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The ecology of macroinvertebrates inhabiting native grasslands and their role in the feeding ecology of sandhill cranes

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by

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GENERAL INTRODUCTION

The Platte River in central Nebraska has undergone significant morphologic and hydrologic changes during the past 130 years (Williams 1978). The changes have coincided with development of irrigation projects along the major tributaries of the Platte (Krapu et al. 1982). From 1909 through 1961, 8 reservoirs with a combined storage capacity of approximately 6,200 million m^3 were constructed along the Platte and its tributaries (Krapu et al. 1982). The result has been a dramatic reduction in flow rates through central Nebraska (Eschner et al. 1981).

The reduction in flows has caused significant decreases in channel widths (Hadley and Eschner 1981). Williams (1978) reported an 80-90% decline in channel width of the 365-km reach between Minatare and Overton, Nebraska, between 1865 and 1969. Similar decreases in channel widths occurred at other locations along the river (Williams 1978, Krapu et al. 1982, Currier and Ziewitz 1986).

Reduction in flows played an important role in changing the vegetative composition along the Platte (USFWS 1981). Prior to 1930, scouring by floods retarded the establishment of woody vegetation within and adjacent to the multiple channels of the river (Eschner et al. 1981). Dams reduced flood peaks and allowed rapid invasion of cottonwoods (*Populus deltoides*), willows (*Salix rigida*, *S. amygdaloides*, *S. exigua*), and other woody species into the river floodplain (Currier and Ziewitz 1986). Consequently, much of the original channel and floodplain was lost (Currier and Ziewitz 1986).

The native grasslands along the river are underlain with sand and gravel deposits that are hydrologically linked to the river (Hurr 1981). Prior to impoundment and flood control, heavy spring flows resulted in a high water table in these grasslands. High subsurface water apparently deterred attempts to cultivate or otherwise develop the grasslands. More recent diversion of water for irrigation and power production reduced streamflows and lowered water tables under the grasslands. These changes facilitated conversion to cropland, homesites, urban sites, or commercial properties (Currier and Ziewitz 1986). Only 25% of the original native grasslands associated with the Platte River system in Nebraska remain (Currier and Ziewitz 1986).

Changes in riverine habitat along the Platte have impacted migratory bird species including sandhill cranes (*Grus canadensis*) (USFWS 1981). During spring, approximately 80% of the continental sandhill crane population enroute to nesting grounds in northern Canada, Alaska, and Siberia stops along the Platte River (Tacha et al. 1984). The Platte River areas utilized by the cranes in spring were significantly reduced over the past 80 years (USFWS 1981). Cranes utilized most of the 327-km stretch of river from Chapman to North Platte, Nebraska, prior to water development. However, cranes are presently restricted to a 113-km stretch between Kearney and Grand Island, and a 29-km stretch between Sutherland and North Platte (USFWS 1981). The crowding of cranes on such a small area has made the birds vulnerable to hail, ice storms, diseases, food shortages, and human disturbances (USFWS 1981).

Remaining native grasslands along the Platte are considered essential to sandhill cranes during their spring stopover (USFWS 1981). Native grasslands are important to cranes for pair formation (Tacha 1988), loafing and drinking (Iverson et al. 1987), and acquisition of needed macroinvertebrates that contain essential proteins and calcium not available from other sources (Reinecke and Krapu 1986).

Because native grasslands are relatively scarce and are increasingly threatened by additional water and/or agricultural development projects, management of the remaining native grasslands for sandhill cranes and other migratory bird species is important. Effective management of the native grasslands requires broad knowledge. This study provides needed knowledge about the relationship between macroinvertebrates and environmental factors and the role of macroinvertebrates in the feeding ecology of sandhill cranes.

The objectives of this study are the following:

1. To determine the distribution, abundance, diversity, and availability of macroinvertebrates inhabiting microhabitats in native grasslands along the Platte River in central Nebraska.

2. To determine abiotic and biotic factors that influence the distribution and abundance of macroinvertebrates inhabiting native grasslands along the Platte River.

3. To determine sandhill crane use of macroinvertebrates within native grasslands.

4. To evaluate sandhill crane use native grasslands relative to availability and abundance of macroinvertebrates.

5. To present recommendations for managing macroinvertebrates inhabiting native grasslands relative to sandhill cranes.

Explanation of Thesis Format

This thesis follows the alternate thesis format described in the 1990 edition of the Iowa State University Graduate College Thesis Manual. Data collection, analysis, and writing of text were completed by the candidate; guidance and editorial assistance were provided by Dr. Paul Vohs. This thesis is composed of 2 papers intended for publication in Journal of Wildlife Management. Section I discusses the ecology of macroinvertebrates in native grasslands along the Platte River in central Nebraska, and Section II discusses the role of macroinvertebrates in the feeding ecology of sandhill cranes during spring.

SECTION I. ECOLOGY OF MACROINVERTEBRATES INHABITING NATIVE GRASSLANDS ALONG THE PLATTE RIVER IN CENTRAL NEBRASKA

ABSTRACT

I quantified abundance, distribution, and diversity of macroinvertebrate populations within 3 different microhabitats (i.e. wet meadow, transitional, lowland grassland) and examined the influence of abiotic and biotic factors on macroinvertebrate abundance and distributions within the top 20 cm of soil in native grasslands at 3 sites along the Platte River in central Nebraska. The study was conducted at Mormon Island Crane Meadows, Lillian Annette Rowe Sanctuary during 1 March-20 May 1989 and 1990 and Deer Creek Property during 1 March-20 May 1990. Twenty-nine macroinvertebrate taxa were collected in 1989 and 32 in 1990. Earthworms (Oligochaeta), beetles (Coleoptera), and Diptera larvae comprised 73-80% of the total number of macroinvertebrates collected. Earthworms and scarab beetles (Scarabaeidae) constituted 93% of the total biomass. Earthworm and scarab beetle numbers and biomass were the only macroinvertebrate numbers and biomass found to be significantly different between habitat types. The greatest numbers and biomass of each occurred in the lowland grassland habitat. Several environmental factors (e.g. water table depth, soil moisture, organic matter) were significantly correlated ($P \leq 0.05$) with a number of macroinvertebrate taxa. Earthworms and scarab beetles appeared to be most influenced by water table depth and soil moisture. The

greatest earthworm numbers and biomass in the upper 20 cm of the soil strata occurred at sites with a water table depth of 55 cm, while the greatest scarab beetle numbers and biomass occurred at sites with a water table depth >70 cm. Moisture conditions at sites with water table depths >40 cm appeared more favorable for earthworm and scarab beetle populations than sites with water table depths <40 cm. The greatest earthworm and scarab beetle numbers and biomass occurred in the lowland grassland habitat. Management of native grasslands should be focused on maintaining abundant and available populations of earthworms and scarab beetles in the upper soil strata in spring. This can be accomplished by maintaining moderate water table depths (40-80 cm) in the lowland grassland habitat.

INTRODUCTION

During spring, native grasslands along the Platte River in central Nebraska play a vital role in the life requisites of many migratory bird species. Sandhill crane (Grus canadensis), mallard (Anas platyrhynchos), northern pintail (A. acuta), lesser yellowlegs (Tringa flavipes), and long-billed dowitcher (Limnodramus scolopaceus) and others forage on macroinvertebrates in native grasslands.

The native grasslands are hydrologically related to the river stage through underlying beds of gravel and sand (Hurr 1981). Past irrigation and diversion projects have dramatically reduced streamflows and resulted in lowered water tables under the grasslands (Currier and Ziewitz 1986). This has facilitated conversion of these lands to cropland, homesites, urban sites, or commercial properties (Currier and Ziewitz 1986). Only 25% of the original native grasslands associated with the Platte River Valley in Nebraska remain (Currier and Ziewitz 1986). Because the remaining grasslands are increasingly threatened by additional water and/or agricultural development projects, management for sandhill cranes and other migratory species is of high priority. A greater understanding of the Platte River ecosystem must be attained to manage these lands for sandhill cranes and other migratory species.

One little known aspect of the Platte River ecosystem is the ecology of macroinvertebrates in the native grasslands. Nagel and Harding (1987) examined the effects of water table depth and soil factors (i.e. soil texture, organic matter, percent roots) on invertebrate population distributions in native grasslands along the Platte. They found that macroinvertebrate populations were influenced by water table levels. However, they reported no relationships between macroinvertebrates and other soil factors and did not examine the relative abundance and distribution of macroinvertebrates in different habitat types. The objectives of this study were to determine which environmental factors influence macroinvertebrate populations and to quantify abundance, distribution, and diversity of macroinvertebrates within different habitat types.

STUDY AREAS

The study was conducted on Mormon Island Crane Meadows (MICM) in Hall County, Lillian Annette Rowe Sanctuary (LARS) in Buffalo County, and Deer Creek Property (DCP) in Kearney County (Fig. 1). MICM and LARS were used in 1989 and 1990, and DCP was added in 1990.

Mean daily temperatures for central Nebraska vary from -9 in winter to 30 C in summer with an annual mean temperature of 11 C (Wahl et al. 1984). Annual precipitation is 61 cm with 80% occurring from April to September (Wahl et al. 1984).

MICM is an 827-ha area owned by the Platte River Whooping Crane Habitat Maintenance Trust. Topography ranges from level to gently rolling with elevations ranging from 575 to 580 m. The area is mostly on subirrigated (Wann soil series) and wetland (Barney soil series) range sites (Yost et al. 1962). The predominant plant species are big bluestem (*Andropogen gerardi*), sedges (*Carex* spp.), switchgrass (*Panicum virgatum*), and Kentucky bluegrass (*Poa pratensis*) (Nagel and Kolstad 1987).

LARS is a 324-ha property owned by the National Audubon Society. Topography of the area is level to gently rolling with elevations of 634 to 636 m. Nearly all of the area is on the subirrigated Platte soil series (Buller et al. 1974). The dominant plant species are big bluestem, goldenrod

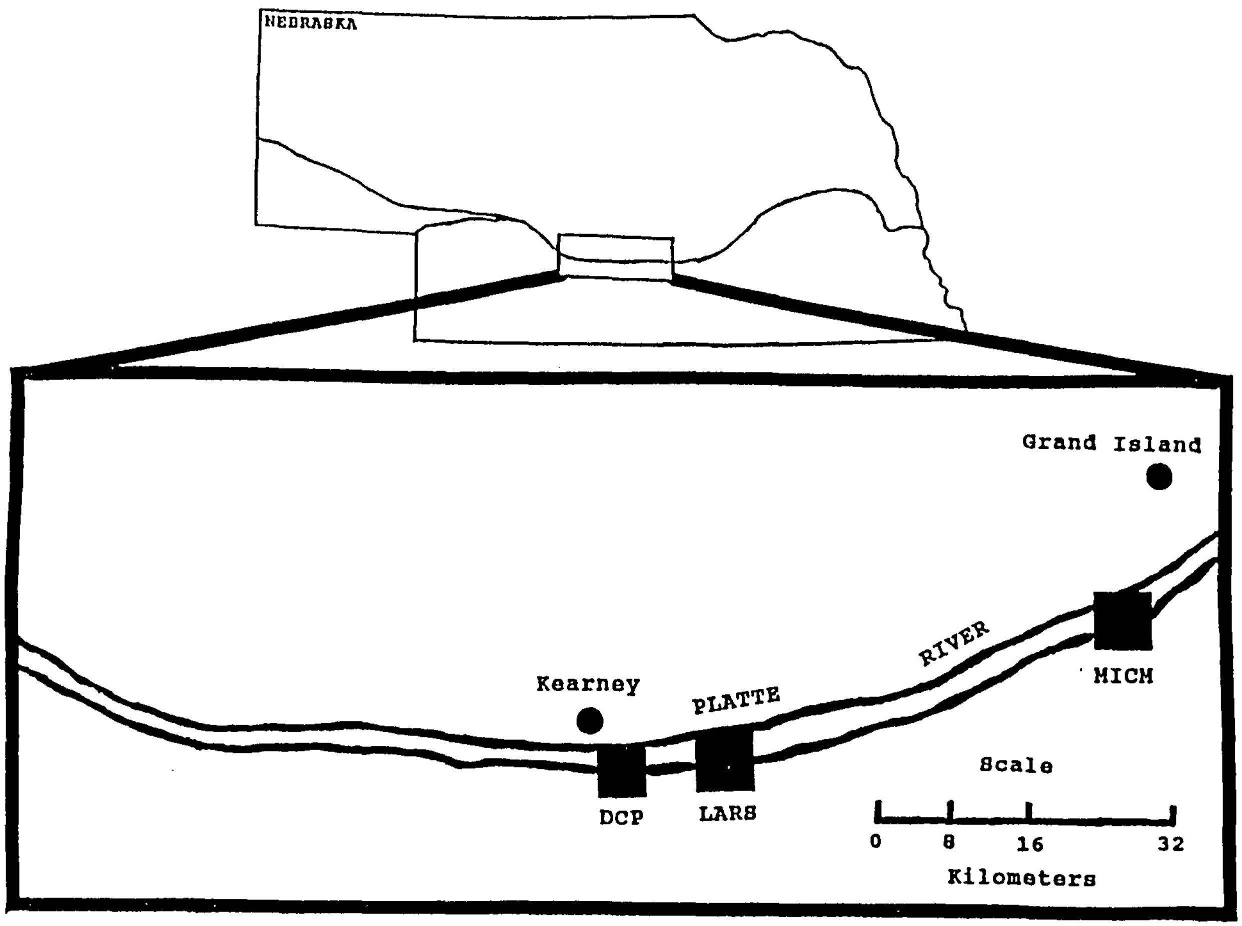

Fig. 1. Location of study areas, Mormon Island Crane Meadows (MICM), Lillian Annette Rowe Sanctuary (LARS), and Deer Creek Property (DCP), along the Platte River in central Nebraska.

(*Solidago* spp.), indian-grass (*Sorghastrum nutans*), and Kentucky bluegrass (Nagel and Kolstad 1987).

DCP is a 54-ha property managed by the U.S. Fish and Wildlife Service. Topography is virtually level with the elevation near 647 m. The area is located on subirrigated range sites of the Gibbon soil series (Wahl et al. 1984). Wheatgrass (*Agropyron intermedium*), common sunflower (*Helianthus annuus*), Kentucky bluegrass, and alsike clover (*Trifolium hybridum*) form the dominant vegetation.

Management practices on the study areas include prescribed burning and haying. Rotational grazing is practiced on MICM and DCP.

METHODS

Data Collection

Transects that traversed the study areas in a north-south direction were established at random locations proportional to the area of each 5-foot contour interval (i.e. 1905-1910 ft) within the study area. The 5-foot contour intervals were determined from topography maps of the study areas. Thirteen transects were located at MICM, and 7 transects each were located at LARS and DCP. A random numbers table was use to determine locations of points on the transects. These points were used to locate macroinvertebrate sampling sites adjacent to the transect. Forty-two points were located on the transects at MICM, and 22 and 21 points were located on the transects at LARS and DCP, respectively. Elevation of each point was determined using surveying instruments.

Macroinvertebrates, defined as invertebrates retained by a 1.00 mm mesh sieve, were collected beginning at the randomly selected point on the transect and proceeding in 1 m increments perpendicular from the point on the transect in an east or west direction. Collection occurred during each of 3, 3-wk sampling periods from 1 March-30 May, 1989 and 1990.

A 25 X 25 cm quadrat was placed at each sampling site. Standing vegetation within the quadrat was clipped to the surface. Surface litter and detritus were removed, examined for macroinvertebrates, and placed in a plastic bag. Litter samples were oven-dried at 50 C for 24 hr and weighed to the nearest 0.01 g.

A total of 182-25 X 25 X 20 cm soil blocks was extracted for collection of macroinvertebrates during 1989, and 255 blocks were extracted in 1990. Blocks were transported in plastic bags to a field laboratory where they were broken apart and macroinvertebrates removed. After the soil block was handsorted, it was placed in a tub of water and stirred to suspension. The suspension was then poured through a 1.00 mm mesh sieve, and macroinvertebrates were removed. Macroinvertebrates, except earthworms, were placed in 70% ethyl alcohol. Earthworms were preserved following the technique described by Fender (1985).

A 2-cm-diameter core was bored to a 1 m depth at each sampling site. A 0.32-cm-diameter dowel rod was placed in the hole to determine water table depth (Nagel and Harding 1987). Water table depths could not be found at all sampling sites because some water table depths exceeded 1 m.

A 20-cm-long soil sample was collected adjacent to the sampling site using a 2.5-cm-diameter soil probe and was sealed in a moisture proof bag. The sample was weighed wet and oven-dried at 100 C to a constant weight, then reweighed to calculate percent moisture on a dry weight basis.

A 20 X 10 cm soil core was obtained adjacent to the sampling site and sealed in a moisture proof bag. Percent roots was determined by breaking apart the sample and removing roots by hand. Soil samples and root samples were then oven-dried at 100 C to a constant weight and weighed to determine the percent roots on a dry weight basis. Soil texture was determined using the hydrometer method (Himes 1984). A 50 g dried-soil sample was analyzed for organic matter content by the Soil Testing Laboratory, Iowa State University, Ames, Iowa. Organic matter content was determined using a potassium dichromate-sulfuric acid solution to oxidize the organic matter in the soil sample (Himes 1984).

Soil temperatures were recorded to the nearest 1 C at 20, 15, 10, and 5 cm depths at each site. Ambient air temperatures were recorded.

Species composition of vegetation near the sampling sites was recorded during August 1989 and July 1990. A visual estimate of percent coverage was made within a 1 m^2 quadrat for each species using the following ranges: 0-5%, 6-15%, 16-25%, 26-50%, 51-80%, and 81-100%.

Macroinvertebrates were identified to the appropriate family or genus (Chu 1949; Peterson 1979a,b). Macroinvertebrate biomass was determined on a dry weight basis. Macroinvertebrates were oven-dried at 100 C for 24 hr, and weighed to the nearest 0.0001 g. Weights of fragmented and damaged earthworms were included in the total biomass of earthworms.

Data Analysis

Prior to statistical comparisons, variables were tested for normality (PROC UNIVARIATE, Schlotzhauer and Littell 1987). Nonnormality for percentages was corrected using arcsine transformations (Zar 1984:239). Macroinvertebrate biomass was transformed (MACRBIO = $\sqrt{\text{MACRBIO} + 0.375}$)(Zar 1984:241). Canonical correspondence analysis was used to separate sampling sites into similar habitat types (CANOCO, TNO Inst. of Applied Computer Science 1987). These habitat types were based on vegetation as related to environmental factors (i.e. water table depth, soil moisture, soil texture, elevation).

Macroinvertebrate biomass and environmental factors were tested for differences between sampling periods, sampling locations, transects, habitat types, and years using analysis of variance (PROC GLM, SAS Inst. Inc. 1985). No significant differences were revealed between macroinvertebrate biomass and sampling periods, therefore data were pooled by years. Differences between sites with and without macroinvertebrates present were tested by analysis of variance (PROC GLM, SAS Inst. Inc. 1985). Differences were considered significant at $P \leq 0.05$.

A multiple comparison test was used to determine differences between macroinvertebrate biomass within habitat types. Macroinvertebrate biomass was related to environmental factors using pairwise correlation and stepwise multiple regression procedures (PROC STEPWISE MAXR, SAS Inst. Inc. 1985). Diversity measures were determined for habitat types using Simpson's Diversity, Shannon-Weiner Diversity, and Brillouin's Index (Program DIVERS, Krebs 1989).

RESULTS

Site Characteristics

Water table depth was significantly different between the study areas for both years (1989: F = 23.93; 1, 180 df; P = 0.0001; 1990: F = 40.58; 2, 233 df; P = 0.0001). During both years, the average water table depth at MICM was closer to the surface than the average water table depth at the other study areas (Table 1). Water table depths at both MICM and LARS were significantly different between years (MICM: F = 38.26; 1, 232 df; P = 0.0001; LARS: F = 17.43; 1, 109 df; P = 0.0001); the average water table depth at MICM in 1990 was 21.1 cm higher (closer to the surface) than the average water table depth in 1989, and the average water table depth at LARS in 1990 was 18.0 cm higher than the average water table depth in 1989 (Table 1).

Soil moisture was not significantly different between MICM and LARS in 1989 (F = 3.05; 1, 179 df; P = 0.082), but was significantly different between the 3 study areas in 1990 (F = 24.70; 2, 232 df; P = 0.0001). Average soil moisture was highest at MICM for both years (Table 1). Soil moistures at both MICM and LARS were not significantly different between years (MICM: F =0.72; 1, 224 df; P = 0.397; LARS: F = 0.09; 1, 126 df; P = 0.764).

The soils at the 3 study areas were predominantly sandy

Table 1. Characteristics of sampling sites at Mormon Island Crane Meadows (MICM), Lillian Annette Rowe Sanctuary (LARS), and Deer Creek Property (DCP) along the Platte River in central Nebraska, March-May 1989 and 1990.

	MICM 1989			MICM 1990		
Variable	N	Mean	SE	N	Mean	SE
Water table depth (cm)	119	49.6	2.4	126	28.5	1.9
Soil moisture (%)	118	40.4	1.8	108	38.6	1.0
Air temperature (C)	119	22.4	0.6	126	13.8	0.4
Soil temperature-20 cm (C)	116	10.2	0.5	108	8.6	0.3
Soil temperature-15 cm (C)	116	11.2	0.5	108	9.0	0.3
Soil temperature-10 cm (C)	118	12.8	0.5	108	9.9	0.3
Soil temperature- 5 cm (C)	118	17.7	0.7	108	11.4	0.3
Clay (%)	118	27.9	1.0	126	29.5	1.0
Silt (%)	118	20.5	0.7	126	18.2	0.6
Sand (%)	118	51.4	1.5	126	52.2	1.4
Organic matter (%)	118	7.3	0.3	126	5.2	0.2
Roots (%)	119	1.4	0.1	126	1.6	0.1
Litter weight (g)	119	163.8	16.9	125	175.2	13.3

LARS 1989			LARS 1990			DCP 1990		
N	Mean	SE	N	Mean	SE	N	Mean	SE
63	67.0	1.9	66	49.0	2.0	63	64.4	3.1
63	35.4	2.0	65	34.7	1.4	62	27.8	0.6
66	15.1	0.9	66	16.5	0.8	63	14.9	0.8
63	7.6	0.6	65	7.4	0.4	62	9.1	0.4
63	8.0	0.6	65	7.9	0.4	62	9.8	0.4
63	9.6	0.8	65	8.9	0.5	62	10.9	0.4
63	12.6	1.0	65	11.2	0.6	62	12.7	0.5
63	24.0	1.0	66	26.7	0.8	63	29.4	0.9
63	24.9	1.2	66	21.9	0.9	63	20.9	0.7
63	51.0	1.7	66	51.4	1.4	63	49.6	1.2
63	6.0	0.4	66	4.9	0.2	63	4.1	0.2
63	1.0	0.1	66	1.1	0.1	63	0.5	0.04
66	185.2	28.5	64	227.9	19.0	63	77.9	9.8

loam, clay loam, and sandy loam soil textures. Soils at MICM and DCP typically contained more clay than soils at LARS (Table 1). Organic matter at both MICM and LARS in 1990 was significantly lower than in 1989 (MICM: $F = 30.89$; 1, 242 df; $P = 0.0001$; LARS: $F = 6.26$; 1, 127 df; $P = 0.014$). Percent roots was significantly different between the study areas (1989: $F = 4.67$; 1, 180 df; $P = 0.032$; 1990: $F = 34.46$; 2, 252 df; $P = 0.0001$), but changed little between years (MICM: $F = 1.72$; 1, 243 df; $P = 0.191$; LARS: $F = 0.04$; 1, 127 df; $P = 0.839$).

In 1989, average ambient air temperature at MICM was 7.3 C greater than at LARS and average soil temperature (5 cm) at MICM was 5.1 C greater at LARS (Table 1). In 1990, ambient air temperature and soil temperatures at the 3 study areas were less variable.

Litter weights at MICM and LARS were much greater than at DCP (Table 1). Litter weights at both MICM and LARS were not significantly different between years (MICM: $F = 0.29$; 1, 242 df; $P = 0.594$; LARS: $F = 1.53$; 1, 128 df; $P = 0.218$).

Sampling sites at the 3 study areas were classified as belonging to 1 of 3 distinct habitat types: wet meadow, transitional, and lowland grassland. Sampling sites in the wet meadow habitat were located in wet, low-lying areas and characterized by 1 or more wetland plant species, while sampling sites in the lowland grassland habitat were located on dry, higher areas and characterized by 1 or more grassland plant species (Table 2). Sites in the transitional habitat were located in a zone between the wet meadow and lowland grassland habitats and were characterized by 1 or more transitional plant species (Table 2).

The environmental conditions within the 3 habitat types were significantly different during both years (Tables 3, 4). Water table depth and soil moisture within wet meadow habitats were significantly greater than within the other habitat types (Tables 3, 4). Wet meadow habitats also contained greater amounts of organic matter, roots, and clay than the other habitat types (Tables 3, 4).

Macroinvertebrate Composition and Diversity

Twenty-nine macroinvertebrate taxa were collected in 1989, whereas 32 taxa were collected in 1990. Earthworms and scarab beetles comprised 93% of the total biomass during both years. Nearly 80% of the total number of macroinvertebrates collected in 1989 was comprised of earthworms (*Aporrectodea* spp., *Diplocardia* spp.), beetles, and Diptera larvae (Table 5). In 1990, earthworms, beetles, and Diptera larvae accounted for 73% of the total number of macroinvertebrates collected (Table 5). The most abundant taxon for both years was the earthworm genus *Aporrectodea* spp. (Table 5). Although snail shells (Gastropoda) were found at 75% of the

Table 2. Plant species commonly associated with 3 habitat types within Mormon Island Crane Meadows, Lillian Annette Rowe Sanctuary, and Deer Creek Property along the Platte River in central Nebraska, 1989 and 1990. These plant species were the predominant plant species recorded in the quadrats during the vegetation survey of the 3 study areas.

Wet meadow	Transitional	Lowland grassland
Fox sedge (*Carex vulpinoidea*)	Big bluestem	Kentucky bluegrass
Sedges	White aster (*Aster ericoides*)	Black medick (*Medicago lupulina*)
Olney's bulrush (*Scirpus americanus*)	Common ragweed (*Ambrosia artemisiifolia*)	Slender wheatgrass (*Agropyron smithii*)
Bald spikerush (*Eleocharis erythropoda*)	Common sunflower	Intermediate wheatgrass (*A. intermedium*)
Rushes (*Juncus* spp.)	Swamp smartweed (*Polygonum coccinieum*)	Smooth brome (*Bromus inermis*)
Narrow-spike small-reedgrass (*Calagrostis inexpansa*)		
Switchgrass		
Spreading bentgrass (*Agrostis stolonifera*)		
Frogfruit (*Phyla lanceolata*)		

Table 3. Environmental conditions present within the 3 habitat types at 3 study areas along the Platte River in central Nebraska from March through May 1989.

	1989									
	Wet meadow			Transitional			Lowland grassland			
Variable	N	Mean	SE	N	Mean	SE	N	Mean	SE	P
Water table depth (cm)	59	33.4	2.0	71	59.4	2.0	21	74.5	2.6	0.0001
Soil moisture (%)	59	51.2	2.5	80	36.9	1.6	40	24.3	2.0	0.0001
Air temperature (C)	59	22.4	0.9	81	17.7	0.9	42	20.0	1.2	0.002
Soil temperature-20 cm (C)	57	9.8	0.6	80	8.3	0.5	40	10.3	0.8	0.061
Soil tempearture-15 cm (C)	57	10.6	0.6	80	8.8	0.6	40	11.3	0.9	0.030
Soil temperature-10 cm (C)	59	11.8	0.8	80	10.4	0.7	40	13.3	1.0	0.043
Soil temperature- 5 cm (C)	59	16.8	1.0	80	14.7	0.8	40	16.8	1.2	0.205
Clay (%)	59	29.4	1.4	80	28.4	1.1	40	19.7	0.8	0.0001
Silt (%)	59	21.3	1.0	80	25.0	1.1	40	17.9	1.1	0.0001
Sand (%)	59	49.3	1.7	80	46.6	1.8	40	62.3	1.4	0.0001
Organic matter (%)	59	9.4	0.4	80	6.3	0.3	40	4.2	0.3	0.0001
Roots (%)	59	2.1	0.1	80	1.1	0.1	40	0.5	0.1	0.0001
Litter weight (g)	59	215.9	28.6	81	147.2	17.5	42	167.9	38.1	0.137

Table 4. Environmental conditions present within 3 habitat types at 3 study areas along the Platte River in central Nebraska from March through May 1990.

	1990									
	Wet meadow			Transitional			Lowland grassland			
Variable	N	Mean	SE	N	Mean	SE	N	Mean	SE	P
Water table depth (cm)	66	17.3	1.5	113	43.1	1.7	51	61.8	2.1	0.0001
Soil moisture (%)	54	45.0	1.2	112	34.7	0.9	69	26.6	0.7	0.0001
Air temperature (C)	66	13.3	0.6	114	15.4	0.5	69	15.5	0.7	0.025
Soil temperature-20 cm (C)	54	8.9	0.4	112	8.0	0.3	69	8.7	0.4	0.136
Soil temperature-15 cm (C)	54	9.2	0.4	112	8.4	0.3	69	9.5	0.4	0.070
Soil temperature-10 cm (C)	54	9.9	0.4	112	9.4	0.3	69	10.7	0.4	0.055
Soil temperature- 5 cm (C)	54	11.2	0.5	112	11.3	0.4	69	12.8	0.5	0.034
Clay (%)	66	33.1	1.3	114	26.4	0.8	69	29.3	1.1	0.0001
Silt (%)	66	19.2	0.7	114	20.1	0.7	69	20.6	0.8	0.437
Sand (%)	66	47.7	1.5	114	53.5	1.2	69	50.1	1.6	0.013
Organic matter (%)	66	6.5	0.4	114	4.6	0.1	69	3.9	0.2	0.0001
Roots (%)	66	1.9	0.1	114	1.1	0.1	69	0.6	0.05	0.0001
Litter weight (g)	66	188.7	21.0	111	194.3	13.3	69	106.9	12.6	0.136

Table 5. Percent of total numbers and percent of total biomass of macroinvertebrates collected from 3 study areas along the Platte River in central Nebraska from March-May 1989 and 1990.

Taxon	Percent of total numbers		Percent of total biomass	
	1989 (N = 182)	1990 (N = 255)	1989 (N = 182)	1990 (N = 255)
Insecta	67	55	25	25
Coleoptera	37	23	22	21
Elateridae (A,L)	8	6	2	1
Carabidae (A,L)	8	2	1	1
Meloidae (L)	2	tr[a]	tr	tr
Curculionidae (L)	4	2	tr	tr
Scarabaeidae (A,L)	13	10	19	19
Chrysomelidae (L)	1	1	tr	tr
Others[b]	1	2	tr	tr
Diptera	14	10	1	2
Asilidae (L)	1	tr	tr	tr
Chironomidae (L)	1	tr	tr	tr
Tipulidae (L)	6	4	tr	tr
Dolichopodidae (L)		2		tr
Stratiomyidae (L)	tr	1	tr	tr
Others[c]	5	3	tr	tr
Lepidoptera[d] (L)	8	2	1	1
Hymenoptera[e] (A)	7	20	tr	tr
Others[f]	1	tr	tr	tr
Oligochaeta	29	40	74	74
Aporrectodea	23	28	46	64
Diplocardia	5	11	5	5
Others[g]	1	1	3	tr
Arachnida[h]	1	2	tr	tr
Diplopoda	tr	tr	tr	tr
Gastropoda		tr		tr
Crustacea[i]	4	1	1	tr

A,L = Adults and larvae.
L = Larvae.

[a] tr = <0.5%.

[b] = includes Lampyridae, Staphylinidae, Dytiscidae, Cerambycidae, Cicindelidae, Cantharidae, and Histeridae.

[c] = includes Syrphidae, Muscidae, Tabanidae, and Bibionidae.

[d] = primarily Noctuidae.

[e] = primarily Formicidae.

[f] = includes Hemiptera, Orthoptera, Homoptera, and unidentified insects.

[g] = includes Enchytraeidae and unidentified earthworms.

[h] = primarily Araneida and Acarina.

[i] = primarily Isopoda.

sampling sites, only 2 live snails were collected from the samples during both years.

Macroinvertebrate diversity at the level of taxa (i.e. family) that I used was similar within the 3 habitat types (Table 6). Diversity indices within each habitat type remained the same or changed little from 1989 to 1990 (Table 6).

Environmental Factors Affecting Earthworms

Habitat type

In 1989, the mean dry earthworm biomass was 4.22 ± 0.31 (SE) g/m^2 and the mean number was 27.16 ± 4.31 earthworms/m^2, whereas in 1990 the mean dry biomass was 5.37 ± 0.34 g/m^2 and the mean number was 54.27 ± 4.40 earthworms/m^2. Earthworm biomass was significantly different between habitat types for both years (1989: $F = 18.01$; 2, 176 df; $P = 0.0001$; 1990: $F = 50.81$; 2, 246 df; $P = 0.0001$) (Fig. 2). Earthworms were more abundant in the drier lowland grassland and transitional habitats than the wetter wet meadow habitats (Tables 3,4). Maximum biomass collected from wet meadows was only 8.78 g/m^2, compared to 51.83 g/m^2 for lowland grassland.

Water table depth, soil moisture, air temperature, percent clay, percent organic matter, and percent roots were significantly different between sampling sites with and without earthworms (Table 7). During both years, average

Table 6. Number of macroinvertebrate taxa and diversity indices for habitat types on 3 study areas along the Platte River in central Nebraska, March-May 1989 and 1990.

Habitat type	Number of taxa		Simpson's diversity index	
	1989	1990	1989	1990
Wet meadow	19	19	0.85	0.85
Transitional	24	30	0.84	0.87
Lowland grassland	22	22	0.89	0.80

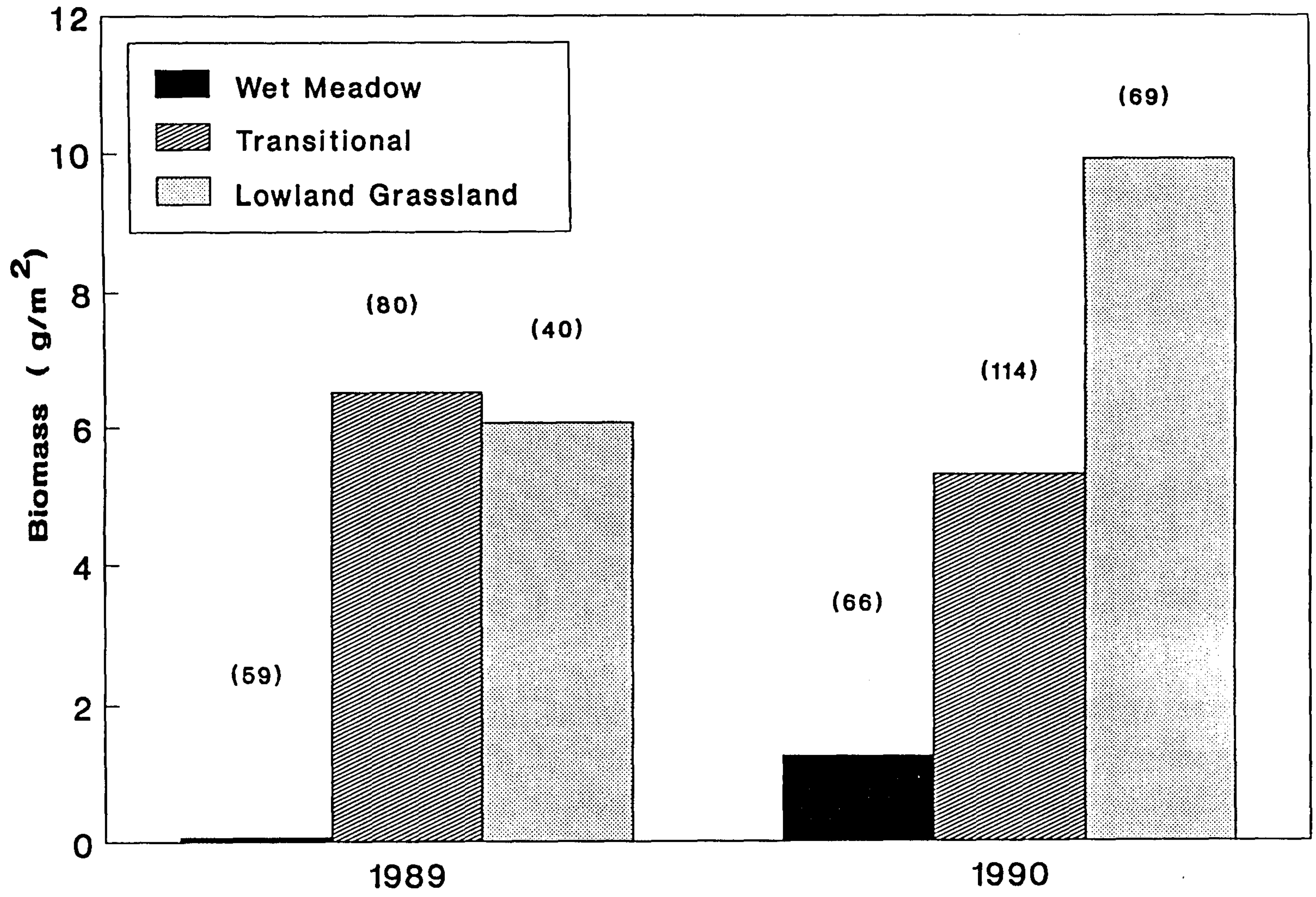

Fig. 2. Mean earthworm biomass related to habitat types along the Platte River in central Nebraska, March-May 1988 and 1990. Sample sizes are shown above each bar.

Table 7. Site characteristics of sampling sites with and without earthworms for 3 study areas along the Platte River in central Nebraska, March-May 1989 and 1990.

	1989					1990				
	without earthworms N = 104[a]		with earthworms N = 78[b]			without earthworms N = 98[c]		with earthworms N = 157[d]		
Variable	Mean	SE	Mean	SE	P	Mean	SE	Mean	SE	P
Water Table Depth (cm)	41.1	2.0	68.1	2.2	0.0001	22.5	1.8	50.0	1.6	0.0001
Percentage Soil Moisture	45.1	1.9	29.2	1.4	0.0001	42.5	1.1	30.8	0.7	0.0001
Ambient Air Temperature	21.4	0.7	17.8	0.9	0.002	13.8	0.5	15.3	0.5	0.04
Soil Temperature (20 cm)	9.2	0.5	9.5	0.5	0.67	8.3	0.3	8.5	0.2	0.73
Soil Temperature (15 cm)	10.0	0.5	10.2	0.6	0.79	8.7	0.4	9.0	0.3	0.45
Soil Temperature (10 cm)	11.4	0.6	12.0	0.7	0.56	9.5	0.4	10.1	0.3	0.25
Soil Temperature (5 cm)	16.3	0.8	15.5	0.8	0.48	11.1	0.4	12.0	0.4	0.11
Percentage Clay	28.8	1.0	23.6	1.0	0.001	30.6	1.1	27.7	0.6	0.02
Percentage Silt	21.3	0.8	23.0	1.1	0.19	19.5	0.7	20.1	0.5	0.51
Percentage Sand	49.8	1.4	53.3	1.8	0.13	49.9	1.5	52.3	1.0	0.17
Percentage Organic Matter	8.0	0.3	5.4	0.3	0.0001	5.7	0.3	4.3	1.7	0.0001
Percentage Roots	1.6	0.1	0.8	0.1	0.0001	1.7	0.1	0.8	0.05	0.0001
Litter Weight	180.6	18.8	137.6	20.2	0.12	177.2	15.9	156.0	11.1	0.26

[a] = sample sizes for water table depth and percentage soil moisture are 100 and 103.
[b] = sample size for water table depth is 54.
[c] = sample sizes for water table depth and percentage soil moisture are 98 and 78.
[d] = sample size for water table depth is 140.

water table depth at sampling sites with earthworms was 27 cm deeper than sites without earthworms (Table 7). In 1989, soil moisture at sites with earthworms was 15.9% lower than sites without earthworms, and in 1990, soil moisture at sites with earthworms was 11.7% lower than sites without earthworms (Table 7). Sites without earthworms contained greater amounts of clay, organic matter, and roots during both years (Table 7).

Specific environmental variables

Earthworm biomass in the top 20 cm of soil increased with deeper water table depths during both years (Table 8). In 1989, the greatest earthworm biomass occurred at sampling sites with a water table depth >55 cm, whereas in 1990, the greatest earthworm biomass occurred at sampling sites with a water table depth >45 cm (Fig. 3). Earthworms were collected from sites with water table depths closer to the surface (15 vs. 45 cm) in 1990 than 1989 (Fig. 3).

Earthworm biomass in the top 20 cm of soil declined with increased soil moistures for both years (Fig. 4). More than 93% of the total earthworm biomass collected in 1989 was from sites with soil moistures between 5 and 45%, whereas in 1990 nearly 96% of the total earthworm biomass collected was from sites with soil moistures between 15 and 45%.

Soil texture appeared to have little influence on presence of earthworms in samples. Only percent clay for

Table 8. Simple correlation coefficients (r) of environmental variables and earthworm biomass in native grasslands along the Platte River in central Nebraska from March through May 1989 and 1990.

Environmental variable	Earthworm biomass 1989	Earthworm biomass 1990
Water table depth (cm)	0.623***[a]	0.718***
Soil moisture (%)	-0.514***	-0.511***
Air temperature (C)	-0.412**	0.345**
Soil temperature-20 cm (C)	-0.219	0.037
Soil temperature-15 cm (C)	-0.215	0.122
Soil temperature-10 cm (C)	-0.154	0.157
Soil temperature- 5 cm (C)	-0.301*	0.216*
Clay (%)	-0.274*	-0.096
Silt (%)	0.059	0.050
Sand (%)	0.160	0.054
Organic matter (%)	-0.374**	-0.369***
Roots (%)	-0.393**	-0.622***
Litter (g)	-0.038	-0.123

[a]Earthworm biomass and environmental variables are correlated: *P < 0.05, **P < 0.01, ***P < 0.001.

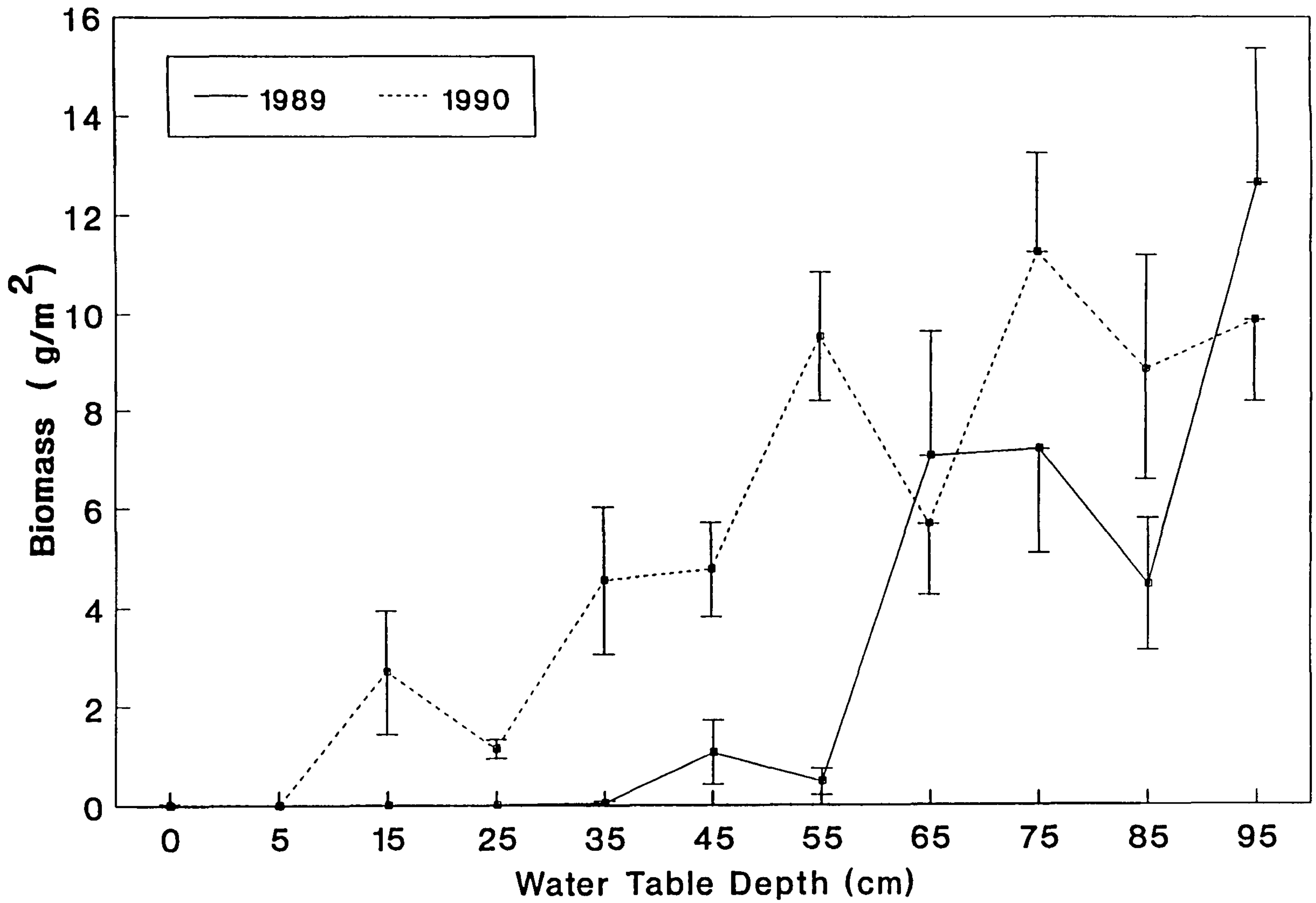

Fig. 3. Mean earthworm biomass related to water table depth in native grasslands along the Platte River in central Nebraska, March-May 1989 and 1990.

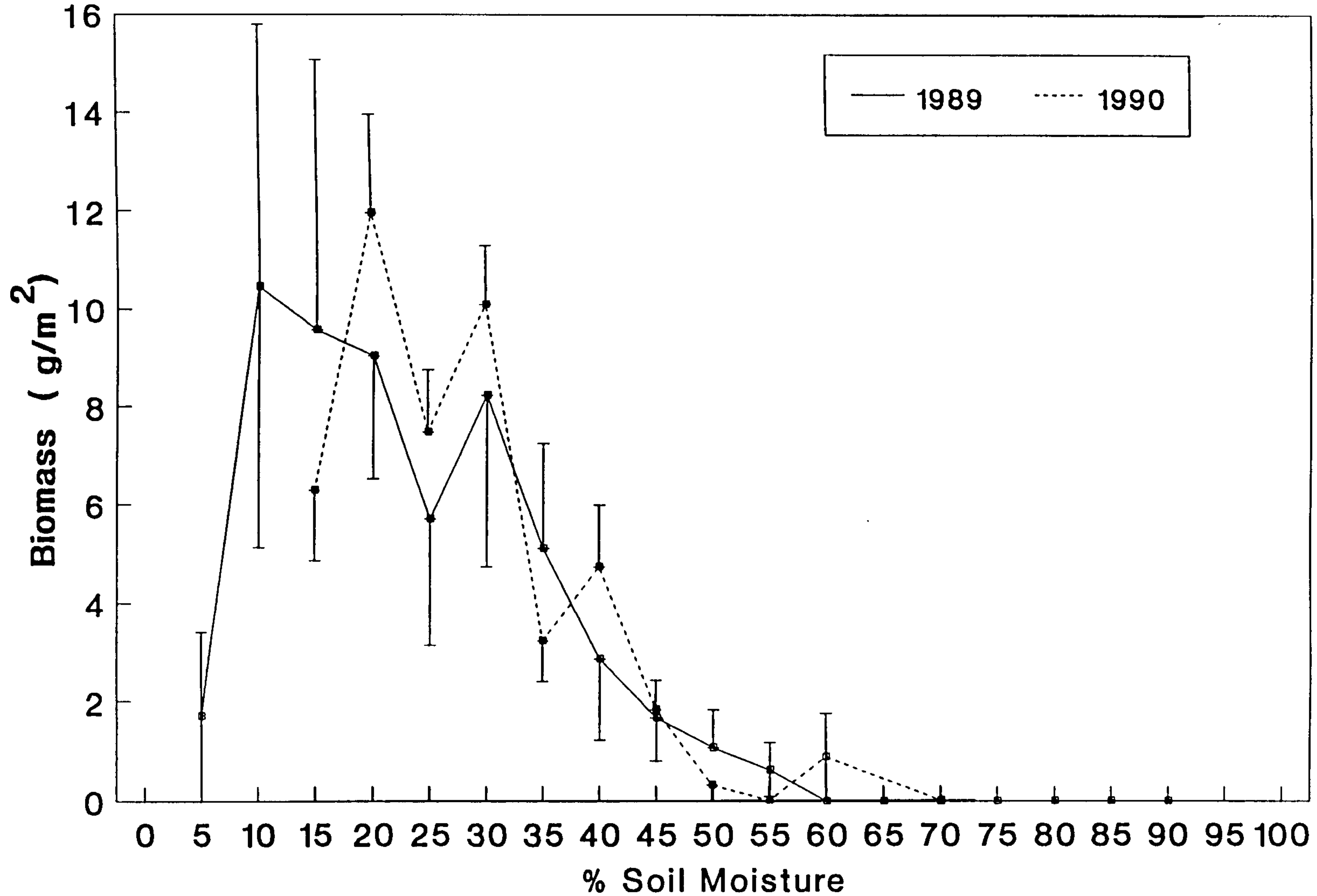

Fig. 4. Mean earthworm biomass related to soil moisture content in native grasslands along the Platte River in central Nebraska, March-May 1989 and 1990.

1989 was negatively, albeit weakly, correlated with earthworm biomass (Table 8). The greatest mean earthworm biomass occurred at sites with sandy clay loam soils (5.75 g/m^2) and sandy loam to loam soils (5.57 g/m^2) , while the lowest occurred at sites with clay soils (1.89 g/m^2) and loamy sand soils (0.38 g/m^2).

Earthworm distribution within the top 20 cm of soil appeared to be influenced by ambient air temperature and soil temperature (5 cm) during both years. In 1989, earthworm biomass was influenced negatively by ambient air temperature and soil temperature (5 cm), whereas in 1990, earthworm biomass was positively influenced by ambient air temperature and soil temperature (5 cm) (Table 8).

Two food sources, organic matter and roots, were negatively correlated with earthworm biomass for both years, while another food source, litter, was not correlated with earthworm biomass (Table 8).

In 1989, water table depth and soil temperature (5 cm) explained 44% of the variation in earthworm biomass ($F = 23.41$; 2, 59 df; $P = 0.0001$). Of this 44%, water table depth accounted for 39% of the variation and soil temperature (5 cm) 5%. In 1990, water table depth and percentage roots accounted for 60% of the variation in earthworm biomass ($F = 59.00$; 2, 80 df; $P = 0.0001$). Water table depth comprised 50% of the variation, and percent roots comprised 10%.

Environmental Factors Affecting Other Macroinvertebrates

Habitat type

Scarabaeidae was the only macroinvertebrate taxon significantly different between habitat types (1989: F = 9.33; 2, 176 df; P = 0.0001; 1990: F = 23.86; 2, 246 df; P = 0.0001) (Fig. 5). The greatest biomass and numbers of scarab beetles occurred in lowland grassland habitats for both years (1989: 18.34 g/m^2; 288.00 beetles/m^2; 1990: 23.50 g/m^2; 128.00 beetles/m^2).

Specific environmental variables

Six macroinvertebrate families (Scarabaeidae, Elateridae, Carabidae, Tipulidae, Noctuidae, and Curculionidae) appeared to be influenced by some of the environmental variables during the study (Table 9).

Scarabaeidae biomass within the top 20 cm of soil increased with deeper water table depths for both years (Fig. 6). During both years, nearly 80% of the total Scarabaeidae biomass was collected from sites with a water table depth $\geq$60 cm. Of this 80%, 55 in 1989 and 33% in 1990 were collected from sites with water table depths $\geq$80 cm. Carabidae biomass also appeared to be influenced by water table depth. It was positively correlated with water table depth for 1990 (Table 9).

Scarabaeidae biomass declined with increased soil moisture during both years (Fig. 7). In general,

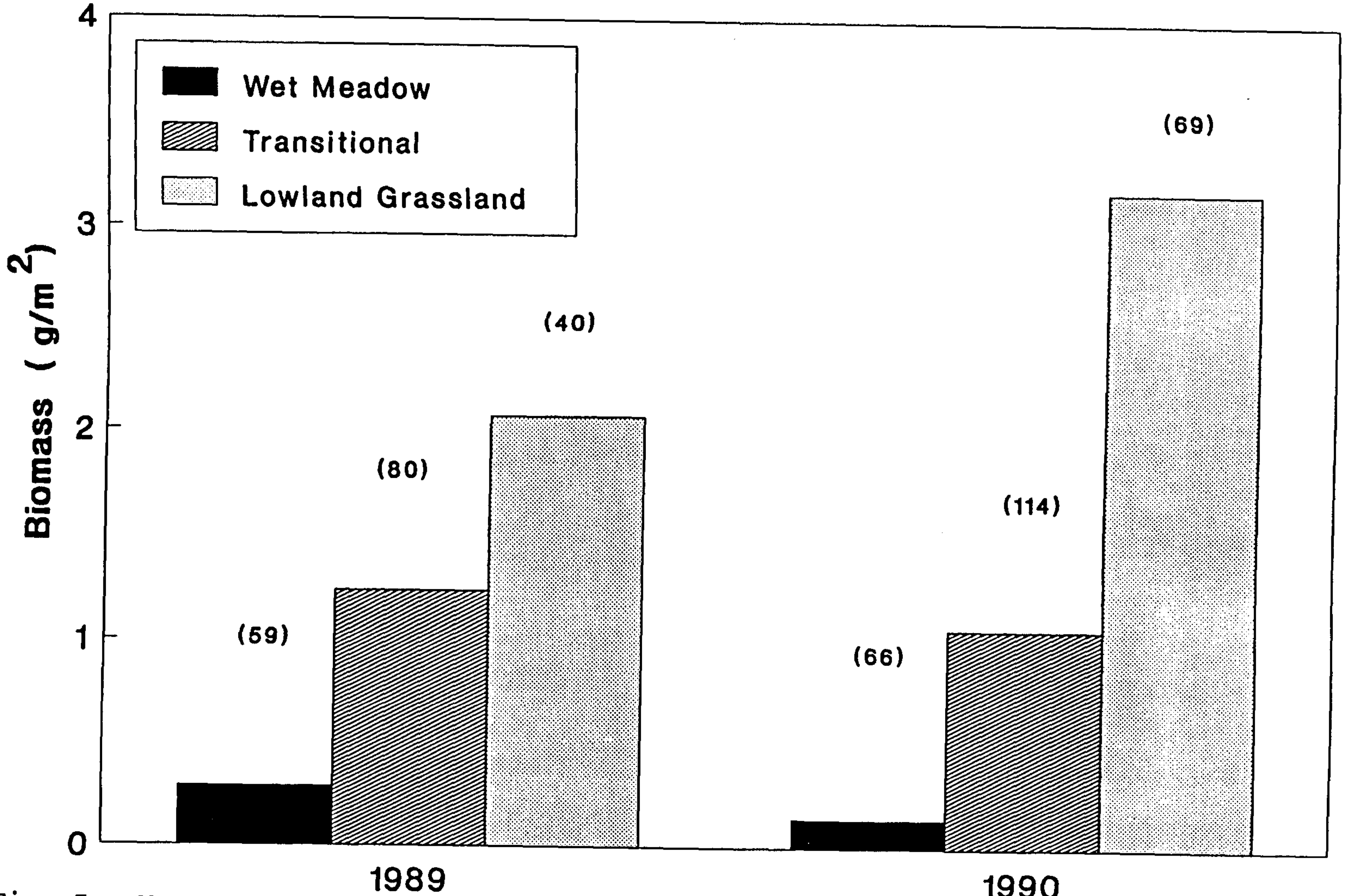

Fig. 5. Mean Scarabaeidae biomass related to habitat types along the Platte River in central Nebraska, March-May 1989 and 1990. Sample sizes are shown above each bar.

Table 9. Simple correlation coefficients (r) of environmental variables and selected macroinvertebrate families (biomass) in native grasslands along the Platte River in central Nebraska from March through May 1989 and 1990.

	Scarabaeidae		Elateridae		Carabidae	
Environmental variable	1989	1990	1989	1990	1989	1990
Water table depth (cm)	0.326*[a]	0.572***	-0.131	-0.024	0.010	0.282**
Soil moisture (%)	-0.273*	-0.367***	0.142	0.019	-0.030	-0.237*
Air temperature (C)	-0.214	0.027	-0.205	0.137	0.094	0.177
Soil temperature-20 cm (C)	-0.083	-0.080	-0.197	0.018	-0.019	-0.183
Soil temperature-15 cm (C)	-0.103	-0.044	-0.221	-0.012	-0.012	-0.147
Soil temperature-10 cm (C)	-0.067	-0.032	-0.181	-0.590	0.030	-0.051
Soil temperature- 5 cm (C)	-0.116	0.015	-0.182	-0.022	-0.011	0.039
Clay (%)	-0.166	-0.132	0.125	-0.168	-0.009	-0.098
Silt (%)	0.047	0.016	0.154	-0.047	0.122	0.138
Sand (%)	0.092	0.106	-0.155	0.141	-0.036	0.009
Organic matter (%)	-0.336**	-0.172	0.093	0.174	0.085	-0.127
Roots (%)	-0.247*	-0.218*	0.169	0.281**	-0.058	-0.150
Litter (g)	-0.253*	-0.228*	0.014	-0.046	0.118	-0.021

[a] Macroinvertebrate families (biomass) and environmental variables are correlated: *P < 0.05, **P < 0.01, ***P < 0.001.

Tipulidae		Noctuidae		Curculionidae	
1989	1990	1989	1990	1989	1990
0.127	-0.173	0.209	0.134	0.170	0.284**
0.099	0.007	-0.163	-0.204	-0.134	-0.176
-0.146	-0.074	-0.051	-0.142	-0.069	0.012
-0.019	0.040	0.004	-0.032	-0.081	0.075
-0.044	0.045	0.024	-0.058	-0.080	0.099
-0.020	0.053	0.015	-0.058	-0.070	0.118
-0.137	0.006	0.027	-0.100	0.048	0.078
-0.255*	-0.162	0.105	0.010	0.195	0.199
0.222	-0.114	-0.137	-0.021	0.254*	0.152
0.072	0.162	-0.004	0.003	-0.265*	-0.206
0.147	0.199	-0.121	-0.125	-0.116	-0.049
0.143	0.165	-0.179	-0.214*	-0.204	-0.263*
0.177	0.024	-0.174	-0.055	-0.025	-0.112

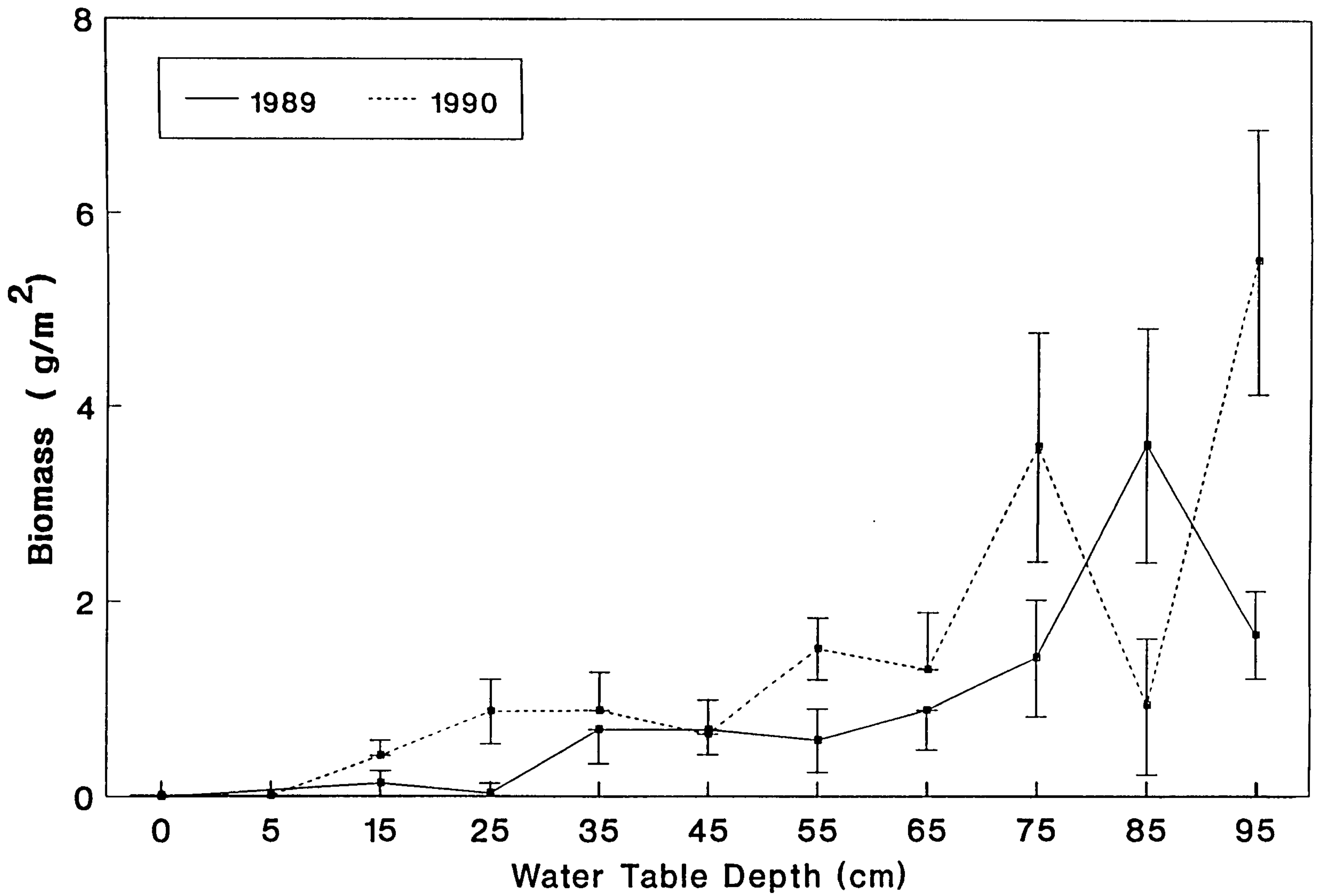

Fig. 6. Mean Scarabaeidae biomass related to water table depths in native grasslands along the Platte River in central Nebraska, March-May 1989 and 1990.

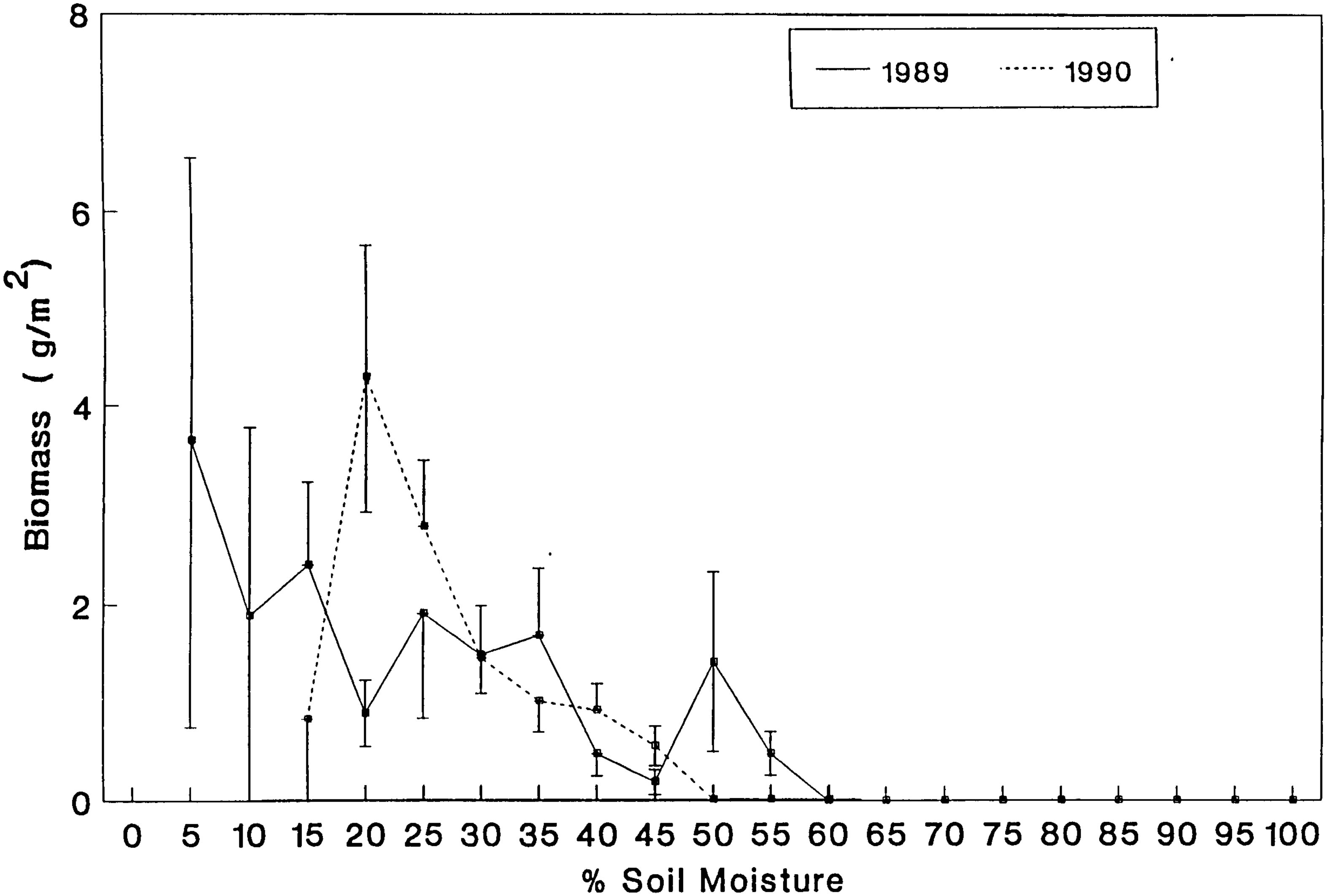

Fig. 7. Mean Scarabaeidae biomass related to soil moistures in native grasslands along the Platte River in central Nebraska, March-May 1989 and 1990.

Scarabaeidae was found at sites that ranged from moist to dry. Nearly 80% of the total Scarabaeidae biomass was collected from sites with soil moistures of 5-35%. Carabidae biomass exhibited a similar relationship with soil moisture; in 1990, Carabidae biomass was negatively correlated with soil moisture (Table 9).

Scarabaeidae, Elateridae, and Curculionidae were all influenced by available food sources (i.e. organic matter, roots, litter). Scarabaeidae biomass was negatively correlated with organic matter, percent roots, and litter weight, while Elateridae biomass was positively correlated with percent roots and Curculionidae biomass was negatively correlated with percent roots (Table 9).

In 1989, a portion of the variation was explained for only 2 macroinvertebrate families, Tipulidae and Scarabaeidae. Percent clay, percent silt, and litter weight accounted for 25% of the variation in Tipulidae biomass ($F = 6.53$; 3, 58 df; $P = 0.0007$). Of this 25%, percent silt accounted for 12%, and litter weight and percent clay accounted for 7 and 6%, respectively. Organic matter explained 11% of the variation in Scarabaeidae biomass ($F = 7.61$; 1, 60 df; $P = 0.008$).

In 1990, a portion of the variation was explained for 3 of the macroinvertebrate families, Carabidae, Scarabaeidae, and Elateridae. Water table depth explained 7% of the variation in Carabidae biomass ($F = 6.51$; 1, 81 df; $P = 0.013$) and 32% of the variation in Scarabaeidae biomass ($F = 38.12$; 1, 81 df; $P = 0.0001$), while percent roots accounted for 7% of the variation in Elateridae biomass ($F = 6.30$; 1, 81 df; $P = 0.014$).

DISCUSSION

Macroinvertebrate Response to Drought Conditions

In 1989, the environmental conditions within the study areas were severely affected by drought that occurred from spring 1988-summer 1989. During the drought, precipitation was more than 23 cm below normal and streamflows were low and variable (Wesche and Skinner 1990). Low precipitation and low streamflows resulted in depressed groundwater levels and low soil moistures in the study areas during 1989 (Wesche and Skinner 1990).

Only 2 live snails were collected on the study areas in 2 years. Normally, snails are able to withstand short periods of dryness by burrowing in mud and aestivating (Pennack 1989), however, the snail populations at the study areas may not have been able to withstand the long dry period.

Diptera larvae composed 14% of the total macroinvertebrates collected from MICM and LARS for each year, whereas Nagel and Harding (1987) reported Diptera larvae composed nearly 25% of the total macroinvertebrates collected from MICM and LARS during spring 1985. Many Dipterans require moist or wet habitats for oviposition of eggs and subsequent development of larvae into adults (Peterson 1979b). A possible explanation for the lower occurrence of Dipterans during this study may be a lack of available moist or wet habitats in summer 1988 and 1989 compared with the Nagel and Harding (1987) study. Due to the drought and low streamflows, moist and wet habitats were not as common during my study, whereas during the Nagel and Harding study, moist and wet habitats were more prevalent (P. J. Currier, Platte River Crane Trust, pers. commun.). Precipitation preceding the Nagel and Harding study was over 18 cm above normal, and precipitation during the study (25 March-7 June 1985) was nearly 6 cm above normal (Matt Warner, Nebr. State Climatological Off., pers. commun.).

Nagel and Harding (1987) reported a mean earthworm biomass of 13.12 $\pm$ 1.75 g/m^2 and a mean number of 91.04 $\pm$ 10.08 earthworms/m^2 for MICM and LARS during spring 1985. In my study, mean earthworm biomass for 1989 was 68% less than the earthworm biomass reported by Nagel and Harding (1987), and mean earthworm numbers for 1989 were 70% less than the earthworm numbers they reported. The lower occurrence of earthworms during my study suggests that at least earthworm distribution in the top 20 cm of soil was influenced by the environmental conditions created by low river stage and drought. Gerard (1967) reported drought affects lumbricids by driving them deeper down the soil profile where moisture conditions are more favorable. Edwards and Lofty (1977) reported droughts drastically decrease earthworm numbers because earthworm fecundity is greatly influenced by soil moisture, however, it is impossible to determine if a decrease in fecundity was responsible for the lower numbers and biomass during my study because samples were only collected to a 20 cm depth.

The environmental conditions after summer 1989 were more normal and wetter; precipitation from June 1989-May 1990 was 5 cm above normal (Wesche and Skinner 1990) and water table levels within the study areas were significantly higher than the previous year. Mean earthworm biomass and numbers in the top 20 cm of soil were 22 and 50% greater than the previous year, which suggests that earthworm distribution within the upper soil strata was influenced by improved environmental conditions in the soil.

Macroinvertebrate Response to Abiotic and Biotic Factors

Abiotic and biotic factors combine to create environmental conditions in the soil microhabitat that have a direct influence on macroinvertebrate composition and distributional patterns of soil fauna in grasslands (Kevan 1968). During this study, I was only able to detect strong relationships between the 2 most abundant macroinvertebrate taxa, earthworms and scarab beetles, and several of the abiotic and biotic factors. Two possible explanations why I was unable to detect strong relationships between other macroinvertebrate taxa and the abiotic and biotic factors may be that the taxonomic groupings (i.e family) that macroinvertebrates were identified to may have been too diverse for detection of relationships with abiotic and biotic factors and that other factors (e.g. prey abundance) may have been more important in governing their distribution.

Nagel and Harding (1987) reported earthworm distribution and abundance at MICM and LARS were influenced by water table levels. In my study, I found that earthworm distribution and abundance in the top 20 cm of soil at MICM, LARS, and DCP was influenced by water table depth, soil moisture, soil temperature, organic matter, and percent roots. Many of these environmental factors are interrelated (e.g. water table depth and soil moisture), therefore, the influence of one factor is likely dependent on other factors.

My results indicate that water table depth is one of the more important environmental factors in determining earthworm distribution and abundance in native grasslands along the Platte River. The importance of the water table stems from its close relationship to soil moisture. During periods of low precipitation, water table is the only source of moisture in the soil profile, thus, earthworm distribution and abundance may be closely associated to the water table level that provides the most favorable moisture conditions.

Nagel and Harding (1987) reported the greatest earthworm numbers and biomass in the top 7 cm of soil occurred at sites with a water table depth of 40 cm. During my study, I found the greatest earthworm numbers and biomass in the top 20 cm of soil occurred at sites with a water table depth of 55 cm. However, sites with water table depths of 45, 65, and 75 cm also contained high earthworm numbers and biomass. It appears that moderate water table levels (i.e. 40-80 cm) may provide more favorable moisture conditions in the top 20 cm of soil than water table levels <40 cm. Soil moistures at sites with water table depths >40 cm averaged 29.1%, while soil moistures at sites with water table depths <40 cm averaged 52.1%.

A possible explanation for sites with water table depths >40 cm being more favorable to earthworms in the upper soil strata is that the soils at those sites are less likely of becoming saturated because of the relatively deep water table. In contrast, soils at sites with a water table depth <40 cm are highly susceptible of becoming saturated because of the shallow water table. Brady (1990) noted that soils that are saturated can incur an oxygen deficit in a short period of time. Lee (1985) reported that earthworms are generally absent from soils that are susceptible to seasonal or permanent oxygen deficits. Therefore, it seems likely that earthworms were not found in great numbers at sites with water table depths <40 cm because of the susceptibility of those sites of incurring an oxygen deficit.

Kevan (1968) noted that it is difficult to dissociate the effects of temperature from those of other factors below the top 23 cm of soil, but at shallower depths the effects of temperature may be more evident because of the wide temperature fluctuations that occur at those depths. Earthworm biomass in 1989 was negatively correlated with soil temperature (5 cm). It is likely that the negative response to soil temperature (5 cm) was due to the high soil temperatures (5 cm) that occurred during April and May in 1989. During those 2 months, soil temperatures (5 cm) were consistently over 25 C because of the drought and unseasonably high air temperatures (>30 C). Earthworm biomass in 1990 was positively correlated with soil temperature (5 cm). Soil temperatures during 1990 were generally between 10 and 16 C. Lee (1985) reported most earthworms are active between soil temperatures of 10 to 15 C. Therefore, the soil temperatures within the top 20 cm during 1990 were probably more conducive to earthworm activity than the soil temperatures during 1989.

Earthworm distribution is greatly influenced by organic matter distribution (Edwards and Lofty 1977). In this study, organic matter and percent roots were significantly correlated with earthworm biomass. It appears that available food sources (i.e. organic matter, roots, litter) in the top 20 cm of soil were adequate during both years, however, these food sources may indirectly be limiting factors to earthworm distribution. Organic matter and roots tend to increase the water-holding capacity of soils and amount of water held at the surface (Nagel and Harding 1987), which may result in an anoxic environment uninhabitable by earthworms.

Few studies have examined the effects of abiotic and biotic factors on the distribution and abundance of Scarabaeidae (Wallwork 1976). During my study, Scarabaeidae distribution and abundance in the upper soil strata appeared to be influenced by water table depth, soil moisture, organic matter, percent roots, and litter weight.

My results indicate that Scarabaeidae distribution and abundance are highly associated with deep water table levels ($\geq$60 cm). Soil moistures at sites with water table depths $\geq$60 cm averaged 25.9%. This suggests that Scarabaeidae distribution is restricted to areas with deep water table depths because they can not tolerate the higher soil moistures found at the shallower water table depths.

Richter (1958) reported that many Scarabaeidae species feed on dung, organic matter in the soil, live roots, and decaying vegetation. During my study, Scarabaeidae were highly correlated with organic matter, percent roots, and litter weight. Scarabaeidae distribution and abundance may have been influenced by available cow dung at MICM. Cattle tended to concentrate on the high ridges at MICM, which resulted in a disproportionate amount of cow dung on those ridges. Although I did not collect an adequate sample size from areas that were heavily used by cattle, I did find some of the highest scarab beetle numbers and biomass from sites within those areas.

Earthworms and Scarabaeidae were strongly associated with lowland grassland habitats. It appears that the environmental conditions within the upper soil strata of lowland grassland habitat are more favorable for maintaining high numbers and biomass of earthworms and scarab beetles than the upper soil strata of transitional or wet meadow habitats. All of these habitats appeared to contain adequate amounts of available food sources (i.e. organic matter, roots, litter), however, the major difference between the 3 habitats was water table depth and soil moisture. Water table depths and soil moistures in the lowland grassland habitats were significantly lower than transitional habitats and wet meadow habitats (Tables 3, 4). This emphasizes the important role that water table depth and soil moisture play in influencing the distribution of earthworms and scarab beetles in upper soil strata of native grasslands along the Platte River.

MANAGEMENT IMPLICATIONS

During spring, earthworms and Scarabaeidae are of great importance to sandhill cranes that forage in native grasslands along the Platte River (Reinecke and Krapu 1986; C. A. Davis, unpubl. data). Since earthworms and Scarabaeidae accounted for 93% of the total biomass in the top 20 cm of soil in native grasslands along the Platte, management of native grasslands along the Platte should be focused on providing and maintaining abundant populations of these 2 macroinvertebrate taxa in the top 20 cm of soil.

This study has shown that an adequate moisture regime in the top 20 cm of soil is important to earthworms and scarab beetles. Water table levels between 40 and 80 cm appear to provide adequate soil moistures (10-35%) in the upper soil strata to maintain high populations of earthworms and scarab beetles. Therefore, management of earthworms and scarab beetles in native grasslands should be concentrated on maintaining moderate water table levels in the lowland grassland habitats during spring.

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SECTION II. ROLE OF MACROINVERTEBRATES IN THE FEEDING ECOLOGY OF SANDHILL CRANES DURING SPRING IN CENTRAL NEBRASKA

ABSTRACT

I examined the feeding ecology of sandhill cranes (Grus canadensis) relative to availability and abundance of macroinvertebrates in native grasslands along the Platte River in central Nebraska, and evaluated crane use of the native grasslands relative to habitat types and macroinvertebrate availability and abundance. The study was conducted at Mormon Island Crane Meadows near Grand Island during 1 March-15 April 1989 and 1990. Two sandhill cranes were collected in 1989 and 13 in 1990 and examined for foods obtained from the grasslands. Macroinvertebrates constituted 89% of the crane diet, while plants constituted 11%. Scarab beetle larvae were the most important macroinvertebrate food, accounting for 68% of the diet. Other foods included earthworms, snail shells, sedge tubers, ground beetles, and crane fly larvae. Cranes extensively used areas that were composed of wet meadow and lowland grassland habitats, but minimally used areas composed entirely of lowland grassland habitat. Cranes appeared to be attracted to wet meadow and lowland grassland habitat areas and used the areas for pair bonding, drinking, loafing, and acquiring macroinvertebrates. Macroinvertebrate numbers and biomass in areas of heavy crane use were significantly lower than areas of minimal use. The reduced numbers and biomass did not preclude cranes from selecting the areas to forage for macroinvertebrates.

Macroinvertebrate numbers and biomass in the heavy use areas appeared to be sufficient to meet crane needs. Native grasslands are threatened by agriculture cultivation and commercial development related to water management strategies involving Platte River waters. Reclaiming and protecting these lands should be a high priority in the management strategies for sandhill cranes and other migratory species along the Platte River.

INTRODUCTION

Native grasslands along the Platte River in central Nebraska are important to the ecology of sandhill cranes (Reinecke and Krapu 1986, Iverson et al. 1987, Tacha 1988). During their annual stopover in early spring, cranes spend approximately 36% of their diurnal time in native grasslands foraging and socializing (Krapu et al. 1984). Reinecke and Krapu (1986) determined that native grasslands are an important source of macroinvertebrates (e.g. earthworms, snails, beetles). These macroinvertebrates apparently contain essential proteins and calcium that are not obtained from other sources and are the foods in shortest supply for the birds (Reinecke and Krapu 1986).

Reduction of flows in the river has resulted in dramatic alterations of the riverine habitat (Currier and Ziewitz 1986). Seventy-five percent of the original native grasslands that bordered the river have been lost to agriculture conversion and commercial development. Nearly 80% of mid-continental population of sandhill cranes use the Platte River during the spring. The continued loss of remaining native grasslands could place the mid-continental population of sandhill cranes in jeopardy because the birds will be crowded on a smaller area, making them vulnerable to hail, ice storms, diseases, food shortages, and human disturbances (USFWS 1981). Thus, a greater understanding of the relationships between sandhill cranes and macroinvertebrates inhabiting these lands must be developed. The objectives of this study were to determine sandhill crane use of macroinvertebrates and to evaluate sandhill crane use of native grasslands relative to availability and abundance of macroinvertebrates.

STUDY AREA

The study was conducted on Mormon Island Crane Meadows (MICM), a 827 ha sanctuary located along the Platte River in Hall County, Nebraska. The study area is mostly on subirrigated (Wann soil series) and wetland (Barney soil series) range sites (Yost et al. 1962). The predominant vegetation includes big bluestem (Andropogen gerardi), sedges (Carex spp.), switchgrass (Panicum virgatum), and Kentucky bluegrass (Poa pratensis) (Nagel and Kolstad 1987).

Topography of MICM is level to gently rolling. The elevation ranges from 575 to 580 m. Mean daily temperatures range from -5 to 25 C with a mean annual temperature of 11 C (Yost et al. 1962). Annual precipitation is 61 cm with 75% falling from April to September (Yost et al. 1962).

MICM is owned and managed by the Platte River Whooping Crane Maintenance Trust. Prescribed burning, rotational grazing, and haying are the management practices used at MICM. No mechanisms are available for manipulating water levels within the study area.

METHODS

Data Collection

Sandhill cranes were collected from MICM during March and April 1989 and 1990. Birds were collected with a .22-250 rifle after being observed feeding for a minimum of 40 minutes. The esophagus of each bird was immediately removed and placed in 80% ethyl alcohol for later analysis. Locations of birds, estimated densities of birds within flocks (low-mean distance between birds of 3 m or more; intermediate-neither low nor high; high-mean distance between birds of 1 m or less) (Tacha 1988), and estimated number of birds observed were recorded during March and April 1990.

Thirteen transects that traversed the study area in a north-south direction were established at random locations proportional to the area occupied by each 5-foot contour interval (i.e. 1905-1910 ft) within the study area. The 5-foot contour intervals were determined from USGS topographic maps of the study areas. A random numbers table was used to determine locations of points on the transects. The points were used to locate permanent macroinvertebrate sampling sites. Forty-two points were located on the transects. Elevation of each sampling point was determined using surveying instruments.

Macroinvertebrates, defined as invertebrates retained by a 1.00 mm mesh sieve, were collected beginning at the randomly selected point on the transect and proceeding in 1 m increments perpendicular from the point on the transect in a west direction. Collection occurred during 2, 3-wk sampling periods from 1 March-21 April 1990. Macroinvertebrates were also collected from 4 sites within an area where collected birds had been foraging. The 4 sites were located north, south, east, and west of the area where the crane concentrated most of its foraging.

Eighty-four 25 X 25 X 20 cm soil blocks were extracted from sampling sites throughout the study area for macroinvertebrate collection, and 56 soil blocks were extracted from crane foraging areas. Soil blocks were transported to a field laboratory where they were broken apart and macroinvertebrates removed. After a soil block was handsorted, the soil was placed in water and stirred to suspension. The soil suspension was then poured through a 1.00 mm mesh sieve and macroinvertebrates were removed. Macroinvertebrates, except earthworms, were placed in 70% ethyl alcohol. Earthworms were preserved following Fender (1985).

Macroinvertebrates were identified to the appropriate family or genus (Chu 1949; Peterson 1979a,b). Macroinvertebrate biomass was determined on a dry weight basis. Macroinvertebrates were oven-dried at 100 C for 24 hr, and then weighed to the nearest 0.0001 g. Weights of fragmented and damaged earthworms were included in the total biomass of earthworms.

Esophagi samples were sorted, identified, and dried for 24 hr at 100 C, and weighed to the nearest 0.0001 g. Cranes usually foraged in corn fields prior to using the grassland. Therefore, esophagi samples that contained corn were only sorted to the corn layer. Macroinvertebrates found in the corn layer were identified, but were not included as food items obtained from grasslands.

Data Analysis

Importance of food items was expressed as frequency of occurrence and percentage of total dry weight. Three empty esophagi were excluded from the analysis. Food preference of sandhill cranes foraging in native grasslands was evaluated with the use of Ivlev's electivity index (Ivlev 1961). Electivity was defined as $E = (r_i - p_i) / (r_i + p_i)$, where r_i is the percentage of the food item in the crane diet, and p_i is the percentage of the food item available in the environment. This index was used to determine how cranes selected food items relative to the availability and abundance of those food items within the environment.

Macroinvertebrate biomass was transformed (MACRBIO = $\sqrt{}$MACRBIO + 0.375) (Zar 1984:241). Differences between macroinvertebrate biomass and numbers within the crane use areas were determined (PROC GLM, SAS Inst. Inc. 1988). Null hypotheses were rejected at the $P \leq 0.05$ significance level.

RESULTS

Food Use

Two sandhill cranes were collected in 1989 and 13 in 1990. Of the 15 collected, 3 contained no food. Macroinvertebrates (animal matter) constituted the greatest proportion of the crane diet from MICM. Scarab beetle larvae (Scarabaeidae) were most important, contributing 68% of the total dry weight and occurring in nearly 60% of the birds (Table 1). Snail shells (Gastropoda) were consumed by 5 cranes and constituted 18% of the total dry weight. The primary plant food consumed by cranes was sedge tubers (<u>Carex</u> spp.) (Table 1). Sedge tubers were present in 42% of the cranes and provided almost 10% of the total food consumed. The esophagi of cranes contained an average of 0.45 $\pm$ 0.10 (SE) g of food.

Food Preference

Snail shells, ants, click beetles, earthworms, and scarab beetles were the most abundant macroinvertebrate foods within the foraging areas of collected birds (Table 2). Snail shells, earthworms, and scarab beetles accounted for 98% of the total biomass collected from foraging areas (Table 2). Snail shells were not preferred by sandhill cranes during this study (Fig. 1), although they accounted for over 72% of

Table 1. Frequency of occurrence and percentage of total dry weight of food items found in the esophagi of 12 sandhill cranes collected from Mormon Island Crane Meadows March-April 1989 and 1990.

Food	Frequency of occurrence	% of total dry wt.
Plant	7	11.1
Sedge tubers	5	9.5
Grass leaves/stems	1	1.2
Miscellaneous	2	0.4
Animal	9	88.9
Gastropoda shells	5	17.6
Oligochaeta	3	2.3
Insecta	7	69.0
Coleoptera	7	68.7
Scarabaeidae larvae	7	67.7
Carabidae adults	1	1.0
Diptera	1	0.3
Tipulidae larvae	1	0.3

Table 2. Mean density (no./m^2) and biomass (g/m^2) of selected macroinvertebrate taxa from foraging areas (N = 56) of collected sandhill cranes at Mormon Island Crane Meadows, March-April 1989 and 1990.

Macroinvertebrates	Density	Biomass
Earthworms	9.14	1.68
Scarab beetles	7.71	0.99
Click beetles	13.43	0.09
Ants	23.14	0.02
Ground beetles	1.43	0.02
Weevils (Curculionidae)	1.43	0.01
Crane fly larvae	1.14	0.005
Long-legged fly larvae	4.57	0.005
Spiders (Araneida)	0.29	0.003
Muscid fly larvae (Muscidae)	0.29	0.001

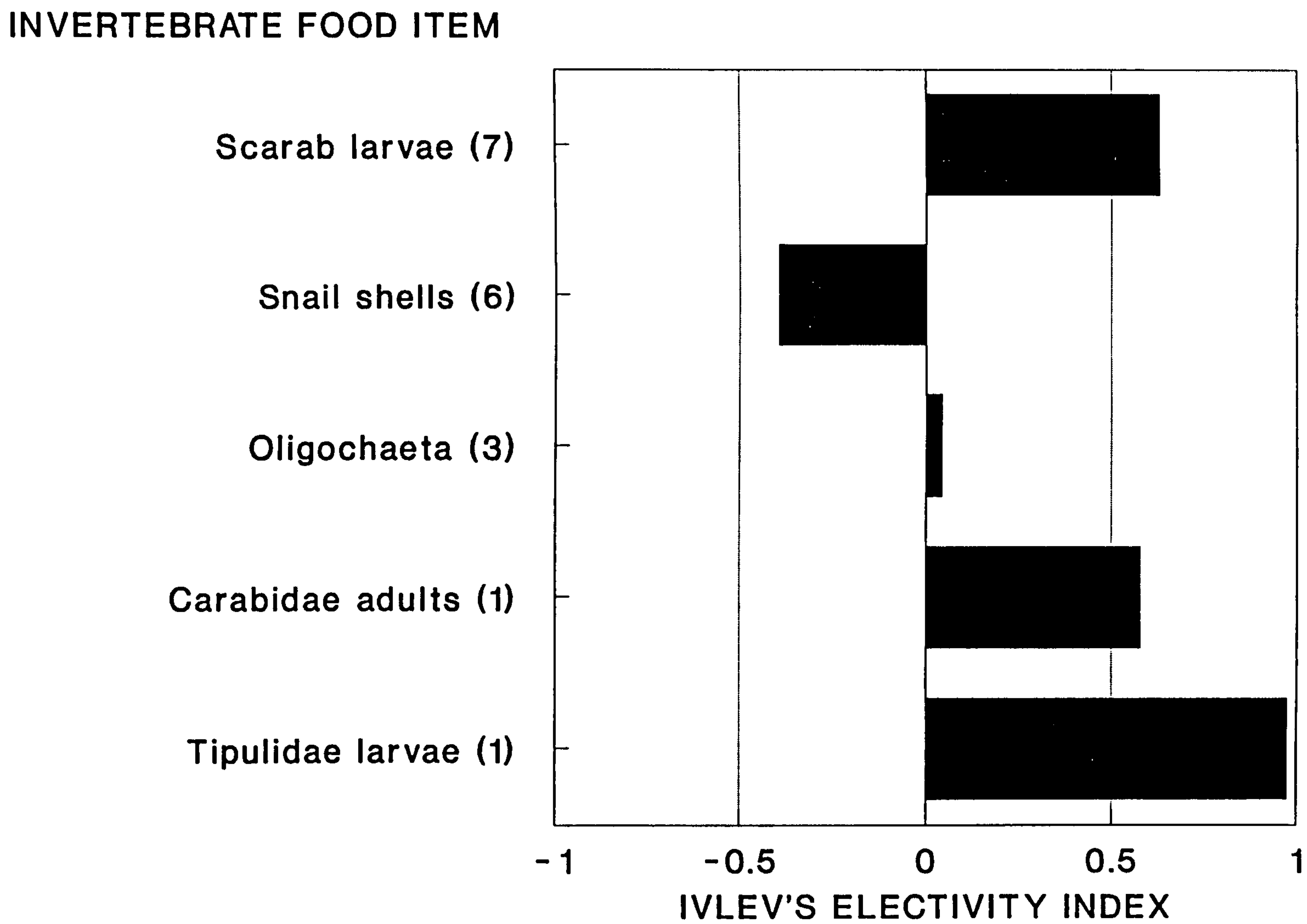

Fig. 1. Food preferences of 12 sandhill cranes collected from Mormon Island Crane Meadows, March-April 1989 and 1990.

the available macroinvertebrate food sources (Table 2). The electivity indices for the 6 birds that consumed snail shells ranged from 0 to -0.77. Sandhill cranes exhibited a strong preference for scarab beetle larvae; the electivity indices for the 7 birds that consumed scarab beetle larvae ranged from 0.33 to 1.00. Preference for earthworms ranged from strongly positive (E = 1.00) to strongly negative (E = -0.87). Overall, preference for earthworms was weak for the 3 birds that consumed earthworms (E = 0.04). The 1 crane that consumed crane fly larvae and ground beetles exhibited moderate preference for ground beetles (E = 0.36) and high preference for crane fly larvae (E = 1.00) (Fig. 1). Admittedly, these sample sizes are small.

Crane Distribution

An average of 7,500 sandhill cranes used the study area daily from 3 March-13 April 1990. Sandhill cranes exhibited differential use patterns of areas within MICM (Fig. 2). Over 80% of the total number of birds observed using MICM occurred on 2 fields (1 and 2) (Fig. 2). Crane use on these 2 fields was considered heavy; large, concentrated flocks of 5,000 to 15,000 cranes were commonly observed. Fields 1 and 2 are predominantly composed of wet meadow habitat interspersed with lowland grassland habitat. The wet meadow habitat is characterized by many water-filled sloughs and shallow depressions.

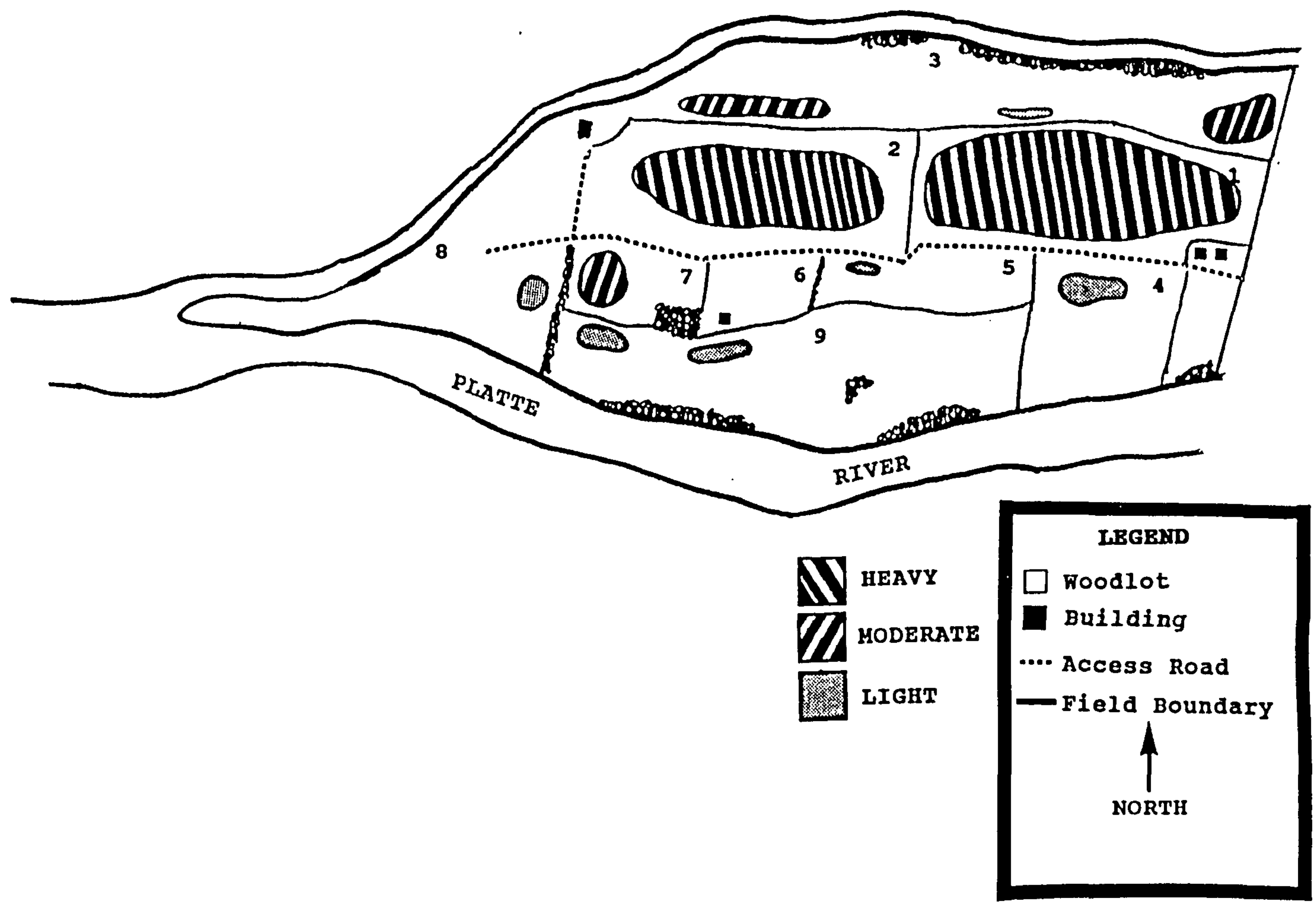

Fig. 2. Locations of crane use areas within 9 fields (designated by numbers) at Mormon Island Crane Meadows from 3 March-13 April, 1990.

Fields 3 and 7 were moderately used by sandhill cranes (Fig. 2). Small to medium sized flocks (100-500 birds) were observed frequently. Fields 4, 5, 8, and 9 were minimally used by sandhill cranes (Fig. 2), and cranes were only occasionally observed in them. All of these fields are entirely composed of lowland grassland habitat.

Sandhill crane used fields 1, 2, and 3 most frequently during late morning and early afternoon, while sandhill cranes used fields 4, 5, 7, 8, and 9 most frequently during early morning. Sandhill cranes generally made brief stops at fields 4, 5, 7, 8, and 9 while enroute from roost sites on the river to agriculture fields. Few cranes were observed in these fields after mid-morning.

Macroinvertebrate Densities and Biomass Within Use Areas

Total macroinvertebrate densities and biomass were significantly different between heavy use areas and moderate to light use areas (density: $F = 12.62$; 1, 82 df; $P = 0.0006$; biomass: $F = 28.38$; 1, 82 df; $P = 0.0001$). The mean density of macroinvertebrates collected from heavy use areas was 62.29 ± 23.66 (SE) macroinvertebrates/m^2, while the mean density for moderate to light use areas was 148.86 ± 37.97 macroinvertebrates/m^2. The mean biomass for heavy use areas and moderate to light use areas were 0.96 ± 0.26 g/m^2 (SE) and 7.32 ± 1.89 g/m^2, respectively.

The most abundant taxa for heavy use areas were ants

(Formicidae), crane fly larvae (Tipulidae), click beetles (Elateridae), and long-legged fly larvae (Dolichopodidae), while the most abundant for moderate to light use areas were ants, earthworms (Oligochaeta), click beetles, and scarab beetles (Table 3). Earthworm and scarab beetle biomass constituted the greatest biomass in both use areas (Table 3). However, earthworm and scarab beetle biomass in moderate to light use areas were significantly greater than the earthworm and scarab beetle biomass in heavy use areas (earthworm: $F = 29.13$; 1, 82 df; $P = 0.0001$; scarab beetle: $F = 6.04$; 1, 82 df; $P = 0.016$).

Snail shells (Gastropoda) were collected from 88% of the sampling sites in heavy use areas and 54% of the sampling sites in moderate to light use areas. Snail shell densities were significantly different between use areas ($F = 14.42$; 1, 82 df; $P = 0.0003$). The mean snail shells for heavy use and moderately to light use areas were 198.29 ± 39.67 (SE) shells/m^2 and 39.43 ± 13.71 shells/m^2, respectively.

Fourteen of the cranes were collected from the heavy use areas. Overall, macroinvertebrate numbers and biomass within the foraging areas were not significantly different from macroinvertebrate numbers and biomass within heavy use areas (number: $F = 0.05$; 1, 110 df; $P = 0.829$; biomass: $F = 3.34$; 1, 110 df; $P = 0.07$). However, scarab beetle numbers and biomass in foraging areas were significantly greater than

Table 3. Mean density (no./m^2) and biomass (g/m^2) of selected macroinvertebrate taxa collected from sites heavily used (N = 56) and minimally used (N = 28) by sandhill cranes at Mormon Island Crane Meadows, March-April 1990.

	Heavily used		Minimally used	
Macroinvertebrates	Density	Biomass	Density	Biomass
Earthworms	2.57	0.53	46.29	6.08
Scarab beetles	3.14	0.22	9.14	0.91
Crane fly larvae	8.00	0.08	8.00	0.04
Click beetles	7.71	0.06	9.71	0.07
Lepidoptera larvae	2.29	0.02	5.71	0.04
Soldier fly larvae	3.43	0.02	0	0
Ants	24.29	0.01	47.43	0.10
Ground beetles	0.86	0.01	2.86	0.02
Spiders	2.00	0.01	3.43	0.03
Long-legged fly larvae	3.71	0.005	2.29	0.01
Leaf beetle larvae	0.29	0.0004	5.14	0.01
Weevils	0	0	2.29	0.01
Muscid fly larvae	0	0	1.14	0.004

scarab beetle numbers and biomass in heavy use areas (number: $F = 4.32$; 1, 110 df; $P = 0.04$; biomass: $F = 6.32$; 1, 110 df; $P = 0.013$).

DISCUSSION

Food Habits

In this study, sandhill crane diets from native grasslands were predominantly composed of macroinvertebrates. Reinecke and Krapu (1986) also found that sandhill crane diets from native grasslands during 1978 and 1979 were predominantly composed of macroinvertebrates; they reported animal and plant foods comprised 98-99 and 1-2% of the crane diet respectively. However, the composition of the animal foods varied between the 2 studies. I recorded only 5 macroinvertebrate foods occurring in the diet which was much less than the 11 macroinvertebrate foods reported by Reinecke and Krapu (1986). I found that scarab beetle larvae (68%) and snail shells (18%) comprised the greatest portion of the diet, whereas in the Reinecke and Krapu study, earthworms (39-56%) and snail shells (23-26%) comprised the greatest portion. Although differences in sample sizes and collection sites may have contributed to the dissimilar macroinvertebrate compositions between the 2 studies, it seems more likely that differences in macroinvertebrate availability resulting from different environmental conditions (i.e. drought) were responsible for the dissimilar compositions.

Drought conditions occurred from spring 1988-summer 1989, whereas during the Reinecke and Krapu study climatic conditions (i.e. precipitation, air temperatures) were near normal; precipitation in 1978 was 4 cm below normal, but precipitation in 1979 was 11 cm above normal (USFWS 1981). As a result of the environmental conditions (i.e. low soil moisture) created by the drought in 1989 and 1990, macroinvertebrate distributions and abundances within the top 20 cm of soil were significantly reduced (C. A. Davis, unpubl. data), however, during the Reinecke and Krapu study, macroinvertebrates within the upper soil strata may have been more available and diverse because of wetter environmental conditions.

Sandhill cranes have evolved an opportunistic foraging strategy that allows them to adapt to changes in food availability (Guthery 1976, Mullins and Bizeau 1978, Reinecke and Krapu 1986). Cranes search for and locate prey by making exploratory probes into the soil while walking (Tacha 1986; C. A. Davis, pers. observ.). Once the cranes locate or capture prey from an area, the birds then begin to intensively probe for additional prey (C. A. Davis, pers. observ.). This foraging strategy may allow cranes to exploit prey foods that are in aggregates or are at high densities (Rabe et al. 1983). For example, sandhill cranes consumed significant amounts of scarab beetle larvae (*Phyllophaga* spp.) which were less abundant than earthworms in 1989 and 1990. However, scarab beetle larvae are relatively immobile and are generally found in aggregates (Richter 1958). These characteristics may have made scarab beetle larvae more susceptible to detection and capture than earthworms. Satchell (1955) and Edwards and Lofty (1977) reported that earthworms are commonly found in aggregates close to the surface, however, I did not detect any earthworm aggregates close to the surface in 1989 or 1990. It appears that earthworms were too widely distributed in 1989 and 1990 for cranes to easily detect and capture them efficiently.

Crane Use of the Study Area

Native grasslands that contained an interspersion of wet meadow and lowland grassland habitats were extensively used by sandhill cranes. Cranes appeared to be attracted to these areas because of the presence of water in the sloughs and shallow depressions. On numerous occasions large flocks (>5,000 birds) were observed landing in the sloughs and depressions after mid-morning and remaining there throughout the rest of the day. These sloughs and depressions appeared important to cranes for conducting pair formation activities (Tacha 1988), drinking, and loafing (Iverson et al. 1987), whereas the lowland grassland habitats adjacent to the sloughs and depressions appeared to be important for acquisition of needed macroinvertebrates that are scarce in the sloughs and depressions.

MANAGEMENT IMPLICATIONS

Sandhill cranes appeared attracted to an interspersion of wet meadow habitat, lowland grassland habitat, and sloughs in native grasslands along the Platte River. These areas provide sandhill cranes sites to forage for macroinvertebrates, to drink and loaf, and to conduct pair formation activities. Therefore, management of existing native grasslands for sandhill cranes should be focused on maintaining a diversity of habitat types (i.e. wet meadow-lowland grassland complex) within these grasslands.

Maintaining water in the sloughs and shallow depressions that traverse the native grasslands attracts cranes to use native grasslands. By maintaining water in the sloughs and shallow depressions, sites are provided for the cranes to conduct pair formation activities, to drink, to loaf, and to forage. Macroinvertebrate (i.e. earthworms, scarab beetle larvae) abundance and availability in the top 20 cm of the soil strata of adjacent lowland grassland habitats may be enhanced by maintaining water in the sloughs and shallow depressions during spring. High populations of earthworms and scarab beetles are related to moderate water table depths (i.e. 40-80 cm) (C. A. Davis, unpubl. data). Thus, by maintaining water in the sloughs and shallow depressions, moderate water table depths in the lowland grassland habitats will be maintained.

Presently, remaining native grasslands not in public ownership are threatened by agricultural conversion or commercial development; protection of existing grasslands and reclamation of the lands that have been converted should be a high priority. Protection can be accomplished by acquisition or easements, whereas reclamation may involve manipulating groundwater levels through changing instream flow rates or using groundwater recharge as well as re-establishing native prairie and meadow plant species.

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SUMMARY

Twenty-nine macroinvertebrate taxa were collected in 1989 and 32 were collected in 1990. Earthworms, beetles, and Diptera larvae comprised 73-80% of the total number of macroinvertebrates collected from native grasslands. Earthworms and scarab beetles constituted 93% of the total biomass. Earthworms and scarab beetles were the only macroinvertebrates found to be significantly different between lowland grassland, transitional, and wet meadow habitats. The greatest numbers and biomass of each occurred in the lowland grassland habitat.

Several abiotic and biotic factors (e.g. water table depth, soil moisture, organic matter) were significantly correlated ($P \leq 0.05$) with a number of macroinvertebrate taxa. Earthworms and scarab beetles appeared to be most influenced by water table depth and soil moisture. The greatest earthworm numbers and biomass in the upper soil strata occurred at sites with a water table depth of 55 cm, while the greatest scarab beetle numbers and biomass occurred at sites with a water table depth >70 cm. The moisture conditions at sites with water table depths >40 cm appeared to more favorable for earthworm and scarab beetle populations than sites with water table depths <40 cm. The greatest earthworm and scarab beetle numbers and biomass occurred in the lowland grassland habitat.

Sandhill crane diets from native grasslands were predominantly composed of macroinvertebrates. Macroinvertebrates composed 89% of the crane diet, while plants composed 11%. The most important macroinvertebrate food was scarab beetle larvae, which constituted 68% of the diet. Other foods included earthworms, snail shells, sedge tubers, ground beetles, and crane fly larvae.

Cranes extensively used areas that were composed of wet meadow and lowland grassland habitats, but minimally used areas composed entirely of lowland grassland habitat. Cranes appeared to be attracted to wet meadow and lowland grassland habitat areas because those areas provided areas for conducting pair bond formation activities, drinking, loafing, and acquiring macroinvertebrates.

Macroinvertebrate numbers and biomass in areas of heavy crane use were significantly lower than areas of minimal use, however, it appeared that macroinvertebrate numbers and biomass in heavy use areas were more than adequate.

Management of native grasslands should be focused on providing available and abundant sources of macroinvertebrates (i.e. scarab beetle larvae, earthworms) in the lowland grassland habitats and maintaining adequate amounts of water in the sloughs and shallow depressions of the wet meadow habitat. Presently, native grasslands are threatened by agriculture conversion and commercial development; protecting and reclaiming native grasslands should be a high priority in the management strategies of sandhill cranes along the Platte River.

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