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1995 Platte River Basin Ecosystem Symposium Proceedings

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BENTHIC MACROINVERTEBRATE COMMUNITIES ASSOCIATED WITH FORESTED AND OPEN RIPARIAN AREAS ALONG THE CENTRAL PLATTE RIVER

Michael J. McBride and Edward J. Peters, Department of Forestry, Fisheries, & Wildlife, University of Nebraska, Lincoln.

Historical inferences of natural vegetation patterns show that the central Platte River consisted of wide channels bordered by wetlands, grasslands, and scattered woodland vegetation (Johnson 1994). Alteration of the natural hydrograph, suppression of natural prairie fires, and elimination of the bison (*Bos bison*) have worked collectively to alter the structure and function of this ecosystem (Williams 1978, Sidle et al. 1989). These changes have allowed for cottonwood (*Populus* sp.) and willow (*Salix sp.)* establishment throughout riparian areas of the central Platte River (Johnson 1994), and have significantly altered habitat for many avian species, including the endangered whooping crane (*Grus americana*), least tern (*Sterna antillarum*), and piping plover (*Charadrius melodus*) (Currier 1985). While forested riparian areas currently dominate the central Platte River, nonforested areas still exist and management for endangered species includes creation of open areas along the River. How these changes have influenced the benthic macroinvertebrate community is unknown, since baseline data for comparison is limited. However, significant changes may be expected since streamside plant communities are major determinants of the abundance and quality of nutritional resources for benthic macroinvertebrates (Cummins et al. 1989).

While considerable attention has been given to stream community organization in the past three decades (see Minshall 1988 for review), little information is available on the stream communities in the Great Plains region of the United states (Wiley et al. 1990). In addition, there are no published investigations about the relationships of benthic macroinvertebrates in braided prairie streams. The central Platte River in Nebraska is a fifth order stream. However, it is unknown how the braided channels with differing riparian vegetation types influence the benthic community. Previous collections of benthic macroinvertebrates along the central Platte River (Bazata 1991, Chadwick & Associates 1990, Chapman 1972) have not accounted for differences in riparian vegetation types.

If the benthic community is affected by riparian vegetation, differences in the functional organization of aquatic invertebrates would be expected (Cummins 1989, Gregory et al. 1991). If woody vegetation affects forested areas more than open areas it should affect benthic community structure by altering abundances of functional feeding groups. Groups specialized to process coarse particulate organic matter, known as shredders (Merritt and Cummins 1978) should be more abundant in forested areas than in open areas. If woody vegetation affects both forested and nonforested riparian areas to the same degree, then the composition of functional feeding groups would be the same in the two habitat types. The objective of this paper is to evaluate the benthic macroinvertebrate communities associated with open and forested riparian vegetation types along the central Platte River.

BENTHIC MACROINVERTEBRATE COMMUNITIES ASSOCIATED WITH FORESTED AND OPEN RIPARIAN AREAS ALONG THE CENTRAL PLATTE RIVER

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INTRODUCTION

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METHODS

Study Sites

Four pairs of sampling stations, each with a forested and open site were selected (Figure 1). The Elm Creek open and forested sites are located approximately 4.6-km east of U.S. Highway 183 at river mile (RM) 230 and 229, respectively on the south channel of the central Platte River. These are two of the narrowest study sites (Table 1). The Cottonwood Ranch open and forested sites occur on the north channel and are located approximately 4.8-km west of U.S. Highway 183 at RM 235 and 234, respectively. These sites are intermediate in channel width compared to the other sites. The Alda forested and open sites occur along the north channel, but are separated by a distance of 44.8-km. The Alda forested site is located approximately 3.2-km east of State Highway 10 at RM 207, and is intermediate in width. The Alda site open is located approximately 3-km south of Alda at RM 182 and is the widest of all the eight study sites. The Wildrose Ranch open and forested sites occur along the middle channel at RM 180 and 179, respectively. The Wildrose open site is one the widest sites (77-m), while Wildrose forested is one of the narrowest sites (10-m).

Field Sampling Protocols

Each study site was 100-m long, and consisted of six transects spaced 20-m apart (Figure 2). Benthic macroinvertebrates were sampled along four randomly chosen transects using a modified Hess sampler. A total of eight Hess samples were collected at each site (four bank samples and four mid-channel samples). Two samples were collected on the north bank and two on the south. Mid-channel samples were collected at a point along the transects 0.4x channel width from the respective bank sample. Detritus, organic matter, and invertebrates were placed in a glass quart jar, labeled, and preserved in 10% formalin. Physical habitat variables including depth, cover type, and substrate type were recorded along each of the six transects at 0.5-m,

1.0-m, or 2.0-m intervals, depending upon channel width, to standardize the number of observations at each site. Depth was measured using a standard wading rod. Instream and cover was recorded as being present or absent. If present, instream cover observations were classified as wood or herbaceous plant material. Substrate data were classified as silt, sand, gravel, and organic matter by inspection. The sampling unit was defined as that point where the wading rod touched the substrate. Both dominant and sub-dominant substrate types were recorded.

Laboratory Analysis

Benthic macroinvertebrate samples were placed in Petri dishes, sorted using a dissecting microscope, and placed in vials containing 70% ethanol. All taxa, except those belonging to the family Chironomidae (Diptera), were identified to the lowest practical taxonomic category using a dissecting microscope. Chironomid larvae were mounted on glass slides using CMC-10 and identified to the lowest practical taxonomic level using a compound microscope. Common taxonomic keys used for identification included Weiderholm (1983) for identifying Chironomidae larvae. Taxa were assigned to functional feeding groups using Merritt & Cummins (1978). After the organisms were removed, organic matter was separated from the inorganic debris and strained through a #60 sieve. This material was then dried for 24 hours at 200° C, weighed, combusted at 500° C, and reweighed to determine particulate organic matter (POM) concentrations (APHA 1992). Data were compiled on a seasonal basis in order to determine differences between sites.

Statistical Analysis

To test for significant differences in occurrences of substrate types and instream cover between forested and open areas, percentages of each were compared seasonally using the General Linear Model Procedure (SAS 1989). Percentages from each category were normalized by taking the square root before tests were performed. Concentrations of POM were compared between forested and open sites, between bank and mid-channel sampling positions, and among stations. This analysis was performed separately for the spring, summer, and fall 1993 seasons using the General Linear Model Procedure (SAS 1989).

Total densities of benthic macroinvertebrates per sample within each functional feeding group were compared using the Categorical Data Modeling Procedure (SAS 1989). Sources of variation included treatment (forested vs. nonforested), station, sampling position (bank vs. mid-channel), and a stationXtreatment interaction term.

Taxonomic richness among sites was compared using the Shannon Weiner diversity index and its associated evenness index (Washington 1984). A cluster analysis was performed using the Cluster Procedure (SAS 1989) which compared sites using the Percentage Similarity Index (Washington 1984).

RESULTS

Physical Habitat

No significant differences ($p>0.10$) in occurrences of substrate types were found between forested and open sites during any of the four seasons. The occurrence of instream cover was significantly higher ($p=0.076$) in forested areas during spring 1993. Particulate organic matter (POM) varied both within and among sites. Samples from bank habitats had significantly higher POM than samples from mid-channel areas during spring, summer, and fall 1993 ($p=0.002$, 0.003, and 0.022, respectively). Samples from forested areas had significantly higher POM ($p=0.017$) than those taken from open areas in spring 1993 (Table 2). No significant differences in POM concentrations were found among stations.

Benthic Invertebrates

Overall diversity values were highest at the Elm Creek forested site in fall 1992 and 1993, and lowest at the Elm Creek site open in spring 1993 (Table 3). Taxonomic richness was highest at the Elm Creek forested site in fall 1993 with 37 taxa present. In each of the four seasons, taxonomic richness was highest at the Elm Creek forested and open sites. Taxonomic evenness was highest in summer and fall 1993. In summer 1993, evenness values were highest at the Alda open and Alda forested sites. In fall 1993, samples taken from the Cottonwood Ranch open, Alda forested, and Wildrose Ranch forested sites had the highest evenness scores. The lowest evenness scores were found at the Elm Creek open site in spring 1993.

Functional Feeding Group Analysis

Collector-filterers and collector-gatherers were the most common functional feeding groups at all sampling locations over the four seasons (Figure's 3 and 4). Numbers of each functional feeding group per sample varied significantly between treatments (forested/open), between positions (bank and mid-channel), and among stations (Table 4). Numbers of collector-filterers varied significantly among stations during all four sampling seasons (p=0.064, 0.0001, 0.08, 0.09) and were most abundant at the Elm Creek station (Figure 3). The Elm Creek open site produced the highest numbers of collector-filterers per sample during fall 1992, spring 1993 and fall 1993).

Collector-gatherers varied significantly among stations during spring (p=0.0001), summer (p=0.0001), and fall (p=0.0001) 1993 , by position during spring (p=0.001), summer (p=0.0.021), and fall (p=0.007) 1993, and by treatment during spring (p=0.006) and summer (p=0.029) 1993 (Table 4). They were most abundant at the Elm Creek station during all four sampling seasons (figure 4).

Significantly higher numbers of shredders were collected in bank samples during spring (p=0.0007), summer (p=0.0537), and fall (p=0.0178) 1993 (table 4; figure 5). In spring and fall 1993 numbers of shredders varied significantly among stations (p=0.0155 and 0.0041, respectively) and were highest at the Elm Creek station.

Predator numbers varied significantly in relation to sampling position and station (Table 4, Figure 6). In spring and fall 1993, total numbers of predators were significantly higher along bank areas (p=0.0480 and 0.0300, respectively). Position was also found to be a significant factor in summer 1993 (p=0.0139), but total numbers of predators were not consistently higher in bank samples than in mid-channel samples. The Wildrose Ranch open, Alda forested, Elm Creek open, and Cottonwood Ranch forested sites had higher numbers of predators along bank areas, while the Wildrose Ranch forested, Elm Creek forested, and Cottonwood Ranch open sites produced higher numbers at mid-channel locations.

Densities of scrapers varied relative to station and sampling position (Table 4, Figure 7). The Elm Creek station exhibited significantly higher numbers of scrapers in the fall 1992 (p=0.0001), and summer 1993 (p=0.0044) samples. Scraper densities were significantly higher along bank areas in the spring (0.0311), summer (p=0.0332), and fall (p=0.0931) 1993 samples.

Taxonomic Similarity of Study Sites

The taxonomic composition of the benthic macroinvertebrate community was found to vary between the eight study sites, as revealed by the cluster analysis (figure 8). While certain sites do appear to be relatively similar, taxonomic peculiarities were found at each of the sites.

The cluster analysis showed the Cottonwood Ranch open and Cottonwood ranch forested to be the most similar of the eight study sites. Dipteran larvae were the most abundant taxa at both of these sites (Figure 9). Simulid and Ceratopogonid larvae were the most abundant Dipterans at the Cottonwood Ranch forested site. Chironomid larvae were the most abundant Dipteran at Cottonwood Ranch open site. Ephemeroptera was the second most abundant order, with *Caenis sp.* comprising most of the mayflies found at both sites.

Taxonomically, the Wildrose Ranch open and forested sites were found to be most similar to the Cottonwood Ranch sites (Figure 8). Ephemeroptera larvae were nearly equal in abundance at both Wildrose Ranch sites with most of these being *caenis sp.*. Samples taken from the Wildrose Ranch forested site had a greater proportion of chironomid larvae than those taken from the Wildrose Ranch open site (Figure 10). Orthocladinae were the most abundant midge larvae at the Wildrose Ranch open site. Chironomini larvae and *Paracladopelma sp.* were dominant at Wildrose Ranch forested. *Paracladopelma sp.* was only abundant at the Wildrose Ranch forested site.

The Alda open and Elm Creek forested sites were taxonomically more similar to each other than the other six sites (Figure 8). Samples from the Elm Creek forested site contained high total numbers and a high proportion of Chironomids dominated by *Tanytarsini* (figure 11). *Physa sp.* and *Fossaria sp.* Gastropods, along with Orthocladin and *polypedilum sp.* midges were the most abundant taxa at the Alda open site (Figure 12). The Alda forested and Elm Creek open sites were the least similar to each other and the rest of the study sites (Figure 8). Tubificid worms, Chironomini and *Chironomus sp.* midge larvae were the most abundant taxa at the Alda forested site (Figure 12). Samples taken from the Elm Creek open site were dominated by Dipteran midge larvae, which accounted for seventy seven percent of the organisms collected (Figure 11).

DISCUSSION

In this study the patchiness of the benthic invertebrate community in the central Platte River was evident spatially and temporally over several scales. This patchiness was measured along several environmental axes which included among sampling stations, among study sites, between forested and open sites, and between sampling positions at a site.

If the abundance of functional feeding groups reflects the quality and quantity of energy present in lotic ecosystems (Peterson and Cummins 1974, Cummins et al. 1980, Vannotte et al. 1980, Cummins 1989), then it is apparent that differences exist in the distribution of organic matter in the central Platte River. Significantly higher concentrations of particulate organic matter from forested areas compared with samples taken from open areas indicates that differences may exist in the relative contribution of allochthonous material (such as leaves) from riparian vegetation. Significantly greater occurrences of instream cover at spring 1993 forested sites related to significantly higher concentrations of POM in the same season. Retention of leaves by organic debris has been documented by many other studies (Bilby 1981, Bilby and Likens 1980, Speaker et al. 1984, Smock et al. 1989, Petersen et al. 1989, Trotter 1990, Bilby and Ward 1991, Jones and Smock 1991, Ehrman and Lamberti 1992, Hill et al. 1992).

Previous investigations of how riparian vegetation effects community structure of benthic macroinvertebrates in lotic ecosystems have yielded differing results. Dudgeon (1988) investigated the functional community structure in four Hong Kong streams with differing riparian vegetation. Shredders were most abundant at forested sites and were associated with high levels of detritus. Scrapers were most abundant in unshaded streams. In the central Platte River, evidence from the analysis of functional feeding groups suggests that the distribution of riparian vegetation does not significantly influence the distribution of benthic invertebrates. Variation in total numbers between open and forested sites occurred only within the Collector-gatherers during the spring and summer 1993 seasons.

Community structure was also found to vary between channels, and lateral sampling position. Differences in communities between bank and mid-channel areas are an integral component of Ward's (1988) theory of the multidimensional nature of stream ecosystems. Abiotic factors such as substrate type, instream cover, and POM concentrations all differ between bank and mid-channel areas. Bank areas are characterized by relatively high amounts of organic matter, silt, and instream cover, while mid-channel habitats are characterized by a shifting sand substrate with less instream cover and lower amounts of organic matter and silt (Table 5). The benthic invertebrate community reflects this dichotomy through differences in relative abundances and densities. Unstable sandy substrates provide little habitat for benthic organisms and have low rates of organic matter retention. Rhodes and Hubert (1991) found that bank areas formed 8.5% of the lateral habitat, but contained 44% of benthic invertebrates in July and 30% in August. Analysis of densities within each functional feeding group supports the idea that patches are based upon lateral position and separate braided channels. Based on densities, the most common source of variation occurred between stations. Differences in total numbers between lateral sampling positions was found to be the second most common factor. Sites located on narrower channels, such as Elm Creek open and forested, tended to have higher occurrences of silt, organic matter, and instream cover compared to wider channels such as Alda open and Wildrose Ranch open. Significant variation between paired sites indicates differences in densities between channels in the central Platte River. Greater occurrences of instream cover and organic matter may indicate that the smaller channels differed less in relation to sampling position when compared to wider channels, and provided a more stable environment for colonization. While significant differences in particulate organic matter were not detected among stations, higher numbers of both collector-filterers and collector-gatherers at the Elm Creek open and forested sites indicate differences in the transport and retention of allochthonous material. Community composition also varies taxonomically between the separate braided channels. This indicates that the taxonomic template may be based upon geographic locality, with physical factors such as substrate composition ultimately influencing community structure (Townsend and Hildrew 1994).

Results of this study agree, in part, with models of community organization in lotic ecosystems (Vannotte et al. 1980; Minshall et al. 1985). The high proportion of collector-filterers and collector-gatherers at all eight sites agrees with predictions with these models in that the majority of detritus consists of fine particulate organic matter in higher order rivers. Macfarlane (1983) investigated community structure in a Minnesota plains stream, and found high proportions of both collector groups. While large river systems, such as the Platte River, may be thought of as being homogeneous in terms of their biotic community and functional organization (Vannotte et al. 1980), the results of this study indicate that such systems are not homogeneous, but rather a mosaic of patches. This may be especially true for braided rivers, like the central Platte, where differences in community structure may reflect differences in the physical processes acting on individual channels. It is apparent that differences in community structure exist between and along channels of the central Platte River. Further research is needed to elucidate the factors and mechanisms responsible for patterns identified in this study.

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CRITICAL THERMAL MAXIMA OF THREE PLATTE RIVER FISH SPECIES RELATIVE TO WATER TEMPERATURE REGIMES

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Temperature is considered to be a controlling factor and has pervasive influences on the biology, physiology, and ecology of fishes. Direct effects of elevated temperatures may stem from decreased metabolic activity in nervous tissue resulting in asphyxiation; however indirect effects on reproduction, ability to resist disease, and maintain performance in the presence of competition and predation may be more influential on the ultimate success of fishes occupying harsh environments (Brett 1956). Harsh environments typically exhibit extreme fluctuations in temperature, discharge, and turbidity and can have significant effects on fish populations therein (Matthews 1987). Exact mechanisms which allow fluctuating temperatures to play a pivotal role in regulating fish populations remain unclear. Fish either evolve physiologically to tolerate high temperatures or avoid temperatures less conducive to physiological performance through behavioral modifications (Hutchinson 1976; Reynolds and Casterlin 1976; Hutchinson and Maness 1979; Neill 1979; and Matthews 1987; Rutledge and Beitinger 1989). Huey and Stevenson (1979) argue that thermal tolerance measurements have limited ecological significance, and they feel behavioral regulation of optimum body temperature may provide more relevant information for extrapolation to ecological influences. However it is difficult to measure and interpret behavioral responses of fish under laboratory conditions and complications are magnified in the field. Information obtained from thermal tolerance studies appears to be reliable for measuring physiological stress and adaptation of fishes giving researchers the ability to set observable limits of tolerance by measuring physiological performance thresholds (Kowalski et al. 1978; and Paladino et al. 1980).

Critical Thermal Maximum (CTM) has been used extensively as a tool to measure thermal tolerance of ectotherms, primarily in laboratory experiments, since it was defined by Cowells and Bogert (1944), modified for statistical analysis by Lowe and Vance (1955), and standardized by Hutchinson (1961). Critical thermal maximum is defined as the "arithmetic mean of collected thermal points at which locomotor activity becomes disorganized to the point at which the organism loses its ability to escape conditions that will promptly lead to its death" (Cowells and Bogert 1944). This is typically characterized by the inability to right oneself and the onset of muscular spasms. Direct field measurements of CTM have been virtually ignored in the literature, therefore it is difficult to effectively correlate laboratory data with field data. Most previous work has examined CTM's of fish acclimated to stable temperatures in the laboratory where little attempt is made to directly correlate laboratory and field data (Reynolds 1977; Magnuson et al. 1979; and Deacon et al. 1987). Both field and laboratory studies were conducted in this project, however only the field component is reported here.

Rivers of the Great Plains often exhibit declines in summer flow as a result of drought and dewatering for agricultural, domestic, and industrial purposes. Consequently, fish communities may be adversely affected through modification of abiotic factors such as temperature or dissolved oxygen (Matthews 1988). The wide, shallow braided channels of the Platte River are typical of Great Plains Rivers. These characterisitcs make the Platte susceptible to drought and diversion of water for power and irrigation districts contributing further to the depletion of summer flows critical for fish populations during this stressful period. Instream temperatures are susceptible to the effects of insolation and have been known to exceed 39o C under such conditions. Fish kills have been reported along several reaches of the Platte River periodically since the summer of 1988 (Dinan 1992). However temperature could not be conclusively implicated in the fish kills reported. The focus of this research was to determine whether temperature can in fact be implicated in fish kills reported. Using the information obtained from this work we hope to predict periods where fish populations may be susceptible to temperature related mortalities. Finally, thermal tolerance estimates of 16 common species in the Platte River will be presented.

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INTRODUCTION

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METHODS

Four sites on the Platte River were selected for fish collection and subsequent testing (Fig 1). Sites near Alda and Elm Creek represented the central Platte River and sites near North Bend and Two Rivers State Park represented the lower Platte River. All sites were visited during four periods in 1994 (mid April, late June/early July, mid August, and mid October).

All fish were collected using a 7.62 x 1.22 m seine with 6.4 mm mesh and maintained in a livewell kept in the river throughout the testing period to ensure the fish would remain subject to ambient river conditions. Ten fish of each species, red shiner Cyprinella lutrensis, sand shiner Notropis stramineus, and plains killifish Fundulus zebrinus, were randomly selected after capture for determination of their CTM and death point. Critical Thermal Maxima were measured using a heating rate of 1o C/min (Lowe and Vance 1955; and Hutchinson 1961). Stirring hotplates were calibrated to heat at 10C/min. Fish were placed in 2000 ml beakers containing ambient temperature river water and heated to their CTM and death point. The CTM was recorded when a fish was unable to maintain equilibrium following erratic attempts to escape thermal discomfort. Death point, characterized by cessation of opercular movement, was also be recorded for each specimen. Each specimen was preserved individually in 10% Formaldehyde for length and weight measurements in the lab. Temperature was measured using a digital thermistor. A 4000 W gasoline powered generator served as a remote power source for hot plates and thermistors.

Field temperature collection

River temperature was recorded continuously throughout the sample period. These data were summarized into two week intervals representing the Mean Ambient River Temperature (MART) two weeks prior to field thermal tolerance measurement and used to evaluate the relationships between river temperature and thermal tolerance of the three target species.

RESULTS AND DISCUSSION

Critical thermal maxima for all three species were averaged over the entire study period from

April to October 1994 (Table 1). Means are reported with ranges for each species in addition to the overall MART for the entire sample season. As expected, ANOVA indicated all three species have significantly different thermal tolerances when measured under field conditions ($p<0.0001$). These general differences in thermal tolerance reflect each species relative susceptibility to elevated temperatures and imply directive adaptation in response to existing river temperature regimes (Feminella and Matthews 1984). Plains killifish exhibited the highest measured thermal tolerance. This is most likely indicative of this species habitat selection strategies and ability to maintain efficient physiological functions at high temperatures where physiological functions may be aided through the employment of isoenzymes unique to particular thermal conditions experienced by this species among others in this genera (Soltz and Naiman 1978). Feldmeth et al. (1974) reported that an increased scope of thermal tolerance allows fish to maintain physiological functions over a wider range of temperatures when exposed to fluctuating temperatures as in the Platte River. Although, it has been observed in the Platte River that killifish do utilize different habitats at different periods during the day, and perhaps these "directive movements" into different habitats serve to maximize the thermal scope of this species in its range in the Platte River (pers. obs.). Thermal lability is clearly exhibited by the red and sand shiner in the Platte River with a range even greater than that of killifish. Again, the general susceptibility to high temperatures is reflected in these species thermal tolerance where sand shiners appear to be the most vulnerable. Further, sand shiners were, in fact, commonly the most abundant species reported in the fish kills of the late 80's (Fannin 1988).

Analysis of variance (ANOVA) was employed to investigate differences in thermal tolerance of the target species from different locations (Central and Lower) in the Platte river and also to determine whether any differences in thermal tolerance could be detected between sites within the locations. No significant differences were observed between sites within locations for any species ($p=0.7357$ Cl; $p=0.6837$ Ns; $p=0.7435$ Fz). Consequently, all data collected at sites within locations were pooled and analyzed accordingly to enhance the statistical rigor of the tests. However, killifish were only collected on one occasion in the lower Platte, therefore no reasonable comparison could be made between location for this species. Initially, t-tests performed to assess the effect of location on thermal tolerance of sand and red shiners indicated no significant difference in thermal tolerance for either species between central and lower locations in the Platte River (Table 2). However it was suspected that Mean Ambient River Temperature (MART) has a direct influence on these fishes thermal tolerances since it essentially represents the thermal history of the fish for a period of two weeks prior to thermal tolerance measurement in the field. Analysis of covariance (ANCOVA) did, in fact, indicate that MART plays a significant role in how location effects the thermal tolerance of sand shiners, but not red shiners (Table 2). This indicates that thermal tolerance of sand shiners is influenced to a greater degree by location effects where MART covaries with thermal tolerance. In practical terms this means that sand shiners from the central Platte have different thermal tolerances than sand shiners in the lower Platte relative to the thermal regimes of the different locations in the Platte River. Conversely, red shiners do not exhibit differences in thermal tolerances between locations in the Platte River, and is most likely indicative of this species thermal lability and capacity to adapt physiologically in the context of its environment. Matthews (1986) reported no significant difference between 18 populations of red shiners from south central Texas to north Kansas, which corroborate the findings of this research. Further, Matthews indicated that this species has been characterized as having a "malleable genome" allowing it to occupy a wide range of habitats. Therefore, in the case of Platte River red shiners, the absolute temperature tolerance of this species most likely plays a more significant role in allowing this species to rapidly adapt to local environmental temperature changes than other species it is commonly associated with, such as the sand shiner.

As indicated by ANCOVA, it was evident for all three species that MART was the primary factor influencing the thermal tolerances of the fish tested as it represents the thermal history of those fish prior to CTM measurement. Characterization of the relationship between MART and CTM was attempted through regression analysis to ascertain the significance of linear, quadratic, and cubic terms in the model, and to estimate coefficients of those terms. All terms were found to be significant for sand shiners and plains killifish, however red shiners showed no significant relationship at any level investigated. The rational for investigating the significance of quadratic and cubic terms and their coefficients was to evaluate the presence of a thermal threshold represented by the cubic term in such a relationship. Unfortunately, the coefficients generated from the analysis proved to be inconsistent with observed thermal tolerances when they were used to predict CTM from MART. A likely reason for this inconsistency is that the actual relationship between MART and CTM is, for all practical purposes, linear to a point where MART equals the upper incipient lethal temperature of these fish which were not measured in this study (Houston 1982). As a result, the linear component of this relationship was investigated using instantaneous river temperature data represented by initial temperatures of the water at the beginning of each individual fishes CTM measurement. Alternatively, thermal thresholds were estimated from log-linear graphs by calculating the mean and standard deviation of the data representative of the highest instantaneous temperatures (Fig 2). Rationale for using instantaneous river temperatures to reflect MART is justified in that correlation between instantaneous and Mean Ambient river temperatures is high. Estimated thermal thresholds were then superimposed over the 1994 sample season thermograph (Fig 3). This graph illustrates the general susceptibility of these species to thermal stress related morality during dry summer months and further emphasizes the importance of water management efforts to preserve adequate instream flow during these critical periods. Furthermore, as indicated by the graph, a breech in the thermal threshold of the sand shiner occurred on June 20, 1994, and, in fact, fish kills including sand shiners were reported in both the central and lower Platte on this date (Hutchinson pers. comm.). Red shiners were the only species which displayed no significant statistical relationship with MART, however graphically this appears to be contradicted (Fig 2). Perhaps an explanation lies, once again, in the ability of this species to adjust their thermal tolerance more readily in the context of their environment. For example, red shiners may require a relatively shorter acclimation period (thermal history) than that of sand shiners and plains killifish in a fluctuating environment such as the Platte River. Furthermore, this apparent advantage may consequently contribute to the relative success of this species in harsh environments.

Thermal tolerances of other common species

The following is a brief report on the estimated thermal tolerances of some other common species of the Platte River (Table 3). These species thermal tolerances were measured on an as encountered basis. Consequently, these species, by no means, represent all species in the Platte

River, however these 16 species do represent some of the most common fishes occupying the Platte River. In addition, many of these species possess thermal tolerances which may leave them vulnerable to high temperatures. These estimates were measured in late August, 1994, therefore should represent the seasonal maximum thermal tolerance relative to ambient temperature conditions of the Platte River. Furthermore, keeping in mind these estimates only represent a snapshot in a temperature tolerance continuum of these species, they never-the-less may be important indicators to relative susceptibility to high summer instream temperatures, and further accentuate the importance of adequate instream flow maintenance for the life requisites of fish in the Platte River.

ACKNOWLEDGEMENTS

We would like to thank the United States Fish and Wildlife Service for the primary financial support of this research. Kenneth Dinan (USFWS) provided valuable information included in his temperature work on the Platte River. The Water Resources Center at the University of Nebraska-Lincoln for the purchase of Tempmentors. I also extend appreciation to Justin King at the Nebraska Public Power District and the Nebraska Game and Parks for providing field equipment much needed for this research. Finally, I thank the many students and technicians who assisted with the field and laboratory work involved in this project.

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FRESHWATER MUSSEL SURVEY OF THE PLATTE RIVER AND ASSOCIATED IRRIGATION AND HYDROPOWER CANALS AND LAKES

Mark M. Peyton and Jeremiah L. Maher, Central Nebraska Public Power and Irrigation District, Holdrege, Nebraska

In response to concerns expressed over the effects of hydropower and irrigation on the presence of freshwater mussels in the Platte River, the Central Nebraska Public Power and Irrigation District (Central) initiated a survey in 1991 for freshwater mussels in the upper Platte River and associated irrigation and power canals and lakes within this stretch of river.

From 1991 through 1994, 19 sites consisting of 30 kilometers of river and 20 kilometers of canals were surveyed, as well as ten canal lakes. The results of those surveys are presented here.

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BACKGROUND

There were three recent studies of freshwater mussels done prior to these surveys on the upper and central Platte River system. Roedel (1990) studied two sites located in the central Platte River near Wood River, Hall County, Nebraska; Lingle (1992) studied a 2.4-kilometer stretch of the central Platte that included the Roedel sites; and Perkins (Freeman and Perkins, 1992) surveyed the entire Platte including associated sloughs and ponds from Plattsmouth to the Wyoming border. Perkins' work incorporated the findings of Roedel, Lingle and the early work of Central. A list of ten species was developed for the Platte River from these studies (Table 1).

STUDY AREA

The area of the Platte River valley surveyed for this study extends approximately 120 kilometers west from Overton, Nebraska (Figure 1). A number of smaller irrigation canals have their diversions at points within this reach. The Phelps Canal has its origin at the terminus of Central's Supply Canal which diverts water near North Platte, Nebraska, and parallels the river for this entire stretch. A number of small and medium-sized lakes are formed by the Supply Canal.

METHODS

Nineteen sites consisting of approximately 30 kilometers of river and 20 kilometers of irrigation canals as well as ten canal lakes were surveyed visually and tactually while walking or swimming. A limited number of specimens were collected as vouchers to verify species identification. All other specimens were returned to their original location. Voucher specimens were submitted to the University of Nebraska State Museum Research Collection.

RESULTS

We located and identified 8,804 specimens representing nine native species of freshwater mussels

(Table 2). Eighteen specimens, representing five native species, were found in 30 kilometers of the Platte River while 8,206 specimens, representing nine native species, were identified in 20 kilometers of irrigation canals. In addition, 580 specimens representing seven species were located within the ten lakes surveyed.

Four species not previously collected in the Platte River system, or whose existence had been questioned, were located in our surveys. The Asiatic clam (Corbicula fluminea), an exotic whose method of introduction into the Platte system is unknown, was located in a number of canals and in the river from the confluence of the North and South Platte rivers to Cozad, Dawson County, Nebraska. The liliput shell (Toxolasma parvus) was located in portions of Johnson Lake and the fingernail clam (Sphaerium sp) was found in a number of places as dead valves only. Live Sphaerium is present in the Sutherland canal west of the study area and it is believed that all finds in this study were those that had been carried down through the system.

The squawfoot (Strophitus undulatus) was first reported from the Platte by Roedel (1990). However, Perkins (Freeman and Perkins, 1992) questioned the find based on a review of the voucher specimens by Dr. David Stansbury of Ohio State University. Specimens collected in this study believed to be S. undulatus were sent to the University of Colorado for verification. Using valve characteristics and softbody dissection, Dr. Hsiu-Ping Liu and Dr. Shi-Kuei Wu verified the identification of these specimens as S. undulatus.

Three species made up 95.6% of all specimens identified (Table 2). The white heelsplitter (L. complanata) (79.6%) was the most numerous species in the smaller irrigation canals, Phelps Canal and the Supply Canal.

The pink paper shell (P. ohiensis), (11%) also called the pink heelsplitter, was the most abundant species of freshwater mussel found in the lakes and in the river channels.

The maple leaf (O. quadrula) was identified by Freeman and Perkins (1992) as the most abundant species of freshwater mussels in the Platte. However, no specimens of maple leaf clams were found in 30 kilometers of river channel during Central's study. The maple leaf accounted for 4.7% of all specimens collected and was the second most abundant species found in the lakes and was fairly common in the smaller irrigation canals.

DISCUSSION

Studies done by Roedel (1990), Freeman and Perkins (1992), Lingle (1992) and now this study, show limited use of the Platte River by freshwater mussels. Based upon the location and identification of more than 8,000 specimens of mussels from hydro and irrigation canals and their associated lakes it is clear that these bodies of water do provide habitat which supports large populations of freshwater mussels.

The common occurrence of mussels in the canal systems as opposed to the sparse collection records from the river channels may have a number of explanations. The shifting sand bottom and constantly changing configuration of channels, along with the extreme flow changes common on the river, may not be as conducive to the existence of mussel beds as is the gravel and mud bottoms and more stable flows found within the canal system.

Also of importance is the presence or absence of fish species that act as hosts for the parasitic larval stages of many species of mussels. The common host fish for the 11 species of freshwater mussels located in the Platte River (Table 3) account for less than 5% of the more than 81,000 fish collected between 1990 and 1993 in a study of the abundance and diversity of fish in the various habitats of the central Platte River (Chadwick, 1994).

SUMMARY

Several species of freshwater mussels live in the canal systems and their associated lakes, drains, and returns of the upper Platte valley. Most of these species prefer habitats of silty, slow moving or ponded water and require host species not historically found in abundance in the Platte River system. Man-made reservoirs and canals and the introduction of new fish species to the system may have contributed to the current distribution and abundance of freshwater mussels in this region of the Great Plains.

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A REPORT ON THE CAPTURE OF 40 SPECIMENS OF THE AMERICAN BURYING BEETLE IN SOUTH CENTRAL NEBRASKA

Mark M. Peyton, Central Nebraska Public Power and Irrigation District, Gothenburg, Nebraska

INTRODUCTION

The American burying beetle (*Nicrophorus americanus*), a federally listed endangered species, was once found throughout temperate eastern North American. Recent collections, however, have come only from Rhode Island, Oklahoma, Arkansas and Nebraska.

Nine specimens of *N. americanus* had been collected in Nebraska prior to 1988 (Ratcliffe, 1992). In 1988 a specimen was collected approximately two kilometers south of the South Platte River near North Platte, Nebraska. This is the western most collection site for this species in the United States (Ratcliffe, 1992) and was the first indication that this species may inhabit the Platte River ecosystem.

An extensive survey using carrion-baited pitfall traps and light traps conducted near Sutherland, Nebraska, 32 kilometers west of the 1988 collection site, resulted in the collection of 3,492 specimens of *Nicrophorus* from 23 May - 16 October 1990. However, no specimens of *N. americanus* were collected (Ratcliffe, 1990).

A survey utilizing similar methods was conducted in the Platte River valley near Kearney from 15 to 30 July 1991. Seventy specimens of *Nicrophorus* were collected along with five other species of Silphids. However, again no specimens of *N. americanus* were found (Jameson, 1991).

Six specimens of *N. americanus* were found in 1992 on the Valentine National Wildlife Refuge in Cherry County, approximately 150 kilometers north of the North Platte site (Ratcliffe, 1992). Two additional specimens were located on the refuge in 1993 and a second specimen was taken at the North Platte site in 1993 (Ratcliffe, personal communication).

On 11 July 1994 I found three dead specimens of *N. americanus* in an inactive mammal pitfall trap along the Platte River in western Dawson County, south of Gothenburg, Nebraska. Following the discovery, I developed a plan to survey for *N. americanus* in the upper Platte River valley between North Platte and Lexington. The results of that survey are presented here.

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METHODS

Anderson (1982) described the habitat for the American burying beetle as northern deciduous and riparian forest, thus the 11 July find matched the expectation that if the species was present in an area, it would be along the river. Based upon that assumption, I placed 15 traps at five sites within the riparian forest along the Platte River between the confluence of the North and South Platte Rivers near North Platte and the J-2 river return near Lexington.

However, because the finds in Cherry County and those near North Platte were in open, upland grasslands, I also placed eight traps at three grassland sites south of this same river stretch (Figure 1).

Utilizing the protocol developed by Kozol (1990), I began trapping on 5 August 1994. After capturing 21 *N. americanus* at two of the original three grassland sites I added three new grassland sites on 19 August and three more on 24 August for a total of nine grassland sites.

Originally there were three traps placed about 100 meters apart per site. The grassland locations added on 19 and 24 August had one trap per site. Traps were checked each morning prior to 9 a.m., when possible. Specimens were photographed and released immediately except when specimens were temporarily held to await verification by Brett Ratcliffe and Mary Liz Jameson of the University of Nebraska State Museum and Wally Jobman from the U.S. Fish and Wildlife Service.

The purpose of the survey was to verify the presence of *N. americanus* in the area. The traps were dismantled after specimens were found at a specific site.

RESULTS

From 5 August to 29 August 1994, I operated 31 pitfall traps at 14 locations for a total of 211 trap nights. I collected 37 live *N. americanus* from one riverine and seven grassland locations between North Platte and Lexington, Nebraska. Thirty-six specimens were taken from the upland grassland sites south of the Platte River and one specimen was taken from the riparian forest along the river. Collection information is summarized in Table 1.

SUMMARY AND DISCUSSION

After finding three dead specimens of the American burying beetle along the Platte River south of Gothenburg in Dawson County, Nebraska, I was able to trap, photograph and release 37 live specimens from seven upland grassland and one riverine location.

Originally, using Kozol's protocol which called for beef liver as bait, only a few *Nicrophorus* were found in each trap. I also noticed that there was little or no odor associated with the liver so I began to collect roadkill animals and use them as bait. All collections of *N. americanus* were in traps utilizing roadkill (Table 1) and the number of individuals of other species of *Nicrophorus* found in each trap increased dramatically with the change in bait.

NEED FOR FURTHER STUDY

It is possible that this population, combined with those present in Cherry County, identify a third large population of *N. americanus* in the Midwest Geographic Recovery Area as outlined in the Recovery Plan for this species.

The University of Nebraska State Museum, using USFWS Section Six grant funds made available through the Nebraska Game and Parks Commission, will be instituting a two-year study of the Gothenburg population starting in the spring of 1995. The purpose of this study will be to determine population size, examine minimal versus optimal prey size, assess interspecific

Nicrophorus competition and determine the geographic range of this species in correlation with any habitat preferences (Ratcliffe, personal communication).

The UNSM study will concentrate on a 15-mile wide band extending south from the Platte River between North Platte and Lexington. Surveys of a variety of other areas extending in all directions from the Gothenburg and Cherry County sites are necessary in order to provide data on range, habitat preference and population size for this species. The need for these surveys is outlined in the Recovery Plan developed by the U.S. Fish and Wildlife Service, however to date, this has not been done in Nebraska.

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SUMMARY OF LEAST TERN AND PIPING PLOVER NESTING ACTIVITIES AT SITES IN THE UPPER PLATTE RIVER VALLEY MANAGED BY THE CENTRAL NEBRASKA PUBLIC POWER AND IRRIGATION DISTRICT

Mark M. Peyton and Jeremiah L. Maher, Central Nebraska Public Power and Irrigation District, Holdrege, Nebraska

In 1992 as a voluntary amendment to its interim license the Central Nebraska Public Power and Irrigation District (Central) began management of nesting areas of the endangered least tern (Sterna antillarum) and threatened piping plover (Charadrius melodus) in the upper Platte River valley.

In 1994 Central personnel surveyed the Platte River valley from Lexington to North Platte. Four areas were identified and monitored at least twice weekly throughout the season.

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INTRODUCTION

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In 1994 Central personnel surveyed the Platte River valley from Lexington to North Platte. Four areas were identified and monitored at least twice weekly throughout the season.

RESULTS

A total of 42 adult least terns and 10 adult piping plovers were located at the four sites. Least terns nested in three of the four areas producing 21 nests. The number of eggs was not determined due to limitations on entry to the site. Thirty-three (33) chicks were identified with a minimum of 24 fledging for a minimum fledge ratio of 1.14 per adult pair (Table 1).

Piping plovers nested at two of the four areas monitored. A total of 10 adult plovers produced five nests. There were 20 eggs, 17 chicks with a minimum of eight fledged juveniles for a minimum fledge ration of 1.6 per adult pair (Table 2).

SUMMARY OF THREE SEASONS

The 1994 season marked the third year that Central has managed nesting areas for least terns and piping plovers in the upper Platte River valley. Over those three seasons 116 adult least terns constructed 69 nests, hatching 105 chick of which a minimum of 53 reached fledge stage. This represents a cumulative fledge ratio of 0.9 chicks per adult pair. Thompson (1982) calculated a fledge per breeding pair ratio necessary to maintain a stable breeding population of 0.7 per adult pair. The fledge ratio achieved at the four sites was 129% of the minimum necessary to insure a stable population (Table 3).

During the same three seasons 32 piping plovers constructed 14 nests, hatching 50 chicks of which a minimum of 15 reached fledge stage for a fledge ration of 0.9 per adult pair. Ryan et al (1993) calculated a fledged per breeding pair ratio necessary to maintain a stable breeding population of 1.13 for piping plovers. The fledge ratio achieved at these four sites over the three years was 80% of the minimum necessary to insure a stable populations (Table 3).

DISCUSSION

It is still somewhat preliminary to make generalized statements on the success and/or failure of the management strategies employed by Central at the four areas in the upper Platte River valley. However, the results reported here do indicate that these areas are important habitat for both least terns and piping plovers and Central's efforts in managing the habitat for these species is helping to achieve nesting success at these sites.

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RECENT USE OF BEACHES AT LAKE MCCONAUGHY BY PIPING PLOVERS (CHARADRIUS MELODUS): A REVIEW

Mark M. Peyton and Jeremiah L. Maher, Central Nebraska Public Power and Irrigation District, Holdrege, Nebraska

ABSTRACT

The presence of piping plovers (Charadrius melodus) along the shore of Lake McConaughy was first documented in 1978 (Rosche, 1994), with the first record of nesting reported in 1985 (Johnsgard, 1990). In recent years the numbers of birds observed at the lake has increased significantly. The sandy beaches surrounding the lake have become one of the most important nesting areas for this species within Nebraska with 50 nests being recorded in 1994 and a total of 199 since 1992. Potential conflict arises because of high recreational activity at the lake. Observation of this subpopulation of birds has shown the birds to be remarkably tolerant of human activity. Experimental management practices using minimal protection measures appear to be successful.

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INTRODUCTION

Study Area. Lake McConaughy formed by Kingsley Dam is located near Ogallala, Nebraska and is the largest reservoir on the North Platte River. The three mile wide dam created a lake about twenty-one (21) miles long with approximately 30,500 surface acres at capacity and 105 miles of shoreline.

Because of its size and the extensive white sand beaches, Lake McConaughy not only provides habitat for wildlife, it is a major recreational area for people interested in boating, skiing, wind surfing, fishing, and beach camping. Estimates of recreational use of the beaches exceed seven hundred thousand visitor-days per year. Precisely because Lake McConaughy attracts large numbers of people and birds, there are inevitable conflicts. It is for this reason that recent attention has focused on habitats used by threatened and endangered species.

Background. The presence of piping plovers (Charadrius melodus) along the shore of Lake McConaughy was first documented in 1978 (Rosche, 1994), with the first record of nesting reported in 1985 (Johnsgard, 1990). In recent years the number of birds observed at the lake has increased significantly. Systematic surveys for piping plovers were first conducted at Lake McConaughy in 1986 (Wingfield, 1993). Regular censusing, however, did not start until 1990, and management of beach areas for piping plover nesting did not begin until the spring of 1992.

The census of 1986 consisted of a one day search in late May by Nebraska Game and Parks personnel. In 1990 and 1991 two cooperative surveys were conducted by Central, NGPC and NPPD. One survey was conducted in May and the second in June (Wingfield, 1993). Beginning in 1992 Central, as a voluntary addition to its annual license for the operation of FERC Project

1417, implemented management plans for protecting piping plovers and least terns along the shores of Lake McConaughy and selected sand pits in the upper Platte River valley. These plans included the census of piping plovers and least terns, monitoring the nesting success of these two species and, when necessary, the isolation and protection of nests from human activity.

METHODS

Since 1992 Piping Plover surveys have been conducted weekly starting in mid May and running until late August. Nests located during the census were noted and management practices were undertaken as needed. Single nests located in high recreational use areas were isolated with diamond shaped exclosures measuring approximately 200 meters square. These exclosures were simply bright orange twine strung between fence posts with "Keep Out" signs placed on the fence posts warning people of the nest. Nests located in areas where human activity was minimal were noted and observed, but no identification or fencing was used. At two sites historical use by least terns and a somewhat higher density of plovers resulted in the fencing of relatively large areas, one a 37 acre tract and the second a 30 acre tract. These areas were fenced with woven wire around the entire area effectively excluding all human activity.

Each nest was monitored a minimum of twice weekly. The success of each nest, determined by the hatching of at least one chick, was recorded and the ratio of fledged young (defined as the ability to fly) to adult pairs was calculated. Causes of nest and/or bird loss were determined when possible.

RESULTS

Population. The number of birds sighted at Lake McConaughy increased from eight (8) in 1986 to a high of 138 in 1993 (Table 1), however, the increase of beach area with the lower reservoir storage in the early 1990s, the change in survey protocols and the timing of the surveys, and a significant increase in the intensity of effort involved in the process make a comparison of pre and post 1992 numbers difficult.

For convenience the lake was divided into twelve areas (See Fig. 1) and the fledgling success for each area was recorded. During the past three seasons 199 nests produced 720 eggs from which 386 chicks hatched (54%). Of the 386 chicks 247 successfully fledged (65%) for a ratio of fledged chicks to adult pair of 1.47 (Table 2).

Root et all (1993) using a stochastic population growth model determined that a minimum annual production of 1.16 fledged chicks per adult pair is necessary in order to effect a 1% annual growth in population. The 1.47 fledge ratio achieved at Lake McConaughy in the three years of District management is 127% of that minimum growth value.

Nest Site Management. Because of the status of the piping plover as a threatened species a rigorous experimental program was not followed to determine the success of the fencing efforts used to protect the nests. However, the data and anecdotal evidence collected indicated that the psychological fencing is a valuable management tool which may result in an increased probability of successful nesting by piping plovers.

From 1992 to 1994 a total of 129 individual nests were protected by the orange twine psychological fencing and protective signs. Of the 129 fenced nests 102 (79%) were successful in producing at least one chick. Fifty-five (55) nests were not fenced because they were located in areas where human recreation is at a minimum; of these, 35 (64%) were successful in producing a minimum of one chick. Fifteen (15) nests were located in the two areas where all human activity was excluded; of these, 13 (87%) were successful in producing at least one chick.

Nest Losses. At Lake McConaughy, over the past three seasons, 59 nests were lost prior to hatching. Five nests were lost directly by human activity. These five represent 2.5% of the total nests initiated. Of these five nests, four were protected by exclosures, however, three losses occurred during the first year of management, one in the second and none in the third. Other nest losses were 6 to cattle, 5 to predators, 7 to weather, and 36 were due to unknown causes.

SUMMARY

Lake McConaughy is one of the most important recreation areas in Nebraska. Data collected since 1990 shows that the lake is also an important nesting site for segments of the Great Plains population of the piping plover. Conflict between human activity and nesting habitat for the piping plover along the beach is inevitable and thus management of the area for the protection of piping plover nests and young is necessary.

Since 1992 Central has provided extensive monitoring and management of the piping plover nesting habitat located at Lake McConaughy. Since management practices were begun only five nests were identified as being lost directly to human activity despite the intensive recreational use of many beach areas. In 1994 record numbers of visitors were recorded on the beach, however, not one nest was lost as a direct result of human activity. Success, however, can be measured not just in terms of reducing losses to vacationers, but in terms of adding birds to the population.

AGRONOMIC AND ECONOMIC IMPACTS OF REDUCED IRRIGATION WATER USE IN THE SOUTH PLATTE-CACHE LA POUDRE AREA

Susanne M. Scheierling, Robert A. Young, Department of Agricultural and Resource Economics, and **Grant E. Cardon**, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO

Recent interest in the impact of reduced irrigation water use is a reflection of the growing competition between agricultural, urban, and environmental uses for limited water supplies. In many parts of the western United States, agriculture is the main user of the water resource, accounting for 80 to over 90 percent of the water consumed. It is increasingly recognized that more efforts to improve irrigation practices and thus reduce water use in agriculture would have several desirable effects (Howe *et al*., 1986; Young, 1986a; Colby, 1990; Dinar and Letey, 1991). It would make water available for emerging, higher-valued uses in non-agricultural sectors. By discouraging excess irrigation and reducing drainage volumes it would help control the discharge of agricultural pollutants into surface and ground waters and, as a consequence, diminish the social costs associated with irrigated agriculture. In addition, water not consumed in agriculture can contribute to increased instream flows for improving fish and wildlife habitat, recreation, and other environmental uses.

However, it is often pointed out that a reduction of irrigation water use would also be associated with serious negative economic impacts on agriculture. According to this viewpoint, the use of less irrigation water than "required" by different crops would lead to significant reductions in crop yields and/or irrigated area and, as a result, to high losses in agricultural income. Furthermore, the local and regional economies due to their close linkages to irrigated agriculture would suffer. Based on a more detailed study (Scheierling, in preparation), this paper attempts to show that this viewpoint neglects the strategies available to farmers for adapting to reductions in the quantity of irrigation water available or, equivalently, to increases in the price of irrigation water. Particularly in the long run, farmers can adapt not only by changing the crop mix or reducing the area irrigated but also by substituting other inputs for water, such as capital (e.g., more efficient irrigation systems) or improved management (e.g., variations in the number of irrigation applications) (Young, 1986b; Gibbons, 1986). The specific objective of this paper is to demonstrate via a case study in northeastern Colorado that by allowing for these adaptation strategies the agronomic and economic impacts can be relatively limited over a wide range of irrigation water reductions.

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STUDY AREA

The service area of the New Cache La Poudre Irrigating Company located near Greeley in northeastern Colorado was chosen as a study area. This irrigation company holds several rights to flow from the Cache La Poudre River, a major tributary to the South Platte River. The water can be used anywhere within the irrigation company's service area of about 40,000 acres. Water deliveries to individual farmers are based on their ownership of capital stock in the irrigation company, and the stock shares can be transferred freely within the service area (Maass and Anderson, 1978).

According to records of the Office of the State Engineer, the irrigation company distributes an average of 60,000 acre feet of irrigation water per season. Additional water is made available by pumping groundwater from the alluvial aquifer along the Cache La Poudre River and the South Platte River. Records in the Division Engineer's Office in Greeley show that there are 460 wells in the area which are entitled to pump up to 60,000 acre feet annually. More than three quarters of the service area are used to grow five major crops: alfalfa, corn for grain, corn for silage, dry beans, and sugarbeets. The predominant irrigation system is open ditch with siphons (55 percent), followed by flexible pipe (25 percent), gated pipe (15 percent), flexible pipe with surge (3 percent), and grated pipe with surge (2 percent).

Agronomic Model. Due to the lack of on-farm data of yield responses to irrigation water use for the study area, a previously developed agronomic model was used to synthesize the data and provided with parameters representing conditions in the study area. The model employed is known as the van Genuchten-Hanks model (Cardon and Letey, 1992a, 1992b). By combining soil-water, plant-water, and yield-evapotranspiration relationships it estimates yields for each of the major crops as a function of the quantity and quality of water applied at different points in time during a growing season. Water flow in the vertical direction is calculated by the Darcy-Richards equation. Plant water uptake is incorporated by the addition of a sink term, S(z,t):

where K is the soil hydraulic conductivity, C is the soil water capacity, h is soil matric pressure head, t is time, and z is soil depth (positive downwards). Transpiration and water and solute redistribution are calculated for a user-specified length of time until an irrigation, rainfall event, or adjustment in crop-dynamic variables occurs.

To take into account basic plant growth dynamics, growth-stage-specific stress tolerance and stress-induced growth reductions, the equation for the sink term used in the model is as follows:

where S(z,t) is the crop water uptake at depth z and time t, $S'_{max}(t)$ is the stress-adjusted value of the time-dependent S_{max} which is the maximum possible crop water uptake, h is the soil matric pressure head, is the osmotic head, $_{50}$ is the osmotic potential at which S_{max} is reduced by 50 percent, a(t) is a time-variable equal to $_{50}/h_{50}$ where h_{50} is the soil matric pressure head at which S_{max} is reduced by 50 percent, p is an empirical constant (which is approximately 3 for many crops), and (z,t) is a depth- and time- dependent root distribution coefficient.

The model does not calculate crop yield directly, rather values of the sink term S(z,t) are summed for the season and must then be converted to yield. The following equation for yield-evapotranspiration relationships is used:

where Y/Y_{max} is relative yield, k is a crop-specific yield response coefficient, ET is evapotranspiration, and PET is potential evapotranspiration. Model-predicted values for relative yield were calculated by substituting cumulative S divided by cumulative S'_{max} for ET/PET and using k values suggested by Doorenbos and Kassam (1979).

All data input was chosen to reflect the situation for crop production in the Greeley area. It was assumed that up to nine irrigation events may occur during the irrigation season, each with a net irrigation application of 3 inches. The dates chosen 6/1, 6/20, 7/10, 7/20, 7/30, 8/10, 8/25, and 9/8. On each of these dates crops can be irrigated or not irrigated, depending on the availability of water. This results in 2^9, or 512 combinations of irrigation events. All possible 512 combinations were used as model inputs to calculate the respective values for evapotranspiration and yield for each of the five crops. In Figure 1 model estimations of evapotranspiration and yield for alfalfa are presented. The estimations for the other crops are similar. These results show that enormous yield variations may occur depending on the timing of irrigation events. However, with careful management of available water the adverse yield impacts can be minimized. It is possible to reduce the number of irrigations and thus the quantity of water applied over a certain range without hardly impacting crop yields if the remaining irrigations are well-timed.

Economic Model. The yield estimations for the five crops as a function of the quantity of irrigation water applied provide the physical component of the economic model developed to estimate the impacts of reduced irrigation water use on the irrigation company's service area under alternative assumptions regarding adaptation strategies. A liner programming model was chosen, since it can be easily adapted to represent a range of irrigation water use availabilities. The model maximized the service area's net return to fixed factors of production and has the following general form:

where TNR is total net revenue, c_j is unit net revenue of output j (revenue less variable and cost), x_j is level of output j produced using the j th technological process, a_{ij} is amount of input i necessary for production of one unit of output j, and b_i is total available quantity of input i.

Farmers are assumed to be economically rational, i.e. to apply irrigation water well-timed so that the highest possible yield for a given number of irrigations can be achieved. Thus in the case of alfalfa, only nine combinations of the 512 shown in Figure 1 need to be considered in the economic model. However, each combination can be used with any of the five surface irrigation systems typical in the study area. Depending on the respective irrigation efficiency, the amount of water actually applied varies with the irrigation system. Net revenue is calculated for each of the relevant combinations. The objective function is maximized subject to constraints on total irrigation water availability and total and individual crop acreage.

To analyze the effect of strategies for adapting to reductions in irrigation water, two scenarios are examined. Scenario A models economic impacts when reducing the area irrigated is the only adaptation allowed. Scenario B models economic impacts assuming farmers can adapt by varying the number of irrigation applications and/or by switching to a more efficient irrigation system. Both scenarios start out with a total irrigation water (surface and well) availability of 120,000 acre feet and a crop mix typical for the area. In scenario A additional constraints are formulated so that the current use of different irrigation systems remains unchanged. Initially with the full amount of irrigation water available, farmers are assumed to choose the number of irrigations for each crop under each irrigation system so that all water is used and net return maximized. As irrigation water is reduced (or as costs go up), farmers can adjust only by having crops gradually drop out of production one by one as they become uneconomic to produce. In scenario B, choices can also be made in the number of irrigations per crop or the irrigation system used.

DISCUSSION OF RESULTS AND IMPLICATIONS

Figure 2 shows the results of the economic model for scenarios A and B. For both scenarios irrigation water availability was varied and a linear programming solution found for each water quantity available, all other constraints remaining unchanged. When water availability is high, farmers would be expected to allocate water even to less valued crops and to irrigation systems with lower irrigation efficiency. As the water availability is reduced, the less valuable crops and the more water-intensive irrigation systems are excluded from the solution, and the marginal value of water rises. The set of shadow prices derived at various levels of water availability is a water demand schedule (the marginal value of water in Figure 2) for the irrigation company's service area. The model's objective function at various levels of water availability makes up the net return schedule shown in Figure 2.

There are important differences in the water demand schedules and net return schedules of scenario A and B. For purposes of water reallocation policy, the relevant parts of the schedules are those which show the impacts of the initial changes in irrigation water availability on the right hand side of the graphs. Under the assumptions of scenario A even relatively small reductions in water availability would result in significant losses in net return to farmers. Under the more realistic assumptions in scenario B water availability could be reduced by a quarter and hardly impact net returns. This is because farmers can adjust, for example, by applying not five but only four irrigations for alfalfa which has only a limited effect on yield. When irrigation water is further reduced, farmers can adapt again, this time for example, by changing the irrigation system from flexible pipe to flexible pipe with surge which allows to keeps the numbers of irrigation constant while reducing irrigation water use and only slightly reducing net revenue (due to higher irrigation costs).

The main implication of this study is that in the long run, when farmers have the opportunity to adjust their irrigation practices and the timing of irrigations is flexible, reduced irrigation water use does not necessarily lead to serious negative economic impacts on agriculture and rural communities. The models used in this study do not consider risk and uncertainty involved in irrigated agriculture, such as variations in rainfall, water availability, or crop prices, but at the same time they allow for only a few of many possible technical adaptations. therefore, it seems quite likely that in actual situations of reductions of irrigation water use in the south Platte-Cache La Poudre Area the agronomic and economic impacts would be less dramatic than often assumed. The model results indicate that efforts towards improving irrigation practices and reducing water use in agriculture are advisable.

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EXTENSION PROGRAMMING FOR IMPROVING NITROGEN AND IRRIGATION MANAGEMENT IN NEBRASKA

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INTRODUCTION

Although the problem of nonpoint source pollution and improving ground water quality seems complex and unmanageable, there are certain factors that current scientific investigation, public awareness and common sense tell us can be changed. We know that the way we use our natural soil and water resources can have a major effect on ground water quality. While the federal government wrestles with major legislation that can ultimately affect water quality (EPA directives, Safe Drinking Water Act reauthorization, the 1995 Farm Bill), many states have already addressed the issue (Ehrman, et al., 1990). Regardless of the method chosen to control land use and farm practices,educational programs will be required to solve ground water quality problems even though there is scientific uncertainty, complex governmental legislation, and changes required in human behaviors and attitudes.

The premise of this paper is that effective management programs, whether voluntary or imposed must have a good research base, extension/education outreach, government/institutional support, and local citizen input and control. The history of these different factors as they relate to Nebraska and how special Cooperative Extension programming has aided progress to the goal of improving ground water quality will be discussed.

EXTENSION PROGRAMMING FOR IMPROVING NITROGEN AND IRRIGATION MANAGEMENT IN NEBRASKA

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INTRODUCTION

Although the problem of nonpoint source pollution and improving ground water quality seems complex and unmanageable, there are certain factors that current scientific investigation, public awareness and common sense tell us can be changed. We know that the way we use our natural soil and water resources can have a major effect on ground water quality. While the federal government wrestles with major legislation that can ultimately affect water quality (EPA directives, Safe Drinking Water Act reauthorization, the 1995 Farm Bill), many states have already addressed the issue (Ehrman, et al., 1990). Regardless of the method chosen to control land use and farm practices,educational programs will be required to solve ground water quality problems even though there is scientific uncertainty, complex governmental legislation, and changes required in human behaviors and attitudes.

The premise of this paper is that effective management programs, whether voluntary or imposed must have a good research base, extension/education outreach, government/institutional support, and local citizen input and control. The history of these different factors as they relate to Nebraska and how special Cooperative Extension programming has aided progress to the goal of improving ground water quality will be discussed.

NEBRASKA IRRIGATION DEVELOPMENT

The earliest record of surface irrigation in Nebraska was in 1870 when an irrigation ditch company was formed near North Platte, Nebraska (Manly, 1993). Irrigation from surface water developed first in major river valleys and on first and second terrace soils. The advent of the center pivot irrigation and an abundant ground water supply caused the next major irrigation development in Nebraska after the 1960's (Kuzelka, 1993). The Ogallala formation underlies much of Nebraska and is in parts of seven other states, however, 70% of the exploitable water in the Ogallala aquifer is under the state of Nebraska. In 1960 Nebraska's had 2 million irrigated acres. Rapid development during the 1970's and 1980's expanded irrigated acres outside river valleys and today there are 8.4 million acres of irrigated land with one half of the total acres surface irrigated and one half irrigated by center pivots.

AGRICULTURE IN TRANSITION

In the United states before the 1930's conversion of virgin forest or prairie land provided increases in food and fiber production. Since then cultivated acres have steadily declined but population has more than doubled (Olson, 1978). This caused pressure to produce increasing food and fiber needs from fewer and fewer acres to meet a growing population and export demand.

After World War II fertilizer N became available and gained general farmer acceptance during the 1950's. The emphasis on and necessity for crop rotations declined because most rotational benefits were associated with N additions. Rotations were gradually abandoned by most farmers as they learned how N could be supplied conveniently and economically as fertilizer. This ushered in a new era of agricultural production which favored grain crops. This transition was also fostered by farm policy. It caused profound changes in cropping patterns with a decrease in forages and hay legumes. The value of weed, insect and disease suppression from rotations was also diminished when chemical pesticides came into wider use during the 1950's and 1960's.

US corn yields increased dramatically after the 1940's because of improved technology from hybrids, weed, disease and insect control, expanded irrigation and N fertilizer (Kurtz, et al., 1984). The increased grain acreage increased total N used, but N rate per acre also increased, especially for corn. The US average N rate increased from 10 lb/A to 140 lb/A, corn yields increased from 40 bu/A to 120 bu/A and N removed in grain increased from 24 to 84 lb/a (Bock and Hergert, 1991). N applied exceeded N removed in corn grain in the mid 1950's. The impact of N fertilization to produce higher yields also produced higher residual nitrate levels in soils as noted by some early investigations (Herron, et al., 1968; White and Pesek, 1959).

Much of the additional grain production during the 1960's to 1980's can be attributed to fertilizer N, but it had an indirect 'cost' that would not be realized for many years. Most agricultural research during the 1950's and 1960's was directed toward the impact of agrichemicals (including N) on the crop with little thought to ecosystem effects.

This oversight was not malicious, but stemmed from the fact that the goal of higher food and fiber production was laudable and 'politically correct' for the time. The consequences of additional chemicals was not seen as a concern, however, the impact was an increase in potentially leachable N (Fried et al., 1976; Meisinger and Randall, 1991).

GROUND WATER NITRATE CONCERNS

In Nebraska, the primary ground water contaminant of concern is nitrate-nitrogen (Spalding and Exner, 1993). The University of Nebraska Cornhuskers come by their name legitimately. In Nebraska 70% of the 8.4 million acres under irrigation is in corn and 77% of the corn acreage is in continuous corn (ERS, 1993).

Interest in the nitrate content of groundwater had its inception with a well water survey conducted in 1962 in Nebraska (Univ. of Nebraska, 1962). In 1962 only 3% of 1,165 water samples had nitrate-N levels above the 10 ppm standard. In 1972, 547 of the original wells were sampled again. The average level of nitrate had increased by 29%.

The rapid expansion of irrigated acres, corn acreage, nitrogen fertilizer use, and livestock feeding in Nebraska has contributed to increases in nitrate-N in ground or surface water in addition to increasing urban population, shallow water tables, and higher percentage of coarse textured soils being irrigated. However, much of the impact has been from continuous irrigated corn production in river valleys and much of the increase occurred in eight counties in the central part of the Platte River system (Spalding and Exner, 1993). Upland soil sampling has shown that the vadose zone beneath irrigated corn production also contains high levels of nitrate (Watts et al., 1991). Past and current government policies have provided the economic incentive for farmers to produce continuous corn (Coady et al., 1992). Growing public awareness and concern about water quality issues may influence future government agricultural policy to encourage more farmers to adopt crop rotations. However, the rotations must still be profitable.

INSTITUTIONAL CHANGES

During the 1950's and 60's the primary attitude of Nebraska state government was that state control was preferable to local control. During the early 1970's, however, there was a shift in attitude that gave rise to legislation favoring local control. The perception was that Nebraska government and its agencies could provide over-sight but regulations and enforcement would be accepted more if they came from local input. In 1972 the Nebraska Legislature created 23 Natural Resource Districts (NRD) to monitor and regulate soil and water activities on a watershed basis that often included several counties. NRDs have taxation capabilities and are governed by a locally elected board of directors. State administration of NRDs is under the Nebraska Department of Environmental Quality (DEQ) which has oversight for natural resource problems. However, the development of plans, procedures, and monitoring reverts to local control by the NRD's. In 1981 DEQ developed a strategy for protecting groundwater quality in Nebraska.

The strategy was developed into a concept called Special Groundwater Quality Protection Areas (SPA) or Ground Water Management Areas (GWMA). Under this concept the local efforts of towns, counties or NRD's to protect groundwater was tied to state authority to regulate certain potential sources of contamination. In 1986 the Nebraska Legislature passed legislation creating SPAs and GWMAs. A GWMA can be created by a NRD for either water quality or quantity concerns. The plan is developed and implemented by the NRD. The DEQ reviews plans but has no control of the managment area. SPAs are requested by NRDs to DEQ or can be designated by DEQ if NRDs do not act on a problem. The NRD writes the action plan but DEQ has final approval.

The first control area was a GWMA created by the Central Platte Natural Resource District CPNRD in 1988. The first SPA was developed in Nuckolls county by the Little Blue and Lower Republican NRDs in 1991.

COOPERATIVE EXTENSION EDUCATION EFFORTS

During the 1950's one of the primary goals of the Cooperative Extension Service in Nebraska was to promote the new technologies of hybrid seed and fertilizer use and to discuss the benefits of irrigation. Many field demonstrations were conducted around the state to show farmers the benefits of these new technologies. Teaching the importance of fertilizer management and soil testing began in the 1960's. Irrigation management information was developed from research and presented at county meetings and an Irrigation Short Course.

During the 1960's input costs were low, newly developed land produced well and farmers prospered. It was not uncommon for many farmers to apply 250 to 300 lbs N/A since N cost only $0.04/lb. During the energy crisis of the 1970's farm prices declined and costs of fertilizers and herbicides increased. This also followed a period of rapidly expanding irrigation (primarily center pivots) outside of major river valleys in uplands. During the 1980's continued low commodity prices emphasized improved profitability by reducing input costs to maintain productivity and profitability. Fertilizer nitrogen rates during this period were actually lower than in the 1960's.

With the steady growth of irrigation and the profitability of corn, the acreage continued to grow, but there was a side effect--ground water nitrate levels were starting to increase in the central Platte valley which had been irrigated extensively for about 30 years. In 1979 the Hall County Water Quality Special Project was initiated in Nebraska's central Platte valley. The Hall County Project dealt with the nitrate problem through voluntary participation of area producers in programs designed to improve irrigation and nitrogen management. The project was one of several across the US selected to help meet national water quality goals set by the Federal Water Pollution Control Act (PL 92-500). The lead agency was the USDA Agricultural Stabilization and Conservation Service which provided cost-share funds to participants for specific management practices. Other agencies involved included the University of Nebraska, the Soil Conservation Service, and the Central Platte Natural Resource District (CPNRD) (Bockstadter, et al., 1984).

Educational efforts initiated by University of Nebraska Cooperative Extension specialists at that time stressed the importance of improved N management including setting proper yield goals, soil testing for nitrate, and accounting for nitrate in irrigation water. Improved irrigation techniques included irrigation scheduling and changing set sizes, set times, length of rows, and monitoring soil moisture. At the end of the project it was felt that producers gained confidence in irrigation scheduling and nitrogen management as they tended to include more acres in the project each year they were in it. Nitrogen management results showed that the recommended N rate was 79 lb N/a less over the 4 years of the project than the normal practice at that time. The irrigation management demonstrations showed that many farmers were over irrigating. Changing past irrigation habits was harder than changing N management practices.

EXTENSION INITIATIVE PROGRAMMING

In 1988 the national Cooperative Extension System (CES) created the Water Quality National Initiative (Weber, 1993). This was the beginning of 'core and 'initiative' programming in CES that is currently used. In 1989 the USDA was designated as the lead federal agency for addressing agricultural nonpoint source contaminants in the President's (Bush) National Water Quality Plan. A water quality program plan was developed and encompassed the CES Water Quality Initiative. The objectives for this National Initiative were to (1) prevent/reduce water degradation from plant nutrients, pesticides, and animal waste; (2) protect/improve the quality of private, domestic-use well water; and (3) protect/improve water quality through public issues education.

At the same time in Nebraska the CPNRD requested assistance from extension specialists to provide educational programs for their GWMA. Richard Ferguson and Dean Eisenhauer of the UNL South Central Research and Extension Center developed a slide-tape presentation on N and irrigation managment that they provided to the CPNRD to conduct this first training series.

Because of additional requests from county extension educators and a perceived state-wide educational need, a CES Priority Initiative on Enhancing Water Quality--Reducing Nitrates in Ground Water Team was created at the University of Nebraska--Lincoln (UNL) in 1988. The educational objectives of the initiative were to improve groundwater quality by reducing nitrogen losses from improved nitrogen and irrigation management. The team included members from the Department of Agronomy, the Department of Biological Systems Engineering, Agricultural Economics, the Conservation and Survey Division, and county Extension Educators.

Putting together specialists from this many disciplines was a challenge. Campus departments often feel 'ownership' of specific research and extension activities and since water quality concerns were a major part of most of the departments represented, agreeing to work together took time. There were historic 'turf battles' between the departments of Agronomy and Agricultural Engineering on nitrate leaching--was it a nitrogen managment problem (Agronomy) or an irrigation management (Agricultural Engineering) problem? Who were the experts, who would develop the program, who would get credit? Many of the team members were from Research and Extension centers off campus and had a history of working together (G.W. Hergert and D.G. Watts at North Platte; R.B. Ferguson and J.E. Cahoon at Clay Center; C.A. Shapiro and W. Kranz at Concord). Those relationships plus the effective leadership of R.A. Wiese helped create an environment of compromise. Early team meetings dealt with conflict resolution, but the goal of putting together an effective program for the producers of Nebraska was accomplished. Preliminary activities of the team centered on developing educational displays for county fairs, media releases, and NebGuides about best management practices.

In 1990 the team began developing an in-depth training program for farmers and Extension Educators on nitrogen and irrigation management. One of the target areas for the training was Merrick county which had a large acreage of furrow irrigated sandy soils in corn production in the central Platte valley (Bockstadter, et al., 1984). The pilot educational program stressed management principles and concepts. The program lasted 5 hours and was presented by 8 specialists. The program format was expanded and presented as a 2-day field/classroom workshop for county Extension Educators in June 1992.

The program was evaluated by the Nitrogen-Irrigation Management team during fall 1992. The consensus was to design a basic course that was shorter (3-4 hours), more interactive and would be more directly applicable to general production agriculture. A reference notebook was also developed by the team that was a compilation of new and existing materials organized into sections that followed the oral presentations. During this time, the CPNRD was implementing the mandatory educational portion of their GWMA plan which was required for all producers in high nitrate ground water areas (>12.5 ppm nitrate-N). The CPNRD asked CES personnel to deliver the educational program. Other SPAs were being created and were also requested programming or assistance in developing their own N and irrigation programming, so the program developed by the team was on target.

During fall 1992 the Nebraska SCS contacted a team member about developing 2 or 3 videos on irrigation management. Since this activity tied directly to efforts of the Nitrogen-Irrigation Initiative team, the team submitted a 319 grant through DEQ to EPA to begin the effort. The grant was received and 5 videos are currently being produced by the team.

A second component of the plan was conducting farmer field demonstrations. The goal was to show that using the University of Nebraska N recommendation algorithm, different application methods and timing, nitrification inhibitors (N-Serve) and improved irrigation water management could provide profits while reducing N losses to groundwater. As opposed to the Hall County

Project, there was no cost-share money to 'encourage' producers to follow guidelines. Their participation was purely voluntary.

An extensive program of N and irrigation demonstrations was initiated by the CPNRD in 1986 in cooperation with the UNL-SCREC. A major boost to the field demonstration effort was the selection of Nebraska as 1 of the first 8 National Water Quality Demonstration sites as part of the 1988 Presidential Water Quality Initiative. This project is called the Mid-Nebraska Water Quality Demonstration Project and had similar educational objectives to the CPNRD demonstrations and N-irrigation team. This project was designed for upland areas of central Nebraska, south of the Platte river with loess soils that overlie groundwater 50 to 150 feet deep. It was a cooperative effort of several NRDs, SCS, ASCS, Nebraska DEQ, USDA ARS, and the University of Nebraska. This project was designed to collect survey data on the impact of the demonstration on changes in producer practices after the demonstration was started.

ACCOMPLISHMENTS

The major impact of this program has been increased awareness and education of farmers, extension educators, agri-business, and the public about the importance of both nitrogen and irrigation as they affect groundwater quality in Nebraska. Nitrogen and irrigation demonstrations continue to influence farmer attitudes about the reliability of University of Nebraska N recommendations for corn and the effects of both nitrogen and irrigation on ground water nitrate. At least 425 cooperators who have participated in demonstrations the past 6 years.

An updated NebGuide on corn fertilization (Penas, et al., 1994) uses a new nitrogen recommendation algorithm which recommends less nitrogen than the past algorithm. Other sources of nitrogen from manure, legumes and irrigation water are also given credit to reduce N use (Ferguson, et al., 1994). Over 100 nitrogen-irrigation management clinics have been presented to address the educational needs of Extension Educators, Special Protection Areas and Groundwater Management Control Areas since 1991.

Improved nitrogen management using deep soil sampling for nitrate nitrogen and crediting nitrate in irrigation water is being used on at least 500,000 acres/year in the Central Platte NRD. Data from producers in the Central Platte NRD shows that the average amount of N applied is lower than past rates. More farmers are using split/delayed N applications or nitrification inhibitors. In 1993 about 40% of the N in the CPNRD Phase II and III areas was applied preplant with the remaining 60% applied sidedressed. Ground water nitrate levels continued to decline for the sixth year since the management area was initiated (18.63 ppm nitrate-N in 1989 to 17.4 ppm in 1993).

Another improvement has been the gradual but continuing acceptance of surge flow irrigation in the CPNRD. Since 1989 about 45,000 acres have been converted from convention furrow irrigation to surge irrigation in furrows. Surge irrigation helps farmers improve nitrogen use efficiency and decrease nitrate leaching.

Producer surveys in the Mid-Nebraska Water Quality Demonstration for 1994 were compared to the baseline survey in 1991. The results showed an 8% increase in deep soil sampling for nitrate, 6% more farmers using water meters, and 7% increase use of surge irrigation valves. A survey conducted at 15 field days had 393 responses. These surveys noted that 69% said their N and irrigation managment was influenced by the project. They reported reducing both N and irrigation applications.

An extensive field demonstration project on residual nitrate management is coordinated by UNL Cooperative Extension in partnership with the SCS and area NRDs (middle Niobrara, Upper Loup, Lower Loup, Upper Elkhorn, Lower Niobrara) in north central Nebraska. To date over 500 fields (average 40 acres) have been sampled for residual nitrate. University of Nebraska N recommendations based on residual nitrate would have applied 35 lb N/a less than using only yield goal on over half of these fields. A survey mailed to producers in the project indicated that 77% followed University guidelines.

The University of Nebraska Soil Testing Lab reported a 10% increase in the number of samples analyzed for nitrate-N during 1993-94. There was a large variation in nitrate levels depending on the part of the state due to excess precipitation in 1993. Results emphasize the importance of yearly nitrate sampling to improve N recommendations.

SUMMARY

Increased awareness through Cooperative Extension educational programming has improved management by convincing farmers to measure water that is applied to fields, take deep soil samples for residual nitrate then modify the rate of nitrogen applied and use improved timing or nitrification inhibitors in appropriate areas to improve fertilizer nitrogen use efficiency. Unfortunately education alone will not do the job, yet government regulations cannot stand alone. Mandatory education can help, but there is resistance to accepting management changes. The ultimate test may be economic. We may have gone as far as economics can help us considering cost savings on N fertilizer and irrigation costs from using less water versus the trade-offs in additional management costs. We may have taken care of the easy changes, and while Nebraska efforts has shown a decrease in nitrate, the levels are not yet near the 10 ppm drinking water standard in some areas. Some research suggests that it will be impossible to reach that standard with large acreages of continuous corn. The dilemma for public policy persists: can we accept something less than full compliance with the 10 ppm standard in some areas and allow farmers to stay on the land, or will we have to abandon agriculture in these areas in the name of water quality?

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A COMPARISON OF 279 PRAIRIES IN CENTRAL NEBRASKA

Harold Nagel, Charles Bicak, Linda Spessard-Schueth, Steven Rothenberger, Marvin Williams, Margaret Biddlecome, Jennifer Crawford, Joseph Osterhaus and Troy Walz, Biology Department, University of Nebraska at Kearney

ABSTRACT

A database was developed of native rangeland sites in the Central Platte Natural Resources District. The data collected also served as the basis for developing and testing rangeland health or condition indices.

Species composition was determined on 279 prairies/rangelands during 1993-94. Most of these were located in Buffalo and Dawson Counties, and approximately 90% were upland sites. An ecologically based approach was used in classifying vegetation on the sites, rather than a production approach since the objective was to provide information on biodiversity.

Reference site comparison and clustering methods were used to group, classify and determine the health of the sites. Reference sites were selected which had little or no history of over-utilization and included cemeteries, hay meadows, and lightly grazed pastures. Lowland (located in the Platte River flood plain) and upland reference sites differed very little. Analysis of upland reference sites indicated the potential vegetation was mostly big and little bluestem. Lowland sites were also dominated by big bluestem but had more Indiangrass and switchgrass than upland sites.

Smooth bromegrass and Kentucky bluegrass were prevalent on 40% of the sites. In comparison with the reference sites, most of the upland sites rated poor to fair, averaging only 32% condition. This contrasts with the traditional range condition (SCS) which averaged 54% or low good condition. Two other ecological health indices are presented. One is based upon two threshold vegetation conditions found in the prairie sites and the second one is a modification of the reference site method.

In addition to loss of the tallgrass component, most native rangelands surveyed also had lost much of the native forb component, especially legumes, when compared with the reference sites. Smooth bromegrass and Kentucky bluegrass are serious invaders into central Nebraska uplandprairie rangeland.

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In addition to loss of the tallgrass component, most native rangelands surveyed also had lost much of the native forb component, especially legumes, when compared with the reference sites. Smooth bromegrass and Kentucky bluegrass are serious invaders into central Nebraska uplandprairie rangeland.

INTRODUCTION

The two major objectives of this research were: 1.) to collect baseline data on prairies in the Central Platte Natural Resources District (CPNRD). These data can be used to establish trends in rangeland health through time, and 2.) to develop new methods for determining rangeland health or condition. New methodology is needed to replace the old range condition index, which was primarily developed and used by the Natural Resource Conservation Service (NRCS, previously SCS).

Few quantitative surveys have been published on Central Nebraska prairies. Weaver and Bruner (1954) did extensive floristic and community work in this area but did not identify the locations of prairies they sampled. Without that information, follow-up studies could not be done and rangeland trend couldn' t be documented.

The concept of range condition developed by Dyksterhuis (1949) and based on the concepts of Clements (1916) regarding succession of prairies to climax condition has been used for several decades by several federal agencies in managing private and public rangeland. This method of range condition (referred to as SCS method hereafter) was rejected recently for philosophical and practical reasons (Busby 1994, Joyce 1993). Friedel (1991) and Laycock (1991) have discussed the concept of thresholds in rangelands:

"The concept of thresholds of environmental change appears to provide a reasonable alternative in some circumstances to the concepts of gradual retrogression and secondary succession which are currently accepted. I suggest that environmental change can be discontinuous, with thresholds between alternative states. Once a threshold is crossed to a more degraded state, the former state cannot be attained without significant management effort, such as prescribed burning, ploughing, or herbicide application, rather than simple grazing control." (Friedel 1991).

Laycock (1991) stated: "In order to develop new concepts and models about range condition, we not only need to identify possible stable states, we also need to identify and understand the factors which can force a stable community across a threshold into a transitional phase moving toward another stable state."

An attempt was made to develop range condition methods and site classification procedures which took the concept of thresholds, transitional phases and stable states into consideration.

METHODS

Two hundred seventy nine prairie/rangeland stands were surveyed during August 199 and June and July of 1994. Most of the stands sampled (246) were upland sites, primarily on silty and limy upland range sites. A few sandy and thin loess sites were surveyed. Only 33 sites were from the wetland and subirrigated sites located in Platte River floodplain. More than 90% of the sites surveyed were located in Buffalo and Dawson Counties.

At each site sampled, owners were asked for permission to survey their land and for information about past land use, including past/present stocking rate. We did not survey without permission. This resulted in a patchy distribution of sites surveyed, because a number of owners did not respond. Before site analysis, we obtained data on soil series, range site, and legal description from county soil survey manuals (Brown et al., 1978 and Butler et al. 1974) At each site, we took a longitude-latitude reading, using a Magellen (Global Positioning System) location finder.

Field sampling was accomplished at each site by 2 or 3 trained botanists. Starting 10-30 m from the fence, a 10 minute walk was begun following an oval shaped path through all major range sites on the area. During this timed survey, all species found were either identified or collected for future identification. At the end of the 10 minute walk, the foliage present was estimated for each species as a percentage of the total foliage that would be present at peak growth season (July).

The contribution to total biomass of major species was estimated to the nearest 5 % . Minor species were rated with a 1 = single plant, 2=rare, but more than one plant, 3=common, and 4=abundant, but not making up 5% of total biomass. Ten minutes was not long enough to find all species on all sites but seemed to present a reasonable compromise between being all inclusive and expediting the field survey. Including the time spent to document biomass estimates, approximately 30 minutes per site plus travel time was required.

Range sites were not surveyed separately at a sample site. The aim was to obtain overall floristic composition at the sites. The silty, limy upland and overflow sites in the loess hills of Central Nebraska are relatively small and irregularly shaped, making differential management nearly impossible, and thus their separate analysis unimportant. Although the range sites were not sampled separately, the data was correlated with the SCS range condition. We calculated the range condition for the silty upland and limy upland based upon the overall species composition for the site (Silty overflow or silty lowland sites were found in drainages of the upland loess plains, but were relatively narrow in mostcases, so they were not included in the range condition calculation). The SCS range condition (Anonymous 1981) that were used in correlative analyses were obtained by averaging the silty upland and limy upland range conditions. Although this did not result in exact estimates of the SCS range condition, it was reasonably close, based upon five sites which were sampled by range site and then overall.

Data entered into microcomputer spreadsheets (Excel) were subjected to analysis. Percentage composition for each species was calculated at all sites (Figure 1). Twenty-two parameters were calculated for each site (including the 18 shown on Figure 2), based upon species composition.

Quantitative coefficients of similarity were calculated for each pair of samples (non-standardized) using NTSYS software and the Morisita II method (Horn 1966, Morisita 1959 and Rohlf 1993). Statistical analyses were done with ABstat software (Anonymous 1990). Cluster analyses were done on NTSYS software using SAHN (sequential, agglomerative, hierarchical and nested) clustering algorithm which corresponds to the program TAXON for mainframe computers. The clustering method used was UPGMA (unweighted, pair-group method with arithmetic average, Rohlf 1993).

RESULTS and DISCUSSION

Survey Results

From the 279 sites surveyed over the 2-year period, 213 species of plants were found. Figure 1 shows species composition comparisons for the lowland sites (Platte floodplain) vs. upland sites (loess hills, mostly north of the Platte River). The 246 upland sites are considered a representative sample of upland sites. The 33 lowland sites are not considered representative, since about half of them were wildlife preserves and nature sanctuaries.

Significant differences ($p<0.05$) were found between upland and lowland sites. Upland sites had more western wheatgrass (Agsm on figure 1 =Agropyron smithii), western ragweed (Amps=Ambrosia psilostachva), little bluestem (Ansc= Andropogon scoparius), buffalo grass (Buda=Buchloe dactyloides), sideoats grama (Bocu=Bouteloua curtipendula), blue grama (Bogr=Bouteloua gracilis) and Kentucky bluegrass (Popr=Poa pratensis). Species which were more abundant on upland, but not significantly so included: smooth bromegrass (Brin=Bromis inermis), Japanese bromegrass (Brja=Bromus japonicus!, and tall dropseed (Spas=Sporobolus asper).

Species which had greater ($p<0.05$) percentage composition on lowland sites included: redtop (Agst=Agrostis stolonifera), big bluestem(Ange=Andropogon gerardii), sedges (CARE=Carex spp.), Indiangrass (Sonu=Sorghastrum nutans) and prairie cordgrass (Sppe=Spartina pectinata).

Figure 2 compares lowland and upland prairies as to prairie characteristics that were calculated from the species composition data. Several of these comparisons, surprisingly, showed little difference. Lowland sites included 23 subirrigated areas and 10 wetland sites . The upland sites included mostly silty, limy upland, silty overflow, silty lowland areas, with a few thin loess and sandy range sites. Several significant differences were found between the upland (loess hills) and lowland sites (Platte River flood plain), including percentage tallgrass, with lowland having almost 3 times more. There were only minor differences in percent tallgrass between reference sites (Table 1).

Decreaser composition mirrored the tall grass component, since most of the decreaser species were tallgrasses. Upland sites had a greater percentage of increaser species biomass (as a replacement for the tallgrasses, primarily big bluestem). This may reflect the fact that the lowland sites included a higher percentage of prairie preserves, and were either not grazed or were lightly grazed. Although upland sites in excellent condition had as much tallgrass as lowlands, they are more fragile or sensitive to poor management practices, and recovered more slowly after conditions improve than did the subirrigated sites. Three of four (all but the SCS method) of rangeland health indices were significantly greater on lowland. Lowlands (wetland range sites) had more sedges than uplands, but were not significantly different. Other differences in Figure 2 were not statistically significant ($p=.05$).

Figures 3 to 10 present distribution histograms of several of the characteristics shown on Figures 1 and 2. The data were combined for all sites, but since the lowland sites made up such a small percentage, (12%) they primarily reflect conditions on upland prairies.

Figure 3 shows that 130 of the sites (total number of sites=279) had 0-5% big bluestem. Big bluestem had a mean of 11.8% species composition at all sites. This species was dominant in both lowland and upland mixed prairie sites, in pristine condition (See reference sites, Table 1) but had disappeared in most upland grazed prairies. Big bluestem is the first species to disappear under heavy or continuous grazing with fenced livestock. It returns quickly in Platte River lowland sites (Nagel 1982) but very slowly on upland sites (Nagel, Nicholson and Steuter 1994, and observations on local rangelands in CPNRD).

Figure 4 shows the distribution of smooth bromegrass in the prairie sites surveyed. About 75% of the sites had less than 6% smooth bromegrass. This species, where it has been seeded into ditches or waterways near rangeland invades very rapidly and may completelydominate the rangeland, with more than 65 % of the species biomass found on some sites contributed by smooth bromegrass.

Kentucky bluegrass, another serious exotic invader in CPNRD, is more widespread, as seen in

Figure 5. About 25% of the sites surveyed had less than 5% bluegrass, but 70% of the sites surveyed had from 5 to 40% composition of bluegrass. This low production grass is considered undesireable in CPNRD rangeland. Especially disconcerting was the fact that Kentucky bluegrass contributed more biomass than any other species of plant in CPNRD prairies, (Fig. 1) which is not a good indication for future productivity.

Figure 6 shows that about half of the prairies had less than 2% legume biomass present. Since nitrogen is the major limiting nutrient on plant production in native rangeland in Nebraska, and most ranchers/farmers do not fertilize rangeland, this lack of legumes is especially important. The original prairies contained greater amounts, if the reference sites are representative of original prairies (upland reference sites had a mean of 4.2% legumes, while lowlands averaged 7.7%). None of the correlations run between rangeland health indices and legume biomass was significant, however.

Total number of species found on a site produced a normally distributed curve seen in Figure 7. Most sites yielded at least 15 species during the 10 minute survey, and some had more than 50 species. The number of grass species were rather constant throughout the sites. Forb species varied widely from site to site, probably attributable to broadcast spraying of many sites for noxious weeds, mainly musk thistle, Carduus nutans L. Loss of forb diversity from many sites is a serious threat to biodiversity in this region of Nebraska.

SCS range condition also produced a normal curve (Figure 8). Most of the sites fell into the fair to good classification with an average of 54%.

METHODS USED TO DETERMINE RANGELAND HEALTH OR CONDITION

Reference Site Approach

Reference sites were identified to compare rangeland/prairie condition with sites where past management was unknown. Sites such as infrequently mowed cemeteries, nature sanctuaries, exceptionally wellmanaged rangelands, and hay meadows were identified (See Table 1 for the 5 lowland and 7 upland sites used as reference sites). An ecological index was used rather than a production based index (Wilson 1984), because our primary objective was to identify and evaluate stands of native rangeland for their biodiversity. We followed Wilson (1984), who recommended use of multiple reference stands since there was greatvariability in the potential vegetation at a site.

The composition of big bluestem varied from 35% to 80% among the 7 upland reference sites. Variation between lowland sites was of less magnitude. Potential reference sites were eliminated from consideration if they had significant amounts of exotic species biomass present. Cemeteries varied greatly in species composition on similar sites, perhaps due to different mowing practices.

Coefficients of similarity were compared between reference sites and sites where rangeland health was unknown. Average values were calculated for each site using all reference sites for the location. The coefficient of similarity was based upon the 9 dominant species of grass, and was calculated by the Morisita procedure in NTSYS program (Rohlf 1993). Coefficients of similarity range from 0 to 100%. In setting the dividing points between the reference classes, the traditional 4 class approach was used (where 0-25% = poor, 25-50 = fair, 50-75 =good and 75- 100 =

excellent condition). Figure 9 shows the results of this analysis . More than one-third of the sites rated in the lower half of the poor condition class. Sites dominated by the exotic species smooth bromegrass and Kentucky bluegrass scored almost no points when compared with the reference sites. This doesn't mean that this rangeland does not have any grazing value, but it has little value in conserving native species, or natural habitats.

The correlation coefficient between the SCS range condition and the reference site range condition was +0.48 (Table 2). The reference site approach rated rangeland much lower than the SCS method (means of 31 % vs 54%). The reason for this difference was that the SCS method gives partial or full credit for many of the species which replace the dominant species, big bluestem, on the upland site after a disturbance such as overgrazing, drought, etc. The reference site approach counts only what is found at the reference sites.

Maximum Reference Site Condition Method

This is a modification of the Reference Site method given above. The reference site index of rangeland health was determined by taking the average coefficient of similarity for all reference sites compared with the site being evaluated.

In the Maximum Reference Site version, the highest coefficient of similarity scored with a n v of the reference sites was used as the index of health. The point has been made that there is no single "best" combination of plant species on a site. Each site will vary somewhat due to soil, fire, grazing, precipitation and other factors historically affecting succession on that site (Risser 1989). This method, if an adequate number of referencesites are chosen, should allow for site variation in the successional process. The results of this index are shown in Figure 10. Range condition scores calculated by this procedure produced a bi-modal histogram with our sites, reaching peaks at 6% (very poor condition) and 94%(high excellent). These are realistic peaks in that most of the prairie sites were either badly degraded and invaded by exotics (including those classified from 0-25% condition, which made up 47% of all sites) or in excellent condition (those rating 75-94%).

Thresholds and the Decreaser-Invader Range Condition Method

The results obtained from the reference site comparison method depended heavily upon which reference sites were found or selected. By looking at such a large number of sites some excellent condition upland sites were found. Table 1 shows the extent of the tallgrass present at these sites.

A criticism of the reference site method is that it reveals nothing about thresholds present in the rangeland. There seemed to be two thresholds in Central Nebraska upland prairies. The first one which can be identified is when the dominant species are first replaced by increaser species, due to some disturbance. Sideoats grama, buffalo grass, blue grama, western wheatgrass, tall dropseed, and many others replace the originally dominant decreaser species big bluestem and little bluestem.

A second threshold was found when the native vegetation was disturbed to the point where it was replaced by bluegrass, bromegrass and other invaders. Species classified as decreasers (Anonymous 1968) are species occupying the stable environment at the left of the first threshold (Fig. 11). Increaser species lie in the center of the 2 thresholds. Invader species lie to the right of the second threshold.

To use this concept in formulating an index of rangeland health the invader species composition was subtracted from the decreaser composition at a site, then corrected the data so + 100 (all decreaser biomass at the site) was top of the excellent range condition class, and 100 (all invaders) was equal to zero. If there are all increaser species at a site, it will rank 50% or low good to high fair. Likewise, if a site has half decreasers and half invaders, it also ranks 50%. This index still rated the brome and bluegrass dominated sites very low (mostly poor and low fair), but rated the sites which still have a stand of native increasers more fairly than the reference site approach This index rated between the reference site method and the SCS method (Fig.12 vs 8 and 9).

If there are 2 thresholds and 3 stable assemblages it would be logical to use only 3 condition classes, 0-33%=low, 33-67=moderate, and 67- 100%=high range condition. Regardless of the number of classes used,all four indexes of rangeland health are significantly positively correlated (Table 2), probably because they are all ecologically based, not productivity based indexes.

Cluster Analysis

Figure 13 shows a cluster diagram of the 279 sites, and Table 3 gives characteristics of each of 7 main clusters identified as being important. This cluster is based upon a Morisita coefficient of similarity calculated from data for the 9 dominant grass species over all the sites. These species included: big bluestem, little bluestem, side-oats grama, blue grama, buffalo grass, tall dropseed, western wheatgrass, smooth bromegrass and Kentucky bluegrass. Uresk (1990) worked in South Dakota mixed prairie and found the dominant grass species gave the best clustering. After trying many data sets (from factors shown in Fig. 2), we also found this to be true.

The sites were clustered from left to right in Figure 13, with sites separating at the right side being very close to identical species composition (high coefficient of similarity or low coefficient of dissimilarity). Starting at the left bottom (righthand graph in Fig. 13), the first separation is at about 20% similarity when the sites dominated by buffalo grass separate from all other sites. Buffalo grass forms almost pure stands on hilltops under heavy continuous grazing . Next, at about 25%, smooth bromegrass dominated sites are separated from all remaining sites. Smooth bromegrass is extremely competitive and forms almost pure stands, even in native sod, under some conditions. This exotic grass, introduced for soil erosion control, is a severe threat to the continued existence of native prairie plants in central Nebraska.

The next separation comes at 30% similarity where big bluestem and sideoats grama sites separate out. Big bluestem forms the excellent sites, whereas sideoats grama tends to replace bluestem under moderate to heavy grazing. At 35%, sideoats is separated from big bluestem sites. At 38%, little bluestem sites are separated from western wheatgrass and bluegrass sites. Little bluestem is found on upland sites which are somewhat drier than where big bluestem grows (Stubbendieck, Nichols and Roberts 1986) under light to moderate grazing. Finally, at 50% similarity, western wheatgrass sites are separated from Kentucky bluegrass sites. These two species are both cool season grasses, preferring cool moist sites, although growing throughout the prairies in Central Nebraska. A small cluster dominated by tall dropseed is present, but does not separate out from the bromegrass sites until 75% similarity.

When separated at 45% coefficient of similarity, the sites form 7 distinct clusters. To the right of each cluster in Figure 13 is listed thedominant species in that cluster. Cluster 1 contained all the sites dominated by big bluestem (N=61) . All of the reference sites for both upland and lowland were located here. The mean condition (reference site method) averaged 82 percent (S.E. = 1.72) in this cluster. The second group or cluster is the sideoats grama dominated sites, averaging 34% condition (N=13). Group 3 included the sites dominated by little bluestem, a codominant on mixed prairie upland sites. Reference site condition was 32% (N = 44, S.E. = 2.24) in this cluster. Group 4 was dominated by western wheatgrass, an increaser especially abundant on lowland sites. Group 5 was the Kentucky bluegrass dominated sites with a variety of subdominants, including western wheatgrass, tall dropseed, and others. This group had 68 sites and averaged only 13% condition (S.E. = 1.70). Group 6 was the smooth bromegrass dominated sites, with much bluegrass present. This cluster had 55 sites with a mean condition of only 11% (S.E. = 2.00. Cluster 7 sites were dominated by buffalo grass (N=15) and had a condition of 8% (S.E. = 3.3). Three other clusters could have been recognized, but represented such a small number of sites that they were merged into adj acent clusters.

A 25% similarity separation yields only 2 major clusters plus buffalograss. This is a useful splitting of the sites because it identifies the 2 stands on either side of a single threshold, another potential model for Central Nebraska prairie. It divides the sites into good-excellent (dominated by big bluestem), and all the rest, mostly bluegrass and bromegrass dominated sites.

Use of Cluster Analysis as Replacement for Rangeland Health Indices

The rangeland health indices discussed above correlate well with the cluster analysis results. Since there is no obvious "best" index at this time, all four indices were summed for each site. These scores were sorted in descending order, and the site sequence compared with the sequence found in the cluster analysis (Fig. 13).

Of the top 50 sites for total rangeland health score, all but four were located in cluster 1, the best cluster from the ecological condition viewpoint (as determined by the reference site comparison). The four exceptions came from cluster 2 (sideoats grama) and cluster 3 (little bluestem), the next best clusters, ecologically speaking.

Of the bottom 30 sites for rangeland health score, 4 were from cluster 7 (buffalograss), 24 were from cluster 6 (smooth bromegrass) and the remaining 2 were from cluster 5 (Kentucky bluegrass). These 3 clusters represent the "worst" rangeland health when compared to the threshold model, Fig. 12, or the reference sites.

The degree of relationship between the indices and the cluster is sogood that perhaps only the cluster analysis is needed to evaluate rangeland health from an ecological perspective. Decisions about the level of similarity at which to break the tree into clusters is similar to the decision about where to break the classes in rangeland health indices. With rangeland health indices, historically the 25% X 4 categories has been used, but no standardized statistical procedure exists to establish this division.

With cluster analysis, however, there are several ways to determine which level of clusters are likely to be statistically important (although not strictly significant, Uresk 1990, Rohlf 1993, several textbooks on multivariate statistics). Cophenetic correlation (use of a cophenetic matrix compared with the original data matrix using the MSCOMP (Rohlf 1993) matrix comparison showed a very good fit.

Causes for Patterns of Vegetative Composition Observed

Evidence to explain vegetative changes outlined in the previous paragraphs has not been easy to find. It is overly simplistic to blame overstocking or lack of rotation grazing for the degradation seen on many of the sites. Some sites in the CPNRD have had excellent management (or in some cases, just rested, i.e., no management) and have degraded as rapidly or even more rapidly than overgrazed pastures. In fact, heavy grazing in some cases causes the intermediate stage (increaser dominated) to persist against invasion by the exotic species.

As part of the landowner questionnaire, 64 landowners provided their stocking rates, expressed as acres per animal unit. Correlation of these rates with range condition (SCS method) and reference site method yielded an r of +0.40, and +0.25, respectively. At best, this explains 16% of the variation in range condition or as little as 6% in the reference site approach. Stocking rates reported ranged from 2.5 acres per animal unit to 10 acres.

Landowners reported that 31 % of the rangeland had at one time been partially or wholly in cultivation.. The possibility that as much as one-third of the area surveyed may have been cultivated at some time in the past is another possible explanation for the vegetation patterns.

Sample sites were plotted on a map of the CPNRD, which was prepared in 1974 from aerial infrared photography (Seevers 1978). Included in mapping units were rangeland (native vegetation) and pasture (plants or lands which are intensively managed, presumably non-native), cropland, etc.

Ground truthing in 1993 of about 30 each of these range and pasture sites shown on the map showed that almost all of the rangeland areas were native vegetation. The pasture sites were quite diverse,ranging from alfalfa to some native rangeland vegetation. Presumably, in 1974 at least, the native vegetation sites labeled as pasture sites on the map were badly overgrazed.

Forty-five of the sites were on the areas marked as pasture in 1974 while the rest were classed as rangeland. These 45 sites were compared with 45 adjacent upland sites and these differences were found (Table 4). Tallgrasses and decreasers were more plentiful on the rangeland sites while annual plant biomass, forb biomass (especially weedy species) and invader biomass was greater on pasture sites. Condition of the vegetation, as measured by the reference site and decreaser-invader approaches both showed significant reductions on the more disturbed pasture sites

CONCLUSIONS

Two hundred seventy nine upland and lowland rangeland or prairie sites in the Central Platte Natural Resources District were surveyed over a two-year period.

Five reference sites for lowland and 7 for upland sites were selected, based upon past land use. Sites with a history of light grazing pressure, haying, or no use, such as sanctuaries and cemeteries, were chosen as reference sites in that they were representative of the potential vegetation on that site.

The most surprising conclusion was that upland and lowland reference prairies differed very little when comparing dominant plant species. Big bluestem was the dominant plant at both site locations. Other species of indicators differed between the two sites, but in the cluster analysis, the reference sites for both upland and lowland came out in the same cluster.

Rangeland condition or health, as determined by comparing the sites with the reference sites averaged only low fair condition (32%), and more than half of the sites rated poor. With a modification of this method, where the highest coefficient of similarity with any of the reference sites was used as the index, sites averaged 43%. With a condition index based upon species rating as decreaser and invader, the index of condition averaged 45%. This index was based upon perceived thresholds in the vegetative succession. With the SCS range condition method, the same sites averaged good (54%). It was important to identify multiple reference sites to get a representative sample. The 7 upland reference sites ranged from 35% big bluestem to 80%, demonstrating great variation.

Reference site comparison by Morisita coefficient of similarity worked very well to determine rangeland ecological health. The cluster analysis proved to be a useful parallel analytical procedure, especially good for identifying threshold conditions between sites and also indetermining species affiliations. At a 25% coefficient of similarity separation, cluster analysis produced a site distribution demonstrating 2 threshold conditions for the upland sites. These thresholds are: 1. Transition from the potential vegetation dominated by big bluestem to species more resistant to grazing, such as the gramas, wheatgrass and buffalo grass, and 2. With further stress due to overgrazing or drought or both, the invasion of exotic grasses, such as Kentucky bluegrass and smooth bromegrass. These 2 species were the dominant species on about half of the sites surveyed.

Once the prairie has moved past either of the thresholds, it is difficult for the successional process to move back to the previous state. Unfortunately, our understanding of how the multiple factors affecting vegetative composition on an area through time operate is not adequate to understand how these thresholds work. In some cases, the composition of an area moves directly from bluestem to invader-dominated composition, passing 2 thresholds at once. Much needs to be learned about the interspecies dynamics on Central Nebraska prairies before we can predict such changes accurately.

Overgrazing (too high stocking rate, coupled with continuous grazing) has been stated to be the major disturbance causing the vegetation to pass over these thresholds. Based on landowner-provided stocking rates from about one fourth of the sites surveyed, overgrazing accounts for little of the effect. Another factor is if the land was plowed at some time in the past. Indirect analysis of this factor showed several significant responses by the vegetation, especially greatly reduced reference site rangeland health.

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GROWTH RESPONSES OF EMERGENT WETLAND PLANTS TO AGRICHEMICAL CONTAMINATION

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INTRODUCTION

Nonpoint source pollution is the major cause of impairment of U.S. surface waters (Baker 1992). It is well known that pesticides, often an important component of NPS, can have a significant and complex impact on the structure and function of non-target food webs and on entire ecosystems (Coman and Dordea 1990). Herbicides also can percolate into subsurface flow and be carried long distances in overland flow (Wu *et al.* 1983).

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), used primarily for pre- and post-emergence control of germinating weeds in corn (Hartley and Kidd 1983), is the most commonly applied herbicide in the U.S. It acts as a powerful photosynthetic inhibitor, interrupting the light-driven flow of electrons (Esser *et al.* 1988). In studies done in the northeast U.S., Wu *et al.* (1983) found that even in areas where alachlor was applied in greater quantities, atrazine was still detected in runoff waters more frequently and in greater concentration. Atrazine concentrations of 13.9 g L^{-1} can negatively affect stream drift populations of both phytoplankton and zooplankton (Lakshminarayana *et al.* 1992). Atrazine (20 $gL^{-1)}$ also affects nonpredatory aquatic insects in artificial pond systems, primarily through indirect effects, i.e. by reduction in food for nonpredators and reduction in habitat because of decreases in periphyton and macrophytes (Dewey 1986). Atrazine has also been shown to inhibit photosynthetic rate and plant development of aquatic macrophytes (Forney and Davis 1981, Jones and Winchell 1984, Jones *et al.* 1986, Christopher and Bird 1992). Communities with submerged macrophytes may experience changes in competitive interactions in response to atrazine contamination (Cunningham *et al.* 1984).

Wetlands are highly dynamic communities located at the interface between terrestrial and aquatic systems (Guntenspergen and Stearns 1985). On a global scale, wetlands are only one-percent or less of the biosphere, yet they serve important functions in water quality enhancement (Richardson *et al.* 1978, Tiner 1991) . However, species composition and primary productivity can be altered by agrichemical contamination. Wetlands exposed to pollutants behave similarly to terrestrial and other aquatic systems, e.g. species abundance and diversity can change temporarily, habitat quality at the landscape scale can deteriorate, and energy transmission through food networks can be altered (Catallo 1993).

Wetlands perform various functions such as transforming, filtering, and storing various nutrients and pesticides (Landers and Knuth 1991, Hook 1993). They receive runoff waters and are recharged through groundwater, both of which have been found to be contaminated by herbicides (Pionke *et al.* 1988, Exner and Spalding 1990, Baker 1992). The greatest quantity of local pesticide inputs to wetlands is probably from runoff during rain events (Clark *et al.* 1993). High concentrations of pesticides in wetlands can result because dilution may be minimized due to the proximity of sources, and degradation may be minimized by the short time between application and transport to the wetland. The greatest potential for pesticide inputs to wetland habitats is at the time of application or immediately afterward, before the material has been incorporated into the soil or is degraded (Clark *et al.* 1993). In stream water samples collected during post-planting storm events, Langan *et al.* (1993) found atrazine in concentrations as high as 691 gL^{-1}, along with 635 gL^{-1} alachlor, 117 gL^{-1} cyanazine, and six other herbicides.

It has been proposed that discharging agricultural runoff into wetlands parallel to stream channels may be a method of reducing NPS herbicides and nutrients entering streams via runoff from tile drains (Osborne and Kovacic 1993). High productivity by emergent vegetation, due to highly efficient leaf display and effective resource allocation in extensive carbohydrate stores in the rhizomes (Boston *et al.* 1989), should further enhance their ability to treat runoff water. Wetlands have been shown to be effective in decreasing nutrient loads in wastewater (Barten 1983). Emergents reduce the flow of sediment in runoff and exchange nutrients with associated ecosystems (Catallo 1993), and keep sediment from resuspending (Dieter 1990).

The purpose of this study was to assess the ability of two wetland macrophytes, *Scirpus* ref. *acutus* Muhl. and *Typha* ref. *latifolia* L., to tolerate atrazine contamination. Experimental microcosm bioassays were conducted to determine the direct effect of atrazine on these common wetland plant representatives, by assessing its impact on plant growth.

GROWTH RESPONSES OF EMERGENT WETLAND PLANTS TO AGRICHEMICAL CONTAMINATION

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Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), used primarily for pre- and post-emergence control of germinating weeds in corn (Hartley and Kidd 1983), is the most commonly applied herbicide in the U.S. It acts as a powerful photosynthetic inhibitor, interrupting the light-driven flow of electrons (Esser *et al.* 1988). In studies done in the northeast U.S., Wu *et al.* (1983) found that even in areas where alachlor was applied in greater quantities, atrazine was still detected in runoff waters more frequently and in greater concentration. Atrazine concentrations of 13.9 g L^{-1} can negatively affect stream drift populations of both phytoplankton and zooplankton (Lakshminarayana *et al.* 1992). Atrazine (20 $gL^{-1)}$ also affects nonpredatory aquatic insects in artificial pond systems, primarily through indirect effects, i.e. by reduction in food for nonpredators and reduction in habitat because of decreases in periphyton and macrophytes (Dewey 1986). Atrazine has also been shown to inhibit photosynthetic rate and plant development of aquatic macrophytes (Forney and Davis 1981, Jones and Winchell 1984, Jones *et al.* 1986, Christopher and Bird 1992). Communities with submerged macrophytes may experience changes in competitive interactions in response to atrazine contamination (Cunningham *et al.* 1984).

Wetlands are highly dynamic communities located at the interface between terrestrial and aquatic systems (Guntenspergen and Stearns 1985). On a global scale, wetlands are only one-percent or less of the biosphere, yet they serve important functions in water quality enhancement (Richardson *et al.* 1978, Tiner 1991) . However, species composition and primary productivity can be altered by agrichemical contamination. Wetlands exposed to pollutants behave similarly to terrestrial and other aquatic systems, e.g. species abundance and diversity can change temporarily, habitat quality at the landscape scale can deteriorate, and energy transmission through food networks can be altered (Catallo 1993).

Wetlands perform various functions such as transforming, filtering, and storing various nutrients and pesticides (Landers and Knuth 1991, Hook 1993). They receive runoff waters and are recharged through groundwater, both of which have been found to be contaminated by herbicides (Pionke *et al.* 1988, Exner and Spalding 1990, Baker 1992). The greatest quantity of local pesticide inputs to wetlands is probably from runoff during rain events (Clark *et al.* 1993). High concentrations of pesticides in wetlands can result because dilution may be minimized due to the proximity of sources, and degradation may be minimized by the short time between application and transport to the wetland. The greatest potential for pesticide inputs to wetland habitats is at the time of application or immediately afterward, before the material has been incorporated into the soil or is degraded (Clark *et al.* 1993). In stream water samples collected during post-planting storm events, Langan *et al.* (1993) found atrazine in concentrations as high as 691 gL^{-1}, along with 635 gL^{-1} alachlor, 117 gL^{-1} cyanazine, and six other herbicides.

It has been proposed that discharging agricultural runoff into wetlands parallel to stream channels may be a method of reducing NPS herbicides and nutrients entering streams via runoff from tile drains (Osborne and Kovacic 1993). High productivity by emergent vegetation, due to highly efficient leaf display and effective resource allocation in extensive carbohydrate stores in the rhizomes (Boston *et al.* 1989), should further enhance their ability to treat runoff water. Wetlands have been shown to be effective in decreasing nutrient loads in wastewater (Barten 1983). Emergents reduce the flow of sediment in runoff and exchange nutrients with associated ecosystems (Catallo 1993), and keep sediment from resuspending (Dieter 1990).

The purpose of this study was to assess the ability of two wetland macrophytes, *Scirpus* ref. *acutus* Muhl. and *Typha* ref. *latifolia* L., to tolerate atrazine contamination. Experimental microcosm bioassays were conducted to determine the direct effect of atrazine on these common wetland plant representatives, by assessing its impact on plant growth.

MATERIALS AND METHODS

Typha latifolia (broad-leaved cattail) and *S. acutus* (hardstem bulrush) were used as representative wetland species. Rhizomes were obtained from Wildlife Nurseries Inc. (Oshkosh, WI). One rhizome and approximately 257 g of dry soil were placed in each 9x8-cm pot, and four pots were put into one plastic 12-L tub (Tucker, Arlington, TX). Distilled water contaminated with the appropriate level of atrazine was added to the tubs to keep the water level approximately 1 cm above the soil surface. Water levels were maintained throughout the experiment by adding distilled water. The combined measurements of four plants in one tub were considered one experimental unit.

Commercially available atrazine (Aatrex®, Ciba-Geigy Corp., Greensboro, NC) was used to establish a concentration gradient. The pesticide was added directly to water used to fill the experimental microcosms. No atrazine was added to the soil prior to the experiment. A randomized complete block design was used because of an east to west temperature and light gradient in the greenhouse. Thus, the experiment consisted of six blocks, two species, and seven treatments: a control with no atrazine added, a gradient of nominal atrazine concentrations including 10, 50, 100, 500, and 1500 gL^{-1}, and a treatment with a nominal atrazine concentration of 500 gL^{-1}, in which the contaminated water was replaced with distilled water after two weeks to simulate a wetland dilution event. At 16 wk, the atrazine levels in both a 50 and 500 g L^{-1} bioassay were found to be 1.27 and 1.55 g L^{-1}, respectively.

Metalarc lamps (400 W) were used to minimize light intensity differences among the blocks and to maximize the amount of incident irradiance. Light, measured with a quantum irradiance meter and sensor (Li-Cor, Model LI-185A), ranged between 75 and 100 mol·m^{-2}s^{-1} without sunlight. Lamps were kept on a 12:12 light:dark cycle and the temperature was maintained at 70 C.

The height of *S. acutus* and the combined length of all leaves of *T. latifolia* was measured at biweekly intervals during a sixteen week period. Means comparisons were made on the contaminated treatments and the control using the least significant difference procedure. Growth curves were compared using an ANOVA with repeated measures. Comparisons between the control, the 500 gL^{-1} treatment, and the decontaminated 500 gL^{-1} treatment were made using a repeated measures ANOVA with orthogonal contrasts on the same measurements.

RESULTS

Scirpus ref. *acutus*

Plant height was negatively affected by atrazine concentrations of 500-1500 g L^{-1} (p=0.0001) (Fig. 1). Plant growth in the 0, 10, 50, and 100 g L^{-1} treatments did not differ significantly, but were significantly different from the 500 and 1500 g L^{-1} levels during the entire 16-wk experiment (Table 1), despite the low parent compound concentration found in the 500 g L^{-1} treatment at 16 wk.

Scirpus acutus was able to recover after short-term exposure to the herbicide, as its linear growth response was not significantly different between the control and the decontaminated treatments (p=0.9070) (Fig. 2). Linear growth of the plants was significantly inhibited for the contaminated treatment (p=0.0003). Growth in both the contaminated and decontaminated treatments was inhibited at 2 wk (p=0.0007, p=0.0022, respectively). Plant growth began to increase in the decontaminated treatment, becoming significantly greater than the contaminated treatment at 10 wk (p=0.0398). Differences in growth between the control and the decontaminated treatments were no longer evident by 16 wk. (Fig. 2).

Typha ref. *latifolia*

Typha latifolia was also affected by high levels of atrazine (p=0.0001) (Fig. 3; Table 1). No strong differences in plant growth were apparent during the first 4 wk of the experiment. However, from 6 wk to 12 wk, the 1500 g L^{-1} treatment had a significant negative effect on growth. At 14 and 16 wk, the 1500 g L^{-1} level remained significantly inhibited. (Fig. 3; Table 1). Plant growth in the contaminated treatment was significantly inhibited at 8 and 10 wk, (p=0.0272, p=0.0426, respectively), but no other effects on total height were found (Fig. 4).

DISCUSSION

Scirpus acutus and *T. latifolia* grew at low levels of atrazine exposure. Growth of *S. acutus* was slower, reaching its greatest height at 12 wk, while *T. latifolia* reached full height at 8 wk. *Typha latifolia* has a much larger rhizome, allowing it to grow more quickly from nutrient stores. When nutrient stores were exhausted, plant growth declined for all concentrations, including the control. Plant growth was inhibited at some atrazine concentrations, but *S. acutus* was not completely prevented from growing except at 500 and 1500 g L^{-1}, and *T. latifolia* at 1500 g L^{-1}. Phytotoxic effects may be greater in greenhouse studies than in the field studies because controlled conditions may make growth more rapid; with moisture conditions closer to optimum and all of the roots in treated soil, the risk from herbicide residues may be exaggerated (Riley and Eagle 1990). Though not statistically significant, a trend towards slightly enhanced growth at the 10 g L^{-1} concentration was seen for both species. This may be a result of plant hormone metabolism being influenced by the triazine herbicides (Esser *et al.* 1988).

Large watersheds with heterogeneous land use have much lower herbicide levels in runoff than those reported for ditches or crop field plots (Wu *et al.* 1983). If wetlands near agrichemical application sites, whether natural or constructed, were receiving atrazine contaminated runoff at concentrations of 500 g L^{-1} or above, it is clear that negative effects at this level are direct and the species assayed in this study would not survive. Consequently, atrazine at these levels would require prior dilution. As this study demonstrates, wetland macrophytes do not tolerate herbicide contamination equally, thus species composition is an important consideration in wetland design for treatment of highly contaminated runoff.

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Table 1. Summary of least significant differences for mean total height of *Scirpus* ref. *acutus* and *Typha* ref. *latifolia*. Means are listed in descending order; means for underlined treatments do not significantly differ. Atrazine concentrations in g L^{-1}. ($p<0.05$).

Species	Least Significant Differences
S. ref. *acutus*	10 100 0 50 500 1500
T. ref. *latifolia*	10 0 50 500 100 150

FATE OF WETLANDS ASSOCIATED WITH THE CENTRAL NEBRASKA IRRIGATION CANAL SYSTEM

Jason D. Ekstein and Scott E. Hygnstrom, Department of Forestry, Fisheries and Wildlife; University of Nebraska; Lincoln, NE 68583

The Rainwater Basin, located in Southcentral Nebraska, provides 1,092,000 ha of wildlife habitat and immeasurable water quality benefits with its numerous wetland depressions and interspersed agricultural land. In spring, 90% of the mid-continental population of white-fronted geese (*Anser albifrons*), 50% of the breeding mallards (*Anas platyrhyncos*), and 30% of the breeding pintails (*Anas acuta*) use depressions in the Rainwater Basin for staging and foraging before final flight to breeding grounds in the United States and Canada (Gersib et al. 1990). In the early 1900s, landowners started converting wetlands into additional cropland acreage, with support from state and federal agencies. Draining and filling progressed slowly during the 1920s and 1930s because of a poor economy and lack of efficient equipment. In the 1940s, efforts to convert wetlands into cropland intensified because of a prosperous post war economy and advances in earth moving equipment and farm machinery (Gersib et al. 1992). By 1965, 82% of the 3,907 major wetlands had been eliminated and nearly 65% of the 94,695 wetland acres in the Rainwater Basin were gone (NGPC 1984). By the early 1980s, an estimated 90% of the original wetlands in the Rainwater Basin of Nebraska had been destroyed or altered by draining, filling or ditching (Gersib et al. 1992).

With the demonstrated need for a stable water source to supplement rainfall for agricultural development (Smith 1924), the CNPPID initiated development of a canal system in 1936 to provide water for irrigation of farmland in Gosper, Phelps and Kearney counties of southcentral Nebraska. Water is stored in Lake McConaughy near Ogallala, Nebraska and then released where it is diverted from the Platte River at North Platte, Nebraska to the tri-county area (Fig. 1). The canal structure consists of an unlined furrow dug into the ground and built up along the sides with soil. The canal runs 85 km and ranges from 1 to 12 m wide and 1 to 5 m deep with a maximum capacity of 39 m^3/sec. Lateral lines connect at various points along the canal to transport water to adjacent cropland.

Since completion of the canal system in 1941 and the subsequent widespread use of surface irrigation, the groundwater table in Gosper, Phelps and Kearney counties has increased 3 to 34 m (Steele and Wigley 1991). A result from the increased groundwater table has been the seepage into depressions and formation of permanent and semipermanent wetlands. Area residents have reported the formation of wetlands where they had not previously occurred within the past 50 years (Soil Conservation Service (SCS), Natural Resources District (NRD), Extension Service; unpublished data). In some cases this led to a loss of cropland acreage which then led to legal action, making the canal system a controversial issue in Nebraska.

Much speculation has surfaced regarding the impact the canal system has on associated wetlands. Our objective was to describe the occurrence and fate of wetlands associated with this canal system in Southcental Nebraska from 1938 to the present.

We would like to acknowledge the US Fish and Wildlife Service (USFWS) for providing support for this study from the Biodiversity Fund, secured by Nebraska Senator J. R. Kerrey.

We would also like to thank Jon Kauffeld, Jay Maher and Mark Peyton for helpful comments on the manuscript and the local SCS offices, NRD, CNPPID and USFWS for supplying aerial photos and assistance.

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STUDY AREA

The study area is located in Southcentral Nebraska in the area known as the Rainwater Basin. The study area is bounded by section lines to include 559 sections (143,104 ha) that are 9.66 km north and south of the Phelps county irrigation canal. This area encompasses all lateral lines and any hydrolic effects of the canal. The area was topographically described by Condra (1939) as a Loess Plains Region. The landscape is characterized by surface depressions and gently rolling upland plains. Average rainfall is 62 cm with the majority occurring during June, July and August. About 80% of the land is cultivated, with the major crops being corn, wheat, and sorghum (Soil Conservation Service 1973). Holdrege silt loam is the dominant upland soil type with Massie, Scott, Fillmore and Butler soils characterizing the depressional areas. Depressional soils are formed by clay particles that move downward in the soil profile to form clay pans. Depressions receive water from rainfall, snowmelt, and irrigation runoff. Semipermanently flooded wetlands characterize the deepest depressions (1 - 2 m) offering the most permanent water regime. Seasonally flooded wetlands occupy the slightly shallower areas (0.5 - 1 m) and usually hold water for 3 to 5 months. Temporarily flooded wetlands occupy the most shallow depressions and usually hold water for up to 2 months. The wetlands range in size from 0.1 to 400 ha with 98% under 4 ha.

METHODS

The only available aerial photos of the study area were taken in 1938, 1941, 1956, 1963, 1969, 1978 and 1981. Photos from 1941, 1956, 1963, 1969 (8 in:1 mi, Department of Defense and SCS) and the 1981 National Wetlands Inventory Maps (USFWS) provided the best resolution and were therefore used for the area analysis. We viewed the series of aerial photos of Gosper, Phelps and Kearney counties by section to identify wetlands and compare the fate of wetlands from year to year. We differentiated wetlands from other habitat types by the presence of water and hydrophilic vegetation types and counted the number of wetlands in each section. We estimated the size of the wetlands to the nearest hectare by comparing them to visible agricultural land-use patterns of a known size. Our null hypothesis was that the number and total area of wetlands remained the same across the years. We used a chi-squared goodness of fit test of means to compare number and area of wetlands. To test the accuracy of our counts and measurements, we compared estimates from 4 in:1 mi photos to estimates from 8 in:1 mi photos that had twice the inherent resolution. Accuracy of wetland counts was 96%. Accuracy of wetland measurements was 92%.

To determine the immediate effect of the canal and associated increasing groundwater levels on the number and area of wetlands, we counted and estimated the area of wetlands within increasing groundwater table contours (Fig. 2, US Geological Survey, 1990) and divided the measurements by the proportional area of each contour. Our null hypothesis was that the number and area of wetlands remained the same across years among the four groundwater change contours. To reduce some environmental variability, we did not include data from the 1956 aerial photos because of dramatically reduced wetland area due to annual precipitation that was only 28 cm that year, compared to a mean annual precipitation level of 62 cm. We used a chi-squared goodness of fit test of means to compare the number and area of wetlands in the contours.

We randomly selected 15 four-section sample areas from the 559-section study area to monitor the fate of specific wetland types during 1938, 1941, 1956, 1963, 1969, 1978 and 1981. The 4 in:1 mi photos (1938 and 1978) were not incorporated in the previous analysis because of their lower resolution. Five of the sample areas were devoid of wetlands, during any of the seven study periods. Thus, we randomly selected five new areas that incorporated wetlands. Aerial photos from each sample area for all available years were scanned and computer files were formed that contained geographic information for each area. We counted and measured the size of wetland areas using digital image processing (NIH-Image 1.43, Wayne Rashand). This system discriminates habitat types by comparisons on a gray scale and determines area by counting pixels (0.5 pixels per m). Our null hypothesis was that the number and area of wetlands types remained the same across the years. We used a chi-squared goodness of fit test of the mean to compare number and area of wetlands types.

Wetland types were classified by size (small - <2 ha, medium - 2 to 10 ha, large - >10 ha) from the 1938 aerial photos for each of the 15 sample areas. We then monitored the geographic location of each wetland year by year to determine their fate. Similarly, wetlands were classified from the 1981 photos (excluding wetlands monitored from 1938) and the geographic locations of each were monitored backwards year by year to 1938 to determine if their formation was associated with the presence of the canal. We used NIH-Image 1.43 to determine the area of each wetland. Our null hypothesis was that the number and area of wetlands remained the same across the years.

We used NIH-Image 1.43 to record the locations and area of hydric soils from old soil survey maps (1 in:1 mi) from Gosper (1934), Phelps (1917) and Kearney (1927) counties and from the latest soil survey maps (4 in: 1 mi; 1981, 1973 and 1984 respectively). We overlayed the old and new geographic images for each of the 15 sample areas and compared the location and area of hydric soils on each sample area to further document the fate of wetlands over time. To reduce the effect of map scale and error on map comparisons, we used a significant difference of 100% and -50% when comparing areas of wetland soils from the different time periods. For example, a change from 4 ha to 8 ha is an increase of 100% and a change from 4 ha to 2 ha is a -50% change. We assumed that the location and area of hydric soils would remain constant across the years for the 15 sample areas. The change is symptomatic with the problem of measuring wetlands that have an inherently indeterminate boundary (Kuzila et al. 1991).

RESULTS AND DISCUSSION

We observed no overall change in the number of wetlands in the 559-section study area from 1941 to 1981 (Fig. 3). This finding is notable, considering the overall loss of 90% of wetlands throughout the entire Rainwater Basin during the same time period (Gersib et al. 1992). The total number ($X^2 = 141.7772$, df = 4, $P < 0.001$) and area ($X^2 = 3946.6558$, df = 4, $P < 0.001$) of wetlands did change from year to year during the 1941 to 1981 time period. No clear pattern of influence is apparent for the canal system because of differences in rainfall, land use and the time of year when aerial photos were taken. The year 1941, was an average year for precipitation (62 cm). The number of wetlands is high but area is low because rainfall came early in the spring and the photo was taken in September when the landscape was dry and entire basins could be hayed. The drop in number and area in 1956 can be attributed to the low annual precipitation of 28 cm. The year 1963 had an average annual precipitation (62 cm) and the increase in number and area of wetlands can be attributed to an increase in the use of irrigation water (400% increase from 1941 to 1963, Gersib et al. 1990) which aides in increasing number and size of wetlands through runoff. The total area of wetlands in the study area in 1969 is high because of an annual precipitation of 84 cm. Over the entire study area in 1969, we observed small adjacent wetlands combining into larger wetlands, thus increasing the area yet decreasing the number of wetlands. In 1981, the number of wetlands remained high but total area declined. The 1981 NWI photos were taken in May, before the seasonal rainfall and irrigation had occurred. The total number may have not changed because the increased groundwater table, due to the canals, may have provided supplemental water to the depressions adjacent to the canals. While the depressions were not filled by the supplemental water, they did retain some water when they otherwise would have been dry.

In the increased groundwater table contours, we observed differences (Fig. 4) in the number of wetlands in the 12-m ($X^2 = 10.3632$, df = 3, $P = 0.0157$) contour and no difference in the 18-m ($X^2 = 3.7639$, df = 3, $P = 0.2881$), 6-m ($X^2 = 1.3908$, df = 3, $P = 0.7077$) and 0-m ($X^2 = 6.9106$, df = 3, $P = 0.0708$) contours. The difference within the 12-m contour can be attributed to the fact that 40% of the study area and 49% of the canal was located within the 12-m contour. In addition, draining, filling and irrigation runoff likely added to the variability in numbers of wetlands in all contours. The number of wetlands in the 18-m contour was consistent only because 8% of the total area is contained within the contour. The number of wetlands in the 6-m and 0-m contours show no difference, indicating that groundwater recharge and irrigation runoff may have supplemented water to some depressions. Differences in area are observed in all contours (18-m ($X^2 = 21.8043$, df = 3, $P < 0.001$), 12-m ($X^2 = 682.9291$, df = 3, $P < 0.001$), 6-m ($X^2 = 252.6948$, df = 3, $P < 0.001$) and 0-m ($X^2 = 250.9792$, df = 3, $P < 0.001$)). The area of wetlands within the 18-m contour were stable until 1981. Photos in 1981 were taken before seasonal rainfall and irrigation occurred, thus decreasing the area in all the contours and causing the difference in the 18-m contour. Area in the 6-m and 0-m contours increased across the years until the 1981 photos, due to irrigation runoff and groundwater recharge from the canal system. The 12-m contour had the largest increase in area in 1963 which also dropped in 1969. The large increase is an indication of supplemental water from the groundwater and/or canal. The drop in 1969 may be attributed to an 83% increase in landleveling activity from 1963 to 1969 (Gersib et al. 1990) which drained and filled wetlands and shaped the landscape to increase irrigated cropland acreage. By this time, center pivot irrigation was developed and additional landscaping was done to allow full circle irrigation.

Detailed observations made on the 15 sample areas (Fig. 5) indicate a difference in the number of temporarily flooded ($X^2 = 86.3873$, df = 6, $P < 0.001$) and seasonally flooded ($X^2 = 20.9966$, df = 6, $P = 0.0018$) palustrine wetlands during 1938 to 1981, with a significant increase in concentration pits ($X^2 = 394.4689$, df = 6, $P < 0.001$) from 1969 to 1981. The variability in the number of temporarily flooded wetlands across the years is expected. They are unstable because they occupy very shallow depressions and are dependent on rainfall and/or runoff. The decline in the number of temporarily flooded wetlands is in part, a response to the increase in land leveling and the number of concentration pits which can hold water year round. The number of seasonally flooded wetlands increased across the years with the supply of a stable water source from the canals, even with the implementation of concentration and reuse pits to drain wetlands and capture irrigation runoff.

Differences were also observed in total area of temporarily flooded ($X^2 = 170.2897$, df = 6, $P < 0.001$) and seasonally flooded ($X^2 = 239.4944$, df = 6, $P < 0.001$) palustrine wetlands, with a significant increase in the total area of concentration pits ($X^2 = 146.1286$, df = 6, $P < 0.001$). The total areas of temporarily and seasonally flooded wetlands fluctuated together, indicating that each responded similarly to the effects of changes in land use and environmental variability. While pits do supply surface water, they have altered the natural wetland hydrology and vegetation of surrounding wetlands (Gersib et al. 1992) by concentrating the water in the pits and stopping the flow of runoff into nearby depressional areas. After 1969, pits were located throughout the study area. Without the presence of these pits, the number and size of naturally-occurring wetlands would likely have been greater.

We monitored 168 small, 30 medium and 11 large wetlands from 1938 to 1981 (Fig.6) on the 15 sample areas to determine the fate of individual wetlands over time. In 1938, the 168 small wetlands ranged in size from 0.1 to 2.0 ha. By 1941, 134 of the 168 wetlands had disappeared but the remaining 34, ranged in size from 0.1 to 18.2 ha. By 1981, only 26 of the original 168 small wetlands remained. In 1938, 30 medium-sized wetlands ranged in size from 2 to 7.5 ha. By 1941, 13 of the medium wetlands remained and ranged in size from 0.1 to 24.2 ha. In 1938, 11 large wetlands ranged in size from 10.4 to 78.0 ha. By 1941, 8 large wetlands remained with a range of 0.1 to 95.7 ha. As individual wetlands disappeared, we observed the growth and decline of existing wetlands and the formation of new wetlands. The reduction in number of small wetlands after 1938 is attributed to temporary wetlands only being present when conditions are favorable. While the number and size of small wetlands fluctuated, the mean area stabilized from 1963 to 1981, indicating that supplemental water from the canals are supplying depressions with water. The size of these wetlands, however, decreased as wetland draining and filling continued. The number of medium-sized wetlands was stable across the years and the mean area fluctuated with annual rainfall. The end result is an increased stability in the number and area of medium-sized wetlands by 1981. The number of large wetlands appeared to be stable across the years, however, 4 of the 11 original large wetlands were less than 2 ha by 1981. The other 7 increased in size and kept the mean area relatively high across the years. These 7 wetlands appear to have received supplemental water from the canal and/or groundwater. The 4 that decreased were drained or ditched.

We monitored an additional 165 small, 7 medium and 3 large wetlands from 1981 back to 1938 (Fig. 7) on the 15 sample areas to determine if they were naturally-occurring or if they may have been the result of surplus groundwater from the canal. In 1981, the 165 small wetlands ranged in size from 0.1 to 2 ha. In 1978, only 51 wetlands existed and ranged in size from 0.1 to 10.8 ha. None of the wetlands selected in 1981 existed in 1938. In 1981, 7 medium-sized wetlands ranged in size from 2.6 to 8.6 ha. In 1978, only 5 medium-sized wetlands existed and ranged in size from 1.4 to 4.6 ha. All but one of these existed back to 1941, and none were present in 1938. Three large wetlands, ranging in size from 16.5 to 20.9 ha were present from 1981 back through to 1963, although the sizes of each varied considerably. Only one of the three was present from 1956 back to 1941, and even that one was not present in 1938. Wetlands monitored from 1981 back to 1938 show that these wetlands formed at a time coinciding with the development and use of the Central Nebraska Irrigation canal system. We speculate that the increased groundwater table caused by the canal resulted in the formation of several small, medium and large wetlands in the area.

Old soil survey maps (1 in:1 mi) represent the location of hydric soils for that period of time and the new soil survey maps (4 in:1 mi) give a more detailed representation of where hydric soil locations exist today. We overlayed the old and new soil survey maps in the 15 sample area and, when comparing aerial delineation, we found a match of 716 ha, a loss of 982 ha and a gain of 825 ha of hydric soils. A survey of the Edgar Northwest quadrangle in nearby Clay County, Nebraska similarly showed a match of 758 ha, a loss of 1,147 ha and a gain of 477 ha (Kuzila et al. 1991). Four sites in the study area (2, 3, 5 and 14) increased in hydric soils and two sites (8 and 10) decreased (Fig. 8). Sites 9, 11, 12 and 13 showed declining trends in hydric soils but the differences were not significant. Five sites (1, 4, 6, 7 and 15) showed relatively little difference in the amount of hydric soils. We feel this change in hydric soil location is more a function of mapping conventions and personnel change than of a location to the canals or groundwater increase.

Determination of the effects of the Central Nebraska Irrigation canal system on associated wetlands is confounded by variation in the environment and land use over time and by the timing of aerial photos relative to rainfall events. Stabilization of the number and area of wetlands within the study area is in stark contrast to the dramatic loss of wetlands documented in other areas of the Rainwater Basin. Despite draining and filling of wetlands, the stabilization is attributed to the increased groundwater table which is a direct result of the canal system. Wildlife benefits of the canal system are expected to be additive, but have yet to be studied.

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LIST OF FIGURES