of times $SI_{land} \leq 0.5$ during the nesting season was negatively correlated with numbers of nests for white ibises ($r = -0.73$) and small herons ($r = -0.51$). A nesting season was defined as March through April for white ibises and small herons, and January through March for wood storks. The mean SI_{land} during the nesting season was positively correlated with nest numbers for wood stork ($r = 0.59$).

Correlations between SI_{land} and the numbers of nests in the entire Everglades tended to be slightly lower than for nests in the water conservation areas. This pattern further supports calculating SI_{land} separately for coastal and interior Everglades regions. The number of times SI_{land} was ≤ 0.5 during the nesting season was negatively correlated with numbers of nests for white ibises ($r = -0.67$) and small herons ($r = -0.41$). The mean SI_{land} during the nesting season was positively correlated with nest numbers for wood storks ($r = 0.57$).

The two analyses suggest that the annual summary variable that best describes that relationship for wood storks (SI_{wost}) is the average SI_{land} from January to the end of March. The most appropriate annual summary variable for white ibises and small herons (SI_{wish}) is the number of weeks during the nesting season when SI_{land} was ≤ 0.5:

$$SI_{wish} = 1 - (\text{number of weeks } SI_{land} \leq 0.5)\ /6, \text{ or}$$

$$SI_{wish} = 0 \text{ if number of weeks } SI_{land} \text{ is } \leq 0.5 \text{ exceeds } 6$$

The model validation indicates that for some species SI_{land} is related to the number of birds that attempt to nest each year; however, the correlations are not strong. This may have as much to do with the validation data set as it does with the habitat suitability model. Although historic wading bird nesting data are a valuable tool for assessing the state of the ecosystem, survey methodologies and effort were not standard among regions, particularly in the earlier years. Thus, as with any large-scale data set, systemwide patterns tend to be robust, whereas the large spatial variability may mask patterns at a finer scale.

6. FISH HABITAT SUITABILITY INDEX

Fish species are primary ecosystem indicators for the Everglades. Fish provide food for many other species, including alligators and birds. During flooding, populations of small fish, crayfish and other species are nourished by detritus and seasonal algal growth. Because these fish are relatively protected in the shallow marshes from larger, predatory fish, they reach large numbers. During the dry period the fish are concentrated into pools and depressions by receding waters (DeAngelis, et al., 1998). There are differences in the fauna of short- and long-hydroperiod areas; in the short hydroperiod areas, fish and prawn densities are generally lower, whereas the crayfish density is higher (Roman, et al., 1994).

Three indices were developed based primarily on the results of studies using a 1-m^2 throw trap. Sampling at this spatial scale produces results that are most reflective of the small-sized fishes that are numerically dominant in the Everglades (generally less than 8.0 cm in maximum adult length). Those species comprise most of the food for many wading birds and are considered an appropriate target group for assessing habitat quality in the context of food web function in this ecosystem (DeAngelis et al., 1997; Howard et al., 1995; Kobza et al., 2000; Kushlan, 1976; Loftus and Eklund, 1994; Nelson and Loftus, 1996).

Based on empirical data from freshwater marsh sampling in Everglades National Park and Water Conservation Area 3, annual estimates of fish densities decline when water levels fall below the ground surface of the marsh for even short periods of the year (Trexler and Loftus, 2001). A habitat suitability function based solely on the number of years since the last drawdown has been developed for the ridge and slough landscape:

$$SI_{drawdown} = 1.052[1 - \exp(-0.9663(t + 0.10336))], \text{ for all } t$$

Where “t” is the number of years of constant inundation since last the drawdown to dry conditions.

“Habitat suitability” is believed to be a misnomer for the fish-related functions that have been produced. Short-hydroperiod marshes will always appear to be “less suitable” because they have a naturally lower density of fishes than do long-hydroperiod marshes, though some species do reach their maximum density in short-hydroperiod marshes. In general, however, habitats in which surface water dries out each year are harsh for fishes, but it is important to point out that the Everglades has always had such habitats along its margins. Thus it would not be desirable to seek to maximize a habitat suitability index for fish across the landscape that would create an ecosystem unlike the Everglades.

It can be argued that the indices that have been produced can only be interpreted in comparison to a “natural system” scenario that seeks to simulate an explicit landscape pattern of habitat types under assumptions of historical or near-historical hydrology. Thus, “suitability” can only be measured by the relative deviation of the indices from a “natural system” scenario.

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