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Project Summary

Response of *Carex*-Dominated Wetlands to Altered Temperature and Flooding Patterns

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This report describes the effects of construction and operation of an 1100-MW coal-fired power plant on surrounding wetland plant communities. Preliminary studies began in 1971, and data collection continued after the second generating unit went into operation in 1978.

In its preconstruction state, about 82% of the 1900-acre site was wetland. Almost half of it was an extensive marsh, in which the cooling lake was sited.

Existing paradigms for ecosystem response gave no consistent answers to what type and extent of impact the cooling lake would have. Therefore, in addition to the monitoring of changes in vegetation which began in 1974, a new basis was sought for predicting ecosystem response. The research included four phases: field inventory and classification of plant communities, monitoring of vegetation, field and laboratory experiments to test hypotheses regarding mechanisms regulating population changes, and assessment of field and theoretical approaches.

The wetland species were not equally sensitive to flooding, heat stress, or increased flow of surface water. Extremely sensitive species, such as the sedges *Carex lacustris* and *C. rostrata*, declined rapidly in all communities. Other species such as *C. stricta* and *Calamagrostis canadensis* responded more slowly. In contrast, the cattail *Typha latifolia* increased continuously in the emergent community and invaded all other communities. Other hydrophytic but non-persistent species such as *Sagittaria latifolia* increased in some communities but not in others. *Lemna minor* (duckweed, a floating annual) increased sharply in expanding areas of open water. Annual species which had been insignificant or even absent before the disturbance, e.g., *Bidens cernua* and *Pilea pumila*, increased where perennial dominants declined. Thus, changes occurred in the structure of the plant communities as well as in populations of individual species.

This study revealed no consistent relationship between species diversity and the intensity of environmental disturbance. Differences in measures of diversity between communities were related to the differential sensitivity of spatially dominant species to disturbance. Where dominant species were sensitive, diversity and equitability increased as new or competitively inferior species colonized or spread to space made available by the decline of dominant populations. Diversity and equitability decreased where disturbance favored one or two dominant species.

It appears that the timing of phenological events (such as the reproductive cycle or the emergence of shoots) in the life history of a plant may be important determinants of a population's response to heat stress. Physiological and phenological data from laboratory and field experiments related the response of *T. latifolia* and *C. lacustris* to altered seasonal patterns of carbohydrate storage and shoot phenology induced primarily by groundwater temperatures

out of phase with normal cycles of plant growth. These data established the causal mechanisms relating changes in vegetation to leakage from the cooling lake, identified field signs of heat stress, and suggested general species characteristics that may be useful indicators of potential sensitivity to stress.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Background

This research on wetland plant responses was part of a larger study of environmental changes caused by construction and operation of a large coal-fired electric power plant in Columbia County north of Madison, Wisconsin. The research objectives of the program as a whole were formulated in 1970 in the context of Wisconsin's Shoreline Zoning Act of 1965, imminent passage of the Wisconsin Environmental Policy Act (1971), and a long history of protection of navigable waters under the Public Trust Doctrine of the State Constitution. Regulatory responsibilities established under these legislative and constitutional mandates required evaluations, in advance, of the prospective effects of the proposed development. The Columbia study, undertaken initially with support from the three Wisconsin utilities building the power plant, was intended to provide information for government and industry in future environmental protection decisions involving coal-fired steam electric plants. Additional support from the U.S. Environmental Protection Agency permitted the study to expand after 1975 to take advantage of the baseline studies and obtain more definitive answers to a wide range of questions.

The project provided a unique opportunity to examine fundamental ecological questions about the response of wetland ecosystems to the external influences of nearby development. The Columbia station and its associated facilities are located in the floodplain of the Wisconsin River. In its preconstruction state, about 82% of the site was wetland. Almost 50% was an extensive marsh (31% sedge meadow, 17% emergent aquatic vegetation), considered to be important as a spawning habitat for walleye and northern pike. These areas represented a major portion of the nonwooded wetlands remaining on the Wisconsin River in Columbia County.

The cooling lake for the generating station was sited in the marsh. The utilities and the project research staff predicted that the lake would leak substantial amounts of warm water. Although the effect of the leakage on the remaining marsh was not examined fully during preconstruction evaluation, it became a major question during later assessment of the effects of the power station.

The monitoring of changes in vegetation associated with leakage from the cooling lake began in 1974. Although it was known that the remaining wetlands would be affected by elevated groundwater levels and temperatures due to leakage from the cooling lake, the type, magnitude, and rate of change were unknown. Based on existing paradigms for ecosystem response, the potential effects cited by the Environmental Impact Statement (Wisconsin Department of Natural Resources, 1973) ranged from a gradual decrease of intolerant species, increase of early-blooming plants, and decreased diversity to disrupted competitive interactions, changed rates of succession, and shifts to types of vegetation (such as cattail) unsuitable for spawning habitat. In response to concern expressed by several state and federal agencies, the U.S. Army Corps of Engineers predicted that there would be no significant effect on the marsh vegetation. The environmental assessment was left in that form.

Research Objectives

The principal objective of the wetland vegetation study, to determine how the wetland plant communities west of the cooling lake might change in response to mild heat and water stress, required answers to five questions:

1. What types of change would occur? Would these changes be at the level of species responses only, or would the entire community change? Would the composition or the structure of the vegetation change?
2. What would be the magnitude of change? Would changes be within the range of natural variability in wetland ecosystems? How large an area would be affected?
3. At what rate would the changes occur? Would they be gradual or would they take place within a short time and be more noticeable to observers?
4. Would a new equilibrium community become established or might the vegetation continue to change throughout almost the entire duration of the stress?
5. Would changes be irreversible, or might the communities recover after a period of complete abatement?

Wetland vegetation is dynamic, and methods for determining the response of vegetation to waste heat and elevated groundwater levels are not widely agreed upon. Wetlands in the upper midwest sometimes undergo natural shifts in species composition and structure without being subject to anthropogenic environmental influences. Thus, this study examines whether changes induced by leakage from the cooling lake could be detected within the limits of existing techniques for field monitoring. It was also necessary to determine whether the theoretical paradigms for analysis provided criteria by which significant impact could be recognized.

The research objectives went beyond a simple documenting of changes in wetland plant communities to an understanding of the process of change itself. Research goals designed to elucidate this process fit into three categories:

1. Documenting the response of wetland plant species and communities to mild heat and water stress.
2. Determining causal mechanisms potentially relating changes in vegetation to environmental varibles that, in turn, could be related to leakage from the cooling lake.
3. Examining available field techniques and paradigms for recognizing, monitoring, and — if possible — projecting the probable effects of waste heat and elevated water levels on wetland vegetation.

The wetland plant ecology research included four phases: field inventory and classification of plant communities, monitoring of vegetation, field and laboratory experiments to test hypotheses regarding mechanisms regulating population changes, and assessment of field and theoretical approaches.

The Study Site

The Columbia Electric Generating Station is located in southcentral Wisconsin, 6.4 km south of Portage, on a 1900-ha site which is almost entirely in the floodplain of the Wisconsin River. Before construction, an extensive and diverse wetland system covered more than 80% of 1100 ha declared for utility purposes. Dominant types of vegetation in the wetland system included marsh (emergent

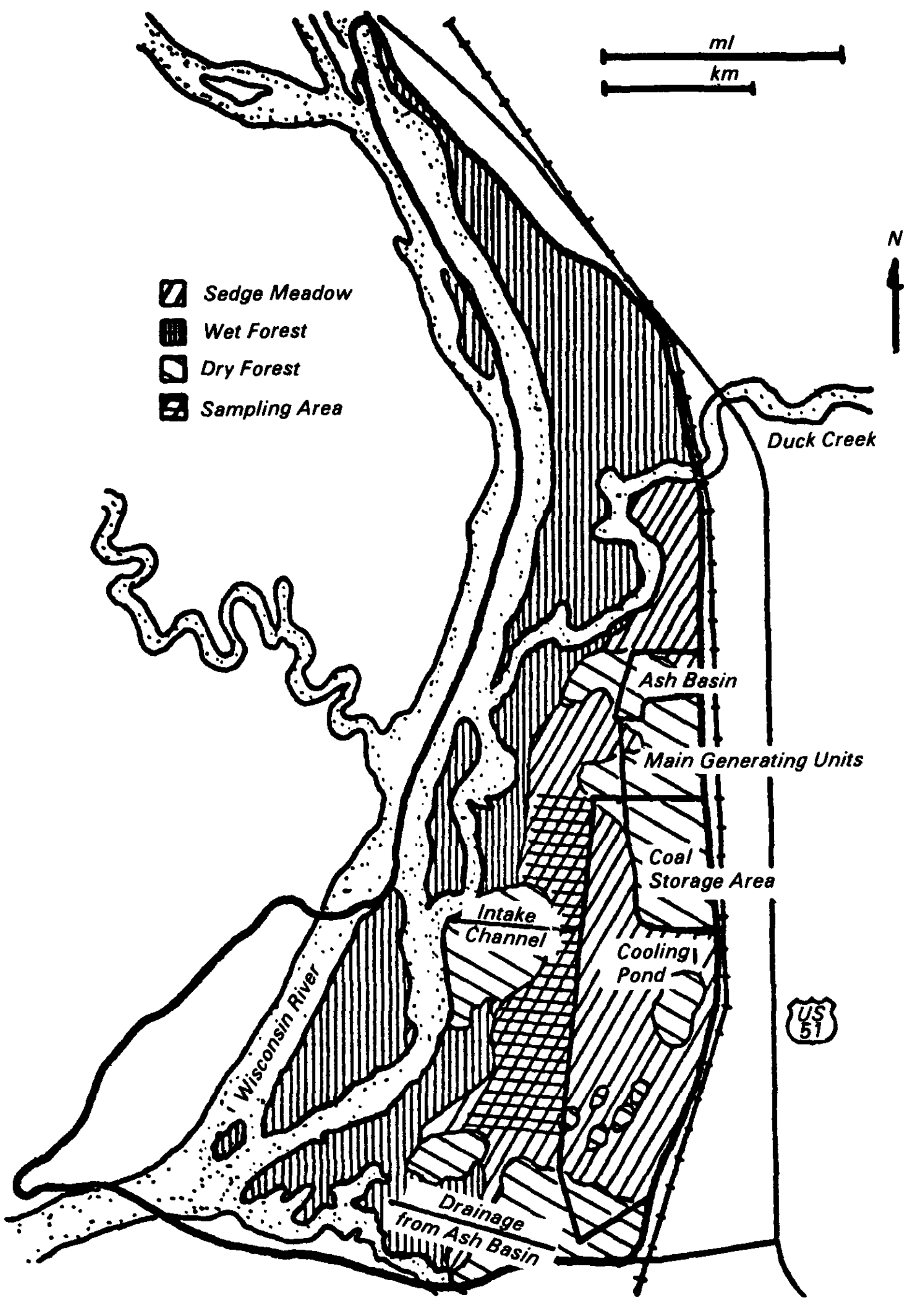

Figure 1. *Distribution of major plant communities before construction, showing future sites of generators and associated facilities.*

aquatics and southern sedge meadow), southern lowland forest, and lowland shrub communities. In 1971, more than 50% of the area was classed as nonforested wetland. Figure 1 shows the plant communities at the site before construction. The future locations of the main generating units and associated facilities are indicated, and the area of sedge meadow sampled in this study is shown.

The wetlands on the Columbia site occupy a former channel of the Wisconsin River in an area of regional groundwater discharge. A layer of peat varying in thickness from 1 to 3 m covers a thin layer of organic clay and silt, which overlies alluvial sands with clay lenses. Bedrock, composed of Upper Cambrian sandstones and Pre-Cambrian granites, occurs at a depth of 125 m below the surface.

Before the cooling lake was filled, groundwater discharge, precipitation, and floodwaters supplied water to the wetland communities on the site. The most important source of water was precipitation. This provided about 76 cm/yr, more than half of it falling between May and September. Inflow from groundwater averaged 22 cm/yr. Floodwaters from the Wisconsin River and Duck Creek frequently inundated the site, usually in early spring. However, their residence time in the wetlands was short, generally less than 3 days, due to the gentle slope of the area toward the Wisconsin River. Other inflows of surface water were minor.

The levels of surface water in the wetlands fluctuated widely before the lake was filled. Generally, levels were high during spring floods, decreased in summer, and rose again in the fall as plant growth and evapotranspiration ceased. Frequently, surface water disappeared entirely during the summer.

The climate around the site is continental. Weather is seasonably variable with a wide annual temperature range. Mean annual temperature is 6.5°C (standard deviation = 0.9°), with a mean summer maximum of 25.7°C, a mean winter maximum of -3.3°C, and a mean minimum of -12.9°C. The first killing frost usually occurs around September 30, and the last frost, around May 1.

The Columbia station consists of two 527-MW coal-fired electric power generating units, a 200-ha cooling lake, a 28-ha ashpit, a 16-ha coal pile, and other associated facilities. Construction began in 1971. Pumping to fill the cooling lake took place during June and July 1974. By September, the lake was almost empty due to high leakage rates. Consequently, the dikes were sealed with bentonite and the lake was again filled during November and December 1974. The first generating unit began operating in May 1975; the second went into operation in the spring of 1978.

Preliminary studies of wetland vegetation on the site were carried out from 1971 to 1973. Collection of data for the study reported here began in June 1974 and has continued to the present time. Studies of the groundwater system and surface flows began in 1972.

Findings

Data collected from 1974 through 1977 showed that changes in water levels and temperatures caused by seepage from the cooling lake led to significant changes in populations and communities of wetland plants.

Types of Change

Population studies revealed that different species were not equally sensitive to flooding, heat stress, or increased flow of surface water. Some species which were extremely sensitive, e.g., *Carex lacustris* and *C. rostrata*, declined rapidly and dramatically in all communities. Other perennial species such as *C. stricta* and *Calamagrostis canadensis* responded more slowly, decreasing only after 1976. *Typha latifolia*, in constrast, increased continuously in the emergent community and invaded all other communities as well. Other hydrophytic but nonpersistent species such as *Sagittaria latifolia* increased in some communities but not in others. *Lemna minor*, a floating annual, increased sharply in expanding areas of open water. Certain annual species, e.g., *Bidens cernua* and *Pilea pumila*, which had been insignificant or even absent before the disturbance, increased markedly where perennial dominants declined. Taken together, these observations show that significant changes occurred in the structure of the plant communities as well as in populations of individual species.

Species diversity frequently seems to be related to the stability of the environment. This study revealed no uniform relationship between species diversity and the intensity of environmental disturbance. Neither the richness of species nor the distribution of their abundances was consistently affected. Although obvious changes in community structure took place during the study period, the ecological significance of different patterns of response in the various communities was not evident from the diversity data alone. Disturbance did not simply increase or decrease diversity. Species richness, diversity, and equitability sometimes varied independently of each other. All of the measures of diversity employed decreased in some cases, increased in others, and frequently did both during the period from 1974 through 1977 as the spatial distribution and intensity of disturbance increased. Observed differences in measures of diversity between communities were related to the differential sensitivity of spatially dominant species to disturbance. Where disturbance was of the type to which dominant species were sensitive, diversity and equitability increased as new or competitively inferior species colonized or spread to space made available by the decline of previously dominant populations. Diversity and equitability decreased where disturbance favored one or two dominant species.

Carex lacustris showed an almost uniformly negative response to disturbance. In contrast, *Typha latifolia* exhibited both positive and negative responses. It showed a clear positive response to elevated water levels, increasing its density where it had been abundant and expanding its distribution substantially by 1977. Adverse effects on *Typha* were limited to areas where temperature increases of more than 7°C occurred during the winter.

Phenological changes (associated with the relationships between climatic variables and periodic biological phenomena such as flowering) appear to be reliable indicators of heat stress. Although changes in population density occurred throughout the study area, obvious phenological changes were not observed outside the area affected by altered temperature patterns. In areas receiving waste heat, individual plants showed visible signs of stress before the population collapsed. Where the species grew in dense stands, the symptoms were visible to the naked eye at distances up to 300 m. In general, phenological changes became evident 1 year before population density declined and 2 years before the population collapsed.

Observable and easily measured characteristics of plants experiencing heat stress included unseasonable chlorosis, reduced height of mature shoots, increased height of new spring and fall shoots, and early or delayed shoot emergence at reduced density.

Magnitude of Change

The magnitude of effect produced at both the population and the community levels appears to be outside the range of natural varibility for this particular wetland. Many records and lines of evidence indicate that densely vegetated perennial wetland plant communities have occupied the site for at least the last 150 years. Thus, although shifts toward more hydrophytic species and decreased vegetative cover are not uncommon for some wetland systems, evidence for the Columbia site suggests that the vegetation mapped in 1974 represented a fairly long-lived community type under historically prevailing environmental conditions.

By 1977, changed water levels significantly affected about 75% of the study area. The area significantly affected by waste heat is more difficult to define. Physiological and phenological data for *C. lacustris* and *T. latifolia* documented adverse effects from waste heat within 100 m of the wet dike in 1977 and apparent subsidy effects on *Typha* at distances up to 300 m from the dike.

Rate of Change

In addition to rapid shifts in dominance and diversity patterns in each plant community, a continuing trend toward decreased vegetative cover occurred from 1974 through 1977. Open water and exposed mudflats replaced the previously closed and densely vegetated perennial plant communities over an increasing portion of the study area. Annuals colonized some of the habitat opened by the removal of perennial species, but large areas remained unvegetated. By 1977, 19% of the quadrats sampled in the area of major impact had no rooted vegetation. Another 2% contained only annual vegetation.

Relationships Between Laboratory Investigations and Field Observations

Laboratory and field experiments began in 1977. Measurements were made of alterations in plant phenology and associated changes in amounts of nonstructural carbohydrates stored in underground organs of two species of perennial plants. These measurements were used to test hypotheses regarding the causes of population decline and to identify ecological criteria by which significant impact on the plant communities could be recognized and monitored in the field.

Physiological and phenological data from laboratory and field experiments related the response of *T. latifolia* and *C. lacustris* to altered seasonal patterns of carbohydrate storage and shoot phenology induced primarily by groundwater temperatures out of phase with normal cycles of plant growth. In addition to establishing the causal mechanism relating changes in vegetation to leakage from the cooling lake, this data set identified field signs of heat stress and suggested general species characteristics that may be useful indicators of potential sensitivity to stress.

Recommendations

The extreme sensitivity of *Carex lacustris* appears to be a consequence of its particular life history cycle and the timing, as well as the magnitude, of the disturbance. Characteristics of a species that may serve as indicators of potential sensitivity to stress include life span, seasonal schedule of various phenophases, seasonal distribution of biomass between above- and below-ground parts, ability to regenerate or colonize, and schedules of reproduction and mortality. Physiological and phenological data for both *C. lacustris* and *T. latifolia* suggest that the likelihood of predicting the response of dominant species would be enhanced by knowing the key features of their life cycles. It is evident that,

- The concept of life history strategies warrants further consideration as a theoretical tool for predicting species sensitivity to disturbance and assessing probable effects on wetland plant communities.

The 1974-1977 data address but cannot answer questions regarding the establishment of an equilibrium community or recovery of the community following disturbance. Temporal patterns in both population and community data reveal that these wetlands are still in a phase of transient behavior. Further changes can be expected. In terms of environmental factors, the wetlands are only one-third through a predicted transient. Water levels have more or less stabilized, but temperature changes are expected to increase in both magnitude and spatial extent after 1978 as the heat load of the second generating unit is added to the cooling lake. Results of population and physiological data through 1977 indicate that dominant perennial populations of rhizomatous sedges and grasses will continue to decline. As they do, the structure of the community will continue to change. In areas subject to minimal temperature increases, tolerant hydrophytic species such as *T. latifolia* probably will become dominant. Areas subject to maximum temperature increase may support only annual vegetation or remain as unvegetated muck or open water. For better understanding of these trends,

- Research should continue on the Columbia site in order to take advantage of the long-term data base and to monitor the eventual outcome of a sustained perturbation of wetland vegetation.

The development of effective tools for assessment and management depends on the identification and understanding of critical system components and interactions. Field observations on the Columbia site indicate that increased erodibility of the peat mass may be associated with the transition in dominants from perennial to annual and from persistent to nonpersistent species. Changes in numbers of species and species diversity values appear to be less relevant than differences in the life histories of spatially dominant species. The grouping of species with similar sets of life history traits may identify meaningful aggregate variables between the level of the individual species and the community. Therefore,

- Future research should address the system-level consequences of change in the vegetation of the wetland, and
- Further research should be directed toward identifying appropriate analytical categories and the components and processes of wetland systems critical to assessment of environmental impact.

Activities that alter physical inputs to wetlands are likely to continue as energy resources are developed and used. Better tools and paradigms for predicting short- and long-term effects of environmental change on wetland plant communities are more likely to come from demographic studies than from existing theories of succession or diversity in plant communities. This study showed no evidence of community replacements predicted by the succession model and no fixed relationship between disturbance and measures of diversity.

To improve the theoretical basis for prediction, future studies should investigate:

- The population biology of important wetland species including the temporal sequence of events in the life history, seasonal changes in population age/size structure, and requirements for germination.
- The relationships between characteristics of a population and the type, severity, and periodicity of natural fluctuations in the physical environment.
- The relationship of aspects of the life history to the probability of extinction and to the capacity for regeneration or recolonization under human-induced fluctuations in the physical environment.

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***Gary E. Glass** is the EPA Project Officer (see below).*
The complete report, entitled "Response of Carex-*Dominated Wetlands to Altered Temperature and Flooding Patterns: Wisconsin Power Plant Impact Study," (Order No. PB 84-198 944; Cost: $14.50, subject to change) will be available only from:*

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