Issues and Approaches in Assessing Cumulative Impacts on Waterbird Habitat in Wetlands

MILTON W. WELLER
Department of Wildlife and Fisheries Sciences
Texas A&M University
College Station, Texas 77843, USA

ABSTRACT / Wetlands are attractive to vertebrates because of their abundant nutrient resources and habitat diversity. Because they are conspicuous, vertebrates commonly are used as indicators of changes in wetlands produced by environmental impacts. Such impacts take place at the landscape level where extensive areas are lost; at the wetland complex level where some (usually small) units of a closely spaced group of wetlands are drained or modified; or at the level of the individual wetland through modification or fragmentation that impacts its habitat value. Vertebrates utilize habitats differently according to age, sex, geographic location, and season, and habitat evaluations based on isolated observations can be biased. Current wetland evaluation systems incorporate wildlife habitat as a major feature, and the habitat evaluation procedure focuses only on habitat. Several approaches for estimating bird habitat losses are derived from population curves based on natural and experimentally induced population fluctuations. Additional research needs and experimental approaches are identified for addressing cumulative impacts on wildlife habitat values.

Wetlands are attractive to many species of wildlife, often because of their great productivity, which provides nutrients and other resources used by diverse groups (Odum 1971, Tiner 1984). In addition, wetlands may be structurally diverse, providing unique habitats to which species have adapted. Certain groups of wildlife, notably birds, are among the most conspicuous of wetland animals, and because they often are tied to specific life forms of vegetation, assessment of habitat involves features such as vegetation structure that are also useful in classification of wetland types and in assessing other wetland values.

Concerns over cumulative impacts of human actions on wetland habitats seem to have focused on two major types of perturbations: (1) cumulative losses of wetlands from multiple causes, resulting in reduced size, changes in pattern, fragmentation, reduced number, or reduced contiguity between wetlands; or (2) repeated perturbations such as contamination by single or multiple pollutants. In both cases, the effect of the impact is that the individual wetlands, wetland complexes, or wetland districts no longer function as habitat at their former levels—if at all. But there are many other perturbations that affect wetlands in less conspicuous but significant ways, such as modification of water levels on a landscape or watershed scale, excessive grazing or repeated fires that modify detrital cycles, increases in siltation that influence the nutrient base or turbidity and hence the nature and rate of plant succession, changes in salinity due to water volume changes or freshwater/saltwater balance, and introductions of exotic plants and animals (see Weller 1981, for a more complete list related to wildlife habitat issues). Moreover, many of these influences can operate at different levels; partial drainage is more serious in concert with heavy siltation, at the early seed germination and plant growth stages, when bird nesting is at its peak, or when it occurs regularly each year or each day with irrigation or other water uses. Thus a cumulative effect can result from a series of repeated perturbations of the same kind or from multiple types of actions.

The feasibility of measuring and interpreting all or even several of these potential impacts simultaneously is complicated by the fact that our understanding of the internal relationships of the ecosystem is in its infancy, so it is natural that we first fragment the problem and try to trace effects of a single impact on a function or value of a wetland system. Later, we dealwith two or more impacts, or use our limited data base for predictive modeling of the consequences of several such actions.

The impact of various perturbations on habitat values is especially dramatic because plant and animal communities are products of the physical, chemical, and biological processes that have evolved in various wetlands. For this reason, vegetation structure and conspicuous wildlife are commonly used as qualitative indicators of wetland condition. However, the assessment of habitat values often is oversimplified and may be misleading or at least misused if not fully understood.

Harris' article (1988) has provided us with a con-

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ceptual framework for understanding the implications of cumulative losses on vertebrate diversity, the scale of the impacts problem as it relates to animal communities and single species, and the life history strategies of various species that influence how they use wetlands as habitats. In this article, the focus will be on some habitat impact issues that consider: (1) landscape-level wetland districts that form major habitat units; (2) wetland complexes formed by several clustered basins of diverse types within a landscape unit; (3) certain wetland habitat and vertebrate characteristics that influence our ability to assess habitat values of single species or assemblages of birds and mammals used as indicators of impacts; (4) current evaluation systems; and (5) some experimental approaches to assessing impacts on habitat at several levels.

Landscape- or Watershed-Level Wetland Districts Serving Species and Assemblages of Vertebrates

Sizable geographic regions resulting from geomorphology and climatic regimes have characteristic wetland forms and vegetative types. Examples are prairie potholes, coastal delta marsh, and intermountain snow-melt basins. Some districts contain isolated (islandlike) basins that are reached by vertebrates through their own efforts and are potentially impacted by loss or degradation of individual basins; others form contiguous habitat and may be impacted by reduction or fragmentation. Wetland units at this scale have been studied as habitat but form the major geographic range for some species and for characteristic communities or assemblages of birds. Loss of such areas is gradual and tends to impact species and groups slowly.

Natural perturbations suggest that partial loss can have a dramatic impact on nesting birds of the region affected, as well as on the area receiving the immigrants. For example, climatic changes in the prairie potholes are known to cause species like pintails (*Anas acuta*) to move from their former habitats to newly flooded areas (Sowls 1955) or to shift to suboptimal habitats in the Alaskan tundra during drought in the prairie wetlands (Derksen and Eldridge 1980).

Wetland Complexes Serving Species at the Level of the Individual

Basin wetlands often differ in vegetation and water regime because of differences in size, depth, location, water quality, or contiguity. Life-support needs of a sedentary species may be met within part or all of a single wetland, but many vertebrates have evolved a mobile existence to tap the resources of several adjacent wetlands or to prevent reduced reproductive success or survival during the dynamic water regimes common to wetlands. We know relatively little about the use of complexes by vertebrates. However, it is apparent that ducks of several species move from wetland to wetland during the nesting season to seek out suitable food, water, and cover (Krapu 1974). Moreover, species richness of birds may be greater in wetland complexes than in isolated wetlands of equal or larger size (Brown and Dinsmore 1986). Thus, assessment of the effect of the loss of one wetland of a complex or of one wetland type in a region is vital to understanding and measuring habitat values (Swanson and others 1979, Weller 1981, 1987). The drastic decline of waterfowl and other bird populations was documented for a small Utah marsh impacted by severe natural drought (Weller and others 1958), and the same area more recently has been totally inundated by rising waters of the Great Salt Lake so that all populations have been eliminated from this and other major wetlands in the area (Kadlec 1984). Comparable population changes have been noted for two marshy lakes flooded during increased rainfall periods (Weller and Spatcher 1965), for experimentally manipulated marshes dewatered for revegetation (Weller and Fredrickson 1974), and for a small pothole complex that experienced both drought and flood (Weller 1979a, Weller and Voigts 1983).

Wetlands may be viewed as habitat islands in a sea of terrestrial vegetation (Weller 1979a), and they seem to follow the rules of island biogeography theory in respect to bird diversity (MacArthur and Wilson 1967, Brown and Dinsmore 1986). However, small and monotypic wetlands still may serve certain species at certain times and tend to be seriously undervalued in many assessments of bird habitats (Evans and Black 1956). Because seasonal and year-to-year variability makes small wetlands inconspicuous except during spring and in wet years, they often are regarded as dispensable and are drained and plowed (Krapu 1974, Swanson and others 1979). The loss of such seemingly insignificant wetlands reduces habitat diversity, and hence biotic diversity, and is one of the most common cumulative impacts on wetlands via sequential drainage and conversion to agriculture and other uses.

Aspects of Individual Wetlands Influencing Use by Wildlife and Measures of Habitat Values

Before one can develop sound measures of cumulative impacts on habitat, it is essential to consider wet-

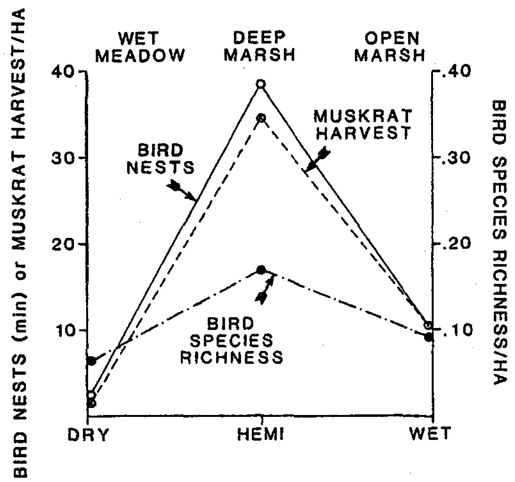

Figure 1. Variation in bird species richness, muskrat populations, vegetation, and water regimes over a seven-year-period in a single prairie wetland (Weller 1981).

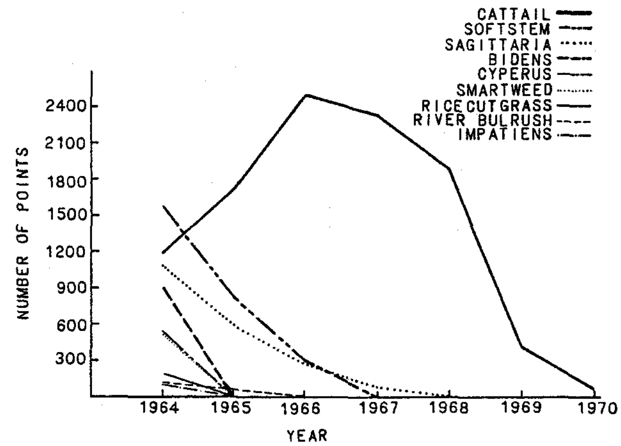

Figure 2. A seven-year record of species abundance of vegetation on point-count transects on a prairie wetland, showing the change in plant dominance from moist-soil annuals to perennial cattail (Weller and Fredrickson 1974).

land characteristics that influence use by birds and other vertebrates. Water-depth gradients in wetland basins result in a zonation of vegetation that produces different types of animal foods and cover in a small area (Weller and Spatcher 1965). Adaptations to these plant zones result in high densities of individuals of certain species (often social and colonial) and the juxtaposition of several species segregated in some way by their resource use. Guilds of species that are similar in the manner in which they seek resources, but that are not necessarily related taxonomically (Root 1967), differ from wetland to wetland and have been suggested as a way to assess the habitat complexity of different wetlands (Short and Burnham 1982).

Water depths in some types of wetlands vary from lakelike conditions to near-dry conditions seasonally (bottomland hardwoods and prairie wetlands), others vary between years (prairie and plains wetlands), and some, like the Great Salt Lake, have longer-term water cycles (Kadlec 1984). Habitats in the same wetland can be utilized by truly aquatic forms at some times and by terrestrial species at others (Weller and Spatcher 1965). Hence, species richness and populations of single species may vary drastically by season or year (Figure 1), and long-term assessments are essential to establish mean habitat values of a wetland. Indicator species recorded at one time may define suitability of the habitat for them, but even several observations will not document the cause of population differences or declines. In addition, species richness (number of species) and other diversity indexes may not be very meaningful unless truly aquatic species are included.

Plant succession varies due to water regimes, and vegetation in the same wetland can differ dramatically from year to year or season to season (Figure 2). Moreover, herbivores and water quality can dramatically influence plant presence and species composition (Errington and others 1963). However, because wetland plants have evolved with physical perturbations, plant species and the resultant community are adaptive, resilient, and responsive. Recovery powers for many of these dominants are greater than might be expected in less variable environments (van der Valk 1978). Thus, while vegetation recorded at a single observation may reflect mean conditions in wetlands dominated by short-lived herbaceous vegetation, this is not invariably true.

Some Characteristics of Vertebrates Influencing Wetland Use and Measures of Habitat Value

Habitat use varies by species, age, breeding stage, and season and strongly influences population assessment. Some vertebrates have quite precise requirements for food, nest sites, or brood cover during the breeding season. In general, most workers seem to feel that there are fewer specific requirements on migration or wintering areas, but this may be due to our modest knowledge of the subject during nonbreeding periods. The young of some species, especially amphibians, require quite different habitats and foods than do adults (Weller 1987).

Knowledge of habitat use patterns is essential to proper selection of species used in assessments of impacts. Habitat strategies of most wetland animals reflect either a broad range of tolerance to diverse and variable wetland habitats (generalist), or specialist needs that are met by moving to another wetland within a complex, as for example occurs with certain prairie waterfowl (Krapu 1974, Swanson and others 1979).

Mobility (especially among fish and birds), periods of hibernation or inactivity (amphibians and reptiles), and lodge building (muskrats and beaver) may be induced by seasonal climatic changes of temperature and water supply that influence availability of food and suitable physical environments (Weller 1987). These population changes require methodological changes when using populations as parameters of use or impact.

Strongly migratory species such as birds shift not only their habitats but also their foods, generally moving down the food chain to become less carnivorous during nonbreeding periods (Weller 1975). Hence, abundance of a bird species in a wetland varies with season and food supplies and may vary significantly from year to year.

Food-seeking behavior has an important evolutionary impact on mobility and how wetlands are used in time and space. Optimal foraging theory suggests that animals utilize foods in proportion to their abundance and caloric value on an energy-efficiency basis (Krebs 1978). Presumably, availability influences energy used in food search and, hence, what is taken. There has been remarkably little study of seasonal variation in food requirements in most vertebrates, but observations on ducks demonstrate that life stage influences food intake on a nutritional rather than caloric basis. Although species vary, most immatures or breeding females require high levels of animal protein, whereas males and birds in nonbreeding periods use a high-calorie carbohydrate diet (Krapu 1974, Swanson and others 1979, Hohman 1985).

Because of the complexities of food requirements for different species at different life stages and in different geographic areas, the ramifications of modifying nutrient cycling and the resulting plant or animal food resources are complex and an extremely difficult area in which to measure impacts of cumulative or multiple influences on habitat value. However, this is also the area where effects are most likely to be observed.

Intraspecific social requirements, such as vocalizations and other social stimuli, territoriality, and social mating systems, influence wetland use and often are related to wetland size, vegetation structure, and water regime (Weller and Spatcher 1965, Orians 1980). These may limit populations when food and other environmental parameters do not, and they can therefore influence assessments of wetland production.

Current Habitat Evaluation Methods

Wildlife biologists have attempted to develop methods useful in evaluating habitat quality. Typically, these use population density as the major parameter of habitat carrying capacity; vegetative characteristics and other less transient parameters are used to measure suitability for certain species (see Schemnitz 1980, Maurer 1986). Such studies often compare the same species in two similar habitats, but even then the techniques are not without serious problems, since reproductive fitness (survival and reproductive success) as well as density should be measured (Van Horne 1983).

Habitat evaluation focuses more on making judgements about units as habitats for many species (assemblages or communities). These observations may then result in a decision as to which habitat is to be preserved from impact or destruction. Systems that attempt to include measures of habitat quality other than populations have resulted (since there may not be time to census populations accurately). The habitat evaluation procedure (HEP) of the US Fish and Wildlife Service (Schamberger and Farmer 1978) uses various habitat parameters in models of selected species that are formulated into habitat suitability indices (HSI) having a maximal value of 1.0. This quality index is multiplied by the area to give habitat units for comparisons of wetlands or other habitats. Indices for several species may be pooled to provide a broader community perspective.

Indices of species diversity are used commonly in appraising community "structure" (Pielou 1975) and therefore may be useful in assessing changes in a vertebrate community or in comparing two or more communities. However, some indices are being questioned because biological information is lost in the mathematical formulation (James and Rathbun 1981); as a result, simple and traditional measures of biodiversity such as species richness and relative abundance have gained renewed importance. These indices offer considerable value for rapid assessment of impacts but must be used on comparable wetlands in a complex or landscape unit, with considerable understanding of the habitat strategies of the key species involved. Examples of species diversity–edge relationships were given by Harris and others (1983) for studies of birds in Great Lakes fringe wetlands. Figure 3 shows species richness–cover/water relationships in a freshwater basin wetland (Weller and Fredrickson 1974).

An innovative system proposed by Short and Burnham (1982) compares guilds of wetland birds to judge whether habitat conditions permit one wetland to support more guilds than another. By identifying habitats used for nesting and those used for feeding, a

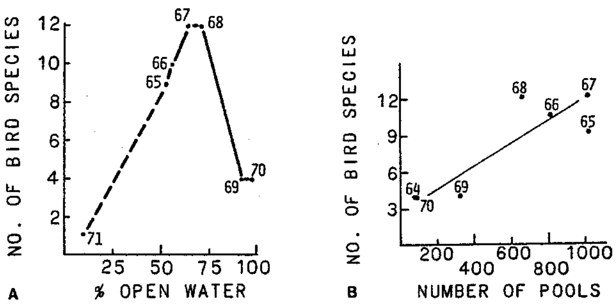

Figure 3. Species richness of birds in relation to cover–water ratios expressed as percent (A) open water and (B) number of pools in the emergent cover (Weller and Fredrickson 1974).

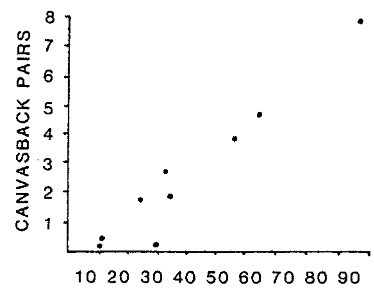

Figure 4. Relationship between wetland density and density of canvasback pairs per 259-ha section, derived from observations on different study areas in southern Canada (after Sugden 1978).

matrix can be developed to compare the complexity of two different wetlands or of the same wetland before and after perturbations. This promising approach needs field testing and comparison with other methods; it may be applicable in cumulative impact assessment.

More recently, the Adamus and Stockwell (1983) system was developed for the Federal Highway Administration to assess multiple values and functions of wetlands; however, this system emphasizes habitat for fish and wildlife (especially waterfowl), because this loss often is an issue of major concern. Office analysis of maps for certain physical and structural parameters and field study of many other characteristics are also included. Although not designed for cumulative impact assessment, few better approaches are currently available. The Adamus system has been improved and computerized and will be available soon from the US Corps of Engineers as the wetland evaluation technique (WET) (E. Clairain, personal communication). The data required in the Adamus system could be used to measure cumulative impacts by comparing assigned values (low, moderate, or high) of a wetland before and after a series of impacts or of an impacted vs nonimpacted wetland. If, for example, turbidity increased and water supply decreased, the double impact would be reflected in significantly lower ratings.

Approaches to Assessing Bird Habitat Losses

The use of impacts on habitat for birds and other vertebrates as an index of wetland disturbance can be approached at several levels. These range from pre- and postimpact observation of impacted areas (which have not been scientifically studied for many reasons) to various kinds of inferences or indices derived from observations of nonimpacted areas. The following examples demonstrate some options.

Density–habitat-quality relationships of single species may allow assessments of effects where the specific impact on the important environmental parameter is known. Density–water-level relationships for blue-winged teal (*Anas discors*) were demonstrated by Weller (1979b) for one study area. By back-calculating on the regression line, an estimate of population size at modified water levels should be possible. In the same way, Sugden's (1978) data on relationships of numbers of prairie potholes to numbers of canvasback (*Aythya Valisineria*) pairs can provide a gross estimate of how a reduction of wetlands or wetland complexes would decrease numbers of breeding pairs (Figure 4). In cases of agricultural drainage, calculation of the population at the resulting smaller wetland area could be compared to the former high point to provide a gross measure of impacts.

Observed changes in wetland habitat values were related to time and environmental gradients by Weller (1981); density of muskrat (*Ondatra zibethicus*) populations and species richness of birds were dictated by experimentally induced water-level regimes (Figure 1). Muskrat and bird populations and bird species richness were greatest at moderate water levels with excellent interspersion of vegetation and water (hemimarsh). Flooded conditions were nearly as detrimental to all species as were extremely dry conditions. Using such density and diversity figures would allow a gross prediction of changes in populations and species composition resulting from effects of single or multiple impacts, such as modification of hydroperiod or water depth, or severe sedimentation or grazing.

Species–area relationships have been known and used in the study of plant communities for many years (Oosting 1948) and are similar to species richness patterns of birds and other organisms on geographic and habitat islands. Typically, as plot, island, or wetland size increases, the numbers of individuals and species

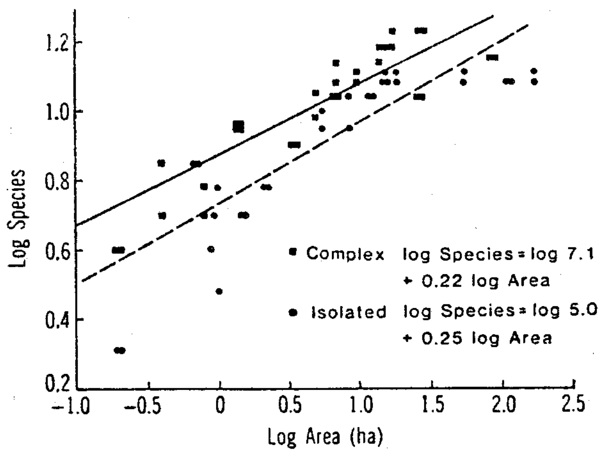

Figure 5. Species richness–wetland size relationship in 15 isolated and 15 wetland complex marshes, plotted on a log-log scale (Brown and Dinsmore 1986).

increase in some pattern (often a sigmoid curve), as shown for prairie potholes (Figure 5) by Brown and Dinsmore (1986). By mapping distributions in detail on large plots, it should be possible to estimate minimal functional habitat or wetland size for a particular species. For example, observations of bird populations in wetlands of different sizes by Brown and Dinsmore (1986) found that 10 of 25 species did not use wetlands smaller than 5 ha. However, these small wetlands might be crucial for some of the remaining 15 species.

Experimental evidence for minimal habitat size could also be gained from nonpermanent destruction of vegetation. Using extensive monocultures such as cattail (*Typha* spp.) or reed (*Phragmites communis*), patterned mowing or burning could be used to create different patch sizes; Weller and Spatcher (1965) and Kaminski and Prince (1981) used cutting to determine minimal size of vegetation openings attractive to birds.

Long-term monitoring of wetland losses concurrent with censusing of selected (preferably resident) bird species is a logical but not very immediate approach to recording data that will permit estimates of minimal habitat size. However, wetland losses continue at an alarming rate, so remote sensing of habitat and extensive censusing of such areas should be established now. Detailed data management and geographic information systems (GIS) are essential. These and other study approaches would be facilitated by the selection and management of long-term study sites where continuity of observations can ensure the validity of data.

Expert systems, a division of current-generation artifical intelligence, offers an approach to gain immediate insights by amassing, synthesizing, and interpreting opinions of experts who have observed but perhaps not documented changes or of persons whose knowledge of the life histories of selected species allows predictions that few others can make.

Conclusions and Recommendations

Assessment of the effects of cumulative impacts on habitat for vertebrates presents major methodological problems. The structure of vegetation and avian communities is dynamic, and a single measurement may be highly misleading. It is essential that the evaluator understand water regimes, vegetation patterns, and vertebrate habitat strategies to derive meaningful patterns and impact assessments.

It is possible that bird populations are too responsive to change to be ideal for assessment of impacts in complexes of wetlands or comparisons between two wetlands. However, because they are so conspicuous, they are excellent indicators of within-wetland change. The challenging problem is to determine which of several impacts might be responsible for any major population change.

To develop immediate and innovative measures of impact response is a legitimate target, but it is also essential that long-term studies be established in various wetland regions that provide evaluators and decision makers with the quantitative framework for identifying and assessing cause and effect in cumulative impacts on wetlands. Research to guide better evaluation of wildlife as indicators of cumulative impacts requires a more controlled environment and experimental format than has been available in the past, as well as some long-range research planning and funding. To assess more precisely the impact of losses of wetland at a landscape level will require sizable study areas, with controls, and a research funding base that spans eight to ten years. Most data now available are for basin wetlands; fringe and riverine wetlands have been little studied. Preservation of wetlands and wetland resources will be a continuing challenge in the future, and long-term studies need to be initiated now to provide answers to current and future questions.

Literature Cited

Adamus, P. R., and L. T. Stockwell. 1983. A method for wetland functional assessment, vol. I. Critical review and evaluation concepts. US Department of Transportation, Federal Highway Administration Report No. FHWA-IP-82-23. National Technical Information Service, Springfield, Virginia, 176 pp.

Brown, M., and J. J. Dinsmore. 1986. Implications of marsh size and isolation for marsh bird management. *Journal of Wildlife Management* 50:392–397.

Derksen, D. V., and W. D. Eldridge. 1980. Drought-displacement of pintails to the Arctic Coastal Plain. *Journal of Wildlife Management* 44:224–229.

Errington, P. L., R. Siglin, and R. Clark. 1963. The decline of a muskrat population. *Journal of Wildlife Management* 27:1–8.

Evans, C. D., and K. E. Black. 1956. Duck production studies on the prairie potholes of South Dakota. US Fish and Wildlife Service Special Science Report (Wildlife) 20, 59 pp.

Harris, L. D. 1988. The Nature of Cumulative Impacts on Biotic Diversity of Wetland Vertebrates. *Environmental Management* 12:675–693.

Harris, H. J., M. S. Milligan, and G. A. Fewless. 1983. Diversity: Quantification and ecological evaluation in freshwater marshes. *Biological Conservation* 27:99–110.

Hohman, W. L. 1985. Feeding ecology of ring-necked ducks in northwestern Minnesota. *Journal of Wildlife Management* 49:546–557.

James, F. C., and S. Rathbun. 1981. Rarefaction, relative abundance, and diversity of avian communities. *Auk* 98:785–800.

Kadlec, J. A. 1984. Rising Great Salt Lake inundates marshes. *National Wetlands Newsletter* 6(4):2–3.

Kaminski, R. M., and H. H. Prince. 1981. Dabbling duck and macroinvertebrate responses to manipulating wetland habitat. *Journal of Wildlife Management* 45:1–15.

Krapu, G. L. 1974. Foods of breeding pintails in North Dakota. *Journal of Wildlife Management* 38:408–417.

Krebs, J. R. 1978. Optimal foraging: decision rules for predators. Pages 23–63 *in* J. R. Krebs, and N. B. Davies (eds.), Behavioural ecology. Sinauer, Sunderland, Massachusetts, 494 pp.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Monographs in population biology 1. Princeton University Press, Princeton, New Jersey, 203 pp.

Maurer, B. A. 1986. Predicting habitat quality for grassland birds using density–habitat correlations. *Journal of Wildlife Management* 50:556–566.

Odum, E. P. 1971. Fundamentals of ecology, 3rd ed. W.B. Saunders, Philadelphia, 574 pp.

Oosting, H. J. 1948. The study of plant communities. W. H. Freeman, San Francisco, California, 389 pp.

Orians, G. H. 1980. Some adaptations of marsh-nesting blackbirds. Monographs in population biology 14. Princeton University Press, Princeton, New Jersey, 295 pp.

Pielou, E. C. 1975. Ecological diversity. John Wiley & Sons, New York, 165 pp.

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37:317–350.

Schamberger, M., and A. Farmer. 1978. The habitat evaluation procedures; their application in project planning and impact evaluation. *Transactions of the North American Wildlife and Natural Resources Conference* 43:274–283.

Schemnitz, S. D. (ed). 1980. Wildlife management techniques manual. Wildlife Society Washington, DC, 686 pp.

Short, H. L., and K. P. Burnham. 1982. Technique for structuring wildlife guilds to evaluate impacts on wildlife communities. US Fish and Wildlife Service Special Scientific Report (Wildlife) No. 22, 34 pp.

Sowls, L. K. 1955. Prairie ducks. Wildlife Management Institute, Washington, DC, 193 pp.

Sugden, L. G. 1978. Canvasback habitat use and production in Saskatchewan parklands. Canadian Wildlife Service No. 34, 32 pp.

Swanson, G. A., G. L. Krapu, and J. R. Serie. 1979. Foods of laying female dabbling ducks on the breeding grounds. Pages 47–57 *in* T. A. Bookhout (ed.), Waterfowl and wetlands—an integrated review. North-Central Section, Wildlife Society, Madison, Wisconsin, 147 pp.

Tiner, R. W., Jr. 1984. Wetlands of the United States: Current status and recent trends. US Department of the Interior. US Fish and Wildlife Service, Washington, DC, 59 pp.

van der Valk, A. G. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. *Ecology* 59:322–335.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. *Journal of Wildlife Managment* 47:893–901.

Weller, M. W. 1975. Migratory waterfowl: A hemispheric perspective. *Publicaciones Biologicas Instituto de Investigaciones Cientificas, Universitad Autonoma de Nuevo Leon* 1(7):89–130.

Weller, M. W. 1979a. Birds of some Iowa wetlands in relation to concepts of faunal preservation. *Proceedings of the Iowa Academy of Sciences* 86:81–88.

Weller, M. W. 1979b. Density and habitat relationships of blue-winged teal nesting in northwestern Iowa. *Journal of Wildlife Management* 43:367–374.

Weller, M. W. 1981. Estimating wildlife and wetland losses due to drainage and other perturbations. Pages 337–346 *in* B. Richardson (ed.), Selected Proceedings of the Midwest Conference on Wetland Values and Management. Minnesota Water Planning Board, St. Paul, 660 pp.

Weller, M. W. 1987. Freshwater marshes. University of Minnesota Press, Minneapolis, Minnesota, 150 pp.

Weller, M. W., and L. H. Fredrickson. 1974. Avian ecology of a managed glacial marsh. *Living Bird* 12:269–291.

Weller, M. W., and C. E. Spatcher. 1965. Role of habitat in the distribution and abundance of marsh birds. Special Report No. 43, Iowa State University, Ames, Iowa, 31 pp.

Weller, M. W., and D. K. Voigts. 1983. Changes in the vegetation and wildlife use of a small prairie wetland following a drought. *Proceedings of the Iowa Academy of Sciences* 90:50–54.

Weller, M. W., B. H. Wingfield, and J. B. Low. 1958. Effects of habitat deterioration on bird populations of a small Utah marsh. *Condor* 60:220–226.