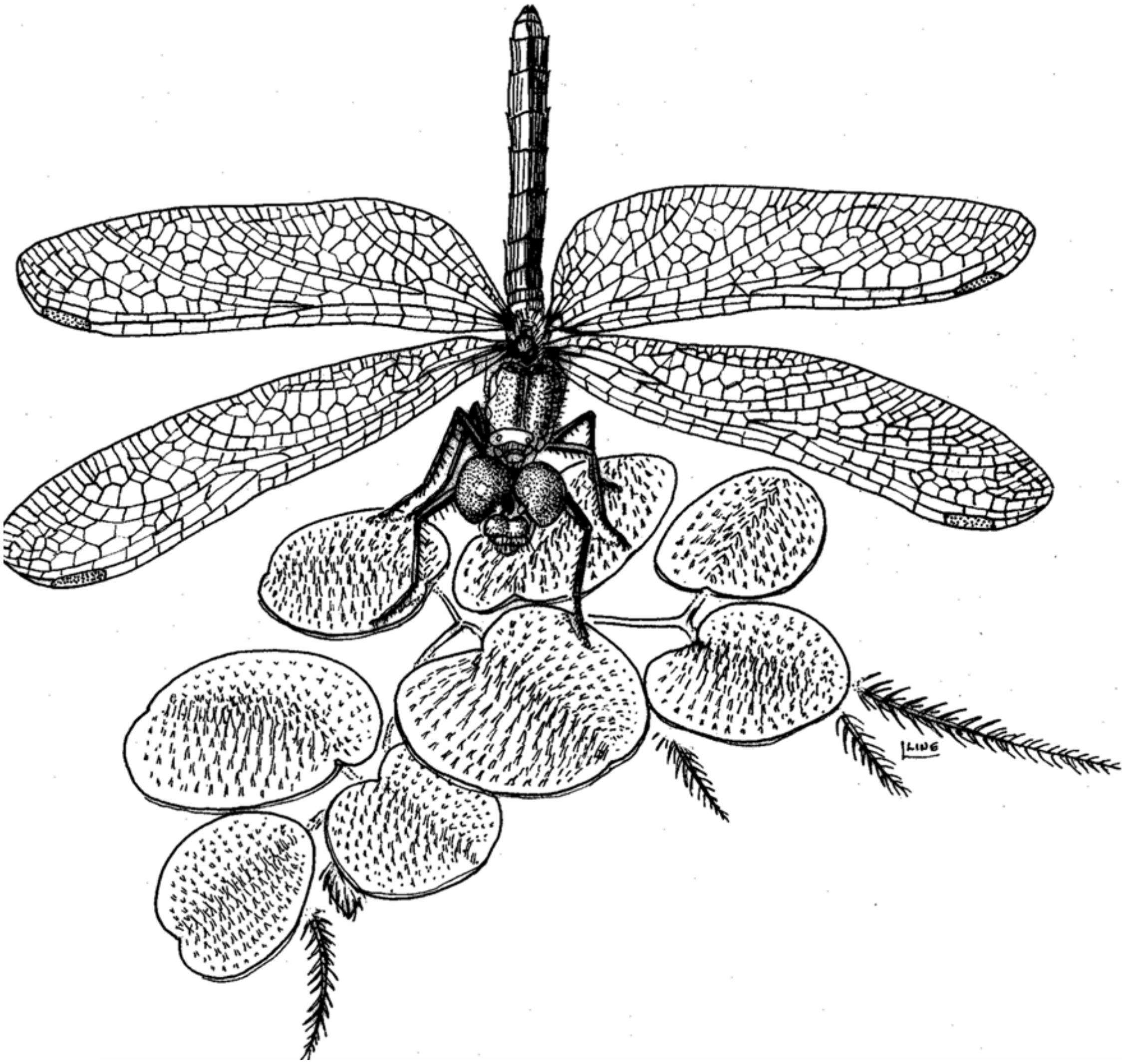
Biological Criteria for Inland Freshwater Wetlands in Florida: A Review of Technical & Scientific Literature (1990-1999)



Biological Criteria for Inland Freshwater Wetlands in Florida:

A Review of Technical & Scientific Literature (1990-1999)

By

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With

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A Report to:
United States Environmental Protection Agency
Biological Assessment of Wetlands Workgroup

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Chapter 1: INTRODUCTION

DESCRIPTION OF REPORT

This review document is a compilation of existing and current knowledge regarding responses of organisms and species assemblages to stressors in Florida inland freshwater wetlands. It is an outcome of an extensive search of technical and scientific literature between 1990 and 1999 in libraries and local, state and federal agencies. The document and database are intended to assist agencies in the development of biological assessment programs for Florida wetlands to better protect this resource. It is designed to aid in the identification of appropriate biological assemblages and to provide a basis for an initial selection of potential metrics and possible methods and field sites for biosurveys. Efforts by Florida Department of Environmental Protection and others will benefit by drawing upon past and current wetlands research and biomonitoring programs in the State.

Development of regionally appropriate multimetric indices of biological integrity for wetlands is requisite of an effective bioassessment program. A first and critical step is identifying, assembling and reviewing current, on-going, and relevant literature. This review, specific to inland freshwater wetlands in Florida and the Southeastern Coastal Plain, may carry more utility for organizations starting biomonitoring programs in Florida that may not be possible in broader literature reviews. As such, this report compliments other reviews, including Adamus and Brandt (1990), *Impacts on Quality of Inland Wetlands of the United States: A Survey of Indicators, Techniques, and Applications of community-level biomonitoring Data*, and Danielson (1998), *Indicators for Monitoring and Assessing Biological Integrity of Inland, Freshwater Wetlands: A Survey of Technical Literature (1989-1996)*.

The report is organized into chapters of 7 assemblage profiles with research and information on the biological response of organisms and species assemblages to 10 stressors reviewed under subheadings within each chapter:

Taxonomic assemblages:

- algae, vascular plants, macroinvertebrates, fish, amphibians and reptiles, birds, and mammals.

Biological response to stressors:

- physical/chemical (including nutrient enrichment, contaminant toxicity, acidification, salinization, sedimentation, turbidity, thermal alteration);
- biological (including vegetation removal, species introductions);
- hydrological (including ground and surface water withdrawals, stormwater runoff, drainage, ditching, and other alterations in frequency, duration, and timing of inundation); and
- regional (including habitat fragmentation, connectivity, landscape heterogeneity)

An introduction (Use as Indicators) to each chapter (3-9) outlines advantages and disadvantages of using a taxonomic assemblage to indicate health in Florida wetlands. If available, and to a lesser extent, information on sampling designs is reviewed, including spatial and temporal variability, appropriate and cost-effective field collection methods, data assembly and analysis. The report includes descriptions of proposed wetland regions and classifications (Chapter 10) and closes with a summary chapter (11) identifying candidate indicator assemblages for biological assessment of Florida's inland freshwater wetlands.

Although the primary aim of this report is to identify possible and appropriate taxonomic assemblages for use in wetland biological assessments in Florida, other relevant information, if present in the collected literature, is also reviewed. This includes documentation of spatial and temporal variability of regionally specific biological groups, indicator tolerances, life histories, habitat preferences, environmental gradients, potentially applicable sampling methods, and reference conditions for wetland types. If possible, depending upon suitability of available data and descriptions in the literature, the location of the research is identified within proposed wetland (eco)regions of Florida (using Lane et al. 1999 and Griffith et al. 1994) and for specific wetland types (using Doherty 1999 et al. and FNAI and HGM classifications).

The majority of literature retrieved and reviewed herein pertains to inland freshwater wetlands in Florida or the Southeastern Coastal Plain and is published or printed between 1990 and 1999. Literature pertaining to other freshwater ecosystems (i.e., streams and lakes), from other regions, or published prior to 1990, is also included if the available literature is limited, if the information is transferable to Florida wetlands, or if the publications are integral to the advancement of wetland biological assessments in general, such as multivariate statistics applications. Success criteria for wetland creation and restoration efforts in Florida are also reported if literature is available, including constructed wetlands for stormwater and wastewater treatment, as mitigation of losses, and for reclamation on phosphate mined lands. Finally, documents shared by members of the USEPA Biological Assessment of Wetlands Workgroup are included if relevant to Florida wetland conditions.

Because available research is descriptive and experimental, qualitative and quantitative, variable in its reporting and general application, and because statistical verification was not always reported, an effort was made to temper adjectives describing results. Instead, research outcomes are reported here in unbiased and general terms, indicating positive and negative correspondence between organisms and stressors, but without qualifiers. This conservative approach requires that the reader take the necessary step of reading relevant referenced literature for better understanding.

Thus, this review is a first step and introduction to the literature and documents the relative extent of knowledge about different taxonomic assemblages and stressors in inland freshwater wetlands of Florida. Interested persons are encouraged to further process the information overviewed here based on directives and their own interests.

There are 2 outcomes of this literature retrieval and review project. The report reviews the literature, and a database allows users to search the collected literature for information relevant to their inquiry. Because the report is cursory in its review, the reader is encouraged to access the database (described in Procedures, Chapter 2) to locate literature pertinent to their needs and specific to wetland type and regions within the State.

BACKGROUND

Assessments of wetland condition and the degree of impairment due to human actions are essential to effectively manage Florida's surface and ground water resources and to meet the objectives of the Clean Water Act, namely to "maintain and restore the chemical, physical, and biological integrity of the Nation's waters." Under the Clean Water Act, wetlands are considered "waters of the State," requiring that States set water quality standards and develop criteria for monitoring and protecting wetlands (USEPA 1987, 1989). Appropriate criteria include physical/chemical as well as biological conditions.

Assessment methods and indicators are needed that integrate a range of cumulative impacts on [wetland] ecosystem condition (McCarron et al. {no date}). Biological assessments can provide effective information about ecological condition (Karr 1991). Numerous studies have documented the responses of biological attributes across diverse taxa and regions to human disturbance. Biological indicators are species, species assemblages, or communities whose presence, abundance, and condition are indicative of a particular set of environmental conditions (Adamus 1996). Measurement of empirical change in biological indicators can identify appropriate metrics (biocriteria) sensitive to a range of human activities. The aggregation of metrics into multi-metric indexes of biological integrity (i.e., IBIs) can assess stressor gradients and communicate biological condition, both in numeric and narrative form (Karr and Chu 1999).

The Florida Department of Environmental Protection (FDEP) has developed indices of biological integrity (IBIs) for assessing the ecological health of streams (Stream Condition Index, SCI; Barbour et al. 1996) and lakes (Lake Condition Index, LCI; Gerritsen and White 1997). FDEP has conducted limited biosurveys on created wetlands (Division of Technical Services 1994) and to measure mitigation success (Division of Technical Services 1992, 1996) relating physical and chemical parameters to macroinvertebrate assemblages and algal community structure. However, prominent assessment protocols for freshwater inland wetlands in Florida, including the Wetland Rapid Assessment Procedure - WRAP (Miller and Gunsalus 1998) and hydrogeomorphic models - HGM (Brinson 1995, 1996; Trott et al. 1997), do not fully utilize biological information to measure disturbance or assess condition, and there is currently limited coordination between efforts.

A statewide committee of water management district and FDEP representatives (Subcommittee on Impacts to Natural Systems) issued a report on methods and criteria for assessing water resources and concluded that a coordination of water management and monitoring efforts was necessary to develop a set of criteria suitable for determining unacceptable harm to natural systems (Lowe et al. 1995). A comprehensive evaluation of constructed wetlands on phosphate mined lands in Florida (Erwin et al. 1997) indicated the overall adequacy of monitoring data is poor and lacking in standardization due to conflicting and disparate evaluation techniques.

Development of an index of biological integrity (IBI) for Florida wetlands can help assess the degree of impairment, identify the source and type of disturbance, monitor the effectiveness of management programs (e.g., pollution abatement), and evaluate restoration, creation, and mitigation projects. FDEP in coordination with the University of Florida Center for Wetlands is developing a biological approach for assessing the health of inland freshwater wetlands in Florida. In addition to development of wetland classes and ecoregions for bioassessments, the identification of appropriate biological criteria is needed.

A review of scientific and technical literature is a first step by identifying information relevant to wetland biological assessment in Florida in order to benefit from past and current research and to pre-select possible species assemblages that have been noted in the literature to be sensitive to stressors. Information on regional biological variability, wetland association, and possible sampling methods is also highlighted in a survey of the literature. Compiled information on the response of organisms and species assemblages to stressors can then be tested in field studies to determine its utility in the development of biological assessments for Florida wetlands.

Chapter 2: PROCEDURES

LITERATURE SEARCH

Technical and scientific literature on inland freshwater wetlands in Florida was located through library searches of electronic databases, abstracts and indexes, and collected from participating local, state and federal agencies. Several articles were supplied from members of the EPA Biological Assessment of Wetlands Workgroup (BAWWG). EPA documents served as prototypes for this effort, including *Indicators for Monitoring and Assessing Biological Integrity of Inland Freshwater Wetlands* (Danielson 1998) and *Bioindicators for Assessing Ecological Integrity of Prairie Potholes* (Adamus 1996).

Geographic extent of the literature search included Peninsula and Panhandle Florida and, where applicable studies were located for wetland types also found in Florida, the Outer Coastal Plain Ecoregion Province of the United States (Omernick and Griffith1987) (i.e., the Southeastern Coastal Plain). This project surveyed literature published between 1990 and 1999 covering the period following a 1990 review document by Adamus and Brandt (*Impacts on Quality of Inland Wetlands of the United States: A Survey of Indicators, Techniques, and Applications of Community-level Biomonitoring Data*). Relevant publications and biomonitoring programs conducted prior to 1990 that have been integral to the advancement of biological assessments of wetlands in Florida were also reviewed. Some literature published in year 2000, located during the review and writing components of this project are also included here.

Library databases and online providers were used in keyword searches, and included:

- BIOSYS (CD ROM)
- Web of Science
  (University of Florida Web LUIS, Library User Information Service)
- AFSA (Internet)
- AbSearch (Internet)
- ZoolRecord (CD ROM)
- NISC (Internet)
  - Biblioline
- Cambridge Scientific
  - Aquatic: AFSA, NTIS, Water Resources Abstracts
  - Environ: Environmental Sciences and Pollution Management, TOXLINE

Series of keywords were used in each search, combined using Boolean operators and limited by geographic area and publication date. Three primary keyword (associations) were repeated in each search to narrow the range of possible matches:

- Wetland
- Florida
- Years, 1990-present

Categories were defined for keyword associations, including: general, wetland type, taxonomic assemblage, impact/stressor, methodology, agency, and classification/type. Series of keywords were then assembled for each category and combined with primary keywords to broaden the search (Table 2.1). Each primary keyword was combined using the Boolean operand AND, narrowing the search references to include all three primary keyword associations. Each array of secondary keywords was separated by an OR which broadened the search within a category. Primary and secondary keywords were combined with the operand AND. All keywords are truncated using an asterisk (*) that defines the word as a wildcard and broadening the search by allowing word variants.

DATABASE DEVELOPMENT

The database searches produced compendiums of literature selections, complete with references and often including article abstracts. Identified references were queried for each search and a subsample of each database was selected for library retrieval based on the perceived relevance of each article to the development of bioassessments for Florida inland freshwater wetlands. Unrelated articles identified by each search were culled from the selection. Each selected article (from journal publications, book chapters, agency reports, university theses and dissertations) was copied, indexed and organized into a local database. Some additional references were located in the literature cited for collected articles, retrieved and added to the local library. Material collected from other sources was also catalogued.

Reference information for selected literature is recorded into a searchable computer file using ProCite bibliographic software. Xerox copies of the articles are placed into file cabinets according to a unique tag identifying the corresponding record in the electronic database. A local library was developed (filename: WBA CFW library) that can be searched by author, journal source, publication date, or keywords (from the abstract or other text within the record). This database is organized and maintained by the University of Florida Center for Wetlands and will continue to archive literature related to inland freshwater wetlands in Florida.

An intention is for this literature database to be available for research and education toward the development of bioassessment approaches and biological criteria for Florida wetlands. The searchable electronic database is available to be placed on websites, possibly linked to the University of Florida Libraries, Florida Department of Environmental Protection, and the homepage of USEPA’s Biological Assessment of Wetlands Workgroup (BAWWG). The database can be made available to District Biologists, Park Managers, researchers, consultants, university faculty and students, and citizens interested wetland health and biological assessments in Florida.

Report chapters (3-9) are organized by taxonomic assemblage (algae, vascular plants, macroinvertebrates, fish, birds, herpetofauna, and mammals; microbes were not reviewed) and stressor effects following the descriptions of Adamus and Brandt (1990) (Table 2.2).

Table 2.1. Categorical terms and secondary keywords used in library database searches.

General:
- (bio)indicator, (bio)assessment, (bio)monitor, (bio)criteria, integrity, function, health

Wetland type:
- palustrine, marsh, emergent, depression, swamp, slough, strand, dome, bog, floodplain, bottomland, cypress, gum, titi, baygall, hydric hammock, seepage slope, wet prairie, wet flatwood

Taxonomic assemblages:
- Macroinvertebrate; Ephemeroptera, Plecoptera, Trichoptera, Odonata, Diptera, Gastropoda, Pelecypoda, Coleoptera, Trombidiformes, Oligochaeta, Hemiptera, Decapoda, Amphipoda, Isopoda
- Fish; Heterandria, Gambusia, Lucania, Fundulus, Lepomis, Ennecanthus, Poecilia
- Algae; diatom, periphyton, plankton, lichen, aquatic moss, aufwuch, adventitious root

Stressor:
- enrichment, chemical, nutrient loading, eutrophication, organic loading, contaminant, toxin, acidification, salinization, agriculture, sedimentation, turbidity, shade, clear cut, thermal, hydrologic drawdown, inundation, hydroperiod, land-use, fragmentation, visitor use, noise, groundwater withdrawal

Methodology:
- IBI (Index of biological integrity), HGM (Hydrogeomorphic model), WRAP (Wetland rapid assessment procedure), Minimum Flows and Levels, WET (Wetland evaluation technique), EMAP (Environmental monitoring and assessment procedure)

Agency:
- FDEP (Florida Department of Environmental Protection), WMD (State Water Management Districts; NWF-, SR-, SJR-, SWF-, SF- WMD), Florida Department of Transportation (FDOT), ACOE (Army Corps of Engineers), DOA (Department of Agriculture, Forest Service), USGS (US Geologic Survey), FFWCC (Florida Fish and Wildlife Conservation Commission), USFWS (US Fish and Wildlife Service), TNC (The Nature Conservancy)

Classification/type:
- FLUCCS (Florida Land Use, Cover and Forms Classification System), NWI (National Wetlands Inventory), HGM (Hydrogeomorphic Wetlands Classification), FNAI (Florida Natural Areas Inventory), FFWCC (Florida Fish and Wildlife Conservation Commission), SCS (Soil Conservation Service)

Table 2.2. Stressors in inland freshwater wetlands addressed in this report.

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN. Increases in concentration or availability of nitrogen and phosphorus. Typically associated with fertilizer application, cattle, ineffective wastewater treatment, fossil fuel combustion, urban runoff, and other sources. DO reduction refers to increases in carbon, to a point where increased biological oxygen demand (BOD) reduces dissolved oxygen in the water column and sediments and can increase toxic gases (e.g., hydrogen sulfide, ammonia).

CONTAMINANT TOXICITY. Increases in concentration, availability, and/or toxicity of metals and synthetic organic substances. Typically associated with agriculture (pesticide applications), aquatic weed control, mining, urban runoff, landfills, hazardous waste sites, fossil fuel combustion, wastewater treatment systems, and other sources.

ACIDIFICATION. Increases in acidity (decreases in pH). Typically associated with mining and fossil fuel combustion.

SALINIZATION. Increases in dissolved salts, particularly chloride, and related parameters such as conductivity and alkalinity. Typically associated with road salt used for winter ice control, irrigation return waters, seawater intrusion (e.g., due to land loss or aquifer exploitation), and domestic / industrial wastes.

SEDIMENTATION / BURIAL. Increases in deposited sediments, resulting in partial or complete burial of organisms and alteration of substrate. Typically associated with agriculture, disturbance of stream flow regimes, urban runoff, ineffective wastewater treatment, dredge and fill activities, and erosion from mining and construction sites.

TURBIDITY / SHADING. Reductions in solar penetration of waters as a result of blockage by suspended sediments and/or overstory vegetation or other physical obstructions. Typically associated with agriculture, disturbance of stream flow regimes, urban runoff, ineffective wastewater treatment, and erosion from mining and construction sites, as well as from natural succession, placement of bridges and other structures, and re-suspension by organisms and wind.

VEGETATION REMOVAL. Defoliation or reduction of vegetation through physical removal, with concomitant increases in solar radiation. Typically associated with aquatic weed control, agricultural and silvicultural activities, channelization, bank stabilization, urban development, defoliation from airborne contaminants, grazing / herbivory, disease, and fire.

THERMAL ALTERATION. Long-term changes (especially increases) in temperature of water or sediment. Typically associated with power plants, other industry, and climate change.

DEHYDRATION / INUNDATION. 1) Reductions in water levels and/or increased frequency, duration, or extent of desiccation of sediments. Typically associated with ditching, channelization of nearby streams, colonization by highly transpirative plant species, outlet widening, subsurface drainage, climate change, and ground / surface water withdrawals for agriculture, industry, or residential use. 2) Increases in water levels and/or increase in the frequency, duration, or extent of saturation of sediments. Typically associated with impoundment (e.g., for cultivation, flood control, water supply, or waterfowl management) or changes in watershed land-use that result in more runoff entering wetlands.

HABITAT FRAGMENTATION / DISTURBANCE / MISCELLANEOUS. Increases in the distance between, and reduction in sizes and connectivity of suitable habitat and increases in noise, predation from pets, disturbance from visitation, and invasion by noxious species capable of out-competing species that normally characterize wetlands.

Chapter 3: ALGAE

USE AS INDICATORS

The term “algae” broadly includes benthic algae (epipelon), algae growing attached to vascular and nonvascular plants (epiphyton), mat algae typically found on the water surface or within the water column (metaphyton), unattached algae in the water column (phytoplankton), and other alga growing on substrata (periphyton). Potential algal species indicators for freshwater biological assessment summarizing the following review are given in Table 3.1.

Algae provide important functions in Florida inland freshwater wetlands (McCormick et al. 1997) including: (1) as a food source for higher trophic level organisms, (2) in biogeochemical cycling, (3) by oxygenating the water column, (4) in nitrogen fixation, (5) by water chemistry regulation, notably pH and major ionic concentrations (Rader and Richardson 1992), (6) as refugia for other organisms, and (7) as physical barriers to erosion. Algae are the primary autotrophs in many freshwater wetlands (Goldsborough and Robinson 1996).

Algae have many features well suited for use as indicators of wetland health. Changes in algal assemblages may have far-reaching effects throughout wetland trophic states. Algae are essentially sessile and cannot avoid loading of deleterious inputs; thus the presence or absence of a species or its relative abundance may provide information on wetland condition. Because of relatively rapid lifecycles, algae are among the first organisms to respond to wetland stressors and often the first to recover (Lewis et al. 1998). Algae are relatively easy to identify, and certain algal structures resist decay and can be used to establish a history of water quality (Browder et al.. 1994). Algal sensitivity to nutrient and toxic inputs is fairly well known (van Dam et al.. 1994, Swift and Nicholas 1987), and due to small size and rapid turnover, algae are well suited for mesocosm and *in situ* dose-response experiments.

Disadvantages of using algae as wetland health indicators are noted. While taxonomic keys exist for algae, most species must be identified using high-powered microscopes. Although most algae are non-motile, winds and currents can translocate individuals and local populations from areas of impact to reference areas and vice versa. Algae generally exhibit seasonal variation in abundance and morphological features that can complicate single season sampling (Vymazal and Richardson 1995).

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN

The majority of scientific and technical literature on algae in Florida inland freshwater wetlands deals with response to nutrient enrichment and eutrophication in the Everglades and associated Water Conservation Areas. The State of Florida Legislature has mandated that by year 2001 total phosphorous (P) standards be set to protect aquatic resources. In the

Table 3.1. Summary of potential algal species indicators for freshwater biological assessments.

Species	Type	Condition Healthy	Impacted	Indications, tendencies	Reference
Achnanthes hungarica	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Achnanthes sublaevis	Diatom		X	Increase with P loading	Pan and Stevenson (1996)
Amphipleura pellucida	Diatom	X		Decrease with P loading	Pan and Stevenson (1996)
Amphora lineolata	Diatom	X		Oligotrophy	McCormick et al.. (1996)
Amphora veneta	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Anabaena sp.	Blue-Green		X	Eutrophy	Grimshaw et al.. (1993)
Anheteromeyenia ryderi	sponge		X	Acidic	Slate and Stevenson (2000)
Anomoeneis serians	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987) McCormick et al.. (1996), McCormick and O'Dell (1996)
Anomoeneis serians var. *brachysira*	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Anomoeneis vitrea	Diatom	X		Oligotrophy	Swift and Nicholas (1987), Raschke 1993, McCormick et al.. (1996)
Bulbochaete sp.	Filamentous Green		X	Eutrophy	Browder et al.. (1994)
Caloneis bacillum	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Chara sp.	Macro-alga		X	Intermediate	Craft et al. (1995)
Chroococcus turgidus	Blue-Green	X		Oligotrophy	McCormick et al. (1998)
Cocconeis placentula var. *lineata*	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Cosmarium sp.	Desmids	X		High mineral concentrations	Gleason and Spackman (1974)
Cyclotella meneghiniana	Diatom		X	Eutrophy	Slate and Stevenson (2000)

Table 3.1 (Continued). Summary of potential algal species indicators for freshwater biological assessments.

		Condition			
Species	Type	Healthy	Impacted	Indications, tendencies	Reference
Cymbella amphioxys	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Cymbella lunata	Diatom	X		Decrease in proportional abundance with P loading	McCormick and O'Dell (1996), McCormick et al. (1996)
Cymbella microcephala	Diatom		X	Oligotrophy	Raschke 1993
Cymbella minuta var. *pseudogracillis*	Diatom		X	Increase with P loading	Pan and Stevenson (1996)
Cymbella munuta var. *silesiaca*	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Cymbella pusilla	Diatom	X			Raschke 1993
Cymbella ruttneri	Diatom	X		High mineral concentrations	Swift and Nicholas (1987)
Cymbella sp.	Diatom	X		Low mineral concentrations	Gleason and Spackman (1974)
Epithemia adnata var. *proboscidea*	Blue-Green		X	Eutrophy	Slate and Stevenson (2000)
Eunotia naegelii	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Fragilaria vaucheriae var. *capitellata*	Diatom		X		Raschke 1993
Frustulia rhomboids var. *saxonica*	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Frustulia rhomboids var. *silesiaca*	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Gomphonema angustatum	Diatom		X	Increase with P loading	Pan and Stevenson (1996)
Gomphonema parvulum	Diatom		X	Eutrophy	Grimshaw et al. (1993), McCormick and O'Dell (1996), Slate and Stevenson (2000), Swift and Nicholas (1987)
Gomphonema truncatum	Diatom		X	Increase with P loading	Pan and Stevenson (1996)

Table 3.1 (Continued). Summary of potential algal species indicators for freshwater biological assessments.

		Condition			
Species	Type	Healthy	Impacted	Indications, tendencies	Reference
Leptobasis sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Lyngbya sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Mastogloia smithii	Diatom	X		Decrease in proportional abundance with P loading	McCormick and O'Dell (1996), McCormick et al. (1996)
Mastogloia smithii var. *lacustris*	Diatom	X		Oligotrophy	Gleason and Spackman (1974), Swift and Nicholas (1987)
Microchaete sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Microcoleus lyngbyaceus	Blue-Green		X	Nutrient Tolerant	Browder et al. (1994), Grimshaw et al. (1993), Swift and Nicholas (1987)
Mougeotia sp.	Filamentous Green	X		Low mineral concentrations	Gleason and Spackman (1974), Swift and Nicholas (1987)
Navicila acicularis	Diatom		X	Increase with P loading	Pan and Stevenson (1996)
Navicula confervacea	Diatom		X	Eutrophy	Slate and Stevenson (2000), Swift and Nicholas (1987)
Navicula cryptocephala var. *exilis*	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Navicula cuspidata	Diatom		X	Eutrophy	Slate and Stevenson (2000), Swift and Nicholas (1987)
Navicula disputans	Diatom		X	Eutrophy (but not dominant)	Swift and Nicholas (1987)
Navicula minima	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Navicula pupula var. *rectangularis*	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Navicula seminulum	Diatom		X	Eutrophy	Slate and Stevenson (2000)

Table 3.1 (Continued). Summary of potential algal species indicators for freshwater biological assessments.

Species	Type	Condition Healthy	Impacted	Indications, tendencies	Reference
Navicula sp.	Diatom	X		Low mineral concentrations	Gleason and Spackman (1974)
Navicula subtilissima	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Nitzschia acicularis	Diatom		X	Increase with P loading	Pan and Stevenson (1996)
Nitzschia amphibia	Diatom		X	Eutrophy	Grimshaw et al. (1993), McCormick and O'Dell (1996), McCormick and Stevenson (1998), Swift and Nicholas (1987)
Nitzschia amphibia f. *frauenfeldii*	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Nitzschia brevissima	Diatom	X?		Decrease with P loading	Pan and Stevenson (1996)
Nitzschia filiformis	Diatom		X	Eutrophy	McCormick and O'Dell (1996), McCormich and Stevenson (1998), Pan and Stevenson (1996)
Nitzschia fonticola	Diatom		X	Eutrophy	McCormick and Stevenson (1998)
Nitzschia frustulum	Diatom		X	Eutrophy	Slate and Stevenson (2000)
Nitzschia palea	Diatom		X	Eutrophy	McCormick and Stevenson (1998), Raschke (1993), Swift and Nicholas (1987)
Nitzschia sigmoidea	Diatom		X	Eutrophy (but not dominant)	Swift and Nicholas (1987)
Nitzschia sp.	Diatom	X		Low mineral concentrations	Gleason and Spackman (1974)
Nitzschia sp. 7	Diatom		X	Eutrophy (but not dominant)	Swift and Nicholas (1987)

Table 3.1 (Continued). Summary of potential algal species indicators for freshwater biological assessments.

		Condition			
Species	Type	Healthy	Impacted	Indications, tendencies	Reference
Nitzschia tarda	Diatom		X	Eutrophy (but not dominant)	Swift and Nicholas (1987)
Oedogonium sp.	Filamentous Green		X	Nutrient Tolerant	Browder et al. (1994), Grimshaw et al. (1993), Swift and Nicholas (1987)
Oscillatoria sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Oscillatoria limnetica	Blue-Green	X?		Decrease in proportional abundance with P loading	McCormick and O'Dell (1996)
Oscillatoria princeps	Blue-Green		X	Eutrophy	McCormick and Stevenson (1998)
Phormidium sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Pinnularia biceps	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Plectonema sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Rhopalodia gibba	Diatom		X	Eutrophy	McCormick and O'Dell (1996), Vaithiyanathan and Richardson (1997), Slate and Stevenson (2000)
Schizothrix sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)
Schizothrix calcicola	Filamentous Blue-Green	X		High mineral concentrations	Swift and Nicholas (1987)
Scytonema sp.	Blue-Green	X		High mineral concentrations	Gleason and Spackman (1974)

Table 3.1 (Continued). Summary of potential algal species indicators for freshwater biological assessments.

Species	Type	Condition Healthy	 Impacted	Indications, tendencies	Reference
Scytonema hofmannii	Filamentous Blue-Green	X		High mineral concentrations	Swift and Nicholas (1987), McCormmick and O'Dell (1996), McCormick et al. (1998)
Shizothrix calcicola	Filamentous Blue-Green	X?		Decrease in proportional abundance with P loading	McCormick and O'Dell (1996)
Spirogyra sp.	Filamentous Green		X	Nutrient Tolerant	Browder et al. (1994), McCormick and Stevenson (1998)
Stenopterobia intermedia	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Stigeoclonium sp.	Filamentous Green		X	Nutrient Tolerant	Browder et al. (1994)
Stigeoclonium sp.	Early Summer Filamentous Green		X	Eutrophy	Swift and Nicholas (1987)
Stigeoclonium tenus	Filamentous Green		X	Eutrophy	Grimshaw et al. (1993)
Synedra pahokeensis sp. nov.	Diatom	X		High mineral concentrations	Swift and Nicholas (1987)
Synedra rumpens var. *familiaris*	Diatom	X		Oligotrophy	McCormick et al. (1996)
Synedra rumpens var. *scotia*	Diatom	X?		Decrease with P loading	Pan and Stevenson (1996)
Synedra tenera	Diatom	X		Low mineral concentrations	Swift and Nicholas (1987)
Synedra ulna	Diatom		X	Eutrophy	Slate and Stevenson (2000)

Everglades, extensive research on algae has been and is currently being undertaken in an effort to acquire baseline data on the effects of nutrient enrichment.

Typically, high nutrient levels favor phytoplankton over macrophytes, especially submerged species that are adversely affected by increased shading (Adamus and Brandt 1990, Adamus et al.. 1991). High nitrogen concentrations relative to phosphorus favor green algae, whereas high P:N ratios favor blue-green algae.

Oligotrophic freshwater marshes, including the Everglades and Savannas State Preserve in South Florida, are generally phosphorus limited. Algal assemblages along a north–south nutrient gradient in Everglades sloughs were correlated with nutrient concentrations emanating from canals in the north that drain the Everglades Agricultural Area (Vymazal and Richardson 1995, McCormick and Stevenson 1998). High and low concentrations of calcium carbonate ($CaCO_3$) and nutrients (mainly P) have been found to variously affect algal species composition in the Everglades.

$CaCO_3$ saturation in the water column is important to Everglades algae (Browder et al.. 1994). Gleason and Spackman (1974) provide an early list of algal species indicative of high and low $CaCO_3$ concentrations in the Everglades. Surface water in the northern reaches generally contains higher concentrations of $CaCO_3$ (from groundwater) than in the south reaches (Browder et al. 1994). In oligotrophic reference areas of the northern Everglades (Water Conservation Areas 1, 2 and 3), both low and high $CaCO_3$ concentrations affect expected algal assemblages (Swift and Nicholas 1987). Gleason and Spackman (1974) found calcareous periphyton populations did not flourish where nutrient and $CaCO_3$ concentrations were low. For example, desmids (Mesotaeniaceae and Desmidiaceae green algae) were present in high numbers only if the reference areas were undersaturated with $CaCO_3$ and low nutrients. Browder et al. (1994) report that desmids are likely to occur not only in low nutrient conditions and undersaturation of $CaCO_3$ but also low pH. Table 3.2 lists algal species typically found in high and low $CaCO_3$ concentrations in low nutrient waters of the Everglades. Reference algae in the Everglades indicative of oligotrophic conditions as reported by McCormick et al. (1996) include: *Amphora lineolata*, *Anomoeneis serians*, *Anomoeneis vitrea*, *Cymbella lunata*, *Mastogloia smithii*, and *Synedra rumpens* var. *familiaris*.

Whereas in some lakes and streams algal mats indicate eutrophication, in the Everglades algal mats with *Utricularia* spp. are viewed as indicators of health (McCormick and Stevenson 1998, Craft et al. 1995, Rader and Richardson 1992). With increasing nutrient loading, however, the polysaccharides that hold algal mats together disintegrate (McCormick et al. 1997, McCormick and Stevenson 1998, Craft et al. 1995, Rader and Richardson 1992). While the mats themselves dissipate the species responsible for the polysaccharides typically remain, unless affected by other variables (Rader and Richardson 1992). In some cases where nutrient loading continues, desmid species that construct the mats are replaced by more nutrient tolerant species. Craft et al. (1995) found that as algae mats dissipated, *Chara* spp. became dominant. Browder et al. (1994) reported that in areas of high nutrients, *Utricularia* -algae mats were not present and a shift to pollution-tolerant species occurred, including: *Microcoleus lyngbyaceus*, *Stigeoclonium* spp., *Spirogyra* spp., and *Oedogonium* spp. Rader

Table 3.2. Algae typically found in low and high $CaCO_3$ concentrations in reference (oligotrophic) waters of the Everglades.

Indicative of low $CaCO_3$	**Indicative of high $CaCO_3$**
Gleason and Spackman (1974): Desmids: 78 species Filamentous green algae *Bulbochaete* spp. *Mougeotia* spp. *Oedogonium* spp. *Spirogyra* spp. Diatoms *Cymbella* spp. *Nitzschia* spp. *Navicula* spp. *Mastogloia smithii* var. *lacustris*	Blue-green algae *Scytonema* spp. *Lyngbya* spp. *Microchaete* spp. *Phormidium* spp. *Oscillatoria* spp. *Plectonema* spp. *Leptobasis* spp. *Schizothrix* spp. Desmids *Cosmarium* spp.
Swift and Nicholas (1987): Desmids (Order Zygnematales) Filamentous green algae *Mougeotia* spp. Diatoms (present, generally not dominant): *Cymbella amphioxys* *Cymbella. minuta* var. *silesiaca* *Anomoeneis serians* *A. serians* var. *brachysira* *Frustulia rhomboids* var. *saxonica* *F. rhomboids* var. *silesiaca* *Nitzschia* spp.7 *Eunotia naegelii* *Synedra tenera* *Pinnularia biceps* *Navicula subtilissima* *Stenopterobia intermedia*	Filamentous blue-green algae: *Schizothrix calcicola* *Scytonema hoffmannii* Diatoms: *Mastogloia smithii* var. *lacustris* *Cymbella ruttneri* *Anomoeneis vitrea* *Synedra pahokeensis* spp. nov.
McCormick et al. (1998):	*Scytonema hofmannii* *Chroococcus turgidus*

and Richardson (1992) report that phosphorus enrichment can cause disintegration of cyanobacteria polysaccharide sheaths, resulting in a shift from cyanobacteria to filamentous green algae and diatoms and a corresponding increase in algal biomass.

Enriched runoff (mainly P) has been identified in the Everglades and elsewhere as a principal factor affecting species composition of algal assemblages. Gleason and Spackman (1974) found that enriched runoff affected desmid species diversity, the number of blue green algae species, blue-green algae abundance, the calcareous nature of blue-green algae, periphyton biomass, and ash content. Browder et al. (1994) list phosphorus along with water chemistry, nutrient concentration, hydrologic conditions, and soil type as determinants of algal community composition. Calcite encrustation, occurring in low nutrient areas of the Everglades, is also affected by phosphorus concentrations (Browder et al. 1994).

With increased P-loading, oligotrophic algal species are replaced by filamentous chlorophytes like *Spirogyra* in moderately enriched areas (McCormick and Stevenson 1998, McCormick and O’Dell 1996). FDEP’s Division of Technical Services (1994) found that moderate nutrient enrichment resulted in a mixed assemblage with no dominant taxa. Highly enriched areas of the Everglades were dominated by *Nitzschia amphibia, N. filiformis, N. fonticola, N. palea* (McCormick and Stevenson 1998). Deleterious affects of P-loading typically occur at values > 10*u*g*L^{-1}, and a complete shift away from oligotrophic (reference) species occurs at values > 20*u*g*L^{-1} (McCormick and Stevenson 1998, McCormick et al. 1996, McCormick and O’Dell 1996).

McCormick et al. (1998) found that enriched Everglades areas contained distinct periphyton assemblages dominated by *Oscillatoria princeps* and a higher percentage of filamentous green algae taxa (e.g., *Spirogyra*). Algal species indicative of eutrophic conditions include *Gomphonema parvulum, Nitzschia amphibia, N. filiformis,* and *Rhopalodia gibba* (McCormick and O’Dell 1996). Browder et al. (1994) report *Spirogyra, Bulbochaetae,* and *Oedogonium* genera tolerate high nutrients. Grimshaw et al. (1993), based on an extensive literature review, identify *Anabaena* spp., *Gomphonema parvulum*, *Microcoleus lyngbyaceus*, *Nitzschia amphibia*, *Oedogonium* spp., and *Stigeoclonium tenus* as indicators of eutrophication in the Everglades. Whitmore (1989) presents an extensive list of algae taxa and expected trophic states from hypereutrophic to dystrophic for Florida lakes (Table 3.3 provides a modified list, potentially applicable to Florida wetlands).

In a study of forested and emergent marshes in Kentucky, Pan and Stevenson (1996) found algal response to P-loading, but their model had difficulty predicting species assemblages at low and high loading rates. Nevertheless, from the ordination of their data one could infer species that respond positively to P-loading (*Cymbella minuta* var. *pseudogracilis, Gomphonema angustatum, G. truncatum, Navicula acicularis, Nitzschia filiformis, Nitzschia acicularis,* and *Achnanthes sublaevis*) and those with the strongest negative response (*Amphipleura pellucida*, *Nitzschia brevissima*, and *Synedra rumpens* var. *scotica*). The authors conclude that diatoms were good indicators of P-loading and recommended the use of planktonic and epiphytic diatoms. Studies in Michigan (Stevenson et al. 1999) and Montana (Apfelbeck in preparation, Charles et al. 1996) also found positive correspondence between diatom assemblages and phosphorus loading.

Table 3.3. Expected algal trophic states for Florida lakes (modified from Whitmore 1989).

Species	Eutrophic	Oligotrophic	Species	Eutrophic	Oligotrophic
Achnanthes linearis var. *linearis*		X	*Fragilaria crotonensis* var. *crotonensis*	X	
Actinella punctata var. *punctata*		X	*Fragilaria pinnata* var. *lancetulla*	X	
Anomoeneis serians var. *serians*		X	*Fragilaria vaucheriae* var. *vaucheriae*	X	
Anomoeneis serians var. *acuta*		X	*Frustulia rhomboides* var. *rhomboides*		X
Anomoeneis serians var. *apiculata*		X	*Frustulia rhomboides* var. *capitata*		X
Capartogramma crucicula var. *crucicula*		X	*Gomphonema acuminatum* var. *acuminatum*	X	
Chaetoceros spp.	X		*Gomphonema parvulum* var. *parvulum*		X
Cocconeis placentula var. *placentula*	X		*Gomphonema parvulum* var. *lanceolata*		X
Cocconeis placentula var. *lineata*		X	*Gomphonema parvulum* var. *micropus*	X	
Cyclotella meneghiniana var. *meneghiniana*	X		*Melosira ambigua* var. *ambigua*	X	
Desmogonium rabenhostianum var. *elongatum*		X	*Melosira granulata* var. *muzzanensis*	X	
Eunotia bidentula var. *bidentula*		X	*Melosira varians* var. *varians*	X	
Eunotia flexousa var. *flexuosa*	X		*Navicula bacillum* var. *bacillum*	X	
Eunotia maior var. *maior*	X		*Navicula cryptocephala* var. *crytocephala*		X
Eunotia microcephala var. *microcephala*		X	*Navicula cuspidata* var. *cuspidata*	X	
Eunotia monodon var. *monodon*		X	*Navicula cuspidata* var. *ambigua*	X	
Eunotia vanheurckii var. *vanheurckii*		X	*Navicula cuspidata* var. *major*	X	
Fragilaria construens var. *construens*	X		*Navicula gastrum* var. *gastrum*	X	
Fragilaria construens var. *pumila*	X		*Navicula gottlandica* var. *gottlandica*	X	

Table 3.3. (Continued) Expected algal trophic states for Florida lakes (modified from Whitmore 1989).

Species	Eu-trophic	Oligo-trophic		Species	Eu-trophic	Oligo-trophic
Navicula halophila var. *halophila*		X		*Pinnularia braunii* var. *amphicephala*		X
Navicula minima var. *minima*	X			*Pinnularia legumen* var. *legumen*		X
Navicula pupula var. *capitata*		X		*Pinnularia maior* var. *maior*		X
Navicula pupula var. *elliptica*	X			*Pinnularia subcaptitata* var. *paucistriata*		X
Navicula radiosa var. *radiosa*	X			*Stenopterobia intermedia* var. *intermedia*		X
Navicula radiosa var. *tenella*	X			*Stephanodiscus aegyptiacus*	X	
Navicula rhyncocephala var. *rhyncocephala*	X			*Surirella biseriata* var. *biseriata*		X
Navicula subtilissima var. *subtilissima*		X		*Surirella delicatissima*		X
Navicula tripunctata var. *tripunctata*	X			*Surirella linearis* var. *linearis*		X
Neidium apiculatum var. *apiculatum*		X		*Surirella linearis* var. *constricta*		X
Neidium floridanum var. *floridanum*		X		*Surirella robusta* var. *robusta*		X
Neidium ladogense var. *densestriatum*		X		*Surirella robusta* var. *splendida*		X
Nitzschia capitellata var. *capitellata*	X			*Surirella tenera* var. *tenera*		X
Nitzschia frustulum	X			*Synedra acus* var. *acus*	X	
Nitzschia ignorata	X			*Synedra delicatissima* var. *delicatissima*	X	
Nitzschia paleaceae	X			*Synedra radicans* var. *radicans*	X	
Pinnularia abaujensis var. *abaujensis*		X		*Synedra ulna* var. *ulna*	X	
Pinnularia biceps var. *petersenii*		X		*Tabellaria fenestrata* var. *fenestrata*		X
Pinnularia borealis var. *borealis*	X					

Nutrient loading can also affect morphological features of algae (Browder et al. 1994). Browder et al. (1981) found a significant negative relationship between inorganic P (orthophosphate) and the percent cell volume in desmids. McCormick and Stevenson (1998) found P-loading increased algal growth rate and biomass volume. Several species are identified by McCormick and O'Dell (1996) that decrease in proportional abundance with increasing phosphorus (*Cymbella lunata, Scytonema hofmanii, Shizothrix calcicola, Oscillatoria limnetica, Mastogloia smithii,* and *Anomoeneis serians*).

Nutrients other than phosphorus have negative and cumulative impacts algal biota. Scheidt et al. (1987) found that nitrate significantly decreased algal biomass and eliminated periphyton within months. McCormick and O'Dell (1996) rank phosphorus as the nutrient with the largest impact on algal assemblages, followed by nitrogen (N) and iron (Fe). McCormick et al. (1998) report that phosphorus concentration limits algal growth in oligotrophic areas of the Everglades. In enriched areas, nitrogen, other nutrients or light limits growth (Vaithiyanathan and Richardson 1997, McCormick and Stevenson 1998). In nitrogen limited areas, Vaithiyanathan and Richardson (1997) found increases in *Rhopalodia gibba* and blue-green algae with heterocyst (*Nostoc)*. Seasonal algal assemblages typically found with eutrophication in the Everglades (high N and P concentrations) are listed in Table 3.4.

CONTAMINANT TOXICITY

Few studies were found in a search of the literature between 1990 and 1999 on the effects of toxic contamination on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Additional literature on toxic contaminants and wetland algae in other states is surveyed by Adamus and Brandt (1990) and Danielson (1998), though both reviews conclude that most research is focused on individual species in laboratory conditions and not on algal community structure in the field. The reader is also referred to Stevenson et al. (1996), especially chapters by Genter and Hoagland.

Toxic stress on algal assemblages can come in many forms from many sources. Toxicity affects algae at biochemical, cellular, population, and community levels (Genter 1996), and may potentially have chronic exposure effects (Hoagland et al. 1996). Lewis et al. (1998) examined the response of *Selenastrum capricornutum* (a freshwater green algae) to *in vitro* additions of different effluent (from two cities, one naval air station, three forest product plants, two agro-chemical industries, one synthetic fibers industry and one steam power generation plant). Water chemistry parameters were measured (pesticides, polynuclear aromatic hydrocarbons, polycyclic biphenyls (PCB's), metals (silver, chromium, cadmium, nickel, lead, aluminum, copper, mercury) and residual chlorine and nutrients). Cumulative, synergistic toxic impacts from constituent combinations were not studied. Several of the metals present in the samples were below detection levels. The authors conclude the most sensitive indicator was algal biomass (which was stimulated in all but one forest product effluent and one city effluent) and that biomass response was primarily a reflection of phyto-stimulatory nutrients present in the effluent.

Table 3.4. Algal species typical of eutrophic conditions in the Everglades (from Swift and Nicholas 1987).

Early Summer Filamentous Greens • *Oedogonium* spp. • *Stigeoclonium* spp.
Late Summer and Fall Filamentous Blue-Greens • *Microcoleus lyngbyaceus* (previously *Oscillatoria tenius*)
Winter Diatoms • *Gomphonema parvulum* • *Nitzschia amphibia* • *Nitzschia palea* • *Navicula disputans* • *Navicula confervacea*
Other diatoms characteristics of high nutrients (present but not dominant) • *Nitzschia tarda* • *Nitzschia sigmoidea* • *Nitzschia* sp. 7 • *Navicula confervacea* • *Navicula disputans* • *Navicula cuspidata*

ACIDIFICATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of acidification on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Literature reviews by Adamus and Brandt (1990) and Danielson (1998) both cite studies that found filamentous and green algae, especially *Mougeotia* spp., increase in abundance with acidification. Typically though, algal species richness declines with acidification in lakes, but algal production can be relatively high in some naturally acidic wetlands.

Florida ecosystems typically underlain by limestone are less at risk from point source acidification than ecosystems in other regions. Also a paucity of geologic ores (phosphate being the exception) also precludes damage from mining acidification in Florida wetlands. However, non-point source acidification can occur from atmospheric deposition, and natural differences in pH and alkalinity may be important determinants of algal assemblages (Rosen and Mortellaro 1998).

Recent studies in Kentucky, Michigan, and Montana may prove relevant to algal research in Florida wetlands. Pan and Stevenson (1996) identified conductivity, not pH, as a determinant of diatom assemblages wetlands receiving acid mine drainage in western Kentucky. The authors conclude that conductivity inference models based on phytoplankton had better predictability than those based on epiphyton. In a study of wetland ponds, emergent marshes, forested systems, bogs, and shrub scrub wetlands in Michigan, Stevenson et al. (1999) found that variance in diatom assemblages could be partially explained by conductivity and pH. Weighted average models based on environmental variables identify that relative abundance of surface sediment diatom assemblages indicates conductivity and pH levels in wetlands. Periphyton assemblages corresponded to conductivity and pH in a study of wetlands, lakes, and reservoirs in Montana (Charles et al. 1996). Here inference models were also used with relative accuracy as predictors of algal species assemblages based on environmental variables.

Numerous studies have documented the impacts of acidification on algal assemblages in freshwater lakes and streams. In a paleolimnological study of the Everglades, Slate and Stevenson (2000), classify species indicative of low pH conditions in South Florida (*Eunotia* spp.; *Eunotia flexuosa*, *Eunotia formica*, *Eunotia glacialis*, *Eunotia quaternary*; and *Amheteromeyenia ryderi*). Whitmore (1989) presents over 200 species of Florida lake algae and a classification for acid tolerance (pH < 5.5, acidobiontic; pH 5.5-6.5, acidophilous; pH 6.5-7.5, circumneutral; pH 7.5-8.5, alkaliphilous; and pH > 8.5, alkalibiontic). Some trends warrant research in Florida wetlands, especially the response of filamentous green algae, diatoms, and Cyanophyceae (blue-green algae). Several genera of filamentous green algae (Zygnemataceae) respond positively to acidification, most notably *Zygogonium*, *Mougeotia*, *Spirogyra*, and *Zygnema*, as well as *Ulothrix* and *Oedogoniium* (Planas 1996). Among the most sensitive algae to acidification are species of Cyanophyceae. Planas (1996) reports tolerance levels (pH 4.8) for blue green algae. Benthic filamentous green algae, diatoms and blue green algae that indicate acid conditions in surface water are summarized in Table 3.5.

Table 3.5. Benthic algae found in acidic lakes and streams (from Planas 1996).

Achnanthes marginulata
Anomoeneis spp.
Anomoeneis serians
Anomoeneis serians brachysira
Diatoma spp.
Eunotia bactriana
Eunotia curvata
Eunotia exigua
Eunotia incisa
Eunotia pectunalis
Eunotia pectunalis var. *minor*
Eunotia tenella
Eunotia vanheurkii
Eunotia veneta
Fragilaria acidobiontica
Fragilaria virescens
Fragilaria virescens var.
Frustulia spp.
Frustulia rhomboides
Frustulia rhomboides var. *crassinervia*
Navicula cumbriensis
Navicula hoeflen
Navicula subtilissima
Navicula tennicephala
Neidium affine
Neidium iridis amphigomphius
Neidium ladogense desentiatum
Pinnularia abaujensis
Stauroneis gracillima
Tabellaria fenestrata
Tabellaria binalis
Tabellaria quadriseptata
Bulbochaete spp.
Microspora spp.
Mougeotia spp.
Mougeotia quadragulata
Spirogyra spp.
Spirogyra fennica
Oedogonium spp.
Ulothrix spp.
Temmogametum tirupatiensis
Zygnema spp.
Zygogonium spp.
Zygogonium tunetanum

SALINIZATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of salinization on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) did not find wetland salinization literature in their review, but state that based on algal responses in other surface waters, it appears likely that suitable assemblages of salt-sensitive algae species could be identified. Danielson's review (1998) found lake algal assemblages, especially diatoms, have been correlated with salinity, with diatom richness highest at specific conductance levels less than 45 mS and declining as specific conductance increased.

Stevenson et al. (1999) report specific conductivity (a surrogate for salinity) strongly affects algal assemblages by altering osmotic pressure within the cell and cell membrane. Apfelbeck (in preparation) reports that diatom abundance was correlated with salinity in freshwater wetlands in Montana, though the preliminary study does not identify species.

SEDIMENTATION / BURIAL

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of sedimentation on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on wetland algal response to sedimentation. Presumably benthic algae (epipelon) and periphyton associated with benthic substrates would be adversely affected from sedimentation and burial. Epiphytic species may be indirectly affected depending on the response of host plants to sedimentation. Studies in the Everglades and other regions have documented shifts in plant community assemblages associated with sedimentation and subsidence (Reddy et al. 1993, Wardrop and Brooks 1998).

TURBIDITY / SHADING

No explicit studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity or shading on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) report a paucity of literature prior to 1990 on wetland algal response to turbidity and shading. Danielson's review (1998) summarizes a limited literature on lake algae from other states, concluding generally that turbidity, shading and tannins likely impact benthic algae more than phytoplankton.

In the Everglades, effects of turbidity and shading on algae appear as ancillary data from phosphorus loading studies. P-loading promotes rapid growth and expansion of *Typha domingensis* (cattail), which then shade out algae or fill open spaces formally occupied by algal mats (Reddy et al. 1993, Browder et al. 1994). In oligotrophic water, P is a limiting factor; in nutrient enriched water, sunlight for photosynthesis is often a limiting factor due to shading by macrophytes (McCormick et al. 1998).

VEGETATION REMOVAL

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of vegetation disturbance on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on wetland algal response to vegetation removal. Epiphyton and periphyton, having lost host substrate, will likely decrease in abundance with the removal of wetland vegetation, with possible increases in the abundance of other types of algae.

THERMAL ALTERATION

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of thermal alteration on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Browder et al. (1994) documented algae in the Everglades present in natural water temperatures as high as 36^{o}C.

Danielson's review (1998) did not find recent literature on wetland algal response to thermal alteration, but Adamus and Brandt (1990) state that based on algal responses in other surface waters it is likely that suitable assemblages of temperature sensitive algal species could be identified. In general, algal biomass increases with warming to an optimal temperature after which there is a decrease (DeNicola 1996). Lake studies generally conclude there is an overall decrease in algal diversity with increasing water temperature with only a few dominant species of green algae, cyanobacteria (blue-greens), and diatoms.

DEHYDRATION / INUNDATION

In their literature review, Adamus and Brandt (1990) state that draw-down of wetland water levels may concentrate available nutrients and mobilize unavailable nutrients which can cause algal blooms, while inundation may dilute nutrients and reduce nutrient mobility which can cause reductions in some algal taxa. Danielson (1998) reviews literature on the response of lotic periphyton and filamentous algae to flood events, finding both positive (increased nutrient availability) and negative (increased turbidity, respectively) correspondence. Increased salinity (higher specific conductance) may result from low water conditions, negatively affecting wetland algal assemblages.

Episodic dehydration and inundation describes many Florida wetland hydroperiods. For several months of a year, typically winter in Peninsular Florida, rainfall is low and wetlands are dry exposing wetland organisms. Adaptations to drying stress include thick cell walls, mucilage and spore production (Rosen and Mortellaro 1998). During summer rains wetland algae acclimate to inundation. Thus many algal species are variously tolerant of pulsed hydroperiods confounding their use as water stress indicators.

Rosen and Mortellaro (1998) found *Microspora pachyderma* in South Florida was tolerant of desiccation and thus a good indicator of wetland draw-down, and that *Microspora* species had unique growth forms (such as thicker cell walls and akinetes) depending on water regime. Van Meter-Kasanof (1973) found that larger algae species were better suited for environmental extremes in the Everglades, and that green periphyton (including some desmids) required year-round inundation. Swift and Nicholas (1987) report a significant negative relationship between water depth and percent cell volume in *Scytonema* spp. and *Schizothrix* spp., and a positive relationship between water depth and percent cell volume of *Microcoleus* spp.

Browder et al. (1981) found that diatoms and blue-green algae were dominant components of Everglade wetlands with long hydroperiods. Hydroperiod and water depth are identified by Browder et al. (1994) as determinants of algal composition in the Everglades: sites with frequent draw-downs were predominantly comprised of benthic cyanobacteria; diatoms and green algae were found at frequently inundated sites; and desmids were present only at sites that were continuously flooded.

McCormick et al. (1998) found algal assemblages in oligotrophic areas of the Everglades were seasonally different. In the wet period (May – October), the predominant algae were cyanobacteria with high biomass; in the dry period (November – April) diatom biomass was high. Although biomass varied, presence (or absence) of oligotrophic species remained relatively constant with seasonal changes. Seasonal effects were muted in eutrophic areas of the Everglades, possibly due to year-round nutrient availability (McCormick et al. 1998). In eutrophied wetlands, metaphyton and epiphyton biomass varied across seasons and inundation regimes, while epipelon biomass remained constant (McCormick et al. 1998). This may indicate that water depth and marsh drying are not strong determinants of algal species assemblages in the Everglades.

In a paleolimnological study of intermittent bay wetlands in South Carolina and Georgia, Gaiser et al. (1998) found that *Eunotia* spp., *Luticola saxophila*, and *Pinnularia borealis* var. *scalaris* were indicators of sustained drying or draw-down; and other *Pinnularia* spp. and *Stenopterobia densestriata* responded positively to persistent ponding.

HABITAT FRAGMENTATION / DISTURBANCE

No studies were found in a search of the literature between 1990 and 1999 on direct effects of habitat fragmentation or landscape scale disturbance on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) report a paucity of literature prior to 1990 on wetland algal response to habitat fragmentation and disturbance, and Danielson's review (1998) similarly finds no recent literature in other states. Effects of habitat alteration on wetland algae would likely be manifested through changes in nutrient loading and hydrology and possibly through removal of planktivorous fish.

Chapter 4: VASCULAR PLANTS

USE AS INDICATORS

Wetland plants have many characteristics suited to biological assessments of condition including: their ubiquitous presence in wetland communities, their relative immobility, the well developed protocols for sampling, and their moderate sensitivity to disturbances (for herbaceous species). Disadvantages of using wetland plant assemblages as biological indicators are that plant species presence and distribution closely reflects wetland hydroperiodicity and that plant response to anthropogenic disturbances and natural wetland variability is difficult to distinguish, especially due to changes in hydropattern (Adamus and Brandt 1990, Danielson 1998).

Sampling procedures for plants are well defined, and several studies have discussed ways of refining sampling protocols to reduce environmental impact (Hsieh 1996), simplify and better quantify statistical analysis (Almendinger {no date} and TerBraak 1986), and fully and effectively characterize the community (Peet et al.. 1996, Division of Environmental Services 1998, Brown 1991, HDR 1992, Brooks and Hughes 1988). Plant community development is often monitored in wetland restoration and construction in Florida as a surrogate to ecosystem remediation and health (Brown et al.. 1997) and the literature is replete with information on constructed wetlands for stormwater and wastewater treatment, as mitigation of losses, and for reclamation on phosphate mined lands (Erwin et al. 1997).

Possible plant metrics include: total species richness, abundance of graminoids (Cyperaceae, Poaceae and Juncaceae), abundance of *Carex* spp., presence/absence of *Utricularia* spp., a floating leaved guild metric, a decomposition metric (i.e., abundance of taxa with persistent litter), annual vs. perennial, and exotics vs. native (BAWWG Plant Focus Group 1997, Danielson 1998). Wetland plant species that are generally tolerant (i.e., increasers) and intolerant (i.e., decreasers) of disturbance (Table 4.1) are used by Southwest Florida Water Management District in a simple index of wetland health [Decreaser Species / (Decreaser + Increaser Species)].

Hoyer et al. (1996) as part of a statewide lake survey, sampled macrophyte communities in lake littoral zones. A range of physical-chemical measurements for each lake was also recorded. The book, titled *Florida Freshwater Plants*, summarizes a useful database of levels and ranges of physical and chemical parameters associated with aquatic plant species in Florida lakes. Because many freshwater plants common in Florida lakes are also component species in inland freshwater wetlands, this database provides information important to identification of stressor response signals in wetland plants. The reader is encouraged to use this compendium as a baseline to identify tolerance ranges of freshwater plants common in Florida wetlands in the development of biotic indicators. Table 4.2 lists Florida wetland plants found in lakes with high and low levels (i.e., levels significantly different than the study average) of selected physical and chemical parameters (phosphorus, nitrogen, pH, and salinity). The reader is also referred to other literature reviews on wetland plant response to stressors from other states and regions (Adamus and Brandt 1990, Danielson 1998). Table

Table 4.1. Wetland plant species that typically increase and decrease with disturbance (adapted from Rochow (1994) and SWFWMD).

DECREASERS:	INCREASERS:
Eriocaulon spp.	*Eupatorium* spp.
Sphagnum spp.	*Andropogon* spp.
Pondeteria cordata	*Amphicarpum* spp.
Nymphaea spp.	*Euthamia minor*
Nymphoides aquatica	*Rubus* spp.
Utricularia inflata, purpurea	*Erianthus* spp.
Hypericum fasciculatum	*Axonopus* spp.
Sagittaria spp.	*Lycopus* spp.
Bacopa caroliniana	*Pinus* spp.
Polygala nana, lutea, rugeli, cymosa	*Paederia* spp.
Xyris fimbriata	*Paspalum notatum*
Rhynchospora tracyii, corniculata, inundata	*Blechnum* spp.
Eleocharis spp. (except *baldwinii*)	*Woodwardia* spp.
Drosera spp.	*Smilax* spp. + *glauca*
Juncus repens	

Table 4.2. Florida wetland plants found in lakes with high and low levels of phosphorus, salinity, nitrogen, and pH (i.e., parameter levels significantly different than the study average, $p < 0.05$). Adapted from Hoyer et al. (1996).

Species typically found in high range	Species typically found in low range
Phosphorus	
Alternanthera philoxeroides	*Eleocharis baldwinii*
Azolla caroliniana	*Eriocaulon spp.*
Brachiaria mutica	*Fontinalis spp.*
Ceratophyllum demersum	*Fuirena scirpoidea*
Cicuta mexicana	*Hypericum spp.*
Cyperus articulatus	*Lachnanthes caroliniana*
Echinochloa spp.	*Leersia hexandra*
Lemna minor	*Mayaca fluviatilis*
Limnobium spongia	*Myriophyllum heterophyllum*
Ludwigia octovalvis	*Nymphoides aquatica*
Myriophyllum aquaticum	*Rhyncospora tracyi*
Paspaldium geminatum	*Utricularia floridana*
Paspalum repens	*Utricularia purpurea*
Phragmites australis	*Utricularia resupinata*
Pistia stratiotes	*Xyris spp.*
Sagitaria latifolia	
Salix spp.	
Salvinia minima	
Spirodela polyrhiza	
Thalia geniculata	
Chloride (salinity)	
Vallisneria americana	*Xyris spp.*
Thalia geniculata	*Utricularia floridana*
Spartina bakeri	*Hypericum spp.*
Salvinia spp.	*Eriocaulon spp.*
Pistia stratiotes	*Brasenia schreberi*
Phragmites australis	
Paspalum repens	
Paspaldium geminatum	
Ludwigia octovalvis	
Lemna minor	
Cyperus articulatis	
Crinum americanum	
Ceratopteris thalictroides	

Table 4.2 (Continued). Florida wetland plants found in lakes with high and low levels of phosphorus, salinity, nitrogen, and pH.

Species typically found in high range	Species typically found in low range
Nitrogen	
Echinochloa spp.	*Eriocaulon spp.*
Lemna minor	*Fontinalis spp.*
Paspaldium geminatum	*Fuirena scirpoidea*
	Hypericum spp.
	Leersia hexandra
	Mayaca fluviatilis
	Utricularia floridana
	Xyris spp.
pH	
Alternanthera philoxeroides	*Brasenia schreberi*
Bacopa monnieri	*Eleocharis baldwinii*
Brachiaria mutica	*Eriocaulon spp.*
Canna spp.	*Fontinalis spp.*
Ceratophyllum demersum	*Fuirena scirpoidea*
Ceratopteris thalictroides	*Hypericum spp.*
Cicuta mexicana	*Lachnanthes caroliniana*
Colacasia esculenta	*Leersia hexandra*
Cyperus articulatus	*Mayaca fluviatilis*
Echinochloa spp.	*Myriophyllum heterophyllum*
Lemna minor	*Nymphoides aquatica*
Limnobium spongia	*Rhyncospora tracyi*
Ludwigia octovalvis	*Utricularia floridana*
Mikania scandens	*Utricularia purpurea*
Myriophyllum aquaticum	*Websteria confervoides*
Najas guadalupensis	*Xyris spp.*
Nymphaea mexicana	
Panicum repens	
Paspaldium geminatum	
Paspalum repens	
Phragmites australis	
Pistia stratiotes	
Potamogeton illinoensis	
Sagitaria lancifolia	
Sagitaria latifolia	
Salix spp.	
Salvinia minima	
Sambucus candensis	
Scirpus californicus	
Spirodela polyrhiza	
Thalia geniculata	
Typha spp.	
Vallisneria americana	

4.3 lists potential plant species indicators of disturbance in inland freshwater wetlands of Florida, summarizing the following review.

Several reservations about the use of plants as indicators are noted. Jordan et al. (1997) found that variation in species composition was high between adjacent sites and within micro-habitats, but that at larger scales variability was reduced. This suggests caution in the use of sampling protocols and in subsequent analysis of sampled data to ensure that broad scale metrics are extracted and not indicators of local variability. Harris et al. (1983) argue that because plants integrate highly localized regions, plant assemblages are better used as surrogate indicators for birds, which can be used to assess landscape health. Tiner (1991) argues that wetland plants are unreliable as sole indicators of change in hydrologic regime or nutrient status. Rather, soil biogeochemistry and physical characteristics need to be used in concert with vegetation to avoid lag times in plant response to hydrologic alteration.

Other issues concern plant identifications and the use of presence/absence metrics, particularly for annual wetland vegetation (BAWWG Plant Focus Group 1997). Briggs et al. (1996) propose that pre- and post-development plant inventories and long-term monitoring are necessary to adequately characterize effects. Crisman et al. (1997) and Bridges (1996) suggest that the high spatial and temporal variability in marsh plants preclude the selection of indicators, but that temporal trends at specific sites may provide more reliable information. Also a large number of rare and threatened plant species occur in wetlands, and although they may be inappropriate for use as robust indicators, their presence is important in wetland valuation (Ward {no date}).

Conclusions from theoretical ecology and modeling are important considerations for wetland plant indicator development. In a study of plant diversity and grassland stability (Tilman 1996) observed that biomass variability at the plant community level decreased with increasing richness but populations of specific taxa fluctuate more widely. This suggests that interspecific competition selects species adapted for current conditions, and phases others out, illustrating the need to distinguish between community measures and population dynamics. Another consideration is the distinction between disturbance regimes, and the possibility that a species may be an indicator of pristine conditions for one disturbance and an indicator of stress for another. From a grassland model of diversity and disturbance, Moloney and Levin (1996) conclude that plant species response was a function of disturbance architecture, implying that spatial and temporal autocorrelation of effects (contingency) was necessary to simulate ecosystem dynamics.

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN

Nutrient enrichment affects wetland plant community characteristics, particularly annual, herbaceous and short-lived assemblages such as emergent, submerged and floating species (Adamus and Brandt 1990, Ewel 1990). Invasions in the Everglades sawgrass (*Cladium jamaicense*) communities by *Typha domingensis* and *T. latifolia* have inspired a plethora of studies on nutrient enrichment gradients that appear responsible. Doren et al. (1997) studied community shifts along a phosphorous enrichment gradient in the northern Everglades and

Table 4.3. Plant species indicators of disturbance in inland freshwater wetlands of Florida, based on a review of the literature.

Stressor	Tolerant or increasing species	Intolerant or decreasing species	Reference
Phosphorus Enrichment	*Typha domingensis* *Amanthus australis* *Rumex crispa*	*Cladium jamaicense* *Utricularia spp.* *Eleocharis spp.* *Nymphaea odorata* *Rhycospora spp.*	Doren et al. (1996)
Phosphorus Enrichment	*Chara sp.*	*Utricularia spp.*	Craft et al. (1995)
Phosphorus Enrichment	*Hymenocallis palmeri* *Typha spp.*	*Peltandra virginica* *Pontedaria cordata* *Sagitaria lancifolia* *Panicum hemitomon* *Cladium jamaicense*	Daoust and Childers (1999)
Phosphorus Enrichment	*Lemna spp.* *Eichhornia crassipes*		Ewel (1990)
TNT & RBX (Explosives) Toxicity	*Potamogeton nodosus* *Ceratophyllum demersum* *Phalaris arundinacea*		Best et al. (1997)
Lead Toxicity	*Eleocharis baldwinii*		Ton et al. (1993)
Salinization	*Juniperus silicicola* *Baccharis angustifolia* *B. halimnifolia* *B. glomerulifolia* *Iva frutescens*		Vince et al. (1989)
Sedimentation and Burial	*Typha latifolia* *Ludwigia peruviana* *Mikania scandens*		Carr (1994)
Agricultural activities	*Eleocharis spp.*	*Hypericum fasiculatum*	Broth (1998)
Cattle grazing	*Digitaria serotina* *Paspalum paspalodes* *Polygonum punctatum* *Hydrocotyle spp.* *Juncus effusus*		Winchester et al. (1995)

Table 4.3. (Continued). Plant species indicators of disturbance in inland freshwater wetlands of Florida.

Stressor	**Tolerant or increasing species**	**Intolerant or decreasing species**	**Reference**
Silviculture	*Persea borbonia* *Magnolia virginiana* *Gordonia lasianthus*	*Taxodium distichum* *Taxodium ascendens*	Conde et al. (1987)
Fire suppression and subsequent hotter fires	*Pinus elliottii* *Pinus taeda*	*Sabal palmetto*	Vince et al. (1989)
Fire suppression	*Cephalanthus occidentalis* *Salix carolinana*	*Hypericum fasiculatum*	Winchester et al. (1995)
Subsequent hotter fires	*Rhyncospora spp.* *Panicum hemitomon*	*Pontedaria cordata*	Winchester et al. (1995)
Fire suppression	Shrubs	Emergent macrophytes	Kushlan (1990)
Off-Road-Vehicle Tracks	*Bacopa caroliniana* *Utricularia spp.* *Dichromena colorata*	*Cladium jamaicense* *Muhlenbergia sp.*	Duever et al. (1981)
Physical disturbance due to Right-of-Way Installation	*Micranthemum umbrosum* *Paspalum notatum* *Justicia ovata* *Juncus marginatus* *Dicanthelium dichotomum*		Shem et al. (1994) & Van Dyke et al. (1993)
Turbidity/Shading	*Vallisneria americana* *Myriophyllum spicatum* *Ceratophyllum demersum*		Davis and Brinson (1981)
Desiccation	UPL and FACU species	OBL and FACW species	FWS (1990)
Excessive inundation	*Typha latifolia*	*Salix caroliniana* *Eleocharis spp.* *Rhycospora spp.*	David (1994)
Increased hydroperiod	*Sagitaria lancifolia* *Nympaea odorata* *Utricularia spp.*	*Rhycospora tracyii* *Baccharis spp.*	David (1996)
Increased hydroperiod	*Utricularia spp.*	*Cladium jamaicense*	Busch et al. (1998)
Stabilized high water	*Typha spp.*	*Cladium jamaicense*	Kludze and Delaune (1996)

Table 4.3. (Continued). Plant species indicators of disturbance in inland freshwater wetlands of Florida.

Stressor	Tolerant or increasing species	Intolerant or decreasing species	Reference
Increased inundation		*Quercus spp.* *Carpinus caroliniana* *Morus rubra*	Titus (1990)
Decreased inundation depth	*Cladium jamaicense*	*Typha latifolia*	Koch and Rawlik (1993)
Increased hydroperiod	*Utricularia spp.* *Nympaea odorata* *Bacopa caroliniana* *Eleocharis elongata* *Panicum hemitomon*	*Oxypolis filiformis* *Dichromena colorata* *Ludwigia repens* *Sacciolepis striata* *Rhycospora tracyii* *Andropogon spp.* *Aster spp.* *Erianthus giganteus* *Pluchea odorata*	Wood and Tanner (1990)
Increased inundation stress	*Mikania scandens*	*Sarcostemma clausum*	Moon et al. (1993)
Decreased hydroperiod	*Toxicodendron redicans* *Smilax spp.* *Quercus spp.* *Liquidambar styraciflua* *Sabal palmetto*		Titus (1996)
Desiccation	*Eupatorium cappillifolium* *Amphicarpum muhlenbergianum* *Rubus betulifolius* *Panicum hemitomon*		Rochow (1994)
Desiccation	species listed in Rochow (1994) *Myrica cerifera* *Paederia foetida* *Phytolacca americana* *Passiflora incarnata*		Ormiston et al. (1995)
Desiccation	*Andropogon glomeratus* *Diospyros virginiana*		Edward and Denton (1994)

Table 4.3. (Continued). Plant species indicators of disturbance in inland freshwater wetlands of Florida.

Stressor	Tolerant or increasing species	Intolerant or decreasing species	Reference
Decreased Hydroperiod	*Panicum hemitomon* *Rhyncospora spp.* *Serenoa repens* *Sagitaria lancifolia*	*Pontedaria cordata*	Kushlan (1990)
Desiccation	*Melaleuca quinquenervia* *Myrica cerifera*	*Typha spp.* *Crinum americanum* *Eleocharis spp.*	Hofstetter (1990)
Desiccation	*Dicanthelium ensifolium* *Hypericum tetrapeletum* *Lyonia fruticosa* *Xyris caroliniana*	*Bacopa caroliniana* *Gratiola racemosa* *Eriocaulon compressum*	SFWMD (1996)
Shortened hydroperiod	*Melaleuca quinquenervia*		Ewel (1990), Kushlan (1990)
General urbanization	*Boehmaria cylindrica* *Pilea pumila* *Impatiens capensis* *Hypericum mutilatum* *Juncus effusus* *Polygonum sagitatum* *Galium obtusum*		Small (1996)
Habitat fragmentation	*Typha spp.* *Salix carolinana* *Eupatorium cappillifolium* *Biden alba* *Schinus terebinthefolius* *Melaleuca quinquenervia* *Urena lobata* *Paspalum notatum*		Brown and Tighe (1991), Gunderson (1994), Schmitz and Simberloff (2000)
Phosphate mining effects	*Wolfiella spp.* *Wolfia spp.* *Azolla spp.*		Crisman et al. (1997)

documented the reduction of nutrient sensitive species such as *Utricularia* spp., *Eleocharis* spp., *Nymphaea odorata*, and *Rhyncospora* spp. In addition to *Typha* spp., non-native species such as *Amaranthus australis* and *Rumex crispa* increase in response to elevated nutrients. Biogeochemical studies identify phosphorus as a primary agent driving nutrient enrichment in the Everglades (Craft and Richardson 1997, Craft et al. 1995, Reddy et al.1993).

Bladderwort (*Utricularia* spp.) has attracted attention as a potential early-warning indicator of nutrient enrichment. Moderate levels of P-enrichment in the water column encouraged growth of *Chara* spp., a macroalga, which replaced bladderwort several years before other measurable shifts in wetland plant community composition or dominance were apparent (Craft et al. 1995). *Utricularia* spp. is particularly sensitive to enrichment because the periphytic communities upon which it depends are highly nutrient sensitive, decreasing in dominance with subtle changes in water quality (Kushlan 1990).

Daoust and Childers (1999) examined the N:P ratios at which nutrient limitation occurs in the Everglades. Wet prairies were highly P-limited at N:P ratios above 36:1 and *Cladium jamaincense* remained dominant, with sub-dominants including *Peltandra virginica*, *Pontedaria cordata, Saggitaria lancifolia* and *Panicum hemitomon*. When N:P ratios dropped below this threshold, *Typha* spp. became increasingly dominant. *Hymenocallis palmeri* was shown to be N-limited and may signal a change in nutrient regime.

Several studies caution using *Typha* spp. as a direct indicator of P-enrichment. Maceina (1994) suggests that water levels have synergistically interacted with elevated nutrient levels to favor cattail growth, and that removal of the enrichment source may be insufficient to inhibit the pattern. Similarly, Kludze and DeLaune (1996) show that *Typha* spp. responds favorably to increased redox intensity, suggesting that hydropattern (depth and duration of flooding) plays an essential role in cattail colonization. David (1996) reports that *Typha* spp. invaded marsh communities in Lake Okeechobee in response to increased hydroperiod.

Few recent papers were found on wetland plant community response to nutrient enrichment in regions other than the Everglades. Palis (1997) documented the effects of vegetation shifts due to silvicultural based enrichment in depression marshes on the flatwoods salamander. Ewel (1990) reports that a general response to nutrient enrichment in forested wetlands of Florida is an increase in understory and floating vegetation such as *Lemna* spp. and *Eichhornia crassipes*. Hoyer et al. (1996) surveyed macrophyte communities in lake littoral zones throughout Florida listing species typical of eutrophic and oligotrophic conditions.

CONTAMINANT TOXICITY

Effects of toxic substances are generally not manifested in wetland plant community assemblages (Adamus and Brandt 1990), though plants may concentrate contaminants at levels harmful to higher trophic organisms. Cooke and Azous (1993) found metal accumulation in plant tissues rose as a function of urban proximity. Tsuji and Karagatzides (1998) examined lead accumulation in northern marshes from spent gunshot and found no correlation between increased lead in soil and lead in plant tissue, which remained at background concentrations. Emergent or floating species with soft-tissue may be promising indicators of metal toxicity. Several studies document wetland plants propensity for toxic contaminant attenuation. Best et al. (1997) studied the use of emergent and submerged plants to remove TNT and RBX (explosive materials) from contaminated groundwater in Iowa and concluded that *Potamogeton nodosus*, *Ceratophyllum demersum and Phalaris arundinacea* were most effective.

In Florida, several studies have examined accumulation of metals in wetlands. Ton (1990) and Ton et al. (1993) studied the fate of lead from battery manufacturing in a North Florida swamp. A compendium volume of Ton's research and others, edited by Odum et al. (2000), titled Heavy Metals in the Environment – Using Wetlands for Their Removal, provides description and analysis of the ecology, energetics and distribution of lead in swamps. The authors report slow lead accumulation rates in woody and shrub vegetation but effectively higher rates in fast growing species such as *Eleocharis baldwinii* and in components of woody plants with high turnover such as leaves and shallow roots. A conclusion is that marsh systems may be more effective sinks for lead due to shallow rooting of emergent macrophytes.

Miles and Fink (1998) examined the ability of constructed marshes to remove mercury and methyl-mercury from Everglades water. Mercury accumulated primarily in the soil, while methyl-mercury had large fractions in the soil, plants and animals. Marsh attenuation measured 70% and mercury bioaccumulation in large-mouth bass within the marsh was lower than in surrounding areas. McLeod and Ciravalo (1998) studied Boron removal by bottomland tree species, identifying *Betula nigra*, *Nyssa aquatica*, *Platanus occidentalis* and *Taxodium distichum* as tree species with the highest uptake, though no significant changes in growth parameters were observed. The authors conclude that at low concentrations, Boron is not toxic to bottomland hardwoods.

ACIDIFICATION

No studies were found in a search of the literature between 1990 and 1999 on the direct effects of acidification on inland freshwater wetland plants in Florida or the Southeastern Coastal Plain. In general, pH tends to be an important factor in northern depression and lacustrine wetlands (Adamus and Brandt 1990), and less so in southern swamps and marshes. In Florida, depression wetlands dominated by *Taxodium ascendens* tend to have naturally occurring pH levels less than 5.5 (Ewel and Odum 1984). Hoyer et al. (1996) document freshwater plant species typically found in low pH lake fringe wetlands of Central Florida (Table 4.2), though the minimum pH documented in their lake study was 5.2, corresponding to pH levels of Florida freshwater wetlands receiving rain as the primary water source. Low pH associated with acid mine drainage is not common in Florida.

Wetland plants found in phosphorus enriched sites are also common in sites with elevated pH. Acidification effects in Florida may be important by increasing solubility of underlying carbonate geology. Many of the carbonates contain phosphorus, and dissolution may enrich surrounding surface water (Reddy et al. 1993).

SALINIZATION

Gradients between saline and freshwater communities in Florida are generally delineable. Latham et al. (1994) used detrended correspondence analysis (DCA) to distinguish plant community composition of marshes in the Southeastern Coastal Plain along a salinity gradient. With increasing salinity (from oligo- to meso-haline) plant community composition shifted from typical freshwater emergent plants (*Pontedaria cordata, Saggitaria lancifolia*) to typical salt-marsh plants (*Spartina alterniflora, Juncus roemarianus*), with *Scirpus validus* found across the salinity gradient. In hydric hammocks, a measurable species shift occurs with higher salinity with increased dominance by *Juniperus silicicola* and an understory *of Baccharis angustifolia*, *B. halimnifolia*, *B. glomerulifolia* and *Iva frustescens* (Vince et al. 1989). *Cephalanthus occidentalis* and *Nyssa sylvatica* var. *biflora* are both sensitive to salinity in excess of 2 ppt, with responses most evident in gross photosynthesis, stomatal conductance, water pressure potential, and stem and root biomass (McCarron et al. 1998). Under prolonged lower salinity, and in response to short term pulses of high salinity, *Nyssa* was more sensitive than *Cephalanthus*, though the authors conclude that neither species would survive long-term salinity exposure to 10 ppt.

In general, however, despite an increasing potential of saltwater intrusion into ground and surface waters in Florida, particularly in the Lower Peninsula, the literature is limited. Hoyer et al. (1996) document freshwater plant species typical of above and below average lake pH in Florida lakes (Table 4.2). In their survey, salinity peaks at 90 ppm, which is lower than what might be expected in surface waters receiving saline inflows, but the results indicate a marked compositional shift.

SEDIMENTATION / BURIAL

Effects of sedimentation on freshwater inland wetland vegetation in Florida have not been widely studied, though sedimentation rates may be high in wetlands that are impacted by urban or agricultural runoff, and a considerable literature exists on the ability of wetlands to facilitate the settling of suspended sediments. In a study of storm water impacts on wetland vegetation Carr (1994) report a rapid compositional shift in vegetation under high sedimentation rates, with selection for *Typha latifolia*, *Ludwigia peruviana* and *Mikania scandens*, all registered nuisance species in Florida. Changes in plant composition dropped as sedimentation declined with distance from storm water source.

In a study of the effects of sedimentation in central Pennsylvania wetlands, Wardrop and Brooks (1998) found specific species respond positively to increased sedimentation, but community indices such as richness and diversity were uncorrelated. In a related seed germination study, the authors recorded a reduction in seed viability even under low rates of sedimentation. Dittmar and Neely (1999) found seed bank response to sediments was significantly dependent on sedimentation rates but a non-significant function of sediment texture, with a marked decrease in seed germination with coarser sediments. The authors also documented reduced plant species richness and diversity under high sedimentation.

TURBIDITY / SHADING

Few studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity and shading on plants in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) state that effects of turbidity and shading on wetland plants are most pronounced in submerged aquatic vegetation with excess turbidity resulting in shifts from rooted plants to floating plants or microphytes. Davis and Brinson (1981) introduced a ‘turbidity tolerance index’ for submerged aquatic plants as the ratio of depth maxima of a species to recorded Secchi transparency depth. Adamus and Brandt (1990) provide a list of turbidity-tolerant aquatic plants with several Florida examples (*Valliseneria americana*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Eichhornia crassipes*, *Elodea* spp., *Hydrilla verticillata and Lemna minor*)

Grimshaw et al. (1997), studying macrophyte shading of periphytic communities in the Everglades, found that light transmittance by *Typha* spp. is 15% compared with 65% by *Cladium jamaicense*. Reduced light available for periphytic photosynthesis is predicted to influence the replacement of sawgrass by cattail. Reduced capacity to absorb enriched phosphorus due to loss of the periphyton community may further exacerbate the invasion.

VEGETATION REMOVAL / PHYSICAL DISTURBANCE / FIRE SUPPRESSION

Physical disturbance here includes direct vegetation removal, cultivation, cattle grazing, fire and fire suppression, rooting by feral hogs, and off-road vehicle use.

Typical plant responses to grazing and cultivation in Florida wetlands are outline in Winshester et al. (1995). Winshester et al. (1995) describe the displacement of *Hypericum fasiculatum* by grasses *Digitaria serotina* and *Paspalum paspalodes* and forbs *Polygonum punctatum* and *Hydrocotyle* spp. under high cattle stocking densities. Grazing may result in a selection of unpalatable species such as *Juncus effusus*. Arrington (1999) found that feral hog rooting significantly reduced plant cover and biomass in a broadleaf floodplain marsh, but increased plant species diversity and richness.

Conde et al. (1987) used Sorensen’s coefficient of similarity to compare effects of logging in adjacent flatwoods on wetland plant community composition and found herbaceous plant similarity corresponded to silvicultural extent. While woody vegetation similarity was not a robust indicator, the authors predict a greater dominance of bay species (*Persea borbonia, Magnolia virginiana, Gordonia lasianthus*) in cypress wetlands influenced by silviculture. A hydrologic model of flatwoods interspersed with cypress depressions (Sun et al. 1998) predicts increased runoff, sedimentation, and longer hydroperiods resulting from adjacent clearcuts, while selective harvests generate lower impacts.

Fire is an important feature of Florida ecosystems and is often suppressed (Kushlan 1990, Ewel 1990, Gunderson 1994). Fire in hydric hammocks promotes a dominance of *Sabal palmetto* (Vince et al. 1989), and excessively hot fires due to litter accumulation may result in a compositional shift towards *Pinus elliottii* and *P. taeda*. Fire exclusion in marsh depressions changes location and extent of vegetation zones (Winchester et al. 1985) with a *Hypericum fasiculatum* fringe typically invaded by shrubs *Cephalanthus occidentalis* and *Salix caroliniana*. *H. fasiculatum* seeds may be serrotinous, requiring fire for germination. Peat fires can arise if exposed to air for prolonged periods and where fire has been suppressed long enough to allow hotter fires to ignite the organic matter. Peat fires typically result in a shift from mixed emergent communities dominated by *Pontedaria cordata* to communities dominated by *Rhyncospora* spp. and *Panicum hemitomon* (Winchester et al. 1985).

Effects of fire suppression and dehydration are closely linked (Ewel 1990). Drought induced shrub invasions into forested wetlands can promote greater fire frequency and burn intensity. Kushlan (1990) suggests that rapid shrub and tree recruitment in marshes is a direct result of fire suppression, and that most of the plant species that invade are non-native. A study of wetlands in Osceola National Forest (Best et al. 1990) however, found that a composite index of wetland plant status (from 1 = obligate to 5 = upland) was unrelated to fire management. While hydrologic alterations and fire suppression together influence wetland plant community composition and zonation, metrics based on plant assemblages may not be robust enough to separate the stressors. Certainly though plant community characteristics are suitable indicators of cumulative impacts.

Duever et al. (1981) document vegetative shifts due to off-road vehicles in Big Cypress Preserve in South Florida and found that off-road vehicle (ORV) impacts were most pronounced in regions with elevated water tables. *Cladium jamaicense* and *Muhlenbergia* spp. were most sensitive to ORV impact and were generally replaced by *Bacopa carolinana*, *Utricularia* spp. *and Dichromena colorata*. The response of *Utricularia* spp. is notable due to the genera’s known sensitivity to nutrient enrichment. Shem et al. (1994) and Van Dyke et al. (1993) studied vegetation shifts from placement of gas pipelines in North Florida and report that plant species diversity and richness were elevated in the right-of-ways (i.e., disturbed) areas and plant community similarity indices were significantly different. Dominant cover species in the ROW areas were primarily opportunistic non-natives (*Micrantemum umbrosum* and *Paspalum notatum*), and sub-dominants included *Justicia ovata*, *Juncus marginatus* and *Panicum dichotomum*.

Broth (1998) found a shift from annual to perennial plant species in Montana wetlands was a robust indicator of cultivation stress: species of *Eleocharis* increased, while mosses and other non-vascular plants were highly sensitive and declined. Cultivation and grazing also resulted in an increased occurrence of dominant species compared with reference sites. The study also found that wetland edges were more affected than aquatic beds and that plant species generally migrate toward deeper water in the presence of grazing. This suggests that a comparison of plant rooting depths in reference and impacted wetlands might be an indicator of grazing stress.

Wetland plant responses to natural disturbance are difficult to separate from responses to human induced stress but responses may be amplified from coupled influences (Loope et al. 1994. Gunderson 1994). For example, the effects of Hurricane Andrew in 1990 on forest wetlands of the southern peninsula directly resulted in tree-falls, epiphyte removal and extreme hydrologic conditions. Long-term impacts, however, are related to the diffusion of non-native propagules into new regions and the proliferation of vines and ruderal species due in part to loss of canopy cover.

THERMAL ALTERATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of thermal alteration on plants in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Plant physiology is generally affected at extreme high ($> 45^o$ C) and low ($< 0^o$ C) ambient water temperatures. Adamus and Brandt (1990) state that changes in thermal regime can cause changes in production and shifts in herbaceous species composition of wetland plant communities. Danielson (1998) also located few studies on wetland plant response to temperature. Both reviews conclude that vascular plants are likely poor indicators of thermal alteration in freshwater wetlands.

DEHYDRATION / INUNDATION

Hydrology is considered the principal variable directing wetland plant community structure and function (Mitsch and Gosselink 1993, Kushlan 1990, Ewel 1990). Wetland hydrology is determined by landscape position, hydraulics and primary water sources (Brinson 1993, 1995, 1996). Changes in the pattern (duration, frequency and timing) and magnitude of inundation affect plant growth rates and morphology, seed production, germination and diversity. Ewel (1990) notes that lengthening hydroperiod may have fewer effects on plant community composition than shortening it. Longer hydroperiods are generally more conducive to herbaceous plant communities (Sharitz and Gresham 1998). Reviews by Adamus and Brandt (1990) and Danielson (1998) document a vast literature on wetland plant response to hydrologic alteration in other states and from Florida studies prior to 1990. Several recent Florida studies characterize the plant effects of wetland drying and others have examined wetland plant response to water stage stabilization at abnormally high levels.

Wetland plant communities are commonly described using composite indices of state and federally assigned designations of typical hydric affinity for plant species. Wetland plant status is scaled from obligate (OBL) to upland (UPL) with intermediate designations (facultative -FAC and facultative wet - FACW). A test of wetland delineation techniques in Osceola National Forest found a high degree of correlation between wetland status metrics and hydric soil characters (Best et al. 1990). The strongest relationship was recorded for herbaceous plant species and no correspondence was measured for woody species and trees. A study of depression wetland ecotones in longleaf pine-wiregrass communities in southwest Georgia used wetland plant status designations to discern plant communities along a hydrologic gradient (Kirkman et al. 1998). The authors document consistent discontinuities in plant community composition and a delineated boundary identified by plants designated 'facultative', and suggest that frequent fire in part determined co-dominance of hydrophytes and non-hydrophytic plants and a high species diversity in the ecotone. Ormiston et al. (1995) studied floodplain swamps above a wellfield near Tampa and found that average wetland plant status was significantly higher (more 'facultative' and 'upland' species and fewer 'fac-wet' and 'obligate' species) in sites within the 3-ft and 1-ft draw-down contours than outside the cone of depression.

Individual plant species response can be observed from hydrologic change. North of Tampa Bay, where groundwater pumping has significantly lowered aquifer levels, several indicators are observed including: more tree falls, increasing rates of limb loss, greater root exposure from higher soil oxidation and a higher occurrence of peat fires (ESE 1995, Ormiston et al. 1995, Rochow 1994). Wetland tree mortality increased at depths greater than 20 cm in the Ocklawaha River floodplain from elevated water levels after construction of the Rodman Reservoir (Harms et al. 1980). The regeneration of *Taxodium* spp. requires a specific sequence of hydrologic events (prolonged flooding followed by draw-down followed rapidly by moderate inundation) that is not likely to occur under an altered hydrologic regime (Ewel 1990). Wood and Tanner (1990) report that tussock height (i.e., height of the meristem) of *Cladium jamaicense* was greater in sawgrass marshes with elevated water levels, rendering them more susceptible to mechanical disturbance such as airboats.

Keeland and Sharitz (1997) studied the tree growth rates in forest depressions (*Nyssa sylvatica* and *Taxodium distichum*) under two hydrologic regimes: permanently flooded and periodically flooded. Growth rates were correlated with inundation depth for periodically flooded trees but not for permanently flooded ones, but no significant difference was measured between tree growth rates.

Morphological changes in plants may also indicate restructured hydrologic regimes. A study in South Carolina of root response in *Taxodium* spp. to inundation (Megonigal and Day 1992) found that cypress trees that were permanently inundated had shallower roots, less overall below-ground biomass and greater leaf biomass than trees that were not continuously inundated. The presence of adventitious roots, intercellular air-spaces and distinctly different root colors and textures were also noted. The authors observed that periodically flooded cypress trees were more effective at resisting drought stress. These results corroborate Hook and Brown (1973) who identified root morphology response to hydrologic gradients in several tree species (*Liquidambar styraciflua*, *Nyssa aquatica*, *Fraxinas pennsylvanica* and *Platanus occidentalis*). Only *Liriodendron tuliperfera* displayed no resistance to flooding stress.

Miller et al. (1993) using chromatography analysis identified a flavinoid in the tissue of cypress trees under excessive flooding that was absent in unstressed trees and 3 additional compounds were identified only in the unstressed cypress. As such, biomarkers or the use of chemical indicators in plant tissue, may provide early warning of hydrologic alterations.

Shifts in plant community structure and zonation can occur due to changes in hydropattern. On Lake Okeechobee in Southern Florida, David (1994) documented a 35% loss of *Salix* *carolinana* communities due to artificially high water levels, a concurrent decline in cover of *Eleocharis* spp. and *Rhyncospora* spp., and an increase in *Typha domingensis*. Wading bird nesting in the region declined from 10000 to 3 nesting sites over 15 years. David (1996) observed an increase in dominance of *Sagitaria lancifolia*, *Nymphaea odorata* and *Utricularia* spp. due to longer hydroperiods and a concurrent decline in *Rhyncospora tracyii* and *Baccharis* spp. Cattail increased in importance, but this change could not be distinguished from the response to enrichment. Busch et al. (1998) corroborated the positive response of *Utricularia* spp. to longer inundation and deeper water levels, but found that *Cladium jamaicense* dominance was negatively correlated with water depth.

Stabilized water levels in the Water Conservation Areas of South Florida are implicated as a primary factor in the displacement of *Cladium jamaicense* to *Typha* spp. (Kludze and DeLaune 1996). This is primarily due to adaptations in cattail for tolerating highly reduced soil conditions, which the authors directly correlated with water depth. Titus (1990) studied microtopographic relief in floodplain forests and concluded that dry micro-sites were essential for retaining *Taxodium distichum*, *Ulnus americana* and *Fraxinus caroliniana* in wetlands where water levels were stabilized, whose seedling distribution were best correlated with micro-site elevation. In hydric hammocks, it is predicted that increased inundation stress will result in a loss of *Quercus* spp., *Carpinus caroliniana* and *Morus rubra*. Management of higher water levels from 1992 to 1995 in wet prairie habitats of Southwest Florida caused a change from the favored muhly grass (*Muhlenbergia filipes*) dominated habitat to a habitat dominated by sawgrass (*Cladium jamaicense*) (54% muhly in 1992 to 25% in 1995) (Nott et al. 1998).

In the Everglades, Koch and Rawlik (1993) report generally higher transpiration and conductance rates for *Typha domingensis* (11 mmmol/m^2/sec) than for *Cladium jamaicense* (min 7 mmmol/ m^2/sec), measured in the winter and spring months. Annual transpiration rates for both species were 1 to 2 mmmol/ m^2/sec greater at a eutrophic site than at oligotrophic sites. These results at the leaf scale suggest that nutrient enrichment and vegetation shifts have the potential to alter water balances in the Everglades and may amplify the dehydration processes.

Newman et al. (1998) concluded that multiple and interacting factors influenced cattail invasions in the northern Everglades. While nutrient enrichment was a primary variable, vegetation shifts also occurred in areas that were not P-enriched. Rather, a synergistic interaction between increased depth of inundation, P-enrichment, and episodic fires set conditions suitable for sawgrass displacement and cattail invasion. Historically Typha spp. was restricted to deep water areas and around alligator holes, and increased inundation depths may favor cattail over sawgrass. Peat fires may increase availability of mineral nutrients and lower substrate elevation, conditions favorable to cattail.

Wood and Tanner (1990) used ordination techniques to classify Everglades graminoid communities into functional groups with hydropattern as the primary descriptive variable. Plant community associations followed a hydrologic gradient: wet prairies occupied the deepest zones; communities dominated by the medium growth form of *C. jamaicense* occurred in areas with less standing water; and tall sawgrass stands in the shallowest areas.

Increased hydroperiod caused vegetation shifts in all communities. In wet prairies, *Utricularia* spp. and *Nymphaea odorata* increased in extent with elevated water levels, along with *Bacopa carolinana*, *Eleocharis elongata* and *Panicum hemitomon*. Wet prairie species that required annual draw-down for seed germination were not found with increasing hydroperiod, including *Oxypolis filiformis*, *Dichromena colorata*, *Ludwigia repens*, *Sacciolepis striata* and *Rhyncospora tracyii*. In sawgrass communities elevated water levels resulted in a loss of *Andropogon* spp., *Aster* spp., *Erianthus giganteus*, *Pluchea odorata* and *Sarcostemma clausum*.

Climbing hempweed, *Mikania scandens*, a noxious plant in Florida, also responds favorably to inundation stress during early life stages is (Moon et al. 1993). The vine has adapted stem stomata for gas exchange, which is unique, and can readily produce aerenchymous tissue to transport oxygen to the root zone. Climbing hempweed is a noxious plant with strong presence in wetland edges and disturbances in central and South Florida. Normal hydropatterns in riparian wetlands appear to favor the selection of *Panicum rigidulum*, *Panicum dichotomum* and *Chasmanthium laxum*, while sites with lower flood frequency tend to be dominated by *Toxicodendron radicans* and *Smilax* spp. Titus (1996) predicts that reductions in inundation magnitude and duration in forest floodplains would result in an increase in dominance of *Quercus* spp., *Liquidambar styraciflua* and *Sabal plametto*.

Draw-down effects on wetland plant community composition are well documented. Rochow (1994) monitored wetlands overlying cones of depression from groundwater withdrawal in West Florida and found rapid invasions by *Eupatorium capillifolium*, *Amphicarpum muhlenbergianum*, *Rubus betulifoilus* and *Panicum hemitomon*. In addition to the species listed above, Ormiston et al. (1995) documented the recruitment of *Myrica cerifera*, *Paederia foetida*, *Phytolacca americana* and *Passiflora incarnata* in response to groundwater draw-downs. Edwards and Denton (1993) monitored a wellfield site in Pinellas County and found that common invaders include *Andropogon glomeratus* and *Diospyros virginiana*. Kushlan (1990) suggests that common plant indicators of prolonged dry conditions in marshes are *Panicum hemitomon*, *Rhyncospora* spp., *Serenoa repens*. Though both are obligate wetland plants, *Pontedaria cordata* may replace *Sagitaria lancifolia* during periods of drought. In the Everglades, however, David (1996) found the distribution of *Sagittaria lancifolia* increased significantly with longer flooding duration.

Sonenshein and Hofstetter (1990) document marsh vegetation changes within a regional wellfield in the Southern Florida peninsula. In the site most impacted by the cone of depression, *Melaleuca quinquenervia* was highly invasive, along with *Myrica cerifera*. Wetter sites outside the cone of depression, supported *Typha* spp, *Crinum americanum*, *Sagitaria lancifolia* and *Eleocharis* spp., but there was a clear trend of increased dominance by shrubs and trees.

In an effort by South Florida Water Management District to develop metrics of hydrologic alteration in depression wetlands, Bridges (1996) discusses the difficulty of extracting metrics from wetlands for which normal variability is extreme. Certain species, such as *Andropogon* spp., *Aristida rhizomorpha* and *Amphicarmpum muhlenbergianum* may be poor indicators because they have adapted to a wide variety of hydrologic conditions in ephemeral marshes. Trees, long-lived shrubs and some graminoids (*Panicum hemitomon, Cladium jamaicense*) may also be poor indicators because they can withstand intense periodic hydrologic stress. Bridges (1996) recommends some general indicators for the South Florida region including *Bacopa caroliniana*, *Gratiola racemosa* and *Eriocaulon compressum*, as they are all sensitive to desiccation. More specific indicators of a trend towards drier conditions include *Dicanthelium ensifolium*, *Hypericum tetrapetalum, Lyonia fruticosa* and *Xyris carolinana*.

Ewel (1990) and Kushlan (1990) articulate several plant responses to draw-down typical in the Everglades. *Melaleuca quinquenervia* invasion in the Everglades is strongly facilitated by hydropattern changes with drier periods than were normal under historical conditions. Marsh succession to a shrub/scrub community can be attributed to drier conditions. *Taxodium distichum*, though appearing healthy in abnormally dry substrates, will not be able to regenerate. Cooke and Azous (1993) argue that non-native plant species presence and distribution increase with drastic changes in hydropattern.

The Kissimmee River restoration effort has focused on re-hydrating emergent marshes that were characteristic of the region prior to channelization (Toth 1993). A demonstration project showed a marked shift in species composition after rehydration. Former (pre-channelization) dominants that returned were *Eleocharis vivipara*, *Panicum hemitomon, Polutgonum punctatum* and *Salix caroliniana* in addition to the invasive hydrophyte *Alternanthera philoxeroides*. The importance of meso- and xero-phytic species that colonized when the wetlands dried decreased after re-flooding, including *Ambrosia artemisiifolia, Axonopus affinis, Axonopus compressus, Boltonia diffusa, Centella asiatica, Eupatorium capillifolium, Hydrocotyle* spp., *Paspalum conjugatum*, *Sambucus canadensis* and *Urena lobata*.

HABITAT FRAGMENTATION / DISTURBANCE

Despite new research in GIS, few studies were found in a search of the literature between 1990 and 1999 on direct effects of habitat fragmentation and disturbance on plants in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. In general, fragmentation will favor those species that can disperse seeds widely (e.g. *Typha* spp., *Salix caroliniana, Eupatorium capillifolium* and *Bidens alba*) and those that are opportunistic invaders after a disturbance (e.g. *Schinus terebinthefolius*, *Melaleuca quinquenervia, Urena lobata Paspalum notatum*) (Doherty 1991, Brown and Tighe 1991, Gunderson 1994, Schmitz and Simberloff 1997).

There is a large body of research on wetland restoration and construction on phosphate mined lands in Florida (Brown and Tighe 1991, Crisman et al. 1997, Richardson et al. 1998). Erwin et al. (1997) summarize the literature and analyzed the available data base on created wetlands to determine current technical, operational, and ecological success of wetland construction. One of seven research components, a section on ecosystem and landscape organization addresses 3 subject areas: ecological connectedness, hydrological connectedness, and community fitness. An upland to wetland ratio was higher in reclamation projects than in the regional landscape with agriculture the dominant land cover. These landscape parameters likely influence successional trajectories and restoration successes, explaining in part a documented trend of declining obligate wetland species and no concurrent decline in plant species richness in herbaceous wetlands on reclaimed lands.

Doherty (1991) used principle component analysis and general linear models to investigate the role of landscape organization on ecological restoration in phosphate mined and abandoned agricultural lands in Central Florida. Tree species composition on sites 40 years and older were 70% similar to one another and on average 30% similar to natural communities displaced as a result of the land-use. Swamps and sandhills, which have been displaced at the greatest rate in the region, were not returning. Age since abandonment was the most predictive variable in determining structural factors such as tree density, basal area and ground cover, though ‘interaction potential’ of and mean distance to forest areas were better predictors of overall species richness and herbaceous and tree diversity than age alone.

Crisman et al. (1997) compare reclaimed marshes in the phosphate mining district of Central Florida and nearby reference marshes, and conclude that, while plant species similarity indices are low, chemical function and landscape function are comparable. In general, invasive species tend to concentrate in the reclaimed sites, but non-native cover drops to background levels within 7 years. Higher densities of floating plants were found in the reclaimed sites, with an abundance of *Wolfiella* spp., *Wolfia* spp. and *Azolla* spp.

Schmalzer and Hinckle (1990) state that of the 1045 plant species found at John F. Kennedy Space Center, 195 were non-native, and 76 were listed as endangered, threatened or of special concern. They suggest a qualitative relationship between proximity to disturbed regions and the density of non-native (positive) and endangered (negative) species.

Research in other states on plant response to landscape fragmentation and disturbance is available. Miller et al. (1997) measured landscape pattern in central Pennsylvania and conclude that general landscape descriptors (diversity, contagion, mean forest-wetland patch size, proportion of forest cover, forest edge) were most effective at predicting disturbance levels and changes manifested in bird and plant communities. Azous et al. (1998) studied 19 wetlands in Washington, finding significant correlation between disturbance gradient and community attributes, including canopy closure, nesting cavities, vegetation distribution and dominance, woody debris, presence of thin-stemmed emergent vegetation, plant species richness and non-native species cover. Azous and Horner (1997) found direct correspondence between plant species richness and impervious surface in a Washington watershed, but a less significant relationship was found between weedy native and exotic plant species and disturbance.

Fennessey et al. (1998) developed a Floristic Quality Assessment Index (FQAI) to indicate landscape disturbance effects on wetlands. The FQAI is a scoring technique that assigns a quality rating to each plant species present in a wetland based on general disturbance response:

0	Opportunistic native invaders and non-native taxa.
1-3	Widespread ubiquitous taxa that do not indicate a specific community with a wide range of tolerances.
4-6	Taxa that typify some successional phase of a native community, tolerant of some disturbance.
7-8	Taxa associated w/ advanced succession, community specific, tolerant of minor disturbance.
9-10	Taxa that exhibit high degrees of habitat fidelity to ecological condition, endemism, and a narrow range of environmental parameters.

Average index scores [Species Tolerance Score / (No. Native Species)$^{1/2}$] for wetlands correlated with a qualitative disturbance gradient. The FQAI score was also correlated with site biomass, total-P in the water column, buffer zone presence and distance to the nearest propagule source.

Small (1996) quantified macrophyte response to watershed development in the Chesapeake Bay region and found that most (75%) of the riparian wetlands could be categorized along a disturbance gradient using only plant species richness as an indicator. Ten species drop out as landscape disturbance increased: *Boehmaria cylindrica*, *Pilea pumila*, *Impatiens capensis*, *Hypericum mutilum*, *Juncus effusus*, *Polygonum sagitatum* and *Galium obtusum*.

Chapter 5: MACROINVERTEBRATES

USE AS INDICATORS

Macroinvertebrate assemblages are particularly appropriate for use in multi-metric indices of biotic integrity in streams (Karr 1997) and may also be robust indicators for wetland biological assessment. Invertebrates are abundant and easily sampled, and the species living in virtually any water body represent a diversity of morphological, ecological, and behavioral adaptations to their natural habitat. A diverse component of wetland habitats, macroinvertebrates respond quickly to changes in physical, chemical or biological parameters (Stansly et al.. 1997). Structure and function of macroinvertebrate communities reflect biological conditions, and change in predictable ways with increased human influence.

Macroinvertebrates are also an important link in wetland food webs as most vertebrate and higher trophic organisms are dependent upon invertebrate populations (Hart and Newman 1995). Removal of aquatic arthropods would likely cause a local collapse of fish, amphibian, reptile, and wading bird populations (Trott et al.. 1997). However, evaluation of impacts of environmental perturbations to wetland macroinvertebrate assemblages is a daunting task, given poor taxonomic knowledge of groups such as Chironomids (midges) that may represent more than 50% of total secondary production in depression wetlands of South Florida (Stansly et al. 1997).

Macroinvertebrate assemblages are used as biological indicators in streams in several states including Florida (Kerans and Karr 1994; Barbour et al. 1996). Florida Department of Environmental Protection (FDEP) developed the Stream Condition Index (SCI) and the recently employed Rapid BioRecon Method using macroinvertebrate assemblages to evaluate biotic integrity. Samples are collected using dip net sweeps in representative substrate. Biological condition is determined using a multi-metric approach comparing test stream results with regional reference conditions, assumed to be the best attainable condition of the water resource. For Florida streams the best macroinvertebrate metrics are: Florida Index species, EPT taxa (Ephemeroptera, Plecoptera, Trichoptera), percent dominant taxon, and percent gatherers. All indices decrease with increased pollution or disturbance except for the % dominant taxon (Barbour et al. 1996).

FDEP has recently been developing a method of assessing biotic integrity of lakes (Gerritsen and White 1997). This method employs grab samples of macroinvertebrates from lake sediments just beyond the littoral zone, with either a Petit Ponar or Eckman dredge, in 60-100 cm deep water (aquatic bed-littoral zone). Results are compared with reference conditions using multi-metric indices suitable for lakes. Metrics under consideration are: taxa richness, Shannon-Weiner diversity, Hulbert index, ETO taxa (Ephemeroptera, Trichoptera, Odonata), percent dominance, percent filterers, percent ETO, and percent gatherers. Use of two trophic state indicators (Secchi depth and Chlorophyll-a concentration) in conjunction with a lake IBI may best determine the biological condition of a lake (Gerritsen and White 1997).

FDEP uses a preliminary wetland Bio-ReCon field sheet that scores macroinvertebrate taxa present in dip sweeps using a weighted index for sampled taxa (Table 5.1). Three metrics are currently computed (total taxa richness, total lake index, and total ETO taxa). Wetland health or impairment is determined based on deviation from target values. The scoring and selection of metrics is developed from Bio-ReCon protocols for Florida streams and lakes, the SCI and LCI, and best professional judgment of District Biologists.

The Department of Environmental Resources Management is developing a biomonitoring program for the fresh surface waters in Southern Florida canal systems using the SCI as protocol (Snyder et al. 1998) and adapted for the special conditions facing the canal systems as data are collected and analyzed. Benthic macroinvertebrates are also being used to evaluate the success of restoration projects. Merritt et al. (1996) report on the restoration of the Kissimmee River Basin and identify regional species pools of aquatic insects that potentially occur in the basin. The authors also evaluate the assignation of functional groups based on feeding, habit, and voltinism and the use of calculated ratios to make assessments of ecosystem attributes. Toth (1993) documents invertebrate responses to water level manipulation in a Kissimmee River demonstration project.

Macroinvertebrate communities appear to colonize newly constructed wetlands with reasonable success (Erwin et al. 1997). In a study of the biological success of created marshes in Central Florida, FDEP used components of the SCI and the LCI to assess the benthic macroinvertebrates for the wetlands and compared them to a reference marsh (Division of Technical Services 1994). Results indicate that structural and functional groups of created marshes were moderately close to those of the reference wetland. Macroinvertebrate populations in a natural/created wetland system for advanced secondary treated wastewater in Central Florida were similar to a control wetland (Best 1993). Crisman et al. (1997) reviewed research on aquatic fauna in constructed wetlands on phosphate mined lands in Florida and found that within three years invertebrate communities stabilized in numbers and feeding guilds were generally comparable to those of natural wetlands. Erwin et al. (1997) caution the reader that inferences made from this review may not be accurate due to different monitoring programs, constructed wetland design and substrate conditions.

Dip net sweeps are an effective sampling method for wetland macroinvertebrates (Cheal et al. 1993, Rader and Richardson 1994). However, Turner and Trexler (1997) found that use of three complimentary methods – a funnel trap, a D-frame sweep net and a 1-m^2 throw trap – give a complete representation of a wetland invertebrate assemblage. Turner and Trexler (1997) and Fennessy et al. (1998) found Hester Dendy samplers to be ineffective in wetlands. Stansly et al. (1997) and Gore et al. (1998) used bottle-brush samplers to represent macrophyte substrate, as well as dip nets and Hester-Dendy samplers in their surveys of isolated wetlands in South Florida with satisfactory results. In wetlands, as in other aquatic habitats, it is important to sample all types of substrate and plant communities as macroinvertebrate abundance and distribution vary between habitat types. Streever et al. (1995) sampled Chironomidae in vegetated and non-vegetated areas and found the communities different in each habitat type.

Table 5.1. Taxon and weighted index scores for the FDEP preliminary Wetlands Bio-Recon. Total scores are used in combination with 3 metrics (Total Taxa Richness, Total Lake Index, ETO) to indicate wetland health or impairment.

Taxa	WI	Taxa	WI	Taxa	WI
Diptera		**Tromidiformes**		Ephemeroptera	
Ceratopognidae		Acarina		Callibaetis spp.	
Culicidae		**Oligochaeta**		Caenis spp.	
Empididae		Naiidae			
Other Chironomidae		Tubificidae		**Odonata**	
Clinotanypus spp.	2	Hirudinea		Argia spp.	1
Ablabesmyia spp.	2			Enallagma spp.	1
Procladius spp.	1	Megaloptera		Ischnura spp.	
		Neohermes spp.	2	Lestes spp.	2
Gastropoda				Nehalennia spp.	2
Ferrissia spp.	1	**Hemiptera**		Telebasis byersi	
Hydrobiidae	1	Belostoma spp.			
Littoridinops spp.	1	Corixidae		Anax spp.	
Physella spp.		Hydrometra spp.		Coryphaeschna ingens	2
Planorbella spp.		Pelocoris spp.		Gomphaeschna spp.	2
Pomacea paludosa	1	Pleidae			
Viviparus spp.		Ranatra spp.		Aphylla williamsoni	1
				Argomphus pallidus	1
Pelecypoda		**Other groups**			
Pisidiidae				Epitheca spp.	1
		Decapoda		Somatochlora spp.	2
Coleoptera		Palaemonetes spp.	2		
Dytiscidae		Procambarus spp.		Celithemis spp.	1
Curculionidae				Erythrodiplax spp.	
Dineutes spp.		**Amphipoda**		Erythemis spp.	
Haliplus spp.		Gammarus sp.	1	Libellula spp.	1
Peltodytes spp.		Hyalella azteca		Pachydiplax longipennis	
Hydrophilidae		Crangonyx spp.	1	Tramea spp.	1
Noteridae					
		Isopoda		**Tricoptera**	
		Caecidotea spp.			
				Nectopysche spp.	2
				Orthotrichia spp.	2
				Oecetis spp.	1
				Oxyethira spp.	2
				Triaenodes spp.	2
				Leptocercus spp.	1
				Ceraclea spp.	2
Total score:	____	Total score:	____	Total score:	____

Wetland macroinvertebrate ecology in Florida and the Southeastern Coastal Plain is well researched. Wharton et al. (1982) describe macroinvertebrate fauna of bottomland hardwood swamps by vegetative zone. Batzer and Wissinger (1996) reviewed literature on insect community ecology in non-tidal wetlands, including some found in the Southeastern Coastal Plain. Kushlan (1990) documented invertebrate populations of Florida marshes, including amphipods, dragonflies, damselflies, mosquitoes, gnats, deerflies, horseflies, waterbugs, water beetles and ostracods. Freshwater prawns, crayfish and snails are also found in large numbers and are conspicuously important in food chains.

Haag et al. (1987) found that on floating islands in Orange Lake in North Central Florida, the following macroinvertebrates are a major source of food for Boat-tailed Grackles and Redwing Blackbirds: water bugs (*Belostoma* spp.), plant hoppers (Fulgoridae), diving beetles (Dytiscidae), crayfish (*Procambarus fallax*), shell snails (*Planorbella* spp.), dragonflies and damselflies (Odonata, genus *Libellulidae*), leaf beetles (Chrysomelidae, genus *Donacia*), noctuid caterpillars, rat-tailed maggots (*Eristalis* spp.), water beetles (Hydrophilidae), scarab beetles (Scarabaeidae), soldierfly larvae (Stratomyidae), water hyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*), grasshoppers, arachnids and ants.

Pickard and Benke (1996) studied the amphipod *Hyalella azteca* in southeastern wetlands, on 3 habitats (benthos, *Nymphaea odorata* leaves, and submerged wood) and found that *H. azteca* was most abundant in benthic habitat. Birth and death rates were highest in summer, with predation and/or environmental stress were mortality factors. *Hyalella azteca* does not appear to be a dominant primary consumer. This study is a part of a more comprehensive analysis of invertebrate production in southeastern wetlands. Rader (1994) found one hundred forty-eight macroinvertebrate taxa in sloughs in the northern Everglades. Chironomidae, Gastropoda, and Coleoptera, were the most diverse groups with the greatest densities, and the amphipod *Hyallella azteca* was the most abundant species. *Planorbella duryi* was the most abundant snail, and *Callibaetis floridanus* the most abundant mayfly. Stansly et al. (1997) catalogued 225 macroinvertebrate species in 159 general, 49 families and 13 orders of crustaceans, mollusks and insects in isolated wetlands within the South Florida Water Management District. Oligochaetes and acarines were not included. Chironomids dominated, with odonates, hemipterans, and coleopterans all well represented.

In South Florida's hydric pine flatwoods, Gore et al. (1998) catalogued 292 taxa, of which 60 were various species of chironomids. Fishing spiders (*Dolomedes triton*) are found in the Everglades among dense stands of cattails and sawgrass, but density estimates suggest that they are unlikely to play important roles in the marsh food web (Jordan et al. 1994). Jordan et al. (1996) studied the crayfish *Procambarus alleni* in wet prairies. Mean density and biomass of crayfish increases with increased plant biomass found in densely vegetated wet prairies compared with less dense, deep-water sloughs.

Literature available on macroinvertebrate ecology and responses to stressors in Florida wetlands, combined with the SCI, Rapid BioRecon, the LCI, information on wetland types and locations, and successful sampling methods are a basis to develop a macroinvertebrate index of biotic integrity for Florida wetlands.

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN

Benthic macroinvertebrate species composition responds to trophic state (Cairns and Pratt 1993). For example, tubificid oligochaetes increase with organic enrichment (Barbour et al. 1996). High nutrient wastewater added to a cypress swamp changes the invertebrate community (Ewel 1990), and the addition of stormwater or wastewater to cypress ponds is shown to cause the community to shift to a simpler trophic structure (Harris and Vickers 1984). Duckweed (*Lemna* spp.) mats over the water surface in Florida cypress domes blocks sunlight from the water column creating anoxic conditions (Dierberg and Brezonik 1984), reducing the diversity and biomass of benthic invertebrates, and leaving only a few pollution-tolerant organisms (Brightman 1984). Gerritsen and White (1997) found that sublittoral macroinvertebrate communities in Florida lakes also appear to respond to lake trophic status.

Rader and Richardson (1992, 1994) studied macroinvertebrate response to nutrient enrichment in the northern Everglades. A greater number of coleopteran species (especially in the Hydrophilidae and Dytiscidae families) was recorded in enriched and intermediate areas than in unimpacted sites (total mean annual density of macroinvertebrates at enriched and intermediate sites was 6.1 and 3.5 times greater, respectively, than in the unenriched area). Except for decapods, especially *Palaemonetes paludosus*, the density of each order or class was higher within enriched and intermediate areas. Percent composition measured 2.6 times higher and density of dipterans as 16.2 times greater at enriched and intermediate sites than at the unenriched site. Dominant dipterans at enriched sites were *Dasyhelia* spp., *Goelkichironomus holoprasinus*, *Larsia decolorata*, *Polypedilum trigonus*, *Pseudochironomus* spp., and *Tanytarsus* sp. J. The number of taxa (primarily Chironomidae) did not increase, and was very similar for all sites.

Schwartz et al. (1994) studied impacts of reclaimed water from an advanced wastewater treatment facility on wetland communities in Orange County, Florida. Reclaimed water flows through a distribution created wetland to a natural pond cypress swamp. It then flows into a redistribution created wetland, to a natural hardwood swamp and then exits through a final pond cypress swamp. Aquatic and benthic macroinvertebrates were sampled in the water column and substrate with a modified stovepipe sampler. Shannon-Weaver diversity indices increased overall in all the wetlands during the third year of the study, with the hardwood swamp displaying the highest diversity in each sampling event. Numbers of pollution-sensitive species were highest in the control and exit wetlands. However, all pollution tolerant assemblages were represented in each treatment wetland for every sampling event, indicating good water quality in all wetlands.

Stormwater input to the freshwater marsh in Savannas State Preserve increased phosphorus levels, lowered oxygen levels and raised pH and hardness, resulting in macroinvertebrate population shifts toward pollution tolerant species and those intolerant of typical acidic and oligotrophic conditions of the preserve (Graves et al. 1998).

CONTAMINANT TOXICITY

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of contaminant toxicity on macroinvertebrate communities in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. The reader is referred to Danielson (1998) for a review of recent wetland invertebrate toxicity studies from other regions. Here, select studies from other regions that may have relevance to Florida wetlands are reviewed. Lenat (1993) reports that toxic conditions caused increases in the number and types of deformities in *Chironomus* larvae in streams in North Carolina.

Eisemann et al. (1997) found mercury concentration in apple snails (*Pomacea paludosa*) as high as (0.091ppm) at the Panther National Wildlife Refuge in Florida. Apple snails are an important component of food webs in South Florida wetlands and can serve as indicators of bioavailable mercury. From results of stream studies, Barbour et al. (1996) state that some chironomids of the family Orthocladiinae, genus *Cricotopus,* are tolerant of metal pollution. Other Orthocladinae (*Rheocricotopus* spp. and *Corynoneura* spp.) are thought to be sensitive to metal pollution.

Selenium has become an important environmental contaminant in agricultural arid and semi-arid regions of the western U.S. and in areas where fossil hydrocarbons are mined, processed, and used for combustion. Selenium is a trace element present in coal, crude oil, shale, coal conversion materials and their waste by-products. It is highly concentrated in the mineral fraction (fly ash and bottom ash) remaining after coal is burned. A slight increase in selenium concentration in water can quickly bioaccumulate in aquatic organisms and become toxic to the higher trophic levels (Lemly 1996). While no Florida studies on selenium in wetlands were found in this review, it may be an overlooked toxic contaminant in areas where fossil fuels are stored and burned.

Batzer and Wissinger (1996) found the primary influence of herbicides on wetland insects is indirect, killing the macrophyte and algae food base. Buhl and Faerber (1989) performed toxicity tests of selected herbicides and surfactants on the midge *Chironomus riparius*. The relative order of toxicity to this midge is similar of those for other macroinvertebrates and fish, so results may be applicable to wetland chironomids of southeastern wetlands.

Henry et al. (1994) studied macroinvertebrate survival in Prairie Pothole wetlands of South Dakota treated with a mixture of a glyphosate-based herbicide, a surfactant and a drift retardant used for cattail control. Populations of *Chironomus* spp. (midge), *Hyalella azteca* (amphipod), *Stagnicola elodes* (pond snail) and *Nephelopsis obscura* (leech) were monitored. After 21 days, there was no difference in the survival of the study organisms and those of the control. In laboratory tests, based on nominal formulations of the concentrations, the surfactant was approximately 100 times more toxic than the herbicide, which was about 24 times more toxic than the drift retardant. The authors conclude that these formulations pose no threat to aquatic life, when applied according to the directions, but could be hazardous if used improperly.

Various chemical pest applications are used in agriculture, silviculture and lawn care in Florida, and pesticides in water and sediment can adversely affect wetland macroinvertebrate communities, though no recent studies were found. Broad-spectrum pesticides such as organophosphate mosquito larvicide may unintentionally or indirectly impact other wetland insect populations. The microbial mosquito larvicide *Bacillus thuringiensis israelensis* is much more target-specific and has minimal impact on nontarget insects (Batzer and Wissinger 1996) though mortality has been observed in several taxonomic orders (see Danielson 1998 for review).

ACIDIFICATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of acidification on macroinvertebrate assemblages in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Calcium carbonate common in Florida soils buffers acidity, and activities associated with acidification are not common in Florida. Still, natural differences in pH and alkalinity may be important determinants of macroinvertebrate communities. Highly acidic water generally results in impoverishment of fauna, and low acidities generally reflect better buffering and higher productivity (Adamus and Brandt 1990). Stribling et al. (1995) found that in Montana wetlands, low acidities are positively correlated with metrics of percent dominant taxon, percent amphipoda and Hilsenhoff Biotic Index. Circumneutral pH, but on the acidic end of the range, is positively correlated with the metrics of total taxa, Chironomidae taxa, and percent filterer-collectors.

Experimental acidification of wetland habitats often has shown little impact on insects unless the pH becomes very low. In contrast, low pH may benefit insects in some cases where insectivorous fish cannot tolerate the acidic conditions. Apparently, many wetland insects tolerate broad ranges of environmental pH (Batzer and Wissinger 1996) and may be poor indicators of acid pollution stress.

Metals and acidity interact variously affecting toxicity. Short et al. (1990) found lower macroinvertebrate abundance and diversity in wetlands with low pH and high concentrations of dissolved minerals (Al, Cu, Fe, Mn, Zn). Albers and Camardese (1993) studied the effects of acidification on metal accumulation by aquatic plants and invertebrates in constructed wetlands in Laurel, Maryland. The pH of the acidified wetlands was 5.0, not low enough to cause a difference in amount of the twelve metals released into the water column except for zinc, but calcium was lower in the acidified wetland. The low pH could cause adverse effects on the occurrence of crustaceans and mollusks by threatening egg production and development of young.

SALINIZATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of salinization on macroinvertebrate assemblages in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. However, Stribling et al. (1995) found that salinization is positively correlated with percent dominant taxon while all other metrics decreased as salinity increased in Montana wetlands.

SEDIMENTATION / BURIAL

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of sedimentation on macroinvertebrates in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Generally, benthic species composition is determined by substrate (Gerritsen and White 1997) and invertebrate communities change with erosion and sedimentation. Evans (1996) studied sedimentation in constructed wetlands on Florida phosphate-mined lands and found that gently sloping banks were lower in silt content than steeper slopes, and silt content in sediments decreased with age since construction and bank colonization by freshwater plants.

TURBIDITY / SHADING

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity and shading on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Shading from dense stands of emergent vegetation can limit the productivity of benthic algae (Adamus and Brandt 1990) favoring detritivores over grazers. In a study of California wetlands, De Szalay and Resh (1996) found that fine particulate organic matter settles out with increased shading, providing a rich detritus that supports high numbers of benthic detritivores.

VEGETATION REMOVAL

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of vegetation disturbance on macroinvertebrates in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on wetland invertebrate response to vegetation removal. Canopy opening and the loss of vegetative structure will likely shift the macroinvertebrate community to more open water, less sedentary, and predatory species.

THERMAL ALTERATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of thermal alteration on macroinvertebrates in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) in their review conclude that in general, heated effluents reduce the richness of invertebrate communities in wetlands and may either increase or decrease their density and productivity. The former may be true in Florida where ambient temperature increases do not necessarily expand ranges or provide over-wintering conditions.

DEHYDRATION / INUNDATION

Hydropattern (depth, duration and periodicity of flooding) entrain wetland community organisms and influence composition, including associated macroinvertebrate assemblages, which either temporarily relocate or cope using behavioral and biological adaptations. Hydroperiod affects the movement of crayfish *Procambarus alleni*, which has been identified as a critical species in the food webs of freshwater marshes of Southern Florida (Frederick and Spalding 1994). The crayfish prefer shallow waters of wet prairies to deeper areas, and disperse during times of inundation (Jordan et al. 1996). Apple snails (*Pomacea paludosa*) are not as adaptable, however, and water level increases threaten their eggs, which are intolerant of submergence (Turner 1998).

During draw-down or dewatering in lakes, benthic macroinvertebrate populations can experience reduced densities or elimination. After refill however, macrophyte densities may increase due to colonization of the increased littoral zone habitat (Greening and Doyon 1990). A draw-down and sediment removal project in Lake Tohopekaliga, Florida (Butler et al. 1992), resulted in lower densities and numbers of invertebrate taxa associated with macrophytes, and bottom-dwelling macroinvertebrates increased in the restored area. The difference was attributed to fish predation on invertebrates associated with macrophytes. Predatory sport fish in the restored lake area increased to three times the number in the control site.

Rader and Richardson (1994) compare 2 wetlands in the northern Everglades; a nutrient enriched area with a shorter hydroperiod and a control site that remained inundated throughout the study. Invertebrate and small fish diversity and abundance was higher in the enriched site with less standing water and 3-6 weeks of no surface water, though the higher measures may be due to the proximity of permanent water to the site that may act as a source for colonizers. Loftus et al. (1986) found that invertebrate and small fish abundances in Everglades National Park declined in marshes with short hydroperiods.

Small pond cypress swamps can remain flooded all year or dry completely four times or more in a single year. Leslie et al. (1997) sampled benthic macroinvertebrates using a stainless steel coring device in three pondcypress swamps in North Central Florida and documented 85 taxa. This is a higher richness count than some other southern wetlands (though other studies typically do not sample sediments). Ninety percent of the samples were found surviving in sediments of dry ponds. 70% of overall density was accounted for by 3 generalist feeders, *Crangonyx* (Amphipoda) and chironomids *Polypedilum* spp. and *Chironomus* spp. Densities of benthic invertebrates in depressions that had been dry for over one month were similar to those with wet months, suggesting that density and distribution metrics may not be robust indicators.

Wetland macroinvertebrates exhibit both behavioral and physiological adaptations to cope with draw-down. *Crangonyx* spp. and several insects including beetles and odonate nymphs can burrow into moist sediments, and some chironomid larvae can withstand draw-down in a cryptobiotic state, as reported by Gore et al. (1998) for wetland depressions in hydric flatwoods of South Florida. Other insects complete their life cycle or have emerged as adults before drought, and other insects lay eggs that withstand desiccation (Stansly et al. 1997, Gore et al. 1998, Batzer and Wissinger 1996).

Aquatic macroinvertebrates that are predatory or have a long life cycle may be indicators of hydroperiod stability in isolated wetlands of South Florida (Stansly et al. 1997). Indicators of persistent water include mayflies, *Caenis*, and odonates *Anax* spp., *Libellula* spp. and *Pantala* spp. The chironomids *Beardius* spp., some members of *Chironomus* and *Tanytarsus,* and *Zavreliella marmorata* also apparently need permanent standing water. Some common species in isolated wetlands, including *Polypedilum trigonus* and *Tanytarsus* sp. B., rarely if ever were found in intermittently exposed wetland (Gore et al. 1998). Other species were typical of intermittently exposed and ephemeral wetlands, including *Ablabesmyia rhamphe* grp., *Krenopelopia* spp., and *Tanytarsus* sp. G.

HABITAT FRAGMENTATION / DISTURBANCE

No studies were found in a search of the literature between 1990 and 1999 on direct effects of habitat fragmentation and disturbance on macroinvertebrates in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Danielson (1998) and Adamus and Brandt (1990) also report a paucity of literature related to wetland macroinvertebrate response to habitat fragmentation and disturbance prior to 1990 and from other regions. Adamus and Brandt (1990) surmise that as the distance between wetlands with colonizers becomes greater, species with narrow environmental tolerances and which do not disperse easily might be most affected.

An example of an insect that may be at risk from landscape scale wetland fragmentation is a distinctive endemic phenotype of *Euphyes dukesi*, a Lepidopteran that was first discovered in Florida in 1971. *E. dukesi* has been found on wetland sedges, *Rhyncospora* and *Carex* (Calhoun 1995). Harris (1988) proposes that surface water pollution probably reduced the production of macroinvertebrates, in turn affecting swallow-tailed kite (*Elanides forficatus*) populations in the Everglades. Destruction of the Citronelle Ponds, wetlands of the Gulf Coastal Plain of Florida, is pervasive due to agriculture and forestry (Folkerts 1997). Presumably invertebrates and other species associated with this wetland type are imperiled with the loss of their habitat.

Colonization of nonnative and noxious species is common in disturbed wetlands. Local invertebrate populations may be affected by introduction and spread of other exotics, such as fish and plants that change the community composition and food webs of wetlands. Rader (1994) found some macroinvertebrate colonists from Central and South America in the northern Everglades. The snail *Marisa cornuarietis* (Ampulariidae) has been introduced in the canals of Dade County and is likely to invade the Everglades (Robins 1971).

Water hyacinth weevils, *Neochetina eichhorniae* and *N. bruchi,* have been introduced in Central Florida as a biological control agent (Haag et al. 1987) but to date have not colonized in numbers sufficient to impair the productivity of water hyacinth and are not known to disrupt community structure.

In a pilot study for the development of a biomonitoring program for the South Florida canal system, Snyder et al. (1998) found that macroinvertebrate taxa with (relatively) long life cycles were reduced in numbers in urban, industrial and suburban canal sites and higher in canals surrounded by wetlands and relatively protected from human impact. Pioneering taxa with comparatively short life cycles and capable of rapid re-colonization were typical of impacted canal sites with early successional communities. Rader (1994) reports an abundance of amphipods and freshwater shrimp (*Palaemonetes paludosus*) abundance in South Florida canals compared with proximate wetlands.

Chapter 6: FISH

USE AS INDICATORS

Fish community characteristics have been used to assess relative ecosystem health since the beginning of the 20th century. Within the past 20 years, scientists have developed integrative ecological indices that directly relate fish communities to other biotic and abiotic components of ecosystems. Research and development in this area have focused on streams, although fish communities may also be useful indicators of wetland health.

Fish are an important food source for wildlife in wetlands and their health and population status is reflected in the wildlife feeding upon them (Hart and Newman 1995). Benefits of using fish as indicators include: the taxonomy of fishes is well established reducing laboratory time by identification of many specimens in the field; the distribution, life histories and tolerances to environmental stresses of most North American fish species are well documented in the literature; and fish are a highly visible component of the aquatic community to the public (Simon 1999). Multiple factors are believed to be responsible for declining populations and extinctions of North American fishes (Williams et al. 1989, Miller et al. 1989), including habitat destruction and modification, introduced species and hybridization, pollution, chemical alteration, overfishing, acidification, and disease.

Jordan et al. (1998) recommend monitoring small-sized fishes of Florida marshes. Several benefits of using small fish include their short life cycle, their quick response to environmental perturbations, their ability to indicate habitat alteration and ecosystem function, and fish are reliably and effectively quantified (Jordan et al. 1997).

As humans alter watersheds and water bodies, shifts occur in taxa richness, species composition, individual health, and feeding and reproductive relationships of fish (Karr 1997). Key biological features to detect changes in species include: identity and number of species present in standard samples; ecological processes such as nutrient dynamics and energy flow through food webs; and the health of individuals, which influences survival and reproduction. These features provide a comprehensive picture of water resource condition - one that goes beyond the toxicity or extent of chemical pollutants (Karr 1997).

Schultz et al. (1999) released an index of biotic integrity based on fish and limnological data for Florida lakes. Eight metrics were used: total fish, native fish, *Lepomis,* piscivores, generalists, insectivores, and intolerant and tolerant species. A total IBI score was calculated for each of sixty lakes. Other data collected for the lakes included: trophic category of lake, surface area, mean depth, total phosphorus, total nitrogen, total chlorophyll, secchi depth, percent volume infested with macrophytes (PVI), and mean adjusted chlorophyll. Anthropogenic impact was estimated by amount of chloride and road density correlated with lake surface area, adjusted total chlorophyll and PVI. The authors state that numerous environmental factors significantly influence the distribution and abundance of fish species and assemblages found in Florida lakes. Lake trophic status and lake surface area had significant and positive influences on the fish-IBI scores. The study concludes that dominant environmental and ecological factors of a watershed should be clearly understood before an IBI approach is used to indicate watershed disturbance and biological integrity.

Fish are not commonly used as success indicators in wetland restoration; in a comprehensive evaluation of constructed wetlands on phosphate mined lands in Central Florida, Erwin et al. (1997) do not include fish along with other assemblages. Weller (1995) describes the restoration of a South Florida forested wetland in which the natural return of eight fish species occurred, among other groups of flora and fauna. In East Central Florida, an isolated constructed wetland quickly recruited a rich and abundant fish community (Langston and Kent 1997) with fish likely introduced through irrigation or transport on terrestrial or volant fauna. A few differences in fish community assemblages in constructed and unimpacted wetlands are noted by Streever and Crisman (1993) and Streever et al. (1997). The sailfin molly (*Poecilia latipinna*) was represented in five of seven samples collected from a *Pontederia cordata* community in a constructed wetland in Central Florida, though no mollies were found in any of seven samples collected from an adjacent *Hydrocotyl* community. *Lucania goodei* were collected in constructed marshes on phosphate mined lands but not in proximate natural marshes. *Elassoma evergladei* was found in higher percentages in natural marshes than in constructed marshes and never attained the numbers found in natural marshes. Fish species collected in constructed marshes include the mosquitofish (*Gambusia holbrooki*), Least killifish *(Heterandria formosa)*, Golden topminnow (*Fundulus chrysotus)*, Flagfish (*Jordanella floridae),* Sailfin molly (*Poecilia latipinna),* Bluefin killifish *(Lucania goodei),* Everglades pygmy sunfish (*Elassoma evergladei), Fundulus rubifrons* and small fish of the Centrarchidae family.

Fish communities in wetlands of Florida and the Southeastern United States are described in several studies. Wharton et al. (1982) describe fish communities in bottomland hardwoods of the southeast and their relationship to specific plant communities. Kushlan (1990) describe fish populations in Florida marshes as depauperate, especially toward the southern end of the peninsula. Marsh species are typically small and minnow-sized such as the live-bearing mosquitofish (*Gambusia affinis*) and least killifish (*Heterandria formosa*). Marsh cyprinodonts are typically flagfish (*Jordanella floridae*), golden topminnow (*Fundulus chrysotus*), Seminole killifish (*F. seminolis*), and bluefin killifish (*Lucania goodei*). Small sunfishes are also abundant such as the pygmy sunfish (*Elasoma* spp.), bluespotted sunfish (*Enneacanthus gloriosus*), and dollar sunfish (*Lepomis marginatus*). Occasionally warmouth (*L. gulosus*) and redear sunfish (*L. microlophus*) may be found in fluctuating marshes receiving overland flow.

The South Florida Water Management District Isolated Wetland Monitoring Program sponsored a bioinventory of freshwater fish in 20 isolated wetlands (Main et al. 1997). Wetland sites included mature cypress stands, marshes, cypress swamps, savanna marshes and one riverine site. Fish were classified into three functional groups: 1) small omnivorous fishes, 2) small predatory fishes, and 3) large predatory and open-water fishes. The study lists seven small omnivorous fishes common in shallow, ephemeral wetlands of which mosquito fish, least killifish and flagfish were most prevalent. Marsh killifish, redfaced topminnow, pygmy killifish and sailfin mollies were also present. Ten small predatory fish were common in wetlands with deep-water refugia including golden and lined topminnows, sunfishes, Seminole and bluefin killifish, and tadpole madtoms. The large predatory and open-water fish were found in semi-permanent wetlands with deep-water refugia, including gar, pickerel, catfish, bluegill, redear sunfish, largemouth bass, golden shiners and brook silversides. Summary tables from the study list common, scientific and family names of the fish, physical descriptions, reproductive biology, feeding biology, distribution in South Florida, capture techniques, and key references.

Hoyer and Canfield (1994) sampled fish communities and a range of physical-chemical measurements as part of a statewide lake survey. The *Handbook of Common Freshwater Fish in Florida Lakes* presents descriptions, distribution, biology and biologist comments on each fish species, as well as statistics for lake morphology and limnological measurements from the study. The database is also used by Schulz et al. (1999) to develop and test a fish-IBI for Florida lakes.

The U.S. Geological Survey released a publication on methods of sampling fish communities as part of the national water quality assessment program (Meador et al. 1993). Methods for sampling wetland fish depend on habitat. Throw traps of heavy aluminum or sheet metal, generally one meter by one meter-square and 0.5 m to 0.75 m tall can be used in thick, dense vegetation (Chick et al. 1992, Jordan 1996). For most other wetland types, a lighter trap made with a copper pipe frame and 1.5-mm mesh to cover the sides can be used to obtain data which corresponds well with the actual density, size structure, and relative abundance of fish populations sampled (Jordan et al. 1997). Lorenz et al. (1997) describe a nine meter square drop net and removable walkways designed to quantify densities of small fishes in wetland habitats with low to moderate vegetation density. Main et al. (1997) used three methods of collecting fish in a bioinventory of freshwater fish in isolated wetlands of South Florida: 1) rectangular, Plexiglas funnel 'Breder' traps; 2) seines; and 3) D-frame dip nets with a 1.0 mm mesh size. Funnel traps and dip nets work well in heavily vegetated areas. Seines, needed to catch larger and more evasive fish, are useful in deeper marshes and cypress ponds but tend to have the lead line roll up and over rooted plants and get tangled in submerged twigs and branches.

Information on deformities, ectoparasites, lesions, and tumors (i.e., DELTs) found on fish are used as indicators of stream health in other regions and may be a component of a multi-metric approach for freshwater wetlands in Florida.

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN

Wetlands used as receptors for treated wastewater likely have elevated nutrient loads affecting resident fish assemblages. The fish community in an isolated, created wetland receiving water from an advanced wastewater treatment facility in Orange County was limited relative to other proximate natural wetlands (Schwartz et al. 1994). Although immigration was limited, fish tended to move out of the forested portion of the treatment wetland to an adjacent marsh where there was more food, oxygen and water. Fish density and biomass in the created wetland approached natural levels by the third year of use. Fish diversity in the jurisdictional and exit wetlands changed little over the three-year study. In general, wetlands supported higher fish populations after receiving reclaimed water above than before discharge began.

Rader and Richardson (1994) found greater fish densities in nutrient enriched areas of the northern Everglades compared with an unenriched area, although percent composition of fish (primarily *Gambusia affinis* and *Heterandria formosa*) remained the same. Smith (1992) also reports similar trends stemming from nutrient enrichment in forested wetlands in Central Florida, but documented a shift in the relative composition of the dominant assemblages as the abundance of *Heterandria* spp. increased relative to *Gambusia*. In another wetland receiving advanced secondary treated wastewater in Central Florida, fish populations maintained similar characteristics to fish populations in the control (Best 1993). Rader and Richardson (1992) found that fish kills from anaerobiosis occurred with equal frequency in enriched and control sites.

The Florida lake study by Hoyer and Canfield (1994) identified correspondence between fish species presence and median total nitrogen (TN), total phosphorus (TP) and chlorophyll-a. Typical fish found in lakes with the lowest TP (median value of 6-11 ug/L) were lined topminnow, pygmy killifish, chain pickerel and redfin pickerel. The median value for all 60 lakes was 20 ug/L. Many fish species were found in lakes with TP levels as high as1043 ug/L. Fish typically found in lakes with the lowest TN (median values of 353-522 ug/L) included the lined topminnow, pygmy killifish and redfin pickerel. The median value for all 60 lakes was 694 ug/L. Many fish species were found in lakes with TN levels as high as 3789 ug/L. Typical fish found in lakes with low chlorophyll-a corresponded with fish found in low TN and low TP lakes. The reader is encouraged to use this study as a baseline to identify tolerance ranges of freshwater fish common in Florida wetlands in the development of biotic indicators.

CONTAMINANT TOXICITY

Stormwater runoff contains heavy metals from roofs, roads, parking areas, service stations and other nonpoint sources. Wetlands and stormwater ponds used to treat stormwater runoff may experience metal bioaccumulation in component organisms.

In stormwater treatment ponds in Orlando, Campbell (1995) found silver, cadmium, nickel, copper, lead and zinc in red ear sunfish, largemouth bass, and bluegills. The red ear sunfish that dive into sediments in search of food contained significantly higher metal concentrations other fish. The largemouth bass, a predator, accumulated significant amounts of cadmium and zinc. Bluegills accumulated significant amounts of copper, and high (but not statistically significant) amounts of cadmium, nickel, lead and zinc compared to bluegills in control ponds.

Mercury was found in Everglades largemouth bass at concentrations of 0.13 to 3.64 ppm (Eisemann et al. 1997). Miles and Fink (1998) monitored total mercury and methyl mercury at a nutrient removal wetland in the Everglades and found total mercury concentration in bass was about 0.1ug/g. In the adjacent water conservation area (WCA) mercury levels exceeded the standard of 0.5 ug/g. Total mercury found in mosquitofish was lower than in bass and was lower in the wetland interior than in the inflow and outflow sites.

Selenium, which is an increasingly important environmental contaminant, is concentrated in the mineral fraction (fly ash and bottom ash) of combusted coal. Disposal by dumping a wet-slurry into dry-ash basins can overflow into aquatic systems (Lemly 1996). Selenium concentrations can rapidly increase in fish and aquatic organisms in the receiving water, ultimately resulting in tissue damage, reproductive failure, and possible elimination of local fish populations.

Lemly (1996) describe selenium effects in fish living in contaminated power plant reservoirs. Bluegill (*Lepomis macrochirus*) with selenium concentrations of 12-16 ug/g in skeletal muscles and 40-60 ug/g in ovaries were associated with reproductive failure and mortality. Females with selenium levels in tissues of 8-36 ug/g and 12-55 ug/g in ovaries did not produce viable offspring. Mosquitofish (*Gambusia affinis*) and other forage fishes can accumulate 20-370 ug/g of selenium and still maintain stable, reproducing populations. Lemly (1996) concludes, that because selenium bioaccumulates, direct exposure to organisms is not the problem but rather the dietary source of selenium contaminated organisms provide to predatory fish and other wildlife that can be toxic.

Gaines (1994) found dilute landfill leachate had limited short-term impacts on fish populations in a Central Florida wetland. Fish tended to avoid the leachate entry area, and sampled fish assemblages most represented the original fish community structure in areas farthest from the leachate.

ACIDIFICATION

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of acidification on fish in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Hoyer and Canfield (1994) recorded pH levels in 60 Florida lakes and the fish associated with those lakes. Fish typically found in low pH waters include the lined topminnow, Everglades pygmy sunfish, pygmy killifish and redfin pickerel. Acidification of a wetland below 5.0 may be detrimental to the fish populations. Eleven species of fish were found in lakes with a minimum measured pH of 4.3. In Florida acidification is not a common problem due to buffering capacities from substrates and the nature of effluent added to wetlands that tends to raise pH.

SALINIZATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of acidification on fish in inland freshwater wetlands in Florida or the Southeastern Coastal Plain.

SEDIMENTATION / BURIAL

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of sedimentation on algae in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on wetland fish response to sedimentation. Presumably sedimentation can affect fish by altering substrate, submerged vegetation, and invertebrate prey base. Sediment feeders, such as the red ear sunfish (*Lepomis microlophus*) may be directly impacted.

TURBIDITY / SHADING

Few studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity or shading on fish in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature prior to 1990 and in other regions on wetland fish response to turbidity and shading.

The addition of wastewater to a blackwater wetland in Central Florida increased the density and cover of *Lemna* causing shading underwater (Smith 1992). *Gambusia* and *Heterandria* populations were affected, with *Gambusia* most negatively affected. Total suspended solids also increased with *Heterandria* responding positively.

Hoyer and Canfield (1994) recorded Secchi depth in their study of 60 Florida lakes. The median value for all lakes was 1.5 m. The fish typically found in lakes with a median Secchi depth >2.0 m included the chain and redfin pickerel, Everglades pygmy sunfish, lined topminnow and pygmy killifish. Fish typically found in lakes with small Secchi depths include inland silverside, redbreast sunfish, taillight shiner and sunshine bass.

VEGETATION REMOVAL

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of vegetation removal on fish in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on wetland fish response to vegetation removal. In general, increased macrophyte growth and (re)colonization of bare sediments result in higher fish densities, by providing habitat and cover for prey species, and removal of submerged and emergent vegetation may decrease fish density and alter community composition.

THERMAL ALTERATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of thermal alteration on fish communities in inland freshwater wetlands in Florida or the Southeastern Coastal Plain.

DEHYDRATION / INUNDATION

Drawdowns and prolonged inundation are common in Florida wetlands. Marsh fish are influenced by water level fluctuations, and hydroperiod differences may lead to differences in fish communities (Streever and Crisman 1993). Fish populations are frequently absent from isolated marshes subject to seasonal drying. Moler and Franz (1987) note that fish are variably present in oligotrophic marshes of the Ordway Preserve of North Central Florida. Fish tend to follow the water during dry spells and congregate in pools that may or may not dry up entirely. Competition and predation are intensified during drawdowns. Some fish move upstream when overland flow occurs, recolonizing depauperate wetland depressions.

Jordan et al. (1996) observed insect predation on small fish might be significant in semi-isolated ephemeral marshes that lack predatory fish. In aquariums, larval Odonate *Anax junius* predation on small fish (<40mm standard length) can approach 40%. Under natural conditions, habitat complexity likely decreases foraging ability of predatory insects. Sustained drawdowns may also eliminate or reduce invertebrate predators such as dragonfly larvae.

Dominance of small fishes in Everglades wetlands arises from hydropattern, as smaller species can survive in small pools during dry spells (Loftus and Eklund 1994). Flooding in the Okefenokee swamp releases nutrients in peat substrates, increasing algal and invertebrate productivity and may result in short-term increases in abundance of some fish species (Freeman 1989).

Some groups of fish are especially adapted to fluctuating water levels. Jordan et al. (1998) report that mosquitofish and flagfish were aggressive pioneers during flooding in wet prairies and sloughs of the St. Johns River headwaters. Repopulating dried wetlands when inundation reoccurs requires a pathway of recruitment to an adjacent water body or replacement of individuals through reproduction (Streever and Crisman 1993).

When rivers flood bottomland hardwood forests in the Southeastern Coastal Plain, inundation greatly increases the surface area available for fish migration and spawning (Brinson et al. 1981). Leitman et al. (1991) describe fishes in forest floodplains of the Ochlockonee River during flood and drought conditions. Thirty-seven species were collected during flood conditions and only thirteen were found during drought.

Large fluctuations in water level expose spawning areas, denude shoreline vegetative cover, and may reduce aquatic macroinvertebrate populations (Adamus 1983, Adamus et al. 1991). However, Greening and Doyon (1990) state that draw-down of Lake Apopka would potentially result in an improved littoral zone habitat, increasing gamefish species abundance by increasing macroinvertebrate production, fish spawning and refuge areas for game- and forage-fish species. A demonstration project for the Kissimmee River restoration plan documented fish responses to water level manipulation (Toth 1993).

DeAngelis et al. (1997) modeled fish dynamics and effects of stress in a hydrologically pulsed marsh typical of the Everglades-Big Cypress area of South Florida. The model predicts that: 1) there is an effective threshold in the length of the hydroperiod that must be exceeded for high fish population densities to be produced, 2) large, piscivorous fish do not appear to have a major impact on smaller fishes in the marsh habitat, and 3) the recovery of small fish populations in the marsh following a major drought may require up to a year.

Hydric pine flatwoods have the shortest hydroperiods, have small drainage areas, are those most influenced by rainwater, and have the lowest conductivities, among wetlands in the Myakka River basin of Southwest Florida (Dunson et al. 1997). Some fish species are typically found within a certain ranges of dissolved Na, Ca and Mg.

HABITAT FRAGMENTATION / DISTURBANCE

No studies were found in a search of the literature between 1990 and 1999 on direct effects of habitat fragmentation and disturbance on fish in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Adamus and Brandt (1990) report a paucity of literature prior to 1990 on wetland fish response to habitat fragmentation and disturbance, and Danielson's review (1998) similarly finds a limited recent literature in other states. Habitat destruction or modification is estimated to be 73% responsible for North American freshwater fish extinctions and 98% responsible for fish population decline (Williams et al. 1989, Miller et al. 1989).

Fish movement, recolonization rates and survival likely are decreased with increasing distance between wetland depressions in the landscape or as hydrologic connections become severed by dewatering, channelization and diversion. Fish species dependent on floodplain habitats and those that do not disperse easily might be most affected. The magnitude of the effect may depend on the size and intrinsic habitat heterogeneity of the wetlands within the fragmented landscape (Adamus and Brandt 1990). Presumably fish populations are most affected in the South Florida region where emergent marshes comprise 61% of the wetlands and 21% of the landscape and where water diversion projects have been most extensive.

Chapter 7: AMPHIBIANS AND REPTILES

USE AS INDICATORS

Herpetofauna (reptiles and amphibians) are unique as indicators of wetland health in that they are not only obligate users of wetlands, but also the surrounding uplands for part of their life cycle. Many herpetile species depend on suitable corridors of habitat between their breeding and non-breeding areas, and more than any other taxonomic assemblage, may reflect the health of wetland buffers and corridors. Furthermore, reptiles and amphibians can play a substantial role in nutrient and energy transfer between wetlands and uplands. For example, Deutschman and Peterka (1988) estimated maximum density of larval salamanders in three prairie lakes in North Dakota to be 5000/ha. Similarly, Burton and Likens (1975) found that salamander biomass in New Hampshire equaled that of small mammals and was twice that of birds.

The use of amphibians and some reptiles as indicators of wetland health may be advantageous because their distribution, behaviors, and life cycles are dependent on water depth, hydroperiod, water quality (Ohio EPA 1987) and the availability of suitable corridors (Azous et al. 1998). Amphibians absorb water through their skin and may be particularly susceptible to contaminants (Harfenist et al. 1989) and their aquatic life stages may be sensitive to sedimentation and eutrophication (Adamus 1996).

Herpetofauna are not commonly used as indicators of restoration and constructed wetland success in Florida. Kale and Pritchard (1997) provide inventories of reptiles and amphibians known to occur in constructed and restored wetland habitats on phosphate mined lands in Central Florida and list several herpetile species that serve as indicators of suitable habitat. Reptiles include American Alligator, Snapping Turtle, Common Musk Turtle, Florida Mud Turtle, Striped Mud Turtle, Peninsula Cooter, Florida Softshell, Florida Green Watersnake, Brown Watersnake, Florida Watersnake, Striped Crayfish Snake, South Florida Swamp Snake, Eastern Mud Snake, and Florida Cottonmouth. Amphibians include Amphiumas, sirens, newts, salamanders, toads and frogs.

Possible amphibian indicator metrics include, species richness, distribution, abundance (Adamus 1996), quantity of successful metamorphosed larvae, bioaccumulation, proportion of deformities, population structure, and guild or trophic structure (Wetlands Division 1999). Amphibians breed at different times of the year and many breed only in ephemeral or permanent water bodies. Thus, alterations in hydroperiod can cause shifts in species composition and possibly extirpations (Mazzotti et al. 1992). In Ohio, the number of salamander species collected was correlated to increasing Rapid Assessment Methodology (RAM) scores in forested wetlands. However, there did not appear to be a relationship between the numbers of anuran or salamander species in emergent wetlands and RAM scores or Floristic Quality Assessment Index (FQAI) scores (Fennessy et al. 1998).

There are several caveats of using herpetiles as indicators of biological condition (Adamus 1996). First, to gain an accurate representation of amphibian abundance and species richness, repeated visits to the habitat are necessary. Many amphibian species are primarily found after heavy rains following a drought, making the appropriate sampling time annually variable. Similarly, many species are prevalent only at night, during mid-day basking hours or immediately after the first thaw. Some species are fossorial and are rarely encountered. Sampling techniques for amphibians can be cumbersome and relatively expensive (Fennessy et al. 1998, Adamus 1996). Finally, field identification of some larval amphibians may not be possible (Fennessy et al. 1998, Palis and Fischer 1997).

The USEPA Environmental Monitoring and Assessment Program (EMAP) chose not to explore the use herpetofauna as a potential metric of wetland health, because sampling techniques are often cumbersome and amphibian distribution and abundance are inherently variable (Brown {no date}). It may be difficult to account for natural temporal and spatial variation of amphibian species richness, abundance, and distribution. For example, similar habitats were sampled at two sites in Taylor County, Florida, but capture rates were significantly different between the two sites (Enge and Wood 1998) with the difference attributed to substantially higher rainfall (21.2cm) at one of the sites.

At this time, Minnesota, Ohio and the USGS Biological Resource Division are testing amphibian metrics of wetland health (Danielson 1998). In Florida, amphibians have been used as indicators to monitor potential impacts of groundwater withdrawal (Orinston et al. 1995, Division of Environmental Sciences 1998), to aid in the prioritization of lands for habitat conservation (Cox et al. 1994), and to measure restoration success (Weller 1995). Kale and Pritchard 1997 considered several reptiles and most amphibians useful for evaluating constructed wetlands on phosphate mined lands, because they are wetland dependent, wide spread, and abundant.

The Ohio Environmental Protection Agency (1987) determined funnel traps were more effective than several other herpetile sampling techniques (Fennessy et al. 1998). Funnel traps generated relative abundance data and collected more taxa than other sampling techniques tested. Call surveys only sample frogs, are weather dependent, and there is often only a short, annually variable, period of time when anurans are calling. Drift fence sampling was determined to be more labor intensive and setup materials can be relatively expensive. Enclosure sampling devices were more labor intensive, active organisms avoided the traps, it was difficult to separate organisms from plant material and debris, and at times, it was difficult sealing the enclosure bottom substrate. When using seines it was also difficult to separate organisms from the large amounts of debris and plant material, and sampling consistency between individuals and wetlands was difficult. Dipnets were not as effective because it was difficult to separate organisms from debris and because of sampling inconsistencies (sites and samplers). Adamus (1996) suggests the use of pitfall traps and funnel traps is preferable to direct sampling methods (e.g., binocular scans, search transects, anuran calls, egg mass counts) that do not supply quantitative data on abundance. However, direct sampling methods may compliment pit fall trap and funnel trap sampling.

ENRICHMENT/EUTROPHICATION/REDUCED DISSOLVED OXYGEN

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of nutrient enrichment on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) also reports a paucity of literature on the subject in other regions. The review by Adamus and Brandt (1990) concludes that indicator assemblages of the most sensitive herpetiles remain speculative for eutrophication.

In southern England, Beebee (1987) found the bullfrog, *Bufo calamita*, consistently selects more eutrophic wetlands. Amphibians may play an important role in transferring nutrients from eutrophic wetlands into the uplands (Wassersug 1975). Tadpoles reduce blue-green algae biomass, and may contain double the amount of residual nitrogen found in some wetlands (Beebee 1996).

Palis (1996) observed that Flatwoods Salamanders (*Ambystoma cingulatum*) are not found in wetlands of the Southeastern Coastal Plain with excessive amounts of algae. In cypress depression wetlands receiving wastewater, Jetter and Harris (1976) initially noted high proportions of frogs present, but low oxygen levels nearly stopped amphibian production.

CONTAMINANT TOXICITY

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of heavy metals, pesticides and other toxins on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) reviews research on this subject in other regions. Biomarkers in amphibians can sometimes be used to detect exposure to pesticides and heavy metal contaminants (Adamus 1996). Moser et al. (1993) describes the methodology and assessment of contaminant bioaccumulation in amphibians.

Several authors have found correspondence between the distribution and fecundity of some amphibian species and ambient water quality measures, primarily pH, Al, total cations, NO_2, chemical oxygen demand and dissolved organic carbon (Strijbosch 1979, Beattie and Tyler-Jones 1992, Rowe et al. 1992, Sadinski and Dunson 1992, Rowe and Dunson 1993, 1995). Red-legged Frog (*Rana aurora*) embryo mortality corresponded to Ca, Mg, and pH and negatively correlated to total P, total suspended solids, Pb, Zn, Al, total organic content and dissolved oxygen. At the same time, Northwestern Salamander (*Ambystoma gracile*) egg mortality was not correlated with any of the above measures, but did correspond with total petroleum hydrocarbons and fecal coliforms (Platin 1994, Platin and Richter 1995). Rowe et al. (1996) report that bullfrog (*Rana catesbeiana*) tadpoles collected from coal ash deposition basins contaminated with As, Cd, Cr, Cu, Se and other elements had reduced number of labial teeth and deformed labial papillae. Deformed tadpoles were less able to graze algae, which resulted in lower growth rates.

Alligators (*Alligator mississippiensis*) have a high trophic level status in many wetlands and tend to bioaccumulate contaminants. Alligators may be particularly good indicators of methyl mercury contamination. High rates of Hg methylation occur in anoxic wetland environments (St. Louis et al. 1994, Rudd 1995) and methyl mercury is the form most readily taken up by wildlife. The highest concentrations of methyl mercury in alligators sampled throughout the southeast coastal plain were located in the Everglades (Yanochko et al. 1997 and Jagoe et al. 1998). The authors also report that methyl mercury concentrations sampled by non-lethal means (e.g., scutes, blood, claws) do not correspond with concentrations found in muscle tissue and organs but that Hg-concentration in specific tissues varies with alligator location, size, and age.

ACIDIFICATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of acidification or the combined effects of acidity and metals on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) reviews literature on the subject in other regions, including the combined effects of acidity and metals on herpetile communities. From their review of literature prior to 1990, Adamus and Brandt (1990) conclude that most amphibians require a pH higher than 4.5 to 5.0 for embryo survival and metamorphosis. Dunson (1989) reports the LD50 level of nine species of North Florida anurans was reached at pH levels between 3.3 and 4.2.

Sadinski and Dunson (1992) identified direct and indirect effects of acidification on amphibian communities in Central Pennsylvania wetlands. For example the predatory Jefferson’s Salamander (*Ambystoma jeffersonianum*) experiences reduced foraging rates and increased mortality rates at pH levels below 4.5, while the more pH tolerant *Rana sylvatica* experiences increased survival rates due to the reduced predation by *A. jeffersonianum*. Low pH levels not only affect survival and predation rates. With low pH levels (~ 4.2) *Notophthalmus viridescens* reproductive success decreases and emigration rates increase while fewer *Ambystoma maculatum* metamorphose and metamorphosis is delayed.

SALINIZATION

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of salinity on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) also reports a paucity of literature on the subject in other regions. The review by Adamus and Brandt (1990) concludes that indicator assemblages of the most sensitive herpetofauna remain undefined for monitoring salinity effects.

SEDIMENTATION/BURIAL

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of sediments on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on the subject. In the Pacific Northwest, Richter (1997) found sedimentation was detrimental to the aquatic egg stage of many wetland amphibians.

TURBIDITY / SHADING

No recent studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on the subject. Turbidity, especially from suspended particulate material, possibly affects amphibians through respiratory complications and egg vitality. Herpetile response to understory shading from silvicultural practices is reviewed in the vegetation removal section.

VEGETATION REMOVAL

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of direct vegetation removal on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Cattle grazing, logging, herbicide application can act to remove wetland vegetation and potentially affect reptiles and amphibians primarily by exposure and subsequent changes to microclimates.

Several authors studied effects of habitat changes from silviculture on amphibians. Raymond and Hardy (1991) reported higher soil temps and more evaporative water loss from the soil and understory after clearcuts in bottomland hardwood forests, and hypothesized that the habitat changes negatively impacted salamanders. Demaynadier and Hunter (1999) found wood frogs (*Rana sylvatica*) use forest areas significantly more than clearcuts when dispersing from ephemeral breeding ponds. In South Carolina, Phelps and Lancia (1995) document salamanders, gray tree frogs (*Hyla chrysoscelis*) and box turtles (*Terrapene carolina*) were more common in a mature bottomland swamp than in clearcut areas while many lizards and snakes preferred the clearcuts.

In Florida, Enge and Marion (1986) found amphibian species richness did not differ between clearcuts and naturally regenerated 40 years old slash pine stands, though reproductive success was lower in clearcut areas, reducing amphibian abundance. Reptile species richness was lowest in the maximum treatment clearcut, primarily due to the absence of arboreal lizards and snakes. Logging related declines in herpetofauna were primarily due to decreases in the relative humidity, increased insolation and altered hydropattern. Generally, amphibians do not differentiate between open and forested habitats when dispersing under wet conditions (Richter 1997), but moist microclimates, often afforded by forest cover, are selected by some amphibians during drier periods (Gittens et al. 1980, Semlitsch 1981, Kleeberger and Werner 1983).

Fire suppression leads to the shading of understory habitat and may ultimately reduce understory structure, which may impact flatwoods salamanders because their eggs and larvae depend on the herbaceous zone surrounding wetland depressions (Palis 1997b). Understory shading due to fire suppression compromises preferred upland habitat of both the gopher frog

(*Rana capito*) and flatwoods salamander (Palis 1997b, Palis and Fischer 1997). Other silvicultural practices (e.g., densely stocked plantations, mechanical site preparation, herbicides) may also negatively affect the understory habitat. Logging equipment can compact soil used by many fossorial amphibian species. Similarly, military vehicle activity in and around marsh depressions has also been cited as potentially impacting amphibians by reducing the understory vegetation and disrupting the soil (Palis 1997b, Hipes and Jackson 1996, Palis and Fischer 1997).

THERMAL ALTERATION

No recent studies were found in a search of the literature between 1990 and 1999 on ambient water temperature changes on herpetofauna in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Reviews by Adamus and Brandt (1990) and Danielson (1998) also report a paucity of literature on the subject. Amphibians are ectotherms, physiology and egg development are dependent on water temperature, and thermal alteration may affect breeding success.

DEHYDRATION / INUNDATION

Most amphibians and many reptiles are dependent on wetlands for at least one life stage and are likely affected by hydrologic manipulations. For instance, prior to water management actions in the Everglades during the last 30 years, alligators built their nest mounds and placed their eggs within the mounds based on existing water levels, though now water level manipulations have been implicated in an increase in egg mortality from 5% to 20% (Kushlan and Jacobsen 1990). Richter and Azous (1995) document a decrease in amphibian species richness due to larger water level fluctuations from increased impervious surface area in urbanized watersheds of the Pacific Northwest. Azous and Horner (1997) add that the number of amphibians captured in wetlands is reduced when water level fluctuation exceeds 20 cm.

Cypress ponds in Florida that are ditched experience a shift in the herpetile community from mostly aquatic to more terrestrial species. Ditched cypress ponds can have almost 4 times as many lizards, terrestrial snakes, and toads and unditched ponds have 1.4 times as many frogs and salamanders (Hart and Newman 1995). Rewatering of a drained forest wetland depression in Broward County was followed by a return of 15 species of herpetiles (six turtles, 6 snakes, 2 frogs, and alligators) that were extirpated because of hydrologic manipulations. Ditching connects some wetlands to sources of predatory fishes (Babbitt and Tanner 2000) and affects the herbaceous component of marsh margins (Palis 1997b), which may influence amphibian species richness and abundance. Ditching that decreases the hydroperiod can cause a shift from cypress to broadleaf trees, promoting more shading of the understory (Marois and Ewel 1983). Water filled ditches can invoke unsuccessful breeding attempts by amphibians, and eggs laid in ditches with shorter hydroperiods than nearby wetlands can be lost to desiccation (TNC 1995).

Based on their widespread distribution in Florida and their preferred habitat, Meshaka (1997) expected to find Eastern spadefoot (*Scaphiopus holbrookii*) on a ranch in Highlands County. Their absence was thought to be attributable to hydrologic manipulations of the improved pasture that were incompatible with primarily fossorial habits of the species (water levels are maintained higher in the dry season and lower in the wet season).

HABITAT FRAGMENTATION / DISTURBANCE / MISCELLANEOUS

Because many amphibians travel through and live in terrestrial habitats separate from their wetland breeding habitats, amphibians may be particularly susceptible to habitat fragmentation. Two anuran species found in Florida have been known two disperse more than 2 km from the wetland in which they metamorphosed (Breden 1987, Franz et al. 1988). Wetland turtles also use uplands, for hibernation and nesting (Burke and Gibbons 1995). Stenhouse (1985) and Verrell (1987) suggest amphibians use corridors (habitats conducive to dispersal) to gain access to their breeding habitats. Movement to breeding areas can be hindered by development. For example, roads fragment habitat and contribute to amphibian population declines (Fehring et al. 1995). Maintenance of movement corridors will dampen the affect of stochastic events (e.g., drought) (Richter 1997) and help prevent inbreeding depression (Pechman and Wilbur 1994).

In the Pacific Northwest, Richter and Azous (1995) found amphibian species richness highest in wetlands that retain at least 60% of the adjacent area in forest up to 500 m from the wetland. In Florida, Folkerts (1997) hypothesized the reason Citronelle ponds have unexpectedly low amphibian species richness in most cases is because the adjacent landscape was converted to agriculture or was urbanized. Lehtinen et al. (1999) found amphibian species richness decreased with increasing road density and proportion of urbanized land. Based on a literature review and using the known dispersal distances of six salamander species, Semlitsch (1998) recommends a general buffer distance of 164m from the edge of wetlands to protect 95% of the salamander populations. Palis (1997a, 1997b) and Palis and Fischer (1997) note fragmentation may not only affect amphibian dispersal but may reduce the quality of remaining habitat. Fragmented landscapes do not carry fire well, and overtime succession into another habitat type may occur.

Chapter 8: BIRDS

USE AS INDICATORS

There is general agreement that wetland birds may be better indicators of regional or landscape conditions than of the health of a particular wetland type or site (Cowardin et al. 1979, Harris 1988, Adamus et al. 1991, Adamus 1996, USEPA 1997, Danielson 1998). This is due in part because of their mobility (Bennetts and Kitchens 1997, Myers and Ewel 1990) and tendency to use a variety of upland, wetland and aquatic habitats based on resource availability (e.g., prey and nest site availability) (Fleming et al. 1994, Gosselink et al. 1994, Bessinger 1995, Hart and Newman 1995, DeAngelis et al. 1997). Changes in utilization (e.g., presence, timing and duration) of a wetland by birds, regional reductions in population size, and local extirpations may indicate: alterations in the prey base (Gosselink et al. 1994, Hart and Newman 1995), vegetation species composition and structure (Harris et al. 1983, David 1994, Schulz 1999) or other factors important to birds on a regional level. For example, wading birds in wet prairies of the Everglades have declined by 93% in the last 70 years primarily due to habitat loss and reduced prey availability (Ogden 1994), and in the Lake Okeechobee fringe marsh communities, willow (*Salix caroliniana*) died due to artificially maintained high water levels, causing a nesting colony of wading birds to decline from 10,000 to 3 within a 14 year period (Smith et al. 1995).

There are several advantages of using birds as health indicators in wetland bioassessments. First, they are relatively easy to monitor and many species can be surveyed remotely (e.g., aerial surveys). Second, long-term, nationwide databases are available (e.g., waterfowl hunting returns, Breeding Bird Surveys - BBS, and Christmas Bird Counts - CBC) supplying information on trends, habitat needs and distribution (e.g., McCrimmon et al. 1997). Other advantages include: temporal and spatial integration of birds (Adamus 1996, USEPA 1997), standardized and established survey methodologies are available, avian response guilds show a continuum of sensitivity (Croonquist and Brooks 1991), and wetland birds represent a wide array of feeding strategies (Adamus et al. 1991). Also, many bird species are good indicators of bioaccumulation of toxic substances because they tend to have long life spans and are often top predators (Adamus 1996).

There are several cited disadvantages of using birds as indicators of wetland health. First is their low wetland fidelity. Additionally, bird presence in a wetland does not necessarily reflect wetland health or its ability to support the observed bird or other organisms. Sandhill cranes (*Grus canadensis*), for example, will rest or roost in open inundated areas for protection from predators (Bishop 1992) but this behavior indicates little about the status of the prey base or wetland productivity. Another disadvantage is discerning cumulative affects bird populations. For example, at this time, it is impossible to distinguish the relative impact of lead shot toxicity, hunting pressure and loss of breeding habitat on the decline of waterfowl in the prairie pothole region (Harris 1988). Perhaps another caveat in using birds as indicators is the necessity to make multiple visits throughout the year to gain an accurate representation of wetland bird use (USEPA 1997). Adamus et al. (1991) recommends that wetlands be visited during the breeding, wintering and migration periods to assess bird use. Finally, the ability to detect wetland bird species is variable (USEPA 1997) (e.g., rails and bitterns are cryptic).

In Florida, wetland birds have been used as indicators in the evaluation of constructed wetlands on mined lands (Erwin et al. 1997), to monitor impacts of groundwater withdrawal (Orinston et al. 1995, Division of Environmental Sciences 1998), to aid in prioritization of lands for habitat conservation (Cox et al. 1994), to evaluate wildlife habitat suitability of depression wetlands used for wastewater treatment (Mcallister 1993), and in comparison of hydrologically impacted and unimpacted wet prairie associations in South Florida (Gawlik and Rocque 1998). Birds have been used to assess the restoration of a river marsh (Toth 1993), a South Florida cypress dome (Weller 1995), and mined lands in Central Florida (Mushinsky and McCoy 1996, Doherty 1991). Kale and Pritchard (1997) provide inventories of birds known to occur in wetland habitats on phosphate mined lands.

Nationally, there has been an attempt to place species within a bird community into guilds and monitor the response of each guild to perturbations. Miller et al. (1997) found Neotropical migrants and species dependent on large undisturbed areas of habitat (gamma species) declined with increasing residential and agricultural land-use in Pennsylvania. Croonquist and Brooks (1991) applied guild scores to bird species based on documented information in two Pennsylvania watersheds. A high guild score corresponded to a low tolerance to habitat disturbance. As intensity of habitat alteration increased the percentage of bird species with high-response guild scores decreased. Species in ‘edge’ and ‘exotic’ guild categories were more prevalent in disturbed watersheds. Changes in the bird community were greater than changes in bird species richness as a result of land alteration. O’Connell et al. (1998) developed a Bird Community Index (BCI) in the Mid-Atlantic Highlands and inferred increased biological integrity as the insectivore guild increased and the omnivore guild decreased.

ENRICHMENT / EUTROPHICATION / REDUCED DISSOLVED OXYGEN

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of nutrient enrichment on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Several studies address potential indirect affects of enrichment on wetland birds. Increased amounts of nitrogen and phosphorus can cause increases in the prey base (fish, macroinvertebrates, and herpetofauna) and forage for many wetland birds. In the Everglades, Rader and Richardson (1994) found that enriched sloughs experienced increases in macroinvertebrate and fish metrics, including species richness, Shannon diversity index, number of unique species, and population density.

Hoyer and Canfield (1990) attributed an increase in bird density estimates in a North Florida cypress dome to an increase in prey density due to enrichment. However, increased nutrient inputs have the potential to cause the vegetation structure and composition to change in manner that adversely affects prey availability. In the Everglades, plant community composition in phosphorous enriched wet prairies frequently shift to dense cattail stands

(*Typha* spp.) and several studies have shown that most wading bird species avoid dense stands of vegetation (Bancroft et al. 1994, Hoffman et al. 1994, Smith et al. 1995). There appears to be a threshold where nutrient inputs increase prey density until the vegetation increases to the point of obstructing or shading (e.g., *Lemna* spp.) the prey from wetland birds.

Another potential negative impact on wetland birds due to enrichment is the increased potential for parasite transmission. The parasitic nematode, *Eustrongylides ignotus*, which has only been found in disturbed and enriched wetlands (Spaulding and Forester 1993), negatively affects the health of adult wading birds and the survival of nestlings (Spaulding et al. 1993).

Prolonged reduced dissolved oxygen levels in a wetland can negatively impact the prey base of wetland birds. Prey species not adapted to low oxygen levels will be at a selective disadvantage if low dissolved oxygen levels persist. At the same time, low dissolved oxygen levels may temporarily increase prey availability for many wading bird species. Several species of fish adapted to low dissolved oxygen levels take advantage of the oxygenated water surface, performing aquatic surface respiration (ASR) (Lewis 1970). Prolonged ASR has been found to increase the susceptibility of fish to avian predators (Kramer et al. 1983, Cech et al. 1985).

CONTAMINANT TOXICITY

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of contaminant toxicity on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. While the effects of bioaccumulation of contaminants in wetland bird tissues have been widely measured, the effects of pesticides, heavy metals, and other contaminants on overall structure of wetland bird communities are poorly documented in wetlands (Adamus and Brandt 1990), though it is likely that wetlands free of toxic substances are more likely to have higher wetland bird species density and diversity (Adamus et al. 1991).

Wading birds have been used to document elevated levels of mercury found in Southern Florida. Mercury concentrations in wading bird feathers collected in Southern Florida on average were much higher than similar studies conducted in Costa Rica, Hong Kong and China (Beyer et al. 1997). Within Southern Florida concentrations of mercury in wading birds appears to vary geographically. Birds in the Central Everglades and Eastern Florida Bay had significantly higher levels of mercury than birds sampled in other areas of Southern Florida (Sundlof et al. 1994). Mercury concentrations vary with geographic locations but also with diet and age of the bird (Sundlof et al. 1994, Beyer et al. 1997). Species that eat larger fish, and older birds, tend to have the highest Hg concentrations. Mercury concentrations of many wading bird species in Southern Florida are near or above levels that may cause reproductive impairment, and it has been suggested that mercury poisoning may play a part in the population declines of wading birds in the Everglades (Sundlof et al. 1994, Beyer et al. 1997). However, more controlled studies are needed.

ACIDIFICATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of acidification on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) reviews several studies in other states. Adamus and Brandt (1990) also report a paucity of literature on the subject. Changes in the prey base and vegetation structure in wetlands due to anthropogenic acidification will likely impact the bird community. Birds feeding in acidified waters may have greater potential for calcium deficiency and as a result will lay thinner eggs (Albers and Camardese 1993, Nybo et al. 1997). Parker et al. (1992) found more broods of piscivorous waterfowl in prairie pothole wetlands with a pH greater than 5.5, while at the same time, insectivorous waterfowl seemed to be unaffected by pH levels.

SALINIZATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of salinity changes on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Danielson (1998) documents a few studies in other states, and the Adamus and Brandt review (1990) cite studies outside Florida that indicate breeding birds in coastal wetlands generally select fresher portions, and inland wetlands that are naturally saline generally have fewer nesting waterfowl. Changes in the prey base and vegetation structure in wetlands due to salinization would likely alter the bird community. Thus, bird assemblages used as indicators of salinization are speculative, especially in Florida where little is known about bird response to salinity changes.

SEDIMENTATION / BURIAL

No studies were found in a search of the literature between 1990 and 1999 on the effects of salinity changes on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Searches by Adamus and Brandt (1990) and Danielson (1998) also found the literature limited on bird response to wetland sedimentation in other states. Sedimentation likely will affect wetland birds by impacting growth and survival of aquatic prey and submerged forage plants.

TURBIDITY / SHADING

No studies were found in a search of the literature between 1990 and 1999 on the effects of turbidity and shading on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Effects of turbidity on the community structure of wetland birds in other states are also poorly documented (Adamus and Brandt 1990, Danielson 1998). Shading may affect the wading bird community differentially. Many of the herons and egrets are visual predators while the wood stork (*Mycteria americana*), roseate spoonbill (*Ajaia ajaja*) and the ibises are primarily tactile foragers (Kushlan 1978, Bancroft 1994). Tactile foragers may have a selective advantage in wetlands that are turbid or shaded.

VEGETATION REMOVAL

Bird communities are influenced by vegetation structure, density and composition. Determining expected wetland bird communities for each wetland type within a region may be possible, and changes to vegetation structure within a wetland type or site may alter the bird community. Bird community composition is a more reliant indicator of vegetation alteration than bird species richness. As vegetation changes are made to a wetland, new wetland bird species may find the altered habitat favorable while other species find the disturbance unfavorable. For instance, while dense stands of wetland vegetation are often utilized by rails and bitterns (Dinsmore et al. 1993), complete removal of the vegetation may make the area more attractive to shorebirds and some species of waterfowl that select areas free of vegetation (McMurl et al. 1993). Thus, wetland bird species diversity or richness may be a poor metric of wetland vegetation removal.

Silviculture and grazing are two common forms of vegetation disturbance in wetlands. High cattle stocking rates can have profound effects on wetland habitat. Cattle compact soil, trample vegetation and reduce ground cover (Vince et al. 1989, Hart and Newman 1995). Hart and Newman (1995) report that cows favor wetland grasses (e.g., *Panicum hemitomum*) present in depression wetlands to the grasses (e.g., *Andropogon* spp. and *Aristida stricta*) commonly found in uplands and pastures of Florida. In forested wetlands, structural diversity is decreased by cows browsing on shrubs and tree seedlings (Hart and Newman 1995). Feral pigs can cause severe soil disturbance and depletion of oak mast in hydric hammocks (Vince et al. 1989).

Wetland vegetation impacts may affect wetland bird community composition and reproductive success. Reduced waterfowl reproductive success has been documented because of the loss of cover either due to grazing, herbicides, cultivation or other land-use action. Dobkin et al. (1998) reported greater avian species richness and relative abundance in riparian areas where cows were excluded. Exclosures had higher wetland avifaunal species richness while grazed plots contained more upland bird species. Johnson et al. (1991) report that grazing by cows and feral pigs in herbaceous marshes of South Florida may affect mottled duck (*Anas fulvigula*) populations through habitat alteration.

A common silvicultural practice entails the removal of some or all of the overstory around and or within a wetland. Complete removal of the trees (i.e. clearcut) not only changes the habitat structure, but can also change the hydroperiod, water depth and water quality of a wetland (Hart and Newman 1995). Changes to the wetland bird prey base and understory vegetation due to clearcutting may impact wetland bird communities. The age of a timber stand will also affect the bird community. Mitchell (1989) found 11 bird species were more common in a 127-year-old cypress-tupelo stand (*Taxodium* spp. and *Nyssa aquatica*) than in younger stands.

THERMAL ALTERATION

No studies were found in a search of the literature between 1990 and 1999 on the effects of thermal alteration on birds in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. Temperature changes in ambient water can alter the plant community and the type and availability of the prey base thus indirectly affecting the bird community (Adamus and Brandt 1990 and Danielson 1998). Impoundments, bays, and wetlands receiving thermal effluent discharged from cooling towers at nuclear power stations are favored sites for migratory waterfowl and wading birds in winter.

DEHYDRATION / INUNDATION

As with the other stressors, hydrological impacts most often affect wetland birds indirectly by altering the habitat on which they depend. Hydrological manipulations may be partly responsible for a decreased bird prey base in the Everglades (DeAngelis et al. 1997) and modifications to nest and roost sites in lake fringe wetlands in South Florida (David 1994). Wetland birds may respond through a reduction in local populations, changes in the timing of breeding or foraging, reduced breeding success, or reductions in species diversity and species richness.

Most wading birds in South Florida wetlands depend on aquatic prey that is captured in 10-30 cm of water (Powell 1987). Too much water will limit access to prey. Conversely, a decreased hydroperiod will increase the frequency of drought, which negatively impacts fish populations and subsequently the wading birds that depend on them (DeAngelis et al. 1997). The density, distribution, demographics and availability of wetland bird food sources are influenced by present and past water conditions (Gosselink et al. 1994). Sustained high water levels over a 10 year period on Lake Okeechobee, converted much of the foraging habitat (*Eleocharis* spp., *Rhynchospora* spp., mixed grasses) to dense cattail stands (*Typha* spp.) which are not used by most wading birds (Smith et al. 1995).

Toth (1993) estimated that a constant source of 5 billion forage fish and 6 billion shrimp were unavailable to wetland birds due to the channelization of the Kissimmee River. In a dechannelization experiment, wading bird use of the river's wetlands nearly doubled. Other birds were also affected by the drying of Kissimmee River wetlands. Bald eagle territories declined by 74% (Shapiro et al. 1982) and waterfowl use of the area declined by 92% (Perrin et al. 1982). A rehydration project in Central Florida precipitated the return of 16 wetland bird species to a cypress dome (Weller 1995).

Changes in spatial and temporal availability of foraging habitat can affect the reproductive success of wetland birds (Gosselink et al. 1994). Canals in the Everglades have altered the seasonal drying trend, and the rate and degree of water recession is partly responsible for making areas within the region suitable for foraging. As a result of the hydrological impacts in the Everglades, wood storks begin breeding later in the season, and in most years a late start is followed by nest failures (Ogden 1994). Anthropogenic and natural reversals in wetland drying have also resulted in failed nesting attempts in wood stork colonies in the South Florida (Bancroft et al. 1994) and Central America (Ramo and Busto 1992).

Nesting colonies of wading birds in the Everglades require a minimum of 5-10 cm of water underneath nesting trees to deter predators (Frederick and Collopy 1989). Conditions that cause the loss of these depths could result in nest site abandonment. Conversely, artificially maintained hydroperiods were responsible for the death of willows (Salix spp.) along Lake Okeechobee and at least one stand formerly supported a large colony of wading birds (David 1994).

The reproductive success of the endangered Cape Seaside Sparrow (*Ammodramus maritimus mirabilis*) has been directly and indirectly affected by uncommonly high water levels in the Everglades. High water levels flood nests or enable the nests to be preyed upon, and cause changes in vegetation composition and structure. Management of higher water levels from 1992 to 1995 caused a change from the favored muhly grass (*Muhlenbergia filipes*) dominated habitat to a habitat dominated by sawgrass (*Cladium jamaicense*) (54% muhly in 1992 to 25% in 1995) (Nott et al. 1998). Within this same time period Cape Seaside Sparrow populations plummeted.

Many species are adapted to the natural fluctuating water levels found in wetlands. Bessinger's (1995) model of snail kite population response to hydrology predicted that greater than one drought every three to four years would be detrimental to the population. Bennetts and Kitchens (1997), however, report that snail kites in South Florida disperse to other wetland locations with the onslaught of regional droughts and that periodic droughts are necessary to maintain stands of willow vital for snail kite nesting. Wetland birds are adapted to and often dependent on fluctuating water levels. Smith et al. (1995) suggest that high water years succeeded by drought in South Florida may build prey concentrations that then can be exploited by wading birds. However, successive low water years may deplete the prey base. Prolonged hydroperiods may be necessary for the development of populations of large fish (Fleming et al. 1994) that are selected for by wood storks, great egrets (*Ardea albus*) and great blue herons (*Ardea herodias*).

Weller (1995) argues that waterfowl and wading bird guilds as indicators of the Kissimmee River restoration are useful because these guilds allow for comparison of use prior to and after channelization, and of use in restored and channelized portions of the river. Waterfowl and wading bird guilds, because of their high-trophic level status, integrate other components of the ecosystem. Gawlik and Rocque (1998) document lower avian species richness in hydrologically impacted sites than in reference sites of the Everglades.

HABITAT FRAGMENTATION / DISTURBANCE

Bird communities are suited as indicators of landscape change. Birds are highly mobile and use a variety of habitat types and ecosystems. These characteristics confound their use as indicators of wetland fragmentation and habitat disturbance as they can relocate as long as other habitats are locally available. Some bird species, however, require not just a particular density of wetlands, but a particular combination of wetland types and other land cover types (Adamus and Brandt 1990). Thus bird communities and selection preferences of birds may be better indicators of changes across landscapes than of disturbance or loss of specific wetland types or sites.

Danielson (1998) reviews recent literature on bird response to fragmentation and landscape disturbance in other states. Brown and Dinsmore (1986) documented low bird species richness in isolated and small marshes in Iowa. Ten of 25 wetland bird species were absent from marshes less than 5 ha and many species were only observed in smaller wetlands when the wetland sampled was within a complex of wetlands. Large blocks of lowland forest commonly contain forest interior Neotropical migrants (Hamel 1989, Mitchell et al. 1989) and reduced numbers and local extirpation has been correlated with fragmentation (Finch 1991). In Pennsylvania, an increase in the number of Neotropical migrants and gamma species (species dependent on large undisturbed areas of habitat) was recorded as residential and agricultural land-uses decreased within the studied watershed (Croonquist and Brooks 1991). Generalists and bird species most adapted to edge and disturbed habitats, however, increased with residential and agricultural land-uses (Miller et al. 1997). Ogden et al. (1987) surmised the decline in many wood stork colonies throughout Florida was partly attributable to increased urbanization and agricultural development.

In Central Florida uplands Mushinsky and McCoy (1996) used birds as indicators of mined land restoration success, with surveys in reference and impacted sites. Bird species missing from or found in lower numbers at impacted sites were selected as focal species. The authors conclude that habitat requirements of focal species should be prioritized in ecosystem reclamation. From a review of the literature, Doherty (1991) compared avian species common to 5 forest communities in Central Florida (Sandhill, Scrub, Flatwoods, Hammocks and Swamps) with bird use in mined lands, concluding that 97 bird species which have been documented in the natural forest communities have not been observed using any feature of the post-mined landscape. This represented 46% of avian species that occur or have occurred in Central Florida prior to mining. Of the bird species common to swamps (132 species), 53% were not documented using mined lands, representing the largest percent shift in bird composition among the forest communities displaced by mining. Because surface mining creates open water, fringe wetland habitats and marsh communities on clay settling ponds, an increase in wading birds, shore birds and migratory waterfowl is common in the mined landscape (Schnoes and Humphrey 1987, Doherty 1991).

Agricultural land use is at least partly compatible with the habitat requirements of many wetland bird species. For instance, 93% of Florida Sandhill Crane (*Grus canadensis pratensis*) daytime locations were within cropland, plowed pasture, improved pasture and emergent wetlands (Bishop 1992). In a similar study, the relative abundance of Florida Sandhill Cranes was higher in pastures and wetland-pasture associations than in the surrounding landscape (Nesbitt and Williams 1990).

Finally, Adamus et al. (1991) state that wetland birds are also suited as indicators of low level disturbance generated from recreation in or near wetlands (e.g., jet skis, ATV off-road riding, cycling, and hiking). Birds are activity-sensitive and very often show an immediate response in comparison with the other indicators.

Chapter 9 - MAMMALS

USE AS INDICATORS

Mammals may be better indicators of regional or landscape condition than of individual ecosystems or wetlands. Mammals are highly mobile, spend only a portion of their life in wetlands, lack habitat specificity (Ewel 1990) and tend to have low species richness. Brooks and Croonquist (1990) categorized some mammal species according to wetland dependency, but generally it is difficult to define what constitutes ‘wetland dependence’ for mammals. Also, wetlands are typically permanently inhabited by fewer mammal species than are uplands (Adamus and Brandt 1990). Finally, human induced mortality (hunting/roadkills) may cause population fluctuations unrelated to wetland status (Brown {no date}). Because of these factors, the Environmental Monitoring and Assessment Program (EMAP) chose to exclude mammals from a list of potential bioindicators.

Croonquist and Brooks (1991) developed mammalian response guilds using existing literature to determine their sensitivity to disturbance, and then surveyed mammals within disturbed and undisturbed watersheds in Pennsylvania. The mammal guilds did not correspond with habitat disturbance, low sample sizes were collected, and little community variability between watersheds was detected. Furthermore, six trapping methods necessary for unbiased sampling of the mammalian community were considered cost ineffective. Brooks and Hughes (1988) in a set of proposed guidelines for wetland biological assessment in Pennsylvania recommended sampling mammals six times during the year to accommodate for seasonal variability. Snap and live traps are recommended for small mammals, and searches for signs of presence or use along 200meter transects are recommended for large animals.

When compared with other taxa, the number of mammal species that inhabit and use Florida wetlands is low, and most mammals are facultative users of wetlands. Only the round-tailed muskrat (*Neofiber alleni*), rice rat (*Orizymes palustris*) and marsh rabbit (*Syvilagus palustris*) were considered obligate users of wetlands in Florida (Hart and Newman 1995). It is more likely for small mammals to be robust wetland health indicators in the Pacific Northwest where species richness is relatively high. For example, Richter and Azous (1995) captured 22 species of small mammals from 19 wetlands in the Pacific Northwest (though reported that species richness only weakly corresponded with development intensity but positively corresponded with the amount of large woody debris within the wetland buffer).

RESPONSE TO STRESSORS

Few recent studies were found in a search of the literature between 1990 and 1999 on the effects of stressors on mammals in inland freshwater wetlands in Florida or the Southeastern Coastal Plain. A review of recent national literature on the subject is not included in Danielson (1998) and Adamus and Brandt (1990) report a paucity of information on the subject in literature prior to 1990, but offer a few general characterizations.

For most stressors the response of wetland mammals is unknown, difficult to assess and nested in cumulative impacts, rendering speculative indicator assemblages of "most sensitive" species. Hart and Newman (1995) call for more research on small mammals to determine how they use wetlands and how they (especially) respond to hydrological variability. Gosselink and Lee (1987) suggest that the presence of a healthy population of native top carnivores is an indicator of regional biological integrity.

Local stressor effects on wetland mammals are likely to be manifested in changes in their food base. For example, stressors such as organic wastes generating anoxic conditions or severe acidification can eliminate mammal food species, and therefore may influence a shift in community composition from piscivorous species to herbivores or invertebrate consumers. Research on mammal response to toxicity in Florida wetlands is limited. Three panther deaths in the Everglades have been attributed to mercury poisoning (Sundlof et al. 1994).

Changes in wetland hydropattern and soil moisture alter the suitability of mammal habitat and may trigger migrations. For example, in North Florida cypress ponds Harris and Vickers (1984) found an increase in relative abundance of rice rats (*Oryzomys palustris*) and a decrease in cotton rats (*Sigmodon hispidus*) with increases in water levels. During floods many mammals are forced from wetlands into uplands, and while dispersing can experience increased mortality rates primarily due to predation and encounters with automobiles (Hart and Newman 1995), but also possibly due to poor reproductive success during prolonged events.

Research on mammal response to vegetation removal in Florida wetlands is limited In general, species richness of small mammals corresponds with complexity of vegetation structure, and many small herbivorous mammals are more common in denser herbaceous ground cover that results from removal of overstory vegetation. In post-phosphate mined land in Central Florida, Schnoes and Humphrey (1987) attributed higher species diversity and abundance of small mammals in young and middle-aged successional spoils and pits to a greater primary production of consumable forage in dense understory vegetation. Rice rats and cotton rats may be forced to nest in uplands when wetland vegetation is too sparse resulting in higher mortality rates (Hart and Newman 1995). Azous and Horner (1997) found wetlands in the Pacific Northwest were more likely to have diverse mammal communities if a substantial part of the adjacent land was not cleared but retained in forest.

Response to other stressors (salinization, sedimentation, burial, turbidity, shading, and thermal alteration) is not documented for Florida wetland mammals in the recent literature. Indicator assemblages of mammal species "most sensitive" to these stressors remain speculative (Adamus and Brandt 1990). Mazotti et al. (1981) discuss the implications of exotics on higher organisms in Florida wetlands and suggest that while small mammal activity in *Casuarina* sp. swamps is extremely low, there is still extensive use of *Melaleuca quinquenervia* forests, though densities are lower than pristine native communities.

Wetland mammal response to habitat fragmentation in Florida is poorly documented. Doherty (1991), in a review of existing literature on wildlife inventories of Central Florida, documented 27 of 47 mammal species present in forest communities in the region occurring in the post phosphate mined landscape. Of 29 mammal species documented using mixed hardwood swamps in the region, 10 species were not documented using communities developing on the mined landscape, including one endangered, three threatened, and one rare species. Kale and Pritchard (1997) provide additional inventories of mammals known to occur in wetland habitats on phosphate mined lands.

Gosselink and Lee (1987) state that fragmentation has excluded many large carnivores from bottomland hardwood forests. It is likely that wetland dependent mammals respond to changes in hydrologic connectivity, vegetated corridors, and distance between isolated wetlands. Water diversion projects, bank clearing, roads and proximate land-use act to fragment and disturb wetland habitat. Mammals generally, because they are highly mobile can ameliorate effects by dispersing to other areas, but they do so at a probable risk of greater predation and energy expenditure.

Brown et al. (1987, 1989) used home range sizes of wetland mammals to define wildlife guilds and as part of a variable buffer zone determination for the Wekiva River and East Central Florida. Brandt et al. (1993) evaluate regional effects of citrus development on wildlife habitat in South Florida using land cover maps in combination with species models for wildlife, including the Florida panther, and identify areas most susceptible to citrus development and habitat that should be high priorities for protection in order to protect the species. The Florida Fish and Wildlife Conservation Commission (Cox et al. 1994) identifies critical areas for wildlife habitat conservation in Florida, including 6 wetland community types covering 18% of the State.

Chapter 10 – WETLAND CLASSFICATION AND DISTRIBUTION

Appropriate consideration of the factors necessary to create homogenous sets for comparing biological condition requires the identification of wetland classes within ecological regions. A goal of classification for biological assessment is to group wetlands with similar biological attributes and biological response to human disturbance. Because biological assessments measure wetland health relative to reference conditions, classification must distinguish local environments and address regional variability. Karr and Chu (1999) advocate judicious classification, arguing that selection of too few classes [or few too regions] may overlook important characteristics and that too many may unnecessarily complicate development of biocriteria.

Geography, landscape position, geomorphology, hydropattern, climate, physical/chemical variables, and biogeographic processes determine the structure and function of local wetlands. Aspects of these driving forces are incorporated in most hierarchical classification and regionalization efforts, while others are based on plant community structure and species composition. Regardless of the number or resolution of classes and regions, at all levels there is overlap because of common species distributions and intergrading physical environmental conditions.

In conjunction with research in the development of a biological approach to wetland health assessment in Florida, the University of Florida Center for Wetlands proposed wetland classes and regions to test as homogenous sets for comparing biological condition. This chapter is excerpted from Florida Department of Environmental Protection reports: Doherty et al. (1999), *Proposed Classification for Biological Assessment of Florida Inland Freshwater Wetlands*; and Lane et al. (1999), *Proposed Regions for Biological Assessment of Florida Inland Freshwater Wetlands*. Proposed regions and classes for inland freshwater wetlands of Florida are presented here to provide context for assemblage profiles and stressor response reported in the literature reviewed. The reader is encouraged to obtain these reports and contact authors and FDEP personnel with questions and requests for updated material.

PROPOSED WETLAND CLASSIFICATION

Several classification schemes have been developed to describe Florida's inland freshwater wetlands (Table 10.1). Each system is overviewed and cross-referenced by Doherty et al. (1999), with summary provided here. FNAI provides the most comprehensive descriptions for its communities, using species lists and typical hydroperiods (and other information) to classify biologically distinct wetlands organized by landscape position. SCS also provides ecosystem attributes but does not include hydrology or geomorphology as keying characters, resulting in less distinct community types. FLUCCS is not organized by landscape features, rather by dominant vegetation readily identifiable through remote sensing, resulting in nomenclature that is not descriptive for biological assessment. NWI first divides wetlands by landscape features followed by dominant vegetative form, but classification, while

Table 10.1. Classifications of Florida's inland freshwater wetlands.

- Florida Land Use, Cover and Forms Classification System (Florida Department of Transportation 1976/1985)
- National Wetlands Inventory (U.S. Fish and Wildlife Service; Cowardin et al. 1979)
- Guide to the Natural Communities of Florida (Florida Natural Areas Inventory and Florida Department of Natural Resources 1990)
- Florida Land Cover Classification (Florida Fish and Wildlife Conservation Commission; Kautz et al. 1993, Cox et al. 1994)
- Hydrogeomorphic Wetlands Classification (Army Corps of Engineers Waterways Experimental Station; Trott et al. 1997/2000, Brinson 1993)
- 26 Ecological Communities of Florida (Soil Conservation Service 1981)
- Ecosystems of Florida (Myers and Ewel, eds. 1990)
- Wetlands Classification Key (Lake County Water Authority / SJRWMD)

hierarchical, often lacks resolution for assessing biological condition and the nomenclature is not conducive to localities. FWC habitats were chosen based on imaging criteria and with only 7 wetland habitats is too aggregated for biological description. The coarse resolution of HGM functional classes may not distinguish all wetland types within a region, and geomorphic settings may not be distinct, or it may not be possible to identify dominant hydrologic characteristics (e.g., in Peninsula Florida, Flats is not readily discriminated from Depression or Slope classes, and several water sources may exist for a wetland type).

A classification for biological assessment of Florida inland freshwater wetlands is described here as proposed by Doherty et al. (1999). The approach is a preliminary effort to group similar wetlands together for purposes of detecting biological condition. Considerations were made to keep the system simple, user-friendly, related to other classifications, but robust enough to generate a consistent wetland typology. It is a tiered approach using broad landscape categories (River, Depression, Lake, Strand, Seepage and Flatland) subdivided into forested and non-forested classes, generating 13 wetland types (Table 10.2). Additional resolution is provided through (subclass) descriptors: Hydroperiod (depth, duration and frequency of inundation); Primary Water Source (rainfall, surface or groundwater); and Soil Type (organic or mineral).

The proposed classification builds on commonalities between and key elements from prominent classifications (principally HGM, FNAI, and NWI). Other wetland classifications used in Florida are cross-referenced with the proposed approach to generate a framework for common nomenclature and to utilize the best components of existing systems (Table 10.3).

PROPOSED WETLAND REGIONS

Regionalization is important to wetland bioassessment to account for natural variation in species assemblages due to spatial location (Hughes et al.. 1990). Ecoregions are defined as homogenous landscape patterns deduced from various climatic and geographic inputs (Griffith et al.. 1994). The Environmental Protection Agency (EPA) more specifically defines ecoregions as areas with apparent homogeneity in a combination of geographic characteristics that are likely to be associated with resource quality, quantity, and types of stresses (Gibson et al.. 1994). Several ecoregions are developed for Florida. Physiographic regions proposed by Griffith (1994) are used as a basis for the State’s lake regions (Griffith et al.. 1997) and stream regions (Barbour et al.. 1996).

Regions for biological assessment of Florida inland freshwater wetlands are described here as proposed by Lane et al. (1999) and Lane (2000). The approach is a preliminary effort to identify distinct wetland regions within Florida for the purposes of detecting biological condition. Spatial hydrological models and landscape level geostatistical algorithms were used to generate proposed regions and to test correspondence between wetland type (using NWI and FWCC data) and combinations of environmental variables including: precipitation, groundwater inflow, evapotranspiration, surface water runoff, infiltration, pedogenic characteristics, transmissivity, conductivity, imperviousness, and hydrologic gradients. Four

Table 10.2. Proposed classification for biological assessment of Florida inland freshwater wetlands (from Doherty et al. 1999).

1.	wetland is primarily forest	2
	wetland is primarily herbaceous	3
	wetland is shrub dominated	**Shrub-scrub**
2	wetland is within stream channel or floodplain	**River Swamp**
	wetland is an isolated depression	**Depression Swamp**
	wetland is along a lake edge (permanent water >2 meters deep)	**Lake Swamp**
	wetland located on sloped topography	**Strand / Seepage Swamp**
	wetland associated with flat landscape; water source primarily precipitation	**Flatland Swamp**
3	wetland is within a stream channel or floodplain	**River Marsh**
	wetland is an isolated depression	**Depression marsh**
	wetland is along a lake edge (permanent water >2 meters deep)	**Lake marsh**
	wetland located on sloped topography with groundwater source	**Seepage Marsh**
	wetland associated with flat landscape; water source primarily precipitation	**Wet Prairie**

Descriptors:

Hydroperiod: Depth, duration, and frequency of inundation
Primary water source: rainfall, surface water, groundwater
Soil type: organic, mineral
Plant community association

Table 10.3. Classification cross-reference of proposed classes for biological assessment of inland freshwater wetlands in Florida (from Doherty et al. 1999).

Forested wetlands:

- **River Swamp**
  - FNAI: Bottomland Forest, Floodplain Forest, Floodplain Swamp, Freshwater Tidal Swamp, River Floodplain Swamp
  - FLUCCS: 613-Gum Swamp, 615-Stream and Lake Swamp (Bottomland), 617-Mixed Wetland Hardwood, 621-Cypress, 623-Atlantic White Cedar, 624-Cypress-Pine-Cabbage Palm
  - FWC: 12-Cypress, 13-Hardwood Swamp, 17-Bottomland Hardwood
  - NWI: PFO1-Palustrine Forested Broad-leaved Deciduous, PFO2-Palustrine Forested Needle-leaved Deciduous, PFO6-Palustrine Forested Deciduous mixed, PFO7-Palustrine Forested Evergreen mixed
  - SCS: 17-Cypress Swamp, 20-Bottomland Hardwood, 21-Swamp Hardwood
- **Depression Swamp**
  - FNAI: Basin Swamp, Bog, Dome Swamp, Baygall
  - FLUCCS: 611-Bay Swamp, 613-Gum Swamp, 617-Mixed Wetland Hardwood, 621-Cypress
  - FWC: 12-Cypress, 13-Hardwood Swamp, 14-Bay Swamp
  - NWI: PFO2-Palustrine Forested Needle-leaved Deciduous, PFO3-Palustrine Forested Broad-leaved Evergreen, PFO6-Palustrine Forested Deciduous mixed
  - SCS: 17-Cypress Swamp, 22-Shrub Bog/Bay Swamp
- **Lake Swamp**
  - FNAI: Swamp Lake, Basin Swamp, Bottomland Forest
  - FLUCCS: 613-Gum Swamp, 615-Lake Swamp (Bottomland), Mixed Wetland Hardwood, 621-Cypress, 624-Cypress-Pine-Cabbage Palm
  - FWC: 12-Cypress Swamp, 13-Hardwood Swamp, 17-Bottomland Hardwood
  - NWI: PFO2-Palustrine Forested Needle-leaved Deciduous, PFO6-Palustrine Forested Deciduous mixed
  - SCS: 17-Cypress Swamp, 21-Swamp Hardwoods
- **Strand Swamp**
  - FNAI: Strand Swamp
  - FLUCCS: 614-Titi Swamp, 617-Mixed Wetland Hardwood, 618-Willow and Elderberry, 619-Exotic Wetland Hardwood, 621-Cypress, 631-Wetland Scrub
  - FWC: 12-Cypress Swamp, 13-Hardwood Swamp, 15-Shrub Swamp
  - NWI: PFO2-Palustrine Forested Needle-leaved Deciduous, PFO6-Palustrine Forested Deciduous mixed
  - SCS: 12-Wetland Hardwood Hammock, 16-Scrub Cypress, 17-Cypress Swamp
- **Seepage Swamp**
  - FNAI: Baygall
  - FLUCCS: 611-Bay Swamp
  - FWC: 14-Bay Swamp
  - NWI: PFO3-Palustrine Forested Broad-leaved Evergreen, PFO7-Palustrine Forested Evergreen mixed
  - SCS: 10-Cutthroat Seep, 22-Shrub Bog/Bay Swamp
- **Flatland Swamp**
  - FNAI: Hydric Hammock, Wet Flatwoods
  - FLUCCS: 614-Titi Swamp, 616-Inland Ponds and Sloughs, 618-Willow and Elderberry, 619-Exotic Wetland Hardwood, 622-Pond Pine, 624-Cypress-Pine-Cabbage Palm, 625-Hydric Pine Flatwoods, 626-Hydric Pine Savanna, 627-Slash Pine Swamp Forest
  - FWC: 13-Hardwood Swamp, 3-Pinelands
  - NWI: PFO4-Palustrine Forested Needle-leaved Evergreen, PFO7-Palustrine Forested Evergreen mixed
  - SCS: 6/7-Flatwoods

Table 10.3 (Continued.) Cross-reference of wetland types with proposed bioassessment classification.

Non-forested wetlands:

- **River Marsh**
    - FNAI: Floodplain Marsh
    - FLUCCS: 641-Freshwater Marsh, 644-Emergent Aquatic Vegetation
    - FWC: 11-Freshwater Marsh and Wet Prairie
    - NWI: R2AB-Riverine Lower Perennial Aquatic Bed, R2EM-Riverine Lower Perennial Emergent Non-persistent, R3AB-Riverine Upper Perennial Aquatic Bed, R4SB-Riverine Intermittent Streambed, PAB3-Palustrine Aquatic Bed Rooted Vascular, PAB4-Palustrine Aquatic Bed Floating Vascular, PEM-Palustrine Emergent
    - SCS: 25-Freshwater Marsh
- **Depression Marsh**
    - FNAI: Basin Marsh, Bog, Depression Marsh
    - FLUCCS: 641-Freshwater Marsh, 644-Emergent Aquatic Vegetation, 653-Intermittent Pond
    - FWC: 11-Freshwater Marsh and Wet Prairie
    - NWI: PAB3-Palustrine Aquatic Bed Rooted Vascular, PAB4-Palustrine Aquatic Bed Floating Vascular, PEM-Palustrine Emergent
    - SCS: 25-Freshwater Marsh, 24-Sawgrass Marsh
- **Lake Marsh**
    - FNAI: Flatwoods/Prairie/Marsh Lake, Basin Marsh
    - FLUCCS: 641-Freshwater Marsh, 644-Emergent Aquatic Vegetation, 645-Submergent Aquatic Vegetation
    - FWC: 11-Freshwater Marsh and Wet Prairie
    - NWI: L1AB-Lacustrine Limnetic Aquatic Bed, L2AB-Lacustrine Littoral Aquatic Bed, L2EM-Lacustrine Littoral Emergent non-persistent, PAB3- Palustrine Aquatic Bed Rooted Vascular, PAB4- Palustrine Aquatic Bed Floating Vascular, PEM-Palustrine Emergent
    - SCS: 25-Freshwater Marsh
- **Seepage Bog**
    - FNAI: Swale, Slough, Seepage Slope
    - FLUCCS: 641-Freshwater Marsh, 643-Wet Prairie
    - FWC: 11-Freshwater Marsh and Wet Prairie
    - NWI: PEM-Palustrine Emergent
    - SCS: 10-Cutthroat Seep, 23-Pitcher Plant Bog
- **Wetland Prairie**
    - FNAI: Wet Prairie, Marl Prairie
    - FLUCCS: 643-Wet Prairie, 646-Treeles Hydric Savanna
    - FWC: 11-Freshwater Marsh and Wet Prairie
    - NWI: PEM-Palustrine Emergent
    - SCS: 25-Freshwater Marsh, 26-Slough, 24-Sawgrass Marsh
- **Shrub Scrub**
    - FNAI: Seepage Slope, Bog, Slough
    - FLUCCS: 631-Wetland Scrub, 614-Titi Swamp, 616-Inland Pond and Slough, 618-Willow and Elderberry, 619-Exotic Wetland Hardwood
    - FWC: 15-Shrub Swamp
    - NWI: PSS-Palustrine Scrub Shrub
    - SCS: Shrub Bog/Bay Swamp

wetland regions are proposed: Panhandle, North, Central, and South (Figure 10.1). Proposed regions partition the State and further specify wetland classes.

WETLAND DISTRIBUTION IN FLORIDA

Inventorying wetland classes within 4 proposed wetland ecoregions reveals distributional variation across Florida. Lane (2000) used two-way indicator species analysis (TWINSPAN) to identify percent occurrence of NWI palustrine wetlands in Florida based on type, distribution and abundance. Palustrine wetland classes include: Broadleafed Evergreen, Needle-leafed Evergreen, Forested Deciduous, Shrub Scrub, and Emergent Marsh. (Because of different criteria and agency needs, cross-reference of wetland nomenclature generate overlap and it is not possible to translate proposed classes into wetland types for which Statewide coverage exists).

Current wetland area in Florida is estimated between 18% (FWCC) and 23% (NWI) of the inland landscape. Twenty-two percent of the Panhandle Region is wetland; 35% of the South Florida Region is wetland; wetlands in the North and Central Regions cover 16% of the landscape. Florida wetlands are about 53% forest, 37% marsh and 10% shrub. Generally, there is a trend of declining forest wetlands and increasing non-forest wetlands latitudinally from the Panhandle to South Florida.

Deciduous-Forest wetlands are most abundant within the Panhandle Region (52%) followed by Needle-leaved-Evergreen-Forests (32%). Emergent wetlands account for less than 4% of the wetlands in the region. In the North Region, the Deciduous-Forest class is again the most common wetland (63%) but Emergent wetland area proportionally increased (13%). Evergreen-Forest classes (Broad and Needle-leaved together) account for 16% of wetlands in the region. In the Central Region, Emergent and Deciduous-Forest classes are equally represented, each about 40% of area wetlands. Evergreen-Forest wetlands decreased to about 10% of the region’s wetlands. Shrub-Scrub classes in the Panhandle, North and Central Regions represent 7-9% of regional wetlands. In the South Florida Region, Emergent wetlands are prominent landscape features (61% of wetlands and 22% of landscape). Forested wetlands are less common (Deciduous and Evergreen-Forest classes account for 16% and 5% of area wetlands, respectively). Shrub-Scrub wetlands are more common in South Florida (17% of wetlands in the region). These estimates are presented here to provide context for assemblage profiles and stressor response reported in the literature reviewed.

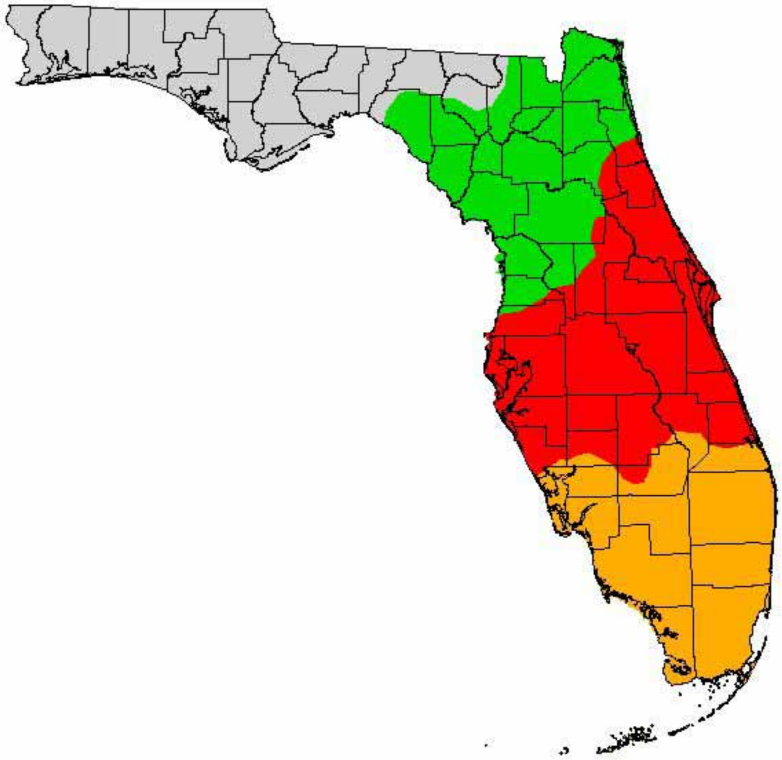

Figure 10.1. Proposed regions for biological assessment of Florida inland freshwater wetlands (from Lane 2000).

Chapter 11 – SUMMARY

Because of the variety of wetland types within and across regions and of cumulative and compound effects of disturbance, biological assessments of wetland condition in Florida's inland freshwater wetlands require a multi-metric approach. It is doubtful that an individual species, a single metric, or one assemblage will alone provide a robust and clear signal. The review of recent scientific literature (Chapters 3-9) identifies numerous possible biological indicators across 7 taxonomic assemblages. Quantitative justification for the possible indicators is not warranted as the literature, except in a few cases, lacks a sufficient number of studies that demonstrate causal relationships or that allow statistical extrapolation to entire taxa, stressor categories, wetland types, or regions within Florida. An overview of the literature base, general comments on stressors and assemblages, and a summary of potential indicators conclude this report.

LITERATURE BASE

Over 500 articles and documents related to wetland biological assessment in general and inland freshwater wetlands of Florida in particular have been catalogued in the library database to date. Representative types and numbers of articles pertaining to research location, wetland type, taxonomic assemblage, and stressor categories are given in Table 11.1. No presumption of importance is given to research reported or ongoing, nor are suggestions made to prioritize future research based on representation of wetland type, region, indicator assemblage, or stressor in the reviewed literature.

Wetland Classes and Regions

While it is not fully possible to group the literature into wetland classes and regions, some trends are evident. The Everglades is by far the most commonly studied wetland in Florida and elsewhere (here comprising one-third of all reviewed Florida wetland literature). Generally wetland research declines from north to south across the State, with research in South and Central Florida wetlands more common than North Florida and the Panhandle wetlands. This is in disproportion to wetland occurrence across Florida, with research in Panhandle River Swamps underrepresented though Panhandle wetlands may be less threatened by human disturbance at least as it is related to population density.

Research in Forest and Herbaceous wetlands is equally represented in the literature but not balanced with wetland occurrence across Florida where Forest wetlands comprise about 53% of all wetlands and Marsh wetlands are approximately 37%. Assuming a designation of 'Herbaceous' includes Marsh and Shrub Scrub classes, research in Non-Forest wetlands is then proportional to Statewide occurrence. More research is reported in Depression wetlands than River or Lake fringe wetlands – a proportional under-representation of River Swamps based on percent occurrence in the State.

Table 11.1. Summary of literature on Florida inland freshwater wetlands.

Location:	No. Articles
Florida	334
Everglades	104
Southeastern Coastal Plain	23
National	131
Assemblage:	
Algae	50
Plants	195
Macroinvertebrates	122
Fish	131
Herpetofauna	49
Birds	82
Mammals	28
Other	9
Abiotic	51
Stressor:	
Enrichment, eutrophication	72
Toxic contaminants	35
Acidification	12
Salinization	4
Sedimentation	7
Turbidity, shading	8
Vegetation disturbance	30
Thermal alteration	2
Dehydration, inundation	45
Habitat fragmentation	41
Exotic species, invasions	15
Biological	96
Physical	39
Chemical	82
Hydrologic	88
Agriculture	45
Urban	45
Siliviculture	7
Wetland type:	
Forest	60
Herbaceous	62
Lacustrine	18
Riverine	38
Isolated, depression	48

Assemblages and Stressors

Research on wetland plants is most documented in recent literature, followed by fish and macroinvertebrates. Together these 3 assemblages receive over 60% of the wetland research attention in the State. Algae and bird literature is common compared to a limited literature found on herpetofauna and mammals.

Wetland nutrient enrichment is the most researched stressor reported in the literature followed by dehydration, inundation and habitat fragmentation studies. Together these 3 stressors receive over 60% of the wetland research attention in the State. Studies on contaminant toxicity, vegetation disturbance and exotic species are common compared to a limited literature found on acidification, salinity, sedimentation, turbidity and temperature alterations.

This literature base documents current (1990-99) and available (published or printed) information on responses of organisms and species assemblages to stressors in Florida inland freshwater wetlands. Table 11.2 is a compilation of the reviewed literature ordered by assemblage and stressor. Numbers of articles tallied are approximate given overlap, differing research objectives, and ill described site information. The majority of wetland algal research in Florida is related to eutrophication, especially in the Everglades. A preponderance of plant literature is associated with studies on wetland hydroperiod, followed by studies on eutrophication and vegetation removal. Macroinvertebrate research is focused on enrichment as well as dehydration and inundation effects. Response to hydroperiod alterations account for the majority of studies conducted on other assemblages (fish, herpetofauna and birds). A very few articles were located on mammalian response to wetland stressors. More or fewer articles on the impacts of any one stressor on an assemblage represent the current relative knowledge base from which to select initial candidate indicators for field trials.

Limited information on impacts from and responses to several selected stressors, especially acidification, salinity, sedimentation and thermal alterations, is reflected in their relative unimportance in Florida inland freshwater wetlands. Other stressors, especially contaminant toxicity and habitat fragmentation, are important even though there is a limited literature on indicator response. Nutrient enrichment and hydroperiod manipulation are both routinely researched in Florida, and both are common disturbances that are difficult to determine origin, whether natural or human-induced or both.

Acidification is not currently a wetland threat in part due to the relative natural acidity of surface waters in Florida, to the absence of mining activities commonly associated with acid mine drainage and to the buffering affects of the underlying carbonate geology. However, carbonates are often phosphorus rich and dissolution may enrich surrounding waters, illustrating the confounding nature of multiple stressor impacts. Salinization is not currently a prominent wetland threat in part due to the small number of ground water fed wetlands that might be subjected to salt water intrusion from aquifer draw-downs and to the limited impact of irrigation on soil salinity in the State. The water source for most wetlands in Florida is either from precipitation or overland and stream flow. Natural salinity gradients exist in tidal wetlands throughout Florida and plant community shifts can be used to indicate salinity impacts in non-tidal wetlands. Sedimentation is more common in areas of high velocity

Table 11.2. Summary of literature between 1990-1999 on taxonomic assemblages and stressors in inland freshwater wetlands of Florida (approximate numbers of articles located in search and reviewed in this report).

	Enrichment, eutrophication	Toxic contamination	Acidification	Salinization	Sedimentation	Turbidity, shading	Vegetation disturbance	Thermal alteration	Dehydration, inundation	Habitat fragmentation	Estimated total
Algae	17	1	4	0	0	3	0	1	6	0	32
Vascular plants	13	4	3	4	3	1	15	0	27	9	79
Macroinvertebrates	9	2	0	0	2	0	0	0	10	7	30
Fish	6	3	1	0	0	2	0	0	11	0	23
Herpetofauna	2	2	1	0	0	0	4	0	6	9	24
Birds	5	2	0	0	0	1	4	0	18	6	36
Mammals	0	1	0	0	0	0	2	0	2	3	8
Estimated total	52	15	9	4	5	7	25	1	80	34	232

runoff and steep slopes, both conditions uncommon in Florida. Ambient thermal changes in wetland water also do not pose a significant threat due to relatively small temperature shifts between seasons in the subtropical climate of Florida, and to the absence of permanent frozen water in winter. Still the discharge of power plant effluents into embayments and wetlands is common in Florida and receiving waters are known refugia for some organisms that otherwise would migrate to warmer climes during winter.

Impacts are generated from multiple sources, both natural and human, and the responses of wetland organisms integrate multiple stressor effects. Some examples follow. Cattle grazing, cultivation and silviculture generate multiple stress impacts with the potential for increasing sedimentation rates and nutrient enrichment or suppressing fire occurrence and intensity. And while invasion by *Melaleuca* or *Schinus* into hydrologically altered wetlands is itself a biological stress, their presence and proliferation are also aided by fire and eutrophication. Such noxious species may accentuate dehydration through high transmissivity promoting conditions conducive to fire and the release of bound nutrients.

These examples illustrate the cumulative and synergistic effects of nested disturbances, both natural and human in origin, and the inherent difficulties in explaining response variability with single stressors or causal relationships between stressors and indicator assemblages. Complexity also underscores the need for a multi-metric approach and the selection of robust attributes that have reliable empirical relationships across a gradient of human influence.

CANDIDATE INDICATORS

The selection of indicators and metrics for biological assessment requires knowledge of characteristic response signatures of organisms, populations and assemblages to various stressors and to disturbance in general. Other considerations are important, including seasonality, type and distribution of wetlands, sampling effectiveness, available expertise and data interpretation. General characteristics of candidate indicator assemblages for biological assessment are given in Table 11.3. General and regular wetland community responses to disturbance are reductions in species richness and species composition shifts to dominance by opportunistic and ubiquitous species. Adamus and Brandt (1990) list advantages and disadvantages of using major taxa as indicators of freshwater inland wetland condition.

This report concludes with an overview of assemblages and their potential as indicators in Florida inland freshwater wetlands. Population and species level recommendations are not given. Instead, literature information is used to identify relative strengths of 7 assemblages as indicators of 10 stressors and of wetland condition in general (Table 11.4). Qualitative assessments generate 3 categories of candidate assemblages:

- Positive,
- Speculative, and
- Unlikely

Table 11.3. General characteristics of candidate indicator assemblages (Danielson 1998)[1].

- Some species with narrow and specific environmental tolerances
- Cosmopolitan distribution
- Numerical abundance
- Low genetic or environmental variability… narrow demands
- Limited mobility
- Known life history (seasonal and daily)
- Reliable response to stressor(s)
- Predictable response to stressor(s)
- Quick response to stressor(s)
- Standardized methods of collection
- Taxonomic soundness
- Easy recognition by non-specialists
- Large body size (esp. for macroinvertebrates)
- Established measures, metrics, indices
- Established databases
- Suitable for use in laboratory studies (to determine causality)
- Cost effective sampling
- Public perceives organisms / assemblages as important

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[1] Citing Hellawell 1986, Adamus and Brandt 1990, Johnson et al. 1993 and Patrick 1994.

Table 11.4. Summary evaluation of taxonomic assemblages as possible indicators for Florida inland freshwater wetlands, based on review of available literature.

Stressor	Algae	Plants	MIs	Fish	Rep/Amp	Birds	Mammals
General disturbance	√+	√+	√+	√	√	√+	√–
Enrichment, eutroph.	█	█	█	▄	▁	▄	▁
Contaminant toxicity	▁	▄	▄	▄	▄	▄	▁
Acidification	▄	▄	▁	▁	▄	▁	▁
Salinity increase	▁	▄	▁	▁	▁	▁	▁
Sedimentation	▁	▁	▄	▁	▁	▁	▁
Turbidity	▄	▁	▁	▁	▁	▁	▁
Vegetation change	▁	█	▄	▁	▄	█	▄
Thermal alteration	▁	▁	▁	▁	▁	▁	▁
Hydropattern change	▄	█	█	█	▄	▄	▁
Habitat fragmentation	▁	▄	▁	▄	▄	█	▄

▁ No Florida research documentation, paucity of pre-1990 and national literature, no dose-response indications, Florida species sensitive to stressor with low abundance/distribution, Poor-rating by other authors; indicator assemblages – Unlikely.

▄ Limited Florida research documentation, some pre-1990 and national literature, few dose-response indications, Florida species sensitive to stressor with medium abundance/distribution, Fair-rating by other authors; indicator assemblages – Speculative.

█ Strong Florida research documentation, abundant pre-1990 and national literature, positive dose-response indication, Florida species sensitive to stressor with high abundance/distribution, Good-rating by other authors; indicator assemblages – Positive.

Appropriateness of using assemblages as indicators is guided by several factors, including current knowledge of organisms reflected in the quantity and outcomes of past research, distribution and relative richness of species within and between wetland types and regions, wetland specificity of a number of species within each assemblage, documented robust response signatures for stressors, and relative ease of sampling.

Plant and macroinvertebrate assemblages appear to have the greatest promise as disturbance indicators in Florida’s inland freshwater wetlands. Algae assemblages also provide good indications of condition, especially in response to nutrient enrichment and turbidity. Bird assemblages may also provide strong response signals, especially for cross-scale and non-point stressors such as habitat fragmentation, excessive and prolonged inundation or dehydration, and vegetation change. Fish as indicators are limited due primarily to habitat ubiquity and general tolerance of most wetland species, but may provide indication of alterations to hydropatterns and eutrophication processes. Herpetofauna assemblages are speculative as indicators due to a restricted variety of species and a limited knowledge on organism response, but may provide good signals of contaminant toxicity, and can also likely indicate hydropattern change and habitat fragmentation. Florida mammals are widespread in distribution, generally unresponsive to stressors and are unlikely candidates as wetland indicators.

The appropriateness of selected indicators is deferred to reader interpretation and the intent of the agency or participants. Information on the strength of individual species as indicators can be drawn from the assemblage profiles given in previous review chapters, and the reader is encouraged to use the literature database for further processing. Because stressors are related, cumulative and reinforcing, and because human incurred stressors are often masked by natural variability and normal patterns of wetland perturbation, a multi-metric approach is warranted. This review identifies numerous attributes in Florida’s freshwater inland wetlands for use in biological assessment. Field testing is requisite of any selection. A combination of assemblages and species, identified for wetland type and region, may provide a reliant basis for monitoring cumulative ecological exposure and signaling impairment to inland freshwater wetlands in Florida.

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