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BRIDGES

BRIDGES is a recurring feature of J-NABS intended to provide a forum for the interchange of ideas and information between basic and applied researchers in benthic science. Articles in this series will focus on topical research areas and linkages between basic and applied aspects of research, monitoring policy, and education. Readers with ideas for topics should contact Associate Editors, Nick Aumen and Marty Gurtz.

Isolated wetlands have received little attention as a specific ecosystem type, yet many development and regulatory programs affect them. This lack of recognition may stem from their small size, their variable hydrology, and lack of recognition of their regional significance in the southeast US. In recognition of this problem, and in response to a US National Research Council recommendation for more research in support of wetland protection, a group of individuals convened a workshop to discuss information needs and to develop strategies to protect southeastern isolated wetlands and their biodiversity. Because the organizers perceived a lack of linkage between researchers and managers, workshop participants included scientists, natural resource managers of public and private lands, and conservationists.

Nick Aumen, naumen@bellsouth.com
Marty Gurtz, megurtz@usgs.gov
Co-editors

Biodiversity in southeastern, seasonally ponded, isolated wetlands: management and policy perspectives for research and conservation

L. K. KIRKMAN AND S. W. GOLLADAY[1],

Joseph W. Jones Ecological Research Center, Route 2, Box 2324, Newton, Georgia USA 31770

L. LACLAIRE

US Fish and Wildlife Service, 6578 Dogwood View Parkway, Jackson, Mississippi USA 39213

R. SUTTER

The Nature Conservancy, Southeast Regional Office, P.O. Box 2267, Chapel Hill, North Carolina USA 27515

Seasonally ponded, isolated wetlands (SPIWs) in the southeastern Coastal Plain of the United States are shallow basins that are not connected to streams or lakes, and their hydrology is primarily driven by rainfall and shallow, subsurface, water flow (Hendricks and Goodwin 1952, Lide et al. 1995). Although SPIWs are conspicuous features of the Coastal Plain, their significance and contribution to regional biodiversity have been largely overlooked. These wetlands support unique communities of plants and animals adapted to cycles of wetting and drying (Richardson and Gibbons 1993, Kirkman and Sharitz 1994, Sutter and Kral 1994), and are especially important habitats for breeding amphibians (Moler and Franz 1987, Semlitsch 1987, LaClaire and Franz 1991, Pechmann et al. 1991, Dodd 1992, Dodd and LaClaire 1995, Jensen et al. 1995, Semlitsch et al. 1996) and invertebrates (Taylor et al. 1988, Mahoney et al. 1990, Golladay et al. 1997) because they typically lack large fish. Locally, these wetlands also are known as non-alluvial depressional wetlands, limesink ponds, Carolina bays, Grady ponds, cypress ponds, Citronelle ponds, flat-bottom ponds, and sinkhole ponds. These wetlands somewhat resemble other depressional wetlands such as vernal pools and prairie potholes that have been better recognized in other parts of the country.

Small, isolated wetlands lack the legal protection afforded riparian or lacustrine wetlands. Nationwide Permit 26 of the US Army Corps of Engineers allows wetlands that occur in shallow basins and that lack connections to streams or lakes to be filled with no federal review process if the wetlands are <0.12 ha, and requires minimal review if they do not exceed 1.2 ha (Federal

[1]To whom correspondence should be addressed. E-mail: sgollada@jonesctr.org

Register 1996). This regulatory policy has been controversial (National Research Council 1995, Kaiser 1998) because, without scientific justification, it attributes less ecological importance to isolated wetlands. The implementation of such permissive legislation is partially a result of a fundamental lack of recognition of these wetlands' contribution to the maintenance of regional biodiversity (Semlitsch and Bodie 1998), and a lack of understanding of basic ecological processes within these systems. In the absence of protection, on-going regional development and agricultural conversion are perpetuating the cumulative loss of sites that are important to the maintenance of wetland biodiversity (Semlitsch and Bodie 1998).

The distribution of these southeastern US wetlands fits within the former range of the longleaf pine forest (Ware et al. 1993), which once dominated the southeastern Coastal Plain. The remaining longleaf pine forests are fragmented, and the associated wetlands are often surrounded by degraded habitat and isolated from some important natural processes, such as fire (Frost 1995, Kirkman 1995, Folkerts 1997). SPIWs are increasingly affected by agriculture (e.g., center pivot irrigation, run-off, cultivation), urbanization, and forest management (Bennett and Nelson 1990, Folkerts 1997).

Working group

The National Research Council (1995) recommended that more studies of wetlands be undertaken to support a stronger foundation for identification and protection of regionally important wetlands. The concern was that, in the absence of scientifically rigorous knowledge to justify conservation and protection, current regulatory protection could be undermined and prevailing threats to SPIWs could even increase.

Thus, a working group was convened 2–4 April 1997, at the Joseph W. Jones Ecological Research Center (Ichauway) in Newton, Georgia, with 2 primary objectives: 1) to define information needs for the conservation of biodiversity in southeastern SPIWs, and 2) to examine constraints, opportunities, and strategies for natural resource management and conservation relative to maintaining biodiversity on private and public wetlands. Participants represented the research community, and public and private resource management sectors. Participants conceptualized research and conservation needs of SPIWs, and identified opportunities for linkages among interdisciplinary groups. The following is a summary of the recommendations from the working group.

Conservation strategies/actions

Classification scheme and inventory of SPIWs

Many communities occur within southeastern SPIWs and each may differ in functions and values, necessitating different conservation approaches. Before identification criteria for restoration or protection priorities can be established, a classification scheme should be developed from a region-wide inventory or adapted from existing schemes (e.g., Florida Natural Areas Inventory and Florida Department of Natural Resources 1990). In particular, geographic range, and geologic and soil factors that may control hydrologic regimes or biota need to be considered in a classification scheme, as well as successional relationships among vegetation types. Defining meaningful subregions (i.e., geographical stratification) could provide the basis for formulating regional protection strategies.

Because SPIWs typically are shallow and easily drained, many have been altered or destroyed by land-use practices. Many SPIWs large enough to qualify for federal regulatory protection continue to be degraded or destroyed because enforcement of wetland regulations is particularly difficult for these less conspicuous wetlands (Folkerts 1997) (i.e., they are easier to ignore, or are often overlooked in wetland inventories). A comprehensive inventory of these wetlands is presently lacking for the southeastern Coastal Plain. Specific information needs include: 1) size and distribution by geographical subunits, 2) ownership (public versus private), 3) adjacent land use (current and projected), and 4) ecological status (degraded or functionally intact). Within each subregion, these wetlands should be additionally classified as to whether they are threatened and/or otherwise represent high priorities for protection or restoration.

Setting priorities

To identify priority wetlands for conservation, biodiversity functions and values need to be detailed in the context of surrounding landscapes. Even though wetlands may provide ecological functions regardless of surrounding landscape, current constraints in developing and prioritizing conservation strategies must be recognized. For example, incentive programs for land owners may be effective for maintaining targeted species habitat in an agricultural or forested landscape, but such programs may not be an effective tool for protecting isolated habitat in a fragmented urban setting. Evaluation of the strengths and weaknesses of regulation and incentive programs for land owners is needed before any comprehensive strategies for conservation can be assembled.

A regional approach, such as gap analysis (Scott et al. 1993, Kiestor et al. 1996), should be used to direct protection efforts. This GIS-based method identifies units in need of protection by examining distribution maps of the units relative to the present degree of long-term protection. Using this technique as a coarse filter, underrepresented units (e.g., SPIW types occurring only on private land or those particularly vulnerable to loss of biodiversity) could be recognized and then examined more closely for their biological qualities and management needs (Wilson and Peter 1988, Scott et al. 1993).

Criteria for determining the restoration potential of degraded wetlands need to be evaluated so that strategies for region-wide restoration efforts can be focused on wetlands with the greatest likelihood of recovery. Reference (benchmark) wetlands should be designated for defining restoration goals and measuring success of restoration efforts (discussed in following section concerning information needs). Hydrogeomorphic assessments of southeastern depressional wetlands is an on-going, subregional effort to identify groups of wetlands with similar hydrologic and geomorphic characteristics and functions (L. Justice, Natural Resources Conservation Service, Athens, Georgia, personal communication). Indices of ecological function, expressed relative to reference conditions, will eventually allow assessments of changes in wetlands as a result of restoration (Brinson and Rheinhardt 1996). These separate efforts need to be synthesized to obtain a regional perspective.

Education: communicating the importance of regional protection of SPIWs

The importance of SPIWs as habitat that contributes significantly to regional biodiversity has not been clearly communicated. In fact, regional assessments of the function of these wetlands in supporting biota have been measured by attributes relative to riparian systems (e.g., carbon export by moving water). As a result, much less significance may be inferred because SPIWs are isolated from stream drainages (Rowell et al. 1995). With increasing interest in restoration of longleaf pine/wiregrass habitats in the southeast, the opportunity to promote SPIWs as a significant part of this species-rich, fire-maintained ecosystem should be emphasized. Education is an essential, but often neglected, part of biodiversity conservation efforts (Blockstein 1995). There are many audiences in the southeast that need to be educated: the general public, land managers (private, industrial, public), environmental regulators, scientists, students, regional planning councils, wildlife/conservation advocacy groups, soil and water conservation districts, and policy makers. Determining the most effective communication tools for each group is a preliminary step toward educating potential constituents. Immediate approaches should include: 1) the development of brochures on depressional wetlands for the general public and private landowners, 2) curricula development with school teachers, 3) development of short courses for public and private land managers, and 4) development of program material for use by conservation groups.

Best management practices and incentive programs

Many private land managers are willing to consider management objectives for their lands that include both commodity production and conservation objectives. The adoption of best management practices (BMPs) by foresters has been an effective method of obtaining voluntary compliance for protection of streams and other types of wetlands (Ice et al. 1997). Thus, the development of BMPs for forestry operations in and around SPIWs is suggested and will require the collective efforts of industrial and private forest managers, conservation groups, scientists, and others. Similarly, BMPs for agricultural activities that affect these SPIWs should be developed in conjunction with the US Department of Agriculture, Natural Resources Conservation Service.

Although many state and federal incentive programs targeting wetland conservation are available to forest and agricultural landowners, information supplied to landowners usually is incomplete because it is supplied according to agency themes. A centralized information source covering the numerous incentive programs currently available to landowners for wetland conservation or restoration would be useful.

Information needs

Significant information gaps constrain development of management options that effectively protect SPIWs from detrimental land-use practices or development of some of the conservation strategies identified above. These information needs are outlined in the following section. The key to protection of wetland biota is understanding the biological integrity, i.e., the collective conditions and processes (Angermeier and Karr 1994) that determine the system's ability to maintain suitable habitat. It is important to resolve variation in the system because of anthropogenic interference versus natural fluctuation in rates of processes (e.g., nutrient cycling, productivity) or population dynamics (Pechmann et al. 1991, Semlitsch et al. 1996).

Hydrology

The physical and biological characteristics of wetlands are driven by the hydrologic regime (Mitsch and Gosselink 1993). Hydrologic regimes vary widely among SPIWs; however, relationships between hydrology, other geomorphic variables, and community development are poorly understood. Depth of inundation, depth to water below ground during dry periods, and average annual duration and timing of inundation are controlled primarily by precipitation, evapotranspiration, shallow groundwater flows and, in some cases, groundwater exchanges (Torak et al. 1991). All of these flowpaths are affected by anthropogenic activities (e.g., ditching, groundwater withdrawal, vegetation removal, and increased run-off with urbanization). Thus, understanding natural hydrologic processes, anthropogenic influences, and their interactions is crucial for developing management approaches for maintaining long-term functional integrity of various wetland types.

Biotic assessment of SPIWs

Obligate species.—We know that many species are highly dependent on SPIWs for all of their life requisites (e.g., obligate wetland plants) or during critical parts of their life cycle (e.g., breeding amphibians). These species include imperiled vertebrates such as the gopher frog (*Rana capito*), striped newts (*Notophthalamus perstritus*), and flatwoods salamander (*Ambystoma cingulatum*). It is likely that many other species also are dependent on these ecosystems, including invertebrates, algae, and fungi. Identification of the plant and animal species that are dependent on this ecosystem type and the distribution of those species are needed.

Facultative or associated species.—Other species of concern may be associated with the margins of isolated wetlands (e.g., American chaffseed, *Schwalbea americana* L., Kirkman 1998) or use these habitats facultatively (e.g., migratory waterfowl, songbirds, amphibians and reptiles, etc., Sharitz and Gibbons 1982). The habitat requirements of these species need to be examined relative to potential land-use impacts.

Exotic and nuisance species.—Alteration of biotic structure, composition, hydroperiod, and water quality in SPIWs because of the introduction of exotic and nuisance species has been suggested (Folkerts 1997, N. Coile, Florida Department of Agriculture and Consumer Service, Gainesville, Florida, personal communication). These observations need to be quantified for SPIWs. Based on such results, control and management strategies for exotic introductions could be developed.

Species diversity and ecosystem processes

As ecosystems, SPIWs represent a unique (and often very diverse) association of physical factors (LaClaire 1995). However, our understanding of how the following factors maintain diversity and ecosystem processes is poor.

Substrate characteristics.—Soil substrate characteristics (e.g., organic matter accumulation, nutrient retention) generally influence the ability of plants to root, fire frequency and intensity, and productivity, which in turn influence vegetation structure, fuel loads, and substrates and nutrients for organisms (Duever 1984). An understanding of detrital dynamics and how they can be affected by anthropogenic influences is needed. Soil textural profiles may reflect hydrologic regimes that relate to biotic community development, and may be key to the identification of reference wetlands for restoration goals.

Importance of fire.—Because SPIWs occur within the former range of longleaf pine forests—a fire-maintained ecosystem—fire likely has been an important component in development of SPIW communities (Kushlan 1994, Frost 1995, Kirkman 1995). The complex interactions of fire and hydrology are important controls in maintaining natural plant and animal communities, although these interactions are poorly understood across regions, landscapes, and soil types. Information is needed on the impacts to biological diversity because of anthropogenic changes in hydroperiod and potential concomitant changes in fire regime. Management recommendations that involve prescribed fire in wetlands require an understanding of the role of fire and interactions with historical legacies (e.g., timber removal, altered hydrology, hardwood encroachment because of fire suppression). Concerns related to smoke management for public safety and liability of burning (Wade 1993) need to be addressed in long-term management plans.

Degree of isolation and connection.—In addition to within-wetland diversity (i.e., alpha diversity), diversity among SPIWs is often high (i.e., beta diversity), even among some with close spatial proximity (DeSteven and Toner 1997). The spatial arrangement of these wetlands (i.e., degree of isolation) in terms of colonization/extirpation of species is important in developing conservation strategies and prioritization of wetland complexes for protection (Noss 1983, Burkey 1989, Semlitsch and Bodie 1998). Information on genetic population structure could enable us to evaluate the degree of isolation in these habitats. Isolation may be particularly important for aquatic animals without active terrestrial stages and for plants with poor long-range dispersal (Semlitsch and Bodie 1998). If natural extirpations occasionally occur, followed by recolonization from other SPIWs or other types of wetlands, strategies that focus on preserving 1 or a few examples of the habitat will fail to maintain the diversity within these communities. Similarly, because of the diversity among wetlands, a large number of SPIWs is necessary to maintain overall regional diversity of habitat and associated biota.

Water-quality issues

Acidification.—Acidification of SPIWs is believed to adversely affect breeding success of gopher frogs (Smith and Braswell 1994) and perhaps other amphibians and aquatic invertebrates. However, discrimination of natural population fluxes and responses to acidification can be difficult (Pechmann et al. 1991). Understanding causes of acidification and its effects is essential to determining whether changes in management can minimize the impact on wetland biota.

Non-point-source pollution.—Non-point-source pollution (e.g., nutrients, pesticides, sediments) from adjacent uplands can cause long-term changes in the water quality and associated biota of wetlands (National Research Council 1992). Effects of pollutants associated with agriculture, silviculture, and urban land use should be documented to develop meaningful BMPs for SPIWs.

Water-quality baseline data.—Because wetlands vary by vegetation, soil type, and geologic origin, their water quality is variable (Newman and Schalles 1990). Information is needed to document water-quality differences among relatively undisturbed wetlands to facilitate classification and improve evaluation of upland management impacts.

Management issues

Buffer structure.—Naturally vegetated buffers generally are recognized as necessary within managed landscapes to protect wetlands and associated biota from adverse impacts (Lowrance et al. 1984, Bren 1995, Burke and Gibbons 1995, Comerford et al. 1996); however, the buffer widths necessary to protect ecological processes and species are unknown (Semlitsch 1998). For example, buffer widths to accommodate terrestrial retreats of reptiles and amphibians may differ from those necessary to protect ecotonal plants. As part of BMPs, buffer widths restricting certain activities need to be assessed (e.g., no soil disturbance, no slash piling, no pesticide application, etc.) relative to specific protection goals. In addition, management options that could be implemented within a prescribed buffer need to be identified.

Silvicultural practices.—Timber in some SPIWs within the managed forest landscape of the southeast will be harvested, particularly for wetlands dominated by pond cypress (*Taxodium ascendens* Brongn.) or slash pine (*Pinus elliotii* Englem.). Management practices that can best meet the objectives of timber extraction and regeneration of desired crop trees while maintaining suitable wetland habitat are untested. Validation of optimal silvicultural prescriptions (e.g., timing of harvest, site preparation, stocking density, fire, and herbicides) that meet both objectives are needed to develop BMP recommendations.

Indicators of disturbance.—Techniques to rapidly assess the degree of degradation associated with various types of disturbances in SPIWs are needed. Although the use of indicator species has gained fairly wide use for stream assessments (USEPA 1990, 1991), the development of metrics to examine wetland and terrestrial systems has lagged (Angermeier and Karr 1994). In particular, there is an acute need to develop taxa-based metrics that can serve as indicators of disturbances such as non-point-source runoff, altered hydrology, or detrimental soil disturbance within SPIWs or in adjacent landscapes, and to identify those taxa associated with undisturbed SPIWs.

Restoration endpoints and techniques.—Because many SPIWs have been negatively affected by anthropogenic activities, restoration is being attempted on recently acquired public and private lands for conservation purposes. Other sites are enhanced as mitigation for wetland impacts elsewhere (i.e., wetland banking). The development of successful and cost-effective approaches to restoring wetlands is highly desirable. However, an adequate knowledge of targets for restoration, the development of appropriate restoration techniques, and methods to measure restoration success are necessary (National Research Council 1992). For functionally similar wetlands, the determination of a threshold of species diversity or group of keystone species necessary to assure recovery of sustainable community function is critical for effective restoration efforts. To develop criteria for identifying wetlands with highest potential of restoration success, indicators of this potential also need to be quantified.

Monitoring strategies.—Monitoring allows evaluation of the successes or failures of current management, and detection of off-site influences on SPIWs. Monitoring can be very expensive, and if conducted improperly, can fail to detect important changes. Thus, the development of efficient and cost-effective monitoring techniques is needed, in which measurements relative to reference SPIWs can be used to assess the rate and degree of successful accomplishment of targeted goals.

Facilitation of partnerships and multistate working groups

New partnerships are needed to develop creative and effective strategies that support positive outcomes for all the participants. Technical information transfer needs to be bidirectional between users and providers. Meaningful answers to management problems require that researchers understand the information needs of land managers, regulatory agencies, and planners so they can develop research questions that address these needs. In turn, the transfer of research findings relevant to management prescription is a key factor for successful application of research findings to further conservation goals. Decisions regarding conservation methods and regulatory policy of SPIWs will need to be made in the face of complex, dynamic conditions and uncertainty about key ecological relationships. Therefore, application of scientific adaptive management, (i.e., the use of iterative experimentation for the design and implementation of natural resource and environmental management policies: Halbert 1993, McLain and Lee 1996) should be a key component of a regional interdisciplinary effort. In turn, a strategy for communication among each group of constituents must be identified.

Symposia featuring management issues relative to biodiversity in SPIWs are recommended as a method for communication among researchers. Topics may be structured to fit various audiences, perhaps focusing on specific processes and presented as special sessions at regional and national meetings.

Networking opportunities require communication among land managers, regulators, and researchers, and a baseline understanding of the current status of information sources for SPIWs. Formalization of a group of persons with interests in SPIWs is suggested as a means to facilitate many of the objectives outlined in this document. Organizations such as the Longleaf Alliance (R. Johnson, Solon Dixon Forestry Education Center, Andalusia, Alabama, personal communication) can be examined as potential models to develop and explore new working relationships. Specific projects planned by the working group as initial efforts toward this end include: 1) compiling a bibliography of important scientific manuscripts on isolated wetlands (see website: www.jonesctr.org/research/aquatics/spiw/spiwmain2.htm) that could provide the impetus for a comprehensive synthesis and review; 2) developing a directory of expertise in wetland research /management /conservation (see above website); 3) maintaining a web site with summary information on importance/values of SPIWs, indexing of funding sources, and establishing homepage links with other conservation/management organizations; 4) seeking funds for a regional liaison person to manage the home page, to develop educational materials, and to develop a repository of wetland maps; 5) initiating a preliminary assessment of regional distribution patterns of these wetlands and identifying focal areas for study; and 6) compiling information regarding current federal and state incentive programs for land owners, and linking information gaps with potential funding sources.

Conclusions

Recognition of the importance of SPIWs in maintaining regional biodiversity has been slow to emerge. Meanwhile, these systems are quietly disappearing as anthropogenic activities reduce their ability to support characteristic fauna and flora. Not only is available scientific information insufficient to support regulatory decision-making, but identification of priorities for protection/conservation of these imperiled ecosystems is difficult given the lack of information on regional distribution and the absence of a classification scheme. A multidisciplinary working group developed a basic framework necessary to initiate a regional approach to ensure the long-term biological integrity of SPIWs. The major components of this conservation framework focused on 5 activity areas: 1) education, 2) research, 3) protection, 4) private property incentives, and 5) restoration. The recommendations for strategic coordination of information flow and identification of information needs are not applicable exclusively to conservation of biodiversity in southeastern SPIWs. However, recognition of these wetlands as integral and significant habitats of the once-dominant, longleaf pine ecosystem in the southeastern US, and the need to emphasize their roles in maintaining biodiversity, is uniquely important to the region.

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In addition to the authors of this paper, the following individuals participated in the **SPIW Working Group**: A. Calhoun, Department of Applied Ecology and Environmental Sciences, University of Maine, Orono, Maine USA 04469; G. Carmody, US Fish and Wildlife Service, Panama City Field Office, 1612 June Avenue, Panama City, Florida USA 32405; D. Crosby, US Army Corps of Engineers, PO Box 889, Savannah, Georgia USA 31402; M. Duever, The Nature Conservancy, Disney Wilderness Preserve, 6075 Scrub Jay Trail, Kissimmee, Florida USA 34759; V. Fasselt, US Environmental Protection Agency, Wetlands Protection Section, 100 Alabama Street, SW, Atlanta, Georgia USA 30365; J. Greis, US Environmental Protection Agency, Water Management Division, 61 Forsyth Street, SW, Atlanta, Georgia USA 30303; M. Hunter, Department of Wildlife Ecology, University of Maine, Orono, Maine USA 04469; J. Jensen, Georgia Department of Natural Resources, Nongame Endangered Wildlife Program, 116 Rum Creek Drive, Forsyth, Georgia USA 31029; J. McGlincy, Southern Forestry Consultants, 305 West Shotwell Street, Bainbridge, Georgia USA 31717; K. Smith, US Department of Agriculture, Natural Resources Conservation Service, 295 Morris Drive, Americus, Georgia USA 31709; J. Sweeney, Champion International Corporation, 1875 Eye Street, NW, Suite 540, Washington, DC

USA 20006; B. Taylor, Savannah River Ecology Laboratory, Drawer E, Aiken, South Carolina USA 29802; and E. Williams, Partners in Flight, Georgia Department of Natural Resources, Nongame Endangered Wildlife Program, 116 Rum Creek Drive, Forsyth, Georgia USA 31029.

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LITERATURE CITED

ANGERMEIER, P. L., AND J. R. KARR. 1994. Biological integrity versus biological diversity as policy directives: protecting biotic resources. BioScience 44:690–697.

BENNETT, S. H., AND J. B. NELSON. 1990. Distribution and status of Carolina bays in South Carolina. South Carolina Wildlife and Marine Resources Department, Columbia, South Carolina. (Available from: Nongame and Heritage Trust Publications, South Carolina Department of Natural Resources Wildlife Diversity Section, P.O. Box 167, Columbia, South Carolina, USA 29202.)

BLOCKSTEIN, D. E. 1995. A strategic approach for biodiversity conservation. Wildlife Society Bulletin 23:365–369.

BREN, L. J. 1995. Aspects of the geometry of riparian buffer strips and its significance to forestry operations. Forest Ecology and Management 75: 1–10.

BRINSON, M. M., AND R. RHEINHARDT. 1996. The role of reference wetlands in functional assessment and mitigation. Ecological Applications 6:69–76.

BURKE, V. J., AND J. W. GIBBONS. 1995. Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina bay. Conservation Biology 9:1365–1369.

BURKEY, T. V. 1989. Extinction in nature reserves: the effect of fragmentation and the importance of migration between reserve fragments. Oikos 55: 75–81.

COMERFORD, N. B., D. G. NEARY, AND R. S. MANSEL. 1996. The utility of buffer strips to protect forested wetlands from impacts due to forest silvicultural operations. Technical Bulletin 631. National Council of the Paper Industry for Air and Stream Improvement. Gainesville, Florida.

DESTEVEN, D., AND M. TONER. 1997. Gradient analysis and classification of Carolina bay vegetation: a framework for bay wetlands conservation and restoration. US Department of Agriculture, Forest Service, Savannah, Georgia. (Available from: US Department of Agriculture, Forest Service, Savannah River Forest Station, P.O. Box 710, New Ellenton, South Carolina, USA 29802.)

DODD, C. K. 1992. Biological diversity of a temporary pond herpetofauna in north Florida sandhills. Biodiversity and Conservation 1:125–142.

DODD, C. K., AND L. V. LACLAIRE. 1995. Biogeography and status of the striped newt (*Notophthalmus perstriatus*) in Georgia, USA. Herpetological Natural History 3:37–46.

DUEVER, M. J. 1984. Environmental factors controlling plant communities of the Big Cypress Swamp. Pages 127–137 *in* P. J. Gleason (editor). Environments of South Florida: present and past II. Miami Geological Society, Coral Gables, Florida.

FEDERAL REGISTER. 1996. Final notice of issuance, reissuance and modification of nationwide permits. Army Corps of Engineers, DOD, Volume 61. p. 65916.

FLORIDA NATURAL AREAS INVENTORY AND FLORIDA DEPARTMENT OF NATURAL RESOURCES. 1990. Guide to the natural communities of Florida. Florida Natural Areas Inventory and Department of Natural Resources, Tallahassee, Florida. (Available from: Florida Department of Natural Resources FNA, 1018 Thomasville Rd., Suite 200-C, Tallahassee, Florida, USA 32303.)

FOLKERTS, G. W. 1997. Citronelle ponds: little-known wetlands of the Central Gulf Coastal Plain, USA. Natural Areas Journal 17:6–16.

FROST, C. C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. Pages 39–60 *in* S. Cerulean and R. T. Engstrom (editors). Fire in wetlands: a management perspective. Proceedings of the Tall Timbers Fire Ecology Conference, No. 19. Tall Timbers Research Station, Tallahassee, Florida.

GOLLADAY, S. W., B. W. TAYLOR, AND B. J. PALIK. 1997. Invertebrate communities of forested limesink wetlands in southwest Georgia, USA: habitat use and influence of extended inundation. Wetlands 17:383–393.

HALBERT, C. 1993. How adaptive is adaptive management? Implementing adaptive management in Washington State and British Columbia. Reviews in Fisheries Science 1:261–283.

HENDRICKS, E. L., AND M. H. GOODWIN. 1952. Water-level fluctuations in limestone sinks in southwestern Georgia. Geological Survey Water Supply Paper 1110-E. US Geological Survey, US Government Printing Office, Washington, DC.

ICE, G. G., G. W. STUART, J. B. WAIDE, L. C. IRLAND, AND P. V. ELLEFSON. 1997. 25 years of the Clean Water Act: how clean are forest practices? Journal of Forestry 95:9–13.

JENSEN, J., J. G. PALIS, AND M. A. BAILEY. 1995. *Rana capito sevosa* (dusky gopher frog) submerged vocalization. Herpetological Review 26:98.

KAISER, J. 1998. New wetlands proposal draws flak. Science 279:980.

KIESTOR, A. R., J. M. SCOTT, B. CSUTI, R. F. NOSS, B. BUTTERFIELD, K. SAHR, AND D. WHITE. 1996. Conservation prioritization using GAP data. Conservation Biology 10:1332–1342.

KIRKMAN, L. K. 1995. Impacts of fire and hydrological regimes on vegetation in depression wetlands of southeastern USA. Pages 10–21 *in* S. I. Cerulean and R. T. Engstrom (editors). Fire in wetlands: a management perspective. Proceedings of the Tall Timbers Fire Ecology Conference, No. 19. Tall Timbers Research Station, Tallahassee, Florida.

KIRKMAN, L. K. 1998. Population effects of experimental fire regimes on the population dynamics of *Schwalbea americana* L. Plant Ecology 137:115–137.

KIRKMAN, L. K., AND R. R. SHARITZ. 1994. Vegetation disturbance and maintenance of diversity in intermittently flooded Carolina bays in South Carolina. Ecological Applications 4:177–188.

KUSHLAN, J. A. 1994. Freshwater marshes. Pages 324–363 *in* R. L. Myer and J. J. Ewel (editors). Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.

LACLAIRE, L. V. 1995. Vegetation of selected upland temporary ponds in north and north-central Florida. Bulletin of the Florida Museum of Natural History 38:69–90.

LACLAIRE, L. V., AND R. FRANZ. 1991. Importance of isolated wetlands in upland landscapes. Pages 9–15 *in* M. Kelly (editor). The role of aquatic plants in Florida's lakes and rivers. Proceedings of the Second Annual Meeting of the Florida Lake Management Society. Florida Lake Management Society, Lakeland, Florida.

LIDE, R. F., V. G. MEENTEMEYER, J. E. PINDER, AND L. M. BEATTY. 1995. Hydrology of a Carolina bay located on the upper coastal plain of western South Carolina. Wetlands 15:47–57.

LOWRANCE, R., R. TODD, J. FAIL, O. HENDRICKSON, R. LEONARD, AND L. ASMUSSEN. 1984. Riparian forests as a nutrient filter in agricultural watersheds. BioScience 34:374–377.

MAHONEY, D. L., M. A. MORT, AND B. E. TAYLOR. 1990. Species richness of calanoid copepods, cladocerans and other branchiopods in Carolina bay temporary ponds. American Midland Naturalist 123: 244–258.

MCLAIN, R. J., AND R. G. LEE. 1996. Adaptive management: promises and pitfalls. Environmental Management 20:437–448.

MITSCH, W. J., AND J. G. GOSSELINK. 1993. Wetlands. Van Nostrand Reinhold, New York.

MOLER, P. E., AND R. FRANZ. 1987. Wildlife values of small, isolated wetlands in the southeastern coastal plain. Pages 234–241 *in* R. R. Odum, K. A. Riddleberger, and J. C. Ozier (editors). Proceedings of the Third Southeastern Nongame and Endangered Wildlife Symposium. Georgia Department of Natural Resources, Atlanta, Georgia.

NATIONAL RESEARCH COUNCIL. 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, DC.

NATIONAL RESEARCH COUNCIL. 1995. Wetlands: characteristics and boundaries. National Academy Press, Washington, DC.

NEWMAN, M. C., AND J. F. SCHALLES. 1990. The water chemistry of Carolina bays: a regional survey. Archiv für Hydrobiologie 118:147–168.

NOSS, R. F. 1983. A regional landscape approach to maintain diversity. BioScience 33:700–706.

PECHMANN, H. D., D. E. SCOTT, R. D. SEMLITSCH, J. P. CALDWELL, L. J. VITT, AND J. W. GIBBONS. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science 253:892–895.

RICHARDSON, C. J., AND J. W. GIBBONS. 1993. Pocosins, Carolina bays, and mountain bogs. Pages 257–310 *in* W. H Martin, S. G. Boyce, and A. C. Echternacht (editors). Biodiversity of the southeastern United States: lowland terrestrial communities. John Wiley and Sons, New York.

ROWELL, M. C., S. C. JOHNSON, AND V. FASSELT. 1995. Draft technical summary document for the central Dougherty Plain, advance identification of wetlands. Wetlands Protection Section, Water Management Division, Region 4, US Environmental Protection Agency, Atlanta, Georgia. (Available from: USEPA, 100 Alabama Street, South West, Atlanta, Georgia, USA 30365.)

SCOTT, J. M., F. DAVIS, B. CSUTI, R. NOSS, B. BUTTERFIELD, C. GROVES, H. ANDERSON, S. CAICCO, F. D'ERCHIA, T. C. EDWARDS, J. ULLIMAN, AND G. R. WRIGHT. 1993. GAP analysis: a geographic approach to protection of biological diversity. Journal of Wildlife Management 67:1–17.

SEMLITSCH, R. D. 1987. Relationship of pond drying to the reproductive success of the salamander *Ambystoma talpoideum.* Copeia 1:61–69.

SEMLITSCH, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12:1113–1119.

SEMLITSCH, R. D., AND J. R. BODIE. 1998. Are small, isolated wetlands expendable? Conservation Biology 12:1129–1133.

SEMLITSCH, R. D., D. E. SCOTT, J. H. K. PECHMANN, AND J. W. GIBBONS. 1996. Structure and dynamics of an amphibian community. Pages 217–248 *in* M. L. Cody and J. A. Smallwood (editors). Long-term studies of vertebrate communities. Academic Press, San Diego.

SHARITZ, R. R., AND W. H. GIBBONS. 1982. The ecology of southeastern shrub bogs (pocosins) and Carolina bays: a community profile. FWS/OBS-82/04. Division of Biological Services, US Fish and Wildlife Service, Washington, DC.

SMITH, S. D., AND A. L. BRASWELL. 1994. Preliminary investigation of acidity in ephemeral wetlands and the relationship to amphibian usage in North

Carolina. Project No. 91-SG-11. North Carolina Wildlife Resources Commission Nongame and Endangered Wildlife Program, Raleigh, North Carolina. (Available from: North Carolina State Museum of Natural Sciences, Box 29555, Raleigh, North Carolina, USA 27626.)

SUTTER, R. D., AND R. KRAL. 1994. The ecology, status, and conservation of two non-alluvial wetland communities in the south Atlantic and eastern Gulf Coastal Plain. Biological Conservation 68: 235–243.

TAYLOR, B. E., R. A. ESTERS, J. H. K. PECHMANN, AND R. D. SEMLITSCH. 1988. Trophic relations in a temporary pond: larval salamanders and their microinvertebrate prey. Canadian Journal of Zoology 66:2191–2198.

TORAK, L. J., G. S. DAVISS, G. A. STRAIN, AND J. G. HERNDON. 1991. Geohydrology and evaluation of the water-resource potential of the upper Floridan aquifer in the Albany area, southwestern Georgia. Open-File Report 91–52. US Geological Survey, US Government Printing Office, Washington, DC.

USEPA (US ENVIRONMENTAL PROTECTION AGENCY). 1990. Biological criteria: national program guidance for surface waters. EPA-440/90-0004. Office of Water, USEPA, Washington, DC.

USEPA (US ENVIRONMENTAL PROTECTION AGENCY). 1991. Biological criteria: state development and implementation efforts. EPA-44/5-91-003. Office of Water, USEPA, Washington, DC.

WADE, D. D. 1993. Societal influences on prescribed burning. Pages 351–355 *in* S. M. Hermann (editor). The longleaf pine ecosystem: ecology, restoration and management. Proceedings of the Tall Timbers Fire Ecology Conference, No. 18. Tall Timbers Research Station, Tallahassee, Florida.

WARE, S., C. FROST, AND P. D. DOERR. 1993. Southern mixed hardwood forest: the former longleaf pine forest. Pages 447–494 *in* W. H. Martin, S. G. Boyce, and A. C. Echternacht (editors). Biodiversity of the southeastern United States: lowland terrestrial communities. John Wiley and Sons, New York.

WILSON, E. O., AND F. M. PETER (EDITORS). 1988. Biodiversity. National Academy Press, Washington, DC.

About the Authors

Katherine Kirkman is a plant ecologist at the J.W. Jones Ecological Research Center with research interests in plant diversity and rare and endangered species. Stephen Golladay is an aquatic ecologist at the Jones Center and studies ecosystem processes and aquatic invertebrates in streams and wetlands. Linda LaClaire is a wildlife biologist with the US Fish and Wildlife Service specializing in the herpetofauna of wetlands. Rob Sutter is a regional director of biological conservation with The Nature Conservancy and is interested in plant communities of wetlands.