Prepared in cooperation with the U.S. Fish and Wildlife Service

Literature Review and Database of Relations Between Salinity and Aquatic Biota: Applications to Bowdoin National Wildlife Refuge, Montana

Scientific Investigations Report 2009–5098

U.S. Department of the Interior
U.S. Geological Survey

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By Robert A. Gleason, Brian A. Tangen, Murray K. Laubhan, Raymond G. Finocchiaro, and John F. Stamm

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KEN SALAZAR, Secretary

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Compact Disc

[In pocket]

Plant and Invertebrate Database
(*http://pubs.usgs.gov/sir/2009/5098/downloads/databases_21april2009.xls*)
Format: American Standard Code for Information Interchange (ASCII), Microsoft Office Excel 97–2003 Worksheet, Windows XP Professional operating system

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
	Volume	
acre-foot (acre-ft)	0.123	hectare meter (ha-m)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
	Volume	
hectare meter (ha-m)	8.107	acre-foot (acre-ft)
	Mass	
megagram (Mg)	1.102	ton, short (2,000 lb)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu S\ cm^{-1}$ at 25°C).

Concentrations of chemical constituents in water are given in milligrams per liter ($mg\ L^{-1}$).

Throughout this report (including the plant and invertebrate databases) $mg\ L^{-1}$ is related to $\mu S\ cm^{-1}$ by using the following formula: $mg\ L^{-1} = \mu S\ cm^{-1} \times 0.64$ (Tchobanoglous and Burton, 1991).

Literature Review and Database of Relations Between Salinity and Aquatic Biota: Application to Bowdoin National Wildlife Refuge, Montana

By Robert A. Gleason, Brian A. Tangen, Murray K. Laubhan, Raymond G. Finocchiaro, and John F. Stamm

Abstract

Long-term accumulation of salts in wetlands at Bowdoin National Wildlife Refuge (NWR), Mont., has raised concern among wetland managers that increasing salinity may threaten plant and invertebrate communities that provide important habitat and food resources for migratory waterfowl. Currently, the U.S. Fish and Wildlife Service (USFWS) is evaluating various water management strategies to help maintain suitable ranges of salinity to sustain plant and invertebrate resources of importance to wildlife. To support this evaluation, the USFWS requested that the U.S. Geological Survey (USGS) provide information on salinity ranges of water and soil for common plants and invertebrates on Bowdoin NWR lands. To address this need, we conducted a search of the literature on occurrences of plants and invertebrates in relation to salinity and pH of the water and soil. The compiled literature was used to (1) provide a general overview of salinity concepts, (2) document published tolerances and adaptations of biota to salinity, (3) develop databases that the USFWS can use to summarize the range of reported salinity values associated with plant and invertebrate taxa, and (4) perform database summaries that describe reported salinity ranges associated with plants and invertebrates at Bowdoin NWR. The purpose of this report is to synthesize information to facilitate a better understanding of the ecological relations between salinity and flora and fauna when developing wetland management strategies. A primary focus of this report is to provide information to help evaluate and address salinity issues at Bowdoin NWR; however, the accompanying databases, as well as concepts and information discussed, are applicable to other areas or refuges. The accompanying databases include salinity values reported for 411 plant taxa and 330 invertebrate taxa. The databases are available in Microsoft Excel version 2007 (*http://pubs.usgs.gov/sir/2009/5098/downloads/databases_21april2009.xls*) and contain 27 data fields that include variables such as taxonomic identification, values for salinity and pH, wetland classification, location of study, and source of data. The databases are not exhaustive of the literature and are biased toward wetland habitats located in the glaciated North-Central United States; however, the databases do encompass a diversity of biota commonly found in brackish and freshwater inland wetland habitats.

Introduction

Bowdoin National Wildlife Refuge (NWR) was established in 1936 to provide habitat for breeding and migrating waterfowl. The refuge is located about 11 km to the east of Malta, in the Milk River Valley of Phillips County, Mont. (fig. 1). Characteristic of refuges located in the arid North-Central United States, Bowdoin NWR is at risk to increased salinization and accumulation of trace elements that can threaten wetland biota (DuBois and others, 1992; Nimick, 1997; Laubhan and others, 2006). Bowdoin NWR has been the subject of various investigations and model simulations (Lambing and others, 1988; Hamilton and others, 1989; Kendy, 1999; Bauder and others, 2007) that suggest that salt concentrations in lakes and marshes are increasing and that the long-term accumulation of salts could pose a significant threat to flora and fauna. The increasing salt concentrations on the refuge have been attributed to changes in water availability and quality that, in conjunction with water management strategies that stabilize water levels and enhance retention time, have amplified the evapoconcentration of salts and reduced the effectiveness of natural salt removal processes such as flushing and deflation (removal by wind) (Hamilton and others, 1989). Further, this increase in salinity has been linked to alteration of vegetation communities that provide important wildlife habitat. For example, Hamilton and others (1989) observed that salt-tolerant plants had replaced cat-tails (*Typha* sp.) and bulrushes (*Scirpus* sp.), and submerged aquatic species such as pondweeds (*Potamogeton* sp.) and widgeongrass (*Ruppia* sp.) had largely disappeared. Additionally, declines in waterfowl use and productivity have been attributed to increased salinity and subsequent changes in vegetative composition.

To ensure the long-term success of Bowdoin NWR in providing healthy, sustainable habitat for waterfowl and other wildlife, the U.S. Fish and Wildlife Service (USFWS) is developing management strategies to maintain salt concentrations within ranges suitable for the establishment of historical plant and invertebrate communities. Currently, the USFWS is evaluating various water management scenarios that will enhance their ability to export salts and manage salinity levels in lakes and marshes on the refuge. Water management scenarios considered by the USFWS range from no action to controlled and uncontrolled (for example, flushing caused by floods)

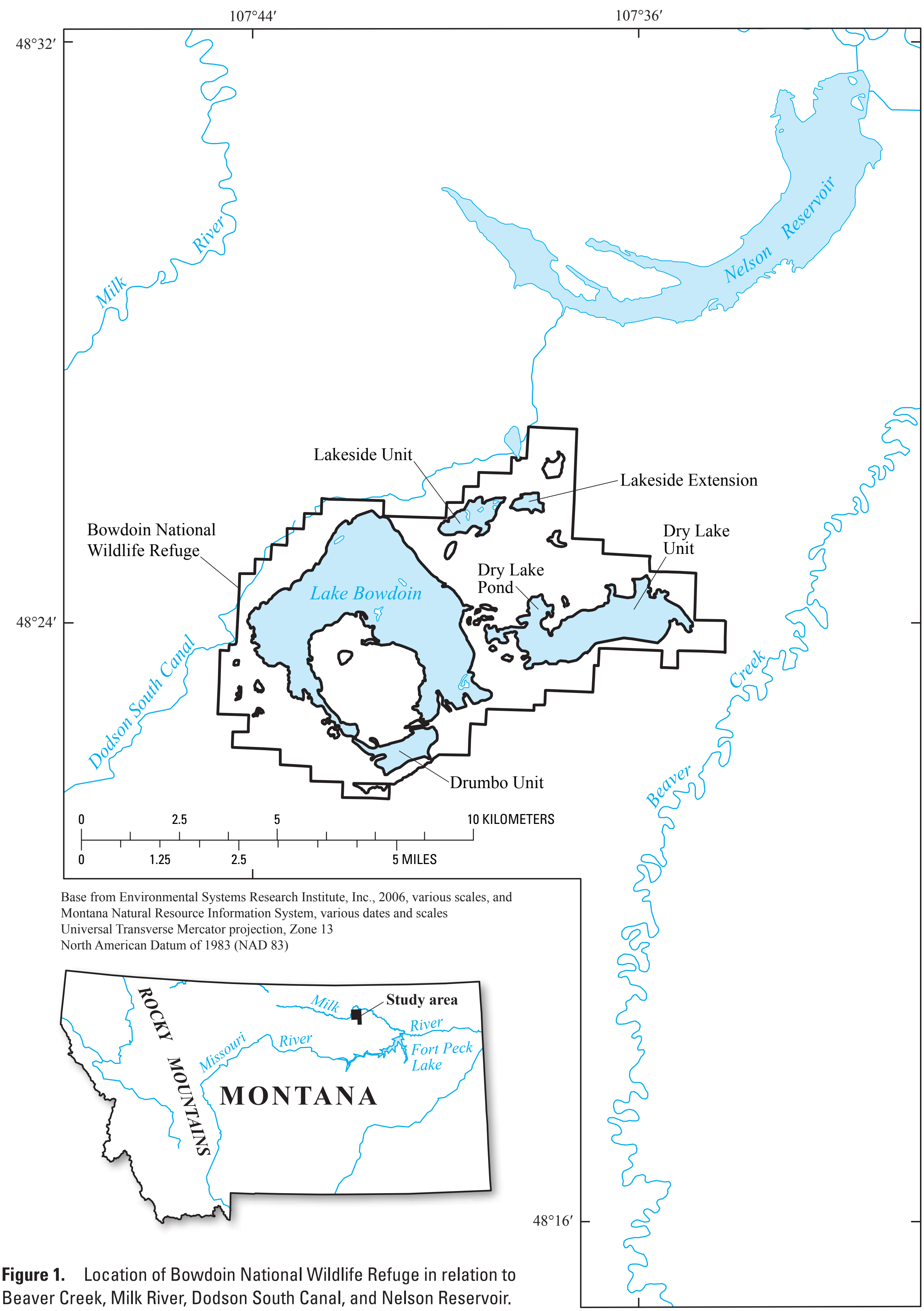


Figure 1. Location of Bowdoin National Wildlife Refuge in relation to Beaver Creek, Milk River, Dodson South Canal, and Nelson Reservoir.

exports of saline water to creeks and rivers (oral commun., Comprehensive Conservation Plan planning committee). Each of these scenarios will result in varying levels of salinity control in lakes and marshes that will ultimately affect wildlife habitat in terms of plant and invertebrate communities.

To support the evaluation of water management scenarios, the USFWS requested that the U.S. Geological Survey (USGS) provide information on suitable ranges of salinity for plants and invertebrates of importance to the refuge. To address this need, we present summarized data obtained from various sources (for example, books, peer-reviewed publications, reports, subject reviews, unpublished data) that relate the occurrences of common aquatic plant and invertebrate species to various water and soil quality variables such as specific conductance and pH. As part of the review, we also discuss general physiological adaptations that allow flora and fauna to survive in salt-affected environments.

Purpose and Scope

The goal of this report is to provide the USFWS with scientifically based information to facilitate a better understanding of the ecological relations between salinity and flora and fauna when developing management strategies. Although the primary focus is to provide information to help address salinity issues at Bowdoin NWR, the databases, as well as concepts and information discussed, are intended to be applicable to other areas or refuges. To address our goal, we conducted an extensive search to locate existing scientific literature that reported occurrences of plants and invertebrates in relation to salinity and pH of the water and soil. Information from this literature search was incorporated into databases and used to address the following objectives:

1. Provide a general overview of salinity concepts and the tolerances and adaptations of biota to salinity.
2. Develop databases that the USFWS can use to summarize the range of reported salinity values associated with plant and invertebrate taxa.
3. Perform database summaries that describe reported salinity ranges associated with plants and invertebrates at Bowdoin NWR.

Description of Bowdoin National Wildlife Refuge

The 6,294-ha refuge is located in the Glaciated Northern Grasslands (level IV ecoregion) (Woods and others, 2002) of northeastern Mont., which is characterized by rolling hills and plains that are the result of glaciation. In general, glacial and alluvial deposits overlay bedrock, and the region is characterized by saline-sodic soils (sodium and sulfate are the dominant ions) and grasslands that contain numerous depressional wetlands. Terrestrial soils of the refuge consist primarily of Bigsag clays and the Phillips-Elloam complex. The portion (36 percent) of the refuge inundated by lakes is bordered, and likely underlain, by Bigsag and Bowdoin soils (Kendy, 1999), which are relatively fine grained with low permeability and a high salt content. An inventory of primary soils and complexes on the refuge is presented in table 1.

Refuge habitats consist primarily of short- and mixed-grass prairie, planted dense nesting cover, shrublands, and both brackish and freshwater wetlands. Wetlands make up about 46 percent (2,924 ha) of the refuge, with the majority of this area consisting of five large, shallow lakes: Lake Bowdoin, Drumbo Unit, Dry Lake Unit, Dry Lake Pond, and Lakeside Unit (fig. 1). Lake Bowdoin, the largest (2,209 ha) and most prominent lake, is an oxbow of the preglacial Missouri River. The modern Missouri River flows nearly 113 km to the south of the refuge. Prior to the establishment of Bowdoin NWR, Lake Bowdoin was managed by the Bureau of Reclamation to store water from spring floods and irrigation return flows.

Direct precipitation and diverted water from the Milk River via the Dodson South Canal are the main sources of water entering the refuge, while irrigation drainage returns from nearby agricultural lands, overland runoff, floodwaters from adjacent drainages (for example, Beaver Creek), and groundwater discharges from saline seeps are secondary sources. An annual water allocation of 431 ha-m from the Milk River Irrigation Project that flows through Dodson South Canal provides a relatively reliable source of water to the refuge; however, this allocation can fluctuate annually and is contingent on the amount of water available for distribution. Measured water deliveries from the years 1938 to 2006 ranged from 70 to 1,419 ha-m and averaged 597 ha-m. Water losses are attributed primarily to evaporation and infrequent surface outflows to neighboring Beaver Creek. The average annual evaporation (92.71 cm) (Kendy, 1999) greatly exceeds the mean annual precipitation (27.94–35.56 cm) (U.S. Department of Agriculture, 2004) in this semiarid region; thus, the refuge experiences a water deficit for much of the year. Currently, USFWS personnel manage refuge wetlands for waterfowl and other wildlife by using a system of channels and dikes that allows for the capture, storage, and movement of water within the refuge.

A total of 210 plant species have been documented on the refuge (app. 1). Dominant emergent vegetation includes hardstem bulrush (*Scirpus acutus*), alkali bulrush (*S. paludosus*), common threesquare (*S. pungens*), and cat-tail (*Typha latifolia*). Other notable species that occur along the shores of lakes and marshes include pickleweed (*Salicornia rubra*) and saltgrass (*Distichlis spicata*). Common aquatic vegetation includes sago pondweed (*Potamogeton pectinatus*), widgeongrass (*Ruppia maritima*), and watermilfoil (*Myriophyllum exalbescens*) (Weydemeyer and Marsh, 1936; Hamilton and others, 1989; Johnson, 1990). Information on invertebrate communities is relatively limited; however, 32 invertebrate taxa have been documented within lakes and marshes on the refuge (app. 2). Common aquatic macroinvertebrates documented on the refuge include midges (Chironomidae), scuds (Talitridae), water boatman (Corixidae), snails (Planorbidae and Physidae), damselflies (Coenagrionidae), mayflies (Caenidae), and water fleas (Cladocera) (Johnson, 1990).

Table 1. Slope and area of primary soils on Bowdoin National Wildlife Refuge.

[Data provided by U.S. Fish and Wildlife Service. Areas are based on 2005 color-infrared imagery and the Natural Resources Conservation Service's Soil Survey Geographic Database. --, no data]

Soil	Slope range, in percent	Area, in hectares	Percent of refuge	Cumulative percent of refuge
Water	--	2,269.13	35.68	35.68
Bigsag clay	0–2	889.50	13.99	49.67
Phillips-Elloam complex	0–4	463.07	7.28	56.95
Bowdoin clay	0–2	387.58	6.09	63.04
Creed-Absher complex	0–4	372.11	5.85	68.89
Scobey-Kevin clay loams	2–8	349.75	5.50	74.39
Scobey-Kevin-Elloam clay loams	2–8	279.08	4.39	78.78
Ferd-Gerdrum complex	0–4	237.77	3.74	82.52
Telstad loam	0–4	219.79	3.46	85.98
Creed-Gerdrum complex	0–4	167.26	2.63	88.61
Lardell clay loam	0–2	154.30	2.43	91.04
Telstad-Joplin loams	2–8	131.13	2.06	93.10
Vanda clay	0–2	113.52	1.79	94.89
Scobey-Phillips complex	0–4	104.53	1.64	96.53
Scobey-Elloam-Absher gravelly clay loams	2–8	53.78	0.85	97.38
Phillips-Absher complex	0–4	44.50	0.70	98.08
Joplin-Hillon loams	2–8	35.15	0.55	98.63
Sunburst-Kevin gravelly clay loams	8–15	28.67	0.45	99.08
Scobey clay loam	0–4	19.03	0.30	99.38
Scobey-Elloam clay loams	2–8	11.70	0.18	99.56
Harlake-Lostriver clays	0–2	10.93	0.17	99.73
Nishon clay loam	0–2	8.18	0.13	99.86
Degrand loam	0–4	4.09	0.06	99.92
Scobey-Kevin complex	2–8	2.91	0.05	99.97
Kobase silty clay	0–2	0.81	0.01	99.98
McKenzie clay	0–2	0.64	0.01	99.99
Hillon-Kevin complex	8–15	0.08	<0.01	99.99

Methods

We developed plant and invertebrate databases by conducting an extensive search to locate existing scientific literature that reported occurrences of plants and invertebrates in relation to salinity and pH of the water and soil. Literature and keyword (for example, wetlands, salinity, salt, invertebrates, plants) searches were conducted by using various electronic databases such as FirstSearch, Cambridge Scientific Abstracts, Water Resources Abstracts, Web of Science, Google Scholar, and others. Additionally, we used unpublished data gathered as part of various investigations conducted primarily by the USGS Northern Prairie Wildlife Research Center.

Information obtained from this search was entered into spreadsheet databases to facilitate data summaries. The detailed databases contain 27 fields that include variables such as taxonomic identification, values for salinity and pH, wetland classification, location of study, and source of data. Appendix 3 provides a detailed description of each variable found in the databases, and appendix 4 includes an annotated description of the data obtained from each source to provide users information on the utility or applicability of the data to their region of interest.

Primer on Salinity Concepts

Salinity Definitions and Measurements

Salinity refers to the concentration of dissolved or soluble salts in water and soil. Salts are generally defined as ionic compounds which in water solution yield a cation other than hydrogen (H^+) and an anion other than hydroxyl (OH^-) or dioxygen (O_2^-). As an example, the following equation displays the chemical formula for common table salt, sodium chloride:

$$Na^+ + Cl^- \leftrightarrow NaCl$$

Common ions (cations and anions) found in northern wetlands, including those within Bowdoin NWR (fig. 2), are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), chloride (Cl^-), and sulfate (SO_4^{2-}) (Swanson and others, 1988; Nimick, 1997; Bauder and others, 2007). When removed from solution (for example, through evaporation), principal salts in water and soils at Bowdoin NWR include sodium sulfate (Na_2SO_4), sodium bicarbonate ($NaHCO_3$), calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), and magnesium sulfate ($MgSO_4$); minor amounts of chlorine (Cl^-) and fluoride (F^-) salts are also found (Bauder and others, 2007).

Measures of salinity for both soil and water are usually expressed as conductance (that is, specific conductance, electrical conductivity) or total dissolved solids (TDS). Specific conductance is a measure of the capacity of an aqueous solution to conduct an electrical current and is highly correlated with the concentration of ions in solution. Conductance measurements also are highly dependent on temperature because an increase in the temperature of a solution will decrease viscosity and increase the mobility of ions in solution; a rise in temperature could also increase the number of ions in solution because of dissociation of molecules. Because of the need to compare conductivity values collected at various temperatures by using differing equipment (that is, probes that differ with respect to electrode distance and area), measurement devices are typically temperature-compensated and provide standardized readings at 25°C with an electrode distance of 1 cm (for example, 1,000 $\mu S\ cm^{-1}$ at 25°C) (Lind, 1985). Specific conductance is commonly reported as millisiemens (mS), microsiemens (µS), millimhos (mmhos), or micromhos (µmhos). Siemens and mhos are equivalent units that are reciprocal of the ohm, the International System (SI) unit of electrical resistance.

Total dissolved solids is a measure of all inorganic and organic substances dissolved in water and is usually presented as parts per thousand (ppt, ‰), percent (%), milligrams per liter ($mg\ L^{-1}$), or total mass (in grams [g]). The concentration of TDS is typically determined by using gravimetry, which involves evaporating a known volume of liquid solvent to leave a residue which is then weighed to determine mass of dissolved solids. Total dissolved solids also may be approximated from specific conductance measurements. For example, specific conductance is typically multiplied by an empirical factor that generally varies from 0.5 to 1.0 to estimate TDS (Lind, 1985). Throughout this report (including the plant and invertebrate databases) $mg\ L^{-1}$ is related to $\mu S\ cm^{-1}$ by using the following formula: $mg\ L^{-1} = \mu S\ cm^{-1} \times 0.64$ (Tchobanoglous and Burton, 1991). As a reference, in figure 3, three common salinity reporting units ($\mu S\ cm^{-1}$, $mg\ L^{-1}$, and ppt) are compared in relation to plant community salinity categories (table 2) described by Stewart and Kantrud (1972).

Sodicity

Sodicity refers to the sodium ion concentration in a soil or solution. Substrates classified as sodic have high sodium ion concentrations relative to other cations such as calcium or magnesium. High sodium concentrations cause soil aggregates to swell and disperse, resulting in destruction of soil structure. In contrast, calcium and magnesium ions cause soil particles to flocculate, forming aggregates that enhance and stabilize soil structure. The extent of soil structure destruction or enhancement caused by cations is not only a function of concentration but also is related to the organic matter content, carbonate and sulfate concentrations (for example, calcite and gypsum), leaching potential, and texture of the soil. The loss of soil structure can affect plant growth by impairing hydraulic conductivity (water movement through soil), drainage, gas exchange, and rooting depth. Additionally, sodicity—and salinity to a certain extent—is often accompanied by high pH, which may impact plant growth by causing nutrient imbalance.

Soils are commonly classified as saline, sodic, or saline-sodic on the basis of a combination of three factors: the sodium adsorption ratio (SAR), specific conductance, and pH (table 3). The SAR is the ratio of sodium to calcium and magnesium cations in solution, defined as

$$SAR = \frac{[Na^{+}]}{\{[Ca^{2+} + Mg^{2+}]/2\}^{1/2}}$$

In general, when the SAR is above 12, physical properties of soil may be altered, and plants can become stressed because of ion toxicity and reduced water absorption (osmotic stress). We do not have specific field data (see table 3) necessary to classify soils found at Bowdoin NWR (table 1); however, on the basis of reported ranges of SAR, specific conductance, and pH values (table 4) for soils on the refuge, all three soil classes likely occur, especially if the classifications were based on the upper end of the reported values (table 4).

Factors Influencing Salinity

When evaluating the suitability of habitats for aquatic biota, it is important to recognize that water and soil salinity can vary considerably both temporally and spatially. Swanson and others (1988) reported that specific conductance measurements for 178 prairie lakes in North Dakota ranged from 365 to 70,000 µS cm^{-1} and that measurements from 1 pothole wetland varied from 522 to 7,700 µS cm^{-1} between a relatively wet and dry year. LaBaugh (1989) reviewed data from northern prairie wetlands and lakes and reported ranges of specific conductance and TDS of 42–472,000 µS cm^{-1} and 31–342,000 mg L^{-1} (approximately 48–534,375 µS cm^{-1}), respectively. Additionally, LaBaugh (1989) described studies in which specific conductance increased twofold to sixfold and salinity increased by 80 ppt (approximately 125,000 µS cm^{-1}) within a season.

Variation in salinity is attributable to many factors, including climate, connectivity to regional and local groundwater flow systems, and intra-annual and interannual fluctuations in water levels that result in the dilution, evapoconcentration, or deflation (blowing of salts from mudflats) of salts (Lieffers and Shay, 1983; LaBaugh, 1989; LaBaugh and others, 1996). For example, between 1975 and 2007 the mean annual salinity in Lake Bowdoin varied from 4,113 (in 1990) to 28,908 (in 1984) µS cm^{-1} (fig. 4). During this 33-year period, Lake Bowdoin was classified as moderately brackish 9 percent, brackish 79 percent, and subsaline 12 percent of the time. Such variation is characteristic of saline lakes, which often experience dynamic shifts in salinity in response to extreme climatic fluctuations that operate at decadal time scales. The influence of climatic variation on Lake Bowdoin salinity flux is illustrated when salinity is examined in relation to the Palmer Hydrological Drought Index (PHDI), which shows long-term cumulative drought and wet conditions (fig. 5). Variation in the PHDI over the past 30 years, or since salinity has been monitored in Lake Bowdoin, indicates two drought periods (1980–85, 1999–2007) and two relatively wet periods (1975–80, 1986–98) (fig. 5). During these alternating wet and dry periods, salinity levels in Lake Bowdoin tended to decrease during wet periods and increase during drought.

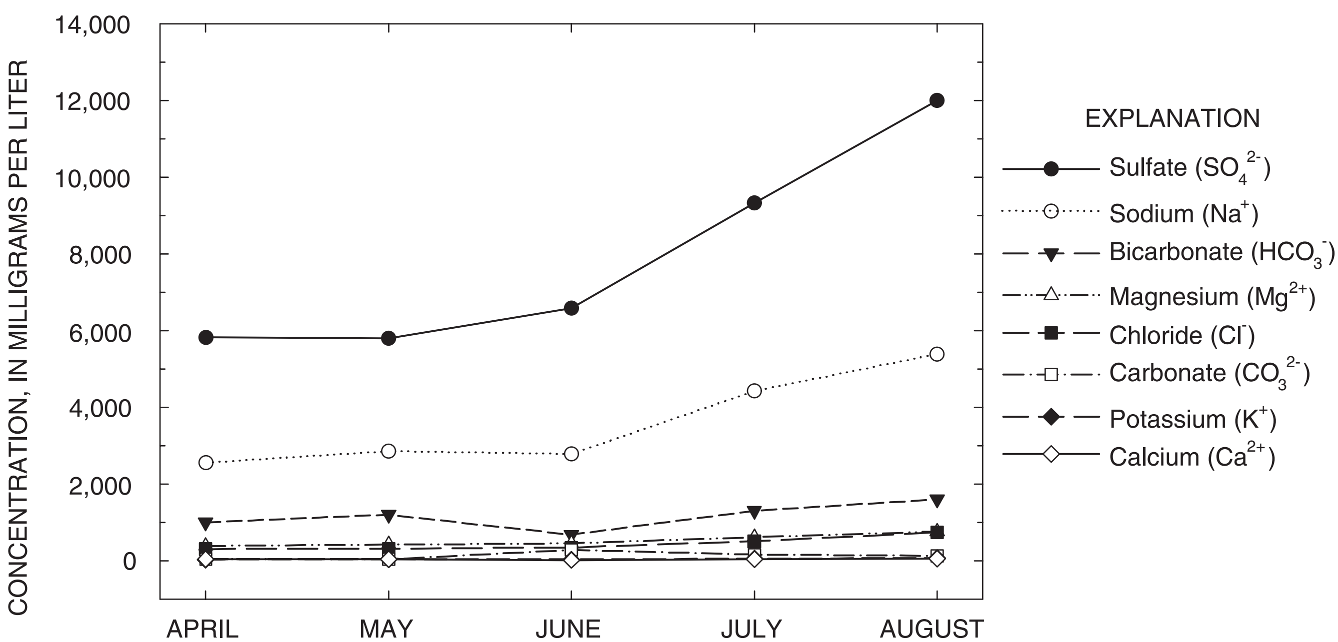


Figure 2. Concentration of major ions in Lake Bowdoin during April–August 2006 (data provided by the U.S. Fish and Wildlife Service).

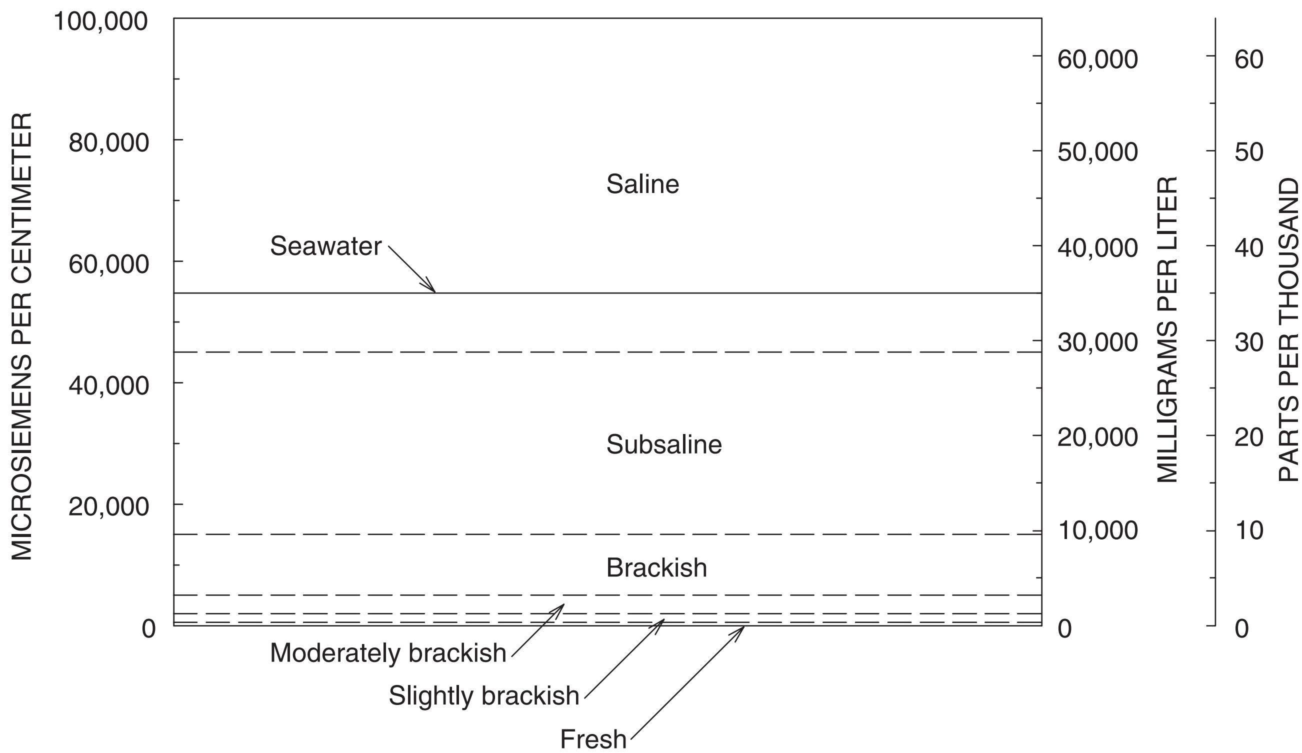


Figure 3. Comparison of common reporting units for salinity in relation to plant community salinity categories (see table 2) and the salinity of seawater (approximately 35 parts per thousand).

Table 2. Plant community salinity categories and the corresponding ranges of specific conductance values of water for three common reporting units.

[Categories from Stewart and Kantrud, 1972. µS cm^{-1}, microsiemens per centimeter; mg L^{-1}, milligrams per liter; ppt, parts per thousand]

Salinity category	µS cm^{-1}	mg L^{-1}	ppt
Fresh	0–500	0–320	0–0.3
Slightly brackish	500–2,000	320–1,280	0.3–1.3
Moderately brackish	2,000–5,000	1,280–3,200	1.3–3.2
Brackish	5,000–15,000	3,200–9,600	3.2–9.6
Subsaline	15,000–45,000	9,600–28,800	9.6–28.8
Saline	>45,000	>28,800	>28.8

Table 3. Classification of saline and sodic soils and related soil condition based on specific conductance, pH, and the sodium adsorption ratio.

[All three criteria—specific conductance, pH, and sodium adsorption ratio (SAR)—are considered for classifying soils as saline, sodic, and saline-sodic (modified from Havlin and others, 1999; North Dakota State University Agriculture and University Extension Service Web site, accessed October 1, 2008, at *http://www.ag.ndsu.edu/pubs/plantsci/soilfert/eb57-2.htm*). µS cm^{-1}, microsiemens per centimeter]

Classification	Soil condition	Specific conductance, µS cm^{-1}	pH	SAR
Saline	Normal[1]	>4,000	<8.5	<13
Sodic	Poor	<4,000	>8.5	>13
Saline-sodic	Normal[1]	>4,000	<8.5	>13

[1]Soil retains “normal” physical conditions as long as sodium does not dominate the exchange complex of the soil.

The increased salinity during drought is attributed to evapoconcentration of solutes; however, drought also provides mechanisms for removal of salt by deflation and seepage to groundwater (Weydemeyer and Marsh, 1936; Hamilton and others, 1989; LaBaugh and others, 1996). Superimposed over these natural processes of deflation and seepage is the effect of water deliveries to the refuge via the Dodson South Canal (fig. 6), which can be used to dilute salts or maintain water levels during dry periods that would normally result in deflation events. Consequently, manipulating water levels provides an opportunity to both trigger and halt deflation episodes.

Decreases in salinity during wet periods are attributed to increased freshwater inputs that dilute salt concentrations. Further, periodic floodwaters that enter the refuge from Beaver Creek not only dilute salts but also flush salts from the system. The most notable Beaver Creek flood event that resulted in significant salt flushing during the past 30 years occurred in 1986 when peak flows exceeded 20,000 ft^3/s (fig. 7*B*); this event coincided with a sixfold salinity decrease in Lake Bowdoin (fig. 5). There are insufficient data to calculate the frequency of Beaver Creek flood events (fig. 7), but refuge personnel estimate that the historical average of floodwater occurrence on the refuge was once every 3–5 years (Rodney and Mohrman, 2006; 2007). More recent observations by refuge staff suggest, however, that the frequency of flood events has decreased to once every 7–10 years. The reduced flood frequency is believed to have been caused by the establishment of small impoundments and irrigation diversions in

Table 4. Reported ranges of specific conductance, pH, and sodium adsorption ratio of soils located at Bowdoin National Wildlife Refuge (see table 1).

[Soil series information obtained from the Natural Resources Conservation Service's Official Soil Series Descriptions, accessed July 2008, at *http://soils.usda.gov/technical/classification/osd/index.html*. µS cm^{-1}, microsiemens per centimeter; SAR, sodium adsorption ratio; --, no data]

Soil series	Total area, in hectares[1]	Taxonomic family	Specific conductance, µS cm^{-1}	pH	SAR
Bigsag	889.5	Fine, smectitic, calcareous, frigid Typic Halaquepts	>16,000	7.9–9.0	13–20
Scobey	820.8	Fine, smectitic, frigid Aridic Argiustolls	--	6.6–8.4	1–8
Elloam	807.7	Fine, smectitic, frigid Aridic Natrustalfs	2,000– 8,000	6.6–9.0	8–25
Kevin	660.5	Fine-loamy, mixed, superactive, frigid Aridic Argiustolls	--	6.6–7.8	--
Phillips	612.1	Fine, smectitic, frigid Aridic Haplustalfs	0–2,000	6.1–7.3	<13
Creed	539.4	Fine, smectitic, frigid Aridic Natrustalfs	0–4,000	6.1–8.4	8–20
Absher	470.4	Fine, smectitic, frigid Leptic Torrertic Natrustalfs	8,000–16,000	6.6–9.6	18–70
Gerdrum	405.0	Fine, smectitic, frigid Torrertic Natrustalfs	1,000–8,000	7.4–9.0	10–20
Bowdoin	387.6	Very-fine, smectitic, frigid Sodic Haplusterts	8,000–16,000	7.4–9.0	5–13
Telstad	350.9	Fine-loamy, mixed, superactive, frigid Aridic Argiustolls	2,000–4,000	6.6–7.8	--
Ferd	237.8	Fine, smectitic, frigid Aridic Haplustalfs	0–2,000	6.6–7.8	<13
Joplin	166.3	Fine-loamy, mixed, superactive, frigid Aridic Argiustolls	0–4,000	6.6–8.4	--
Lardell	154.3	Fine-loamy, mixed, superactive, frigid Typic Aquisalids	>16,000	7.9–10	8–50
Vanda	113.5	Fine, smectitic, calcareous, frigid Torrertic Ustorthents	2,000–8,000	7.8–9.6	1–30
Hillon	35.2	Fine-loamy, mixed, superactive, calcareous, frigid Aridic Ustorthents	--	7.9–9.0	--
Sunburst	28.7	Fine, smectitic, calcareous, frigid Torrertic Ustorthents	--	7.9–8.4	--
Harlake	10.9	Fine, smectitic, calcareous, frigid Aridic Ustifluvents	0–2,000	6.6–8.4	0–8
Lostriver	10.9	Fine, smectitic, calcareous, frigid Aridic Ustifluvents	8,000–16,000	7.4–9.6	13–30
Nishon	8.2	Fine, smectitic, frigid Typic Albaqualfs	--	6.1–8.4	--
Degrand	4.1	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Aridic Argiustolls	--	6.6–7.8	--
Kobase	0.8	Fine, smectitic, frigid Torrertic Haplustepts	0–4,000	6.6–8.4	0–4
McKenzie	0.6	Fine, smectitic, frigid Chromic Endoaquerts	--	--	--

[1]Total area of all soil complexes that include the soil series (see table 1).

the Beaver Creek watershed (fig. 8). For example, Rodney and Mohrman (2006) estimated that irrigation diversion and reservoir retention have reduced total mean annual runoff in the Beaver Creek watershed upstream of Bowdoin NWR by 45 percent.

The observed salinity fluctuations in Lake Bowdoin that occur in relation to changes in climate and associated export mechanisms provide a basis for understanding how management actions and human alterations in the watershed may alter the sustainability of salt-affected lakes. Hence, understanding and defining the key temporal scales of variability in relation to ecological processes are fundamental to saline lake management.

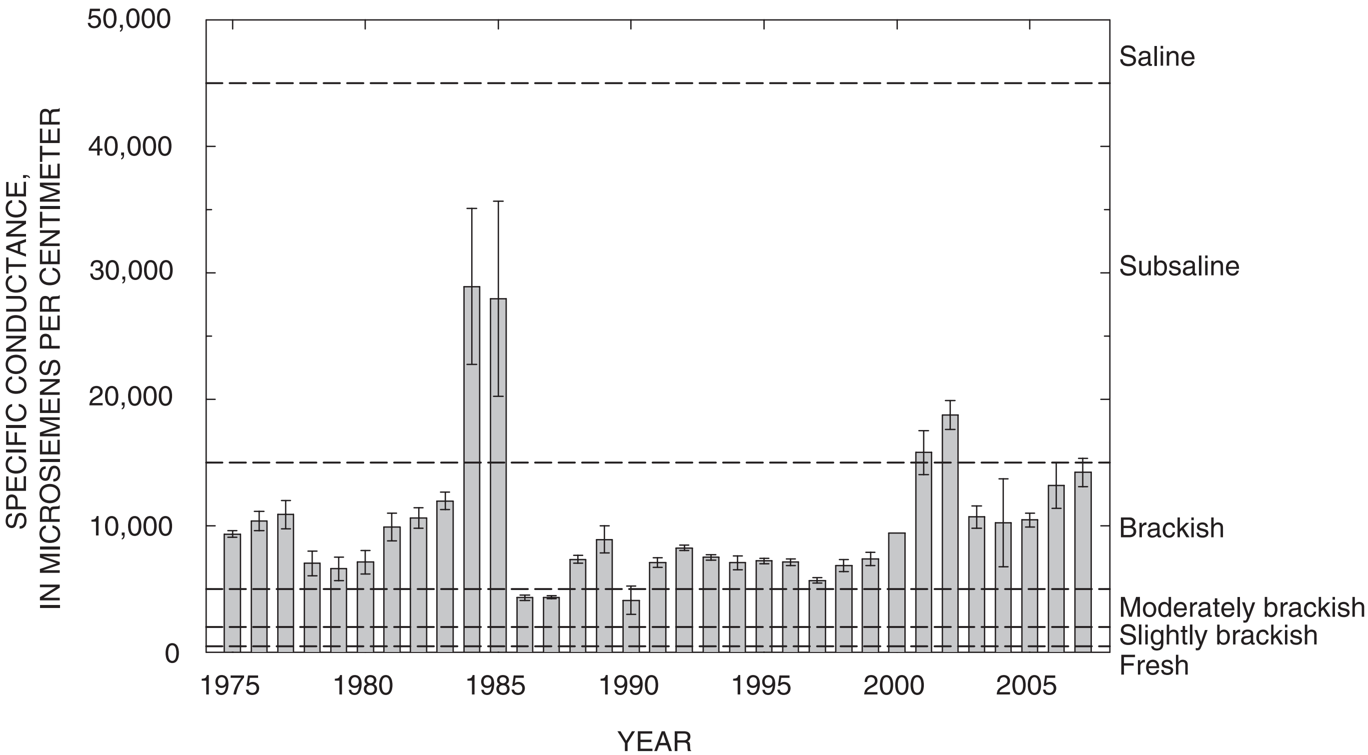


Figure 4. Mean annual (± standard error) specific conductance for Lake Bowdoin from 1975 to 2007. Data were provided by the U.S. Fish and Wildlife Service. Horizontal dashed lines define plant community salinity categories (see table 2) and allow for a general characterization of vegetative composition in Lake Bowdoin from year to year.

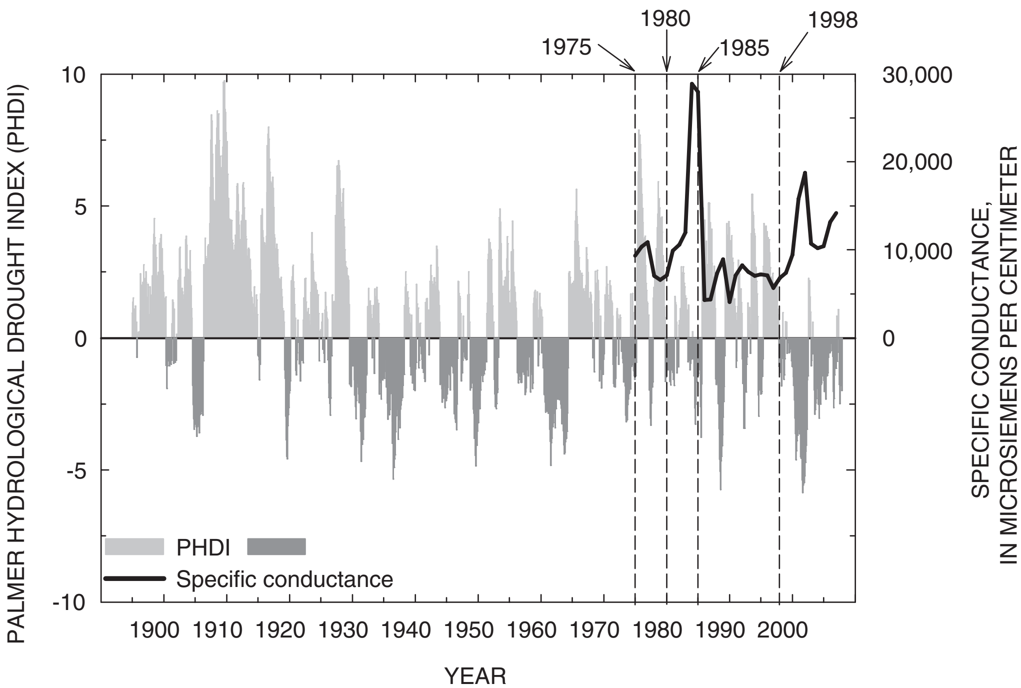


Figure 5. Palmer Hydrological Drought Index (PHDI) from 1895 to 2007 and yearly mean specific conductance for Lake Bowdoin from 1975 to 2007. Positive PHDI values indicate wetter periods, and negative PHDI values indicate dryer periods. Vertical dashed lines represent transitions between recent wet and dry periods. Specific conductance data were provided by the U.S. Fish and Wildlife Service.

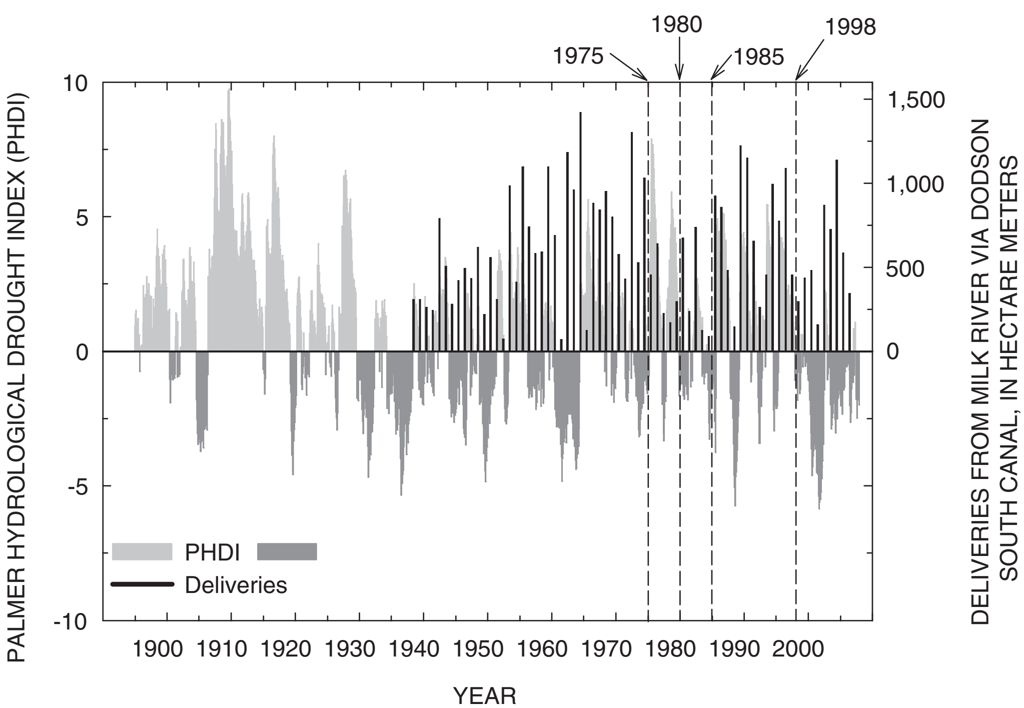


Figure 6. Palmer Hydrological Drought Index (PHDI) from 1895 to 2007 and deliveries to Bowdoin Wildlife Refuge from the Milk River via the Dodson South Canal from 1938 to 2007. Positive PHDI values indicate wetter periods, and negative PHDI values indicate dryer periods. Vertical dashed lines represent transitions between recent wet and dry periods. Delivery data were provided by the U.S. Fish and Wildlife Service.

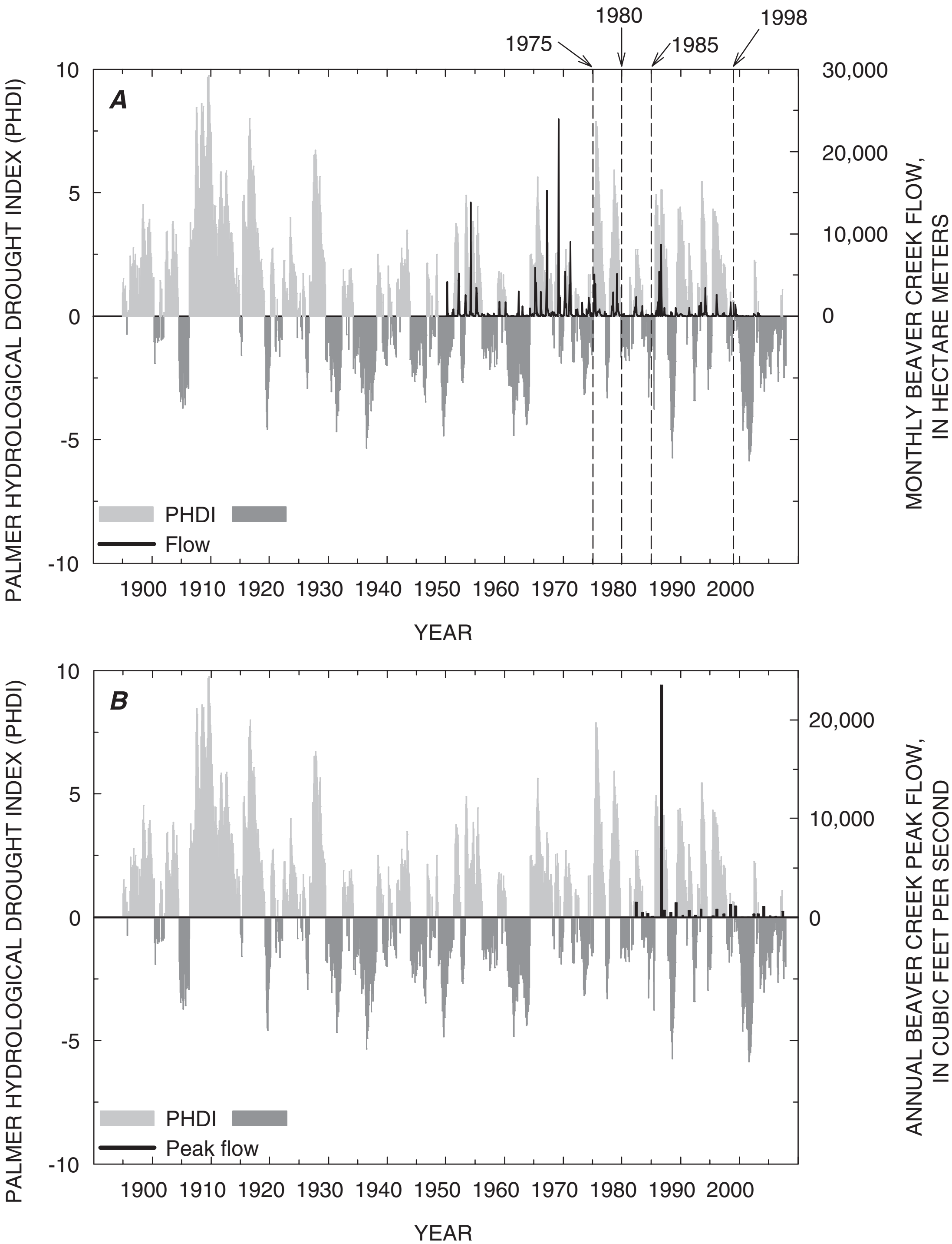


Figure 7. Palmer Hydrological Drought Index (PHDI) from 1895 to 2007 and Beaver Creek flows near Bowdoin National Wildlife Refuge from 1950 to 2007 (monthly) and from 1982 to 2007 (peak). *A*, Monthly flow in hectare meters (data obtained from Parrett, 2005; the streamflow data represent recorded and estimated values). *B*, Annual peak flow in cubic feet per second (data obtained from the U.S. Geological Survey stream gage 06166000). Vertical dashed lines represent transitions between recent wet and dry periods.

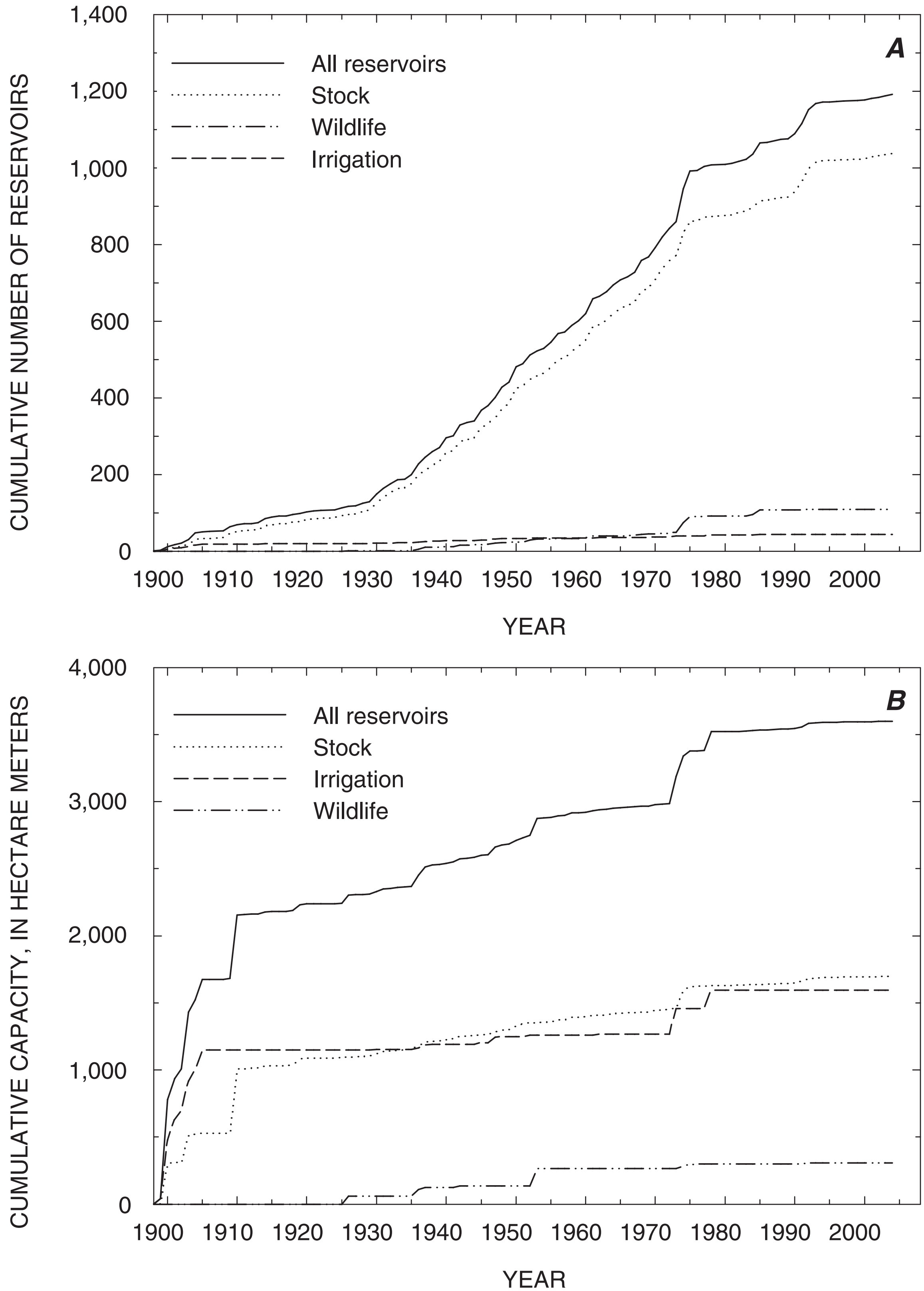


Figure 8. Data on reservoirs in the Beaver Creek watershed created between 1898 and 2004 for watering stock, providing wildlife habitat, and irrigation supply. *A*, Cumulative number of reservoirs. *B*, Water-storage capacity, in hectare meters. Data were provided by Jana Mohrman, Hydrologist, U.S. Fish and Wildlife Service.

Tolerances and Adaptations of Biota to Salinity

Plants

Differences in salinity are often reflected in the species composition of vegetation; thus, salinity has been incorporated as a modifier in many lake and wetland classification systems (Stewart and Kantrud, 1971; Cowardin and others, 1979). Stewart and Kantrud (1972) related the occurrence of 135 plant species in prairie pothole wetlands to six salinity categories (table 2). Of these species, nearly 70 percent did not occur in wetlands classified as brackish, subsaline, and saline (salinity levels greater than 5,000 µS cm^{-1}), and about 35 percent did not occur when salinities exceeded 2,000 µS cm^{-1} (moderately brackish, fig. 9). Hence, relatively few inland wetland plant species can persist in saline environments.

The ability of plants to survive saline environments depends on their capacity to tolerate salts throughout various life cycle stages. Plants capable of growth, flowering, and seed production when rooted in soils with sodium chloride concentrations greater than 0.5 percent are commonly referred to as halophytes (Baskin and Baskin, 1998). In contrast, plants incapable of survival and reproduction in these environments are referred to as glycophytes, or salt-sensitive plants.

The ability of halophytes to grow and survive in saline environments is possible because of various physiological and structural adaptations. Seed germination is affected by many abiotic factors such as temperature, photoperiod, soil moisture, and pH; however, salinity is one of the primary factors that limits seed germination in both glycophytes and halophytes. Baskin and Baskin (1998) reported that concentrations of sodium chloride ranging from about 3,000 (0.3 percent, approximately 4,688 µS cm^{-1}) to 100,000 mg L^{-1} (10 percent, approximately 156,250 µS cm^{-1}) were sufficient to reduce germination rates of many halophytes to about 10 percent

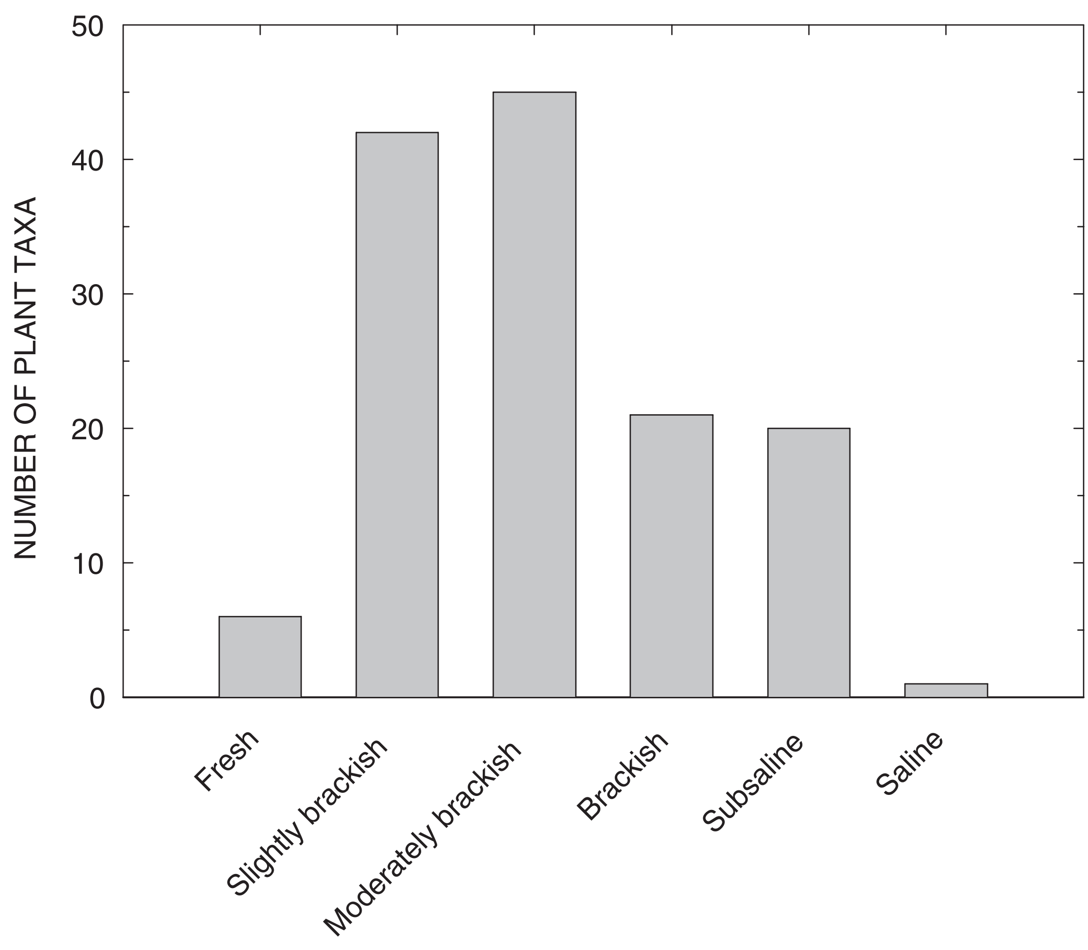


Figure 9. Number of taxa from Prairie Pothole Region wetlands (data from Stewart and Kantrud, 1972) in each plant community salinity category (see table 2); plant taxa were included only in the highest category in which they were found. For example, if a species was found in fresh, slightly brackish, and moderately brackish sites, it was included only in the moderately brackish category for this graph.

(table 5). Reduced germination in halophytes is generally attributed to salinity-induced osmotic stress that inhibits water uptake and production of compounds (for example, enzymes) necessary for germination and embryo development (Baskin and Baskin, 1998). The inhibitory effects also vary by species of salt; for example, potassium chloride (KCl) or magnesium chloride ($MgCl_2$) may affect the germination of a certain plant species more than do other salts, such as sodium chloride or calcium chloride ($CaCl_2$). Additionally, natural ecosystems typically contain a mixture of salts (Swanson and others, 1988), and the presence of one salt may enhance or reduce the adverse effects of another (Baskin and Baskin, 1998; Tester and Davenport, 2003).

Many halophytes exhibit physiological adaptations that allow seeds to remain dormant and not germinate during hypersaline conditions. This trait allows seeds to persist in the soil seed bank until environmental conditions are favorable for germination; for example, seeds will not germinate until climatic events lower salinity through dilution or leaching. Ultimately, dormancy release mechanisms help improve survival during seedling development, which is one of the most salt-sensitive periods of the halophyte life cycle.

After germination and early establishment, salinity can affect halophyte metabolism (for example, decreased rates of photosynthesis and respiration), as well as stimulate anatomical and morphological changes (for example, increased succulence, stomata number and size, cuticle thickness, tylose (bladder-like growth) development, early onset of lignification, and changes in diameter and number of xylem vessels) (Poljakoff-Mayber, 1975). These anatomical adaptations allow halophytes to tolerate osmotic gradients associated with saline environments.

Mature plants absorb salts from the soil solution through their root systems and lose water to the atmosphere via transpiration. These processes result in the accumulation of salts in plant tissues and often lead to high salt concentrations and death in nonhalophytes. In contrast, halophytes have evolved various mechanisms to survive saline environments. Generally, two principal types of halophytes are recognized: those that tolerate excess salts and those that resist excess salts (Ungar, 1974; Baskin and Baskin, 1998). Salt-tolerant halophytes either withstand high intracellular salt concentrations (salt-enduring) or secrete excess salts (salt-excluding) by means of salt glands, by accumulating salts in special hairs, or by transporting salts accumulated in plant structures back to the roots. In contrast, salt-resistant halophytes either do not absorb salts from the soil solution or do not transport salts to sensitive organs or leaves.

High salt concentrations in the soil can also affect plant growth by reducing the water potential gradient. For water to move from the soil to plant tissues, the water potential of the plant must be lower (that is, more negative) than that of the soil. The water potential of the soil is related to the concentration of dissolved solids in the soil-water solution; a high concentration of salts in the soil reduces the soil water potential and decreases the water potential gradient. Essentially, saline soils sequester water, making it unavailable to plants. In addition, as water evaporates from shallow, saline lakes (such as Lake Bowdoin), salts often accumulate as surficial crusts. This crusting can reduce water infiltration, thereby decreasing the availability of water to plants growing on the edges of lakes.

Effective management of salt concentrations to promote the development of vegetation for wildlife habitat will require an understanding of plant adaptations to salinity, which vary by life stage. The general overview provided above is intended only to highlight some of the more common adaptations and life-cycle strategies that should be considered in concert with other important determinants of plant community composition. For example, the simple plant/salinity relations discussed above should be considered in relation to many other factors that significantly influence establishment, growth, and reproduction. Soil pH, texture, temperature, redox potential, moisture, and water depth all influence plant establishment and growth in wetland environments (for example, Stewart and Kantrud, 1972; van der Valk and Davis, 1978; van der Valk, 1981; Fredrickson and Laubhan, 1994; Winter, 2003).

Invertebrates

As with that of plants, the composition of aquatic invertebrate communities can vary greatly in response to changes in salinity. In general, relatively fresh aquatic systems contain diverse invertebrate communities, whereas highly saline systems tend to be dominated by relatively few taxa. It is important to note, however, that even though species richness declines in highly saline systems, biomass often does not (for example, Euliss and others, 1991). Common invertebrates of highly saline systems include copepods and rotifers (particularly some species of the genera *Brachionus* and *Hexarthra*), as well as a small number of insects from the orders Diptera (typically from the families Chironomidae and Culicidae [genus *Aedes*]) and Coleoptera (Pennak, 1989). Shifts in invertebrate community structure that result from increased salinities in prairie wetlands typically include displacement of amphipods (for example, *Hyalella*) and anostracans (for example, *Branchinecta*) by more salt-tolerant brine shrimp (*Artemia*). In addition, a narrow range of insect taxa such as brine flies (Ephydridae) and salt-tolerant water boatmen (Corrixidae) have been found to dominate systems with high salt concentrations (Swanson and others, 1988; Euliss and others, 1999). For example, the insect community of hypersaline (up to 300 mS cm^{-1}) ponds in California was dominated by 1 corixid (*Trichocorixa reticulate*) and 1 midge (*Tanypus grodhausi*) (Euliss and others, 1991), whereas 1 midge species dominated the benthic community of an alkaline lake in central Washington where salinity levels were about 17,000 mg L^{-1} (approximately 26,563 µS cm^{-1}). Species richness in this lake increased two to eight times as salinity levels were reduced to about 1,500 mg L^{-1} (approximately 2,344 µS cm^{-1}), with the highest number of species occurring

Table 5. Sodium chloride concentration at which seed germination of halophytic plant species was reduced from 75–100 percent to approximately 10 percent.

[Modified from Baskin and Baskin, 1998. NaCl, sodium chloride; mg L^{-1}, milligrams per liter]

Genus	Species	NaCl concentration		Genus	Species	NaCl concentration	
		Molarity	mg L^{-1}			Molarity	mg L^{-1}
Melilotus	*indica*	0.05	2,922.0	*Sporobolus*	*virginicus*	0.26–>0.60	15,194.4–>35,064.0
Salicornia	*bigelovii*	0.05–0.06	2,922.0–3,506.4	*Suaeda*	*nudiflora*	0.26	15,194.4
Sarcobatus	*vermiculatus*	0.06–0.15	3,506.4–8,766.0	*Aster*	*tripolium*	0.34–0.60	19,869.6–35,064.0
Zygophyllum	*qatarense*	0.07	4,090.8	*Atriplex*	*halimus*	0.34	19,869.6
Distichlis	*spicata*	0.09	5,259.6	*Atriplex*	*patula*	0.34	19,869.6
Glaux	*maritima*	0.09	5,259.6	*Cotula*	*coronopifolia*	0.34	19,869.6
Plagianthus	*divaricatus*	0.09	5,259.6	*Mesembryanthemum*	*australe*	0.34	19,869.6
Scirpus	*americanus*	0.09	5,259.6	*Phragmites*	*communis*	0.34	19,869.6
Scirpus	*olneyi*	0.09	5,259.6	*Polypogon*	*monspeliensis*	0.34	19,869.6
Selliera	*radicans*	0.09	5,259.6	*Prosopis*	*farcta*	0.34–0.6	19,869.6–35,064.0
Spergularia	*salina*	0.09	5,259.6	*Salicornia*	*patula*	0.34	19,869.6
Triglochin	*striatum*	0.09–0.17	5,259.6–9,934.8	*Atriplex*	*griffithii*	0.35	20,454.0
Iva	*annua*	0.13–0.17	7,597.2–9,934.8	*Cochlearia*	*danica*	0.43	25,129.2
Zannichellia	*pedunculata*	0.13	7,597.2	*Rumex*	*crispus*	0.43	25,129.2
Ceratoides	*lanata*	0.17–0.34	9,934.8–19,869.6	*Puccinellia*	*distans*	0.45	26,298.0
Hordeum	*jubatum*	0.17–0.31	9,934.8–18,116.4	*Puccinellia*	*lemmoni*	0.45	26,298.0
Juncus	*maritimus*	0.17	9,934.8	*Halopeplis*	*amplexicaulis*	0.50	29,220.0
Melaleuca	*ericifolia*	0.17	9,934.8	*Atriplex*	*triangularis*	0.51	29,804.4
Myrica	*cerifera*	0.17	9,934.8	*Limonium*	*bellidifolium*	0.60	35,064.0
Schoenus	*nitens*	0.17	9,934.8	*Limonium*	*vulgare*	0.60	35,064.0
Scirpus	*robustus*	[1]0.17–0.20	[1]9,934.8–11,688.0	*Salsola*	*kali*	0.60	35,064.0
Spergularia	*marina*	0.17–0.34	9,934.8–19,869.6	*Salicornia*	*pacifica*	0.68	39,739.2
Suaeda	*linearis*	0.17	9,934.8	*Spartina*	*alterniflora*	0.68	39,739.2
Melilotus	*segetalis*	0.20	11,688.0	*Puccinellia*	*festucaeformis*	0.75	43,830.0
Melilotus	*messanensis*	>0.20	>11,688.0	*Cressa*	*cretica*	0.85	49,674.0
Sesuvium	*portulacastrum*	0.2–>0.60	11,688.0–>35,064.0	*Salicornia*	*europaea*	0.85	49,674.0
Atriplex	*canescens*	0.21	12,272.4	*Suaeda*	*depressa*	0.85	49,674.0
Salicornia	*brachystachya*	[1]0.24	[1]14,025.6	*Tamarix*	*pentandra*	[1]0.85	[1]49,674.0
Salicornia	*dolichostachya*	[1]0.24	[1]14,025.6–14,025.6	*Suaeda*	*japonica*	0.90	52,596.0
Atriplex	*prostrata*	0.26	15,194.4	*Kochia*	*americana*	1.02	59,608.8
Atriplex	*polycarpa*	0.26	15,194.4	*Zygophyllum*	*dumosa*	1.51	88,244.4
Plantago	*coronopus*	0.26	15,194.4	*Salicornia*	*herbacea*	1.70	99,348.0
Salicornia	*emerici*	0.26	15,194.4				

[1]Highest concentration of NaCl tested; seeds could germinate at higher concentrations.

at levels ranging from 2,000 to 3,000 mg L^{-1} (approximately 3,125 to 4,688 µS cm^{-1}) (Wiederholm, 1980).

A majority of aquatic invertebrates are able to tolerate a relatively large range of salt concentrations, but few species can survive in highly saline waters. Most invertebrate species are unable to maintain their internal salt and water balance when placed in a solution that contains greater than 0.9 percent (9,000 mg L^{-1} or approximately 14,063 µS cm^{-1}) salts, or roughly 25 percent the salt content of seawater (Pennak, 1989; Hart and others, 1991). Only a narrow assemblage of euryhaline organisms (for example, inhabitants of estuaries and tide pools) can thrive in both freshwater and marine environments. In general, habitats that support a large number of common freshwater fauna have concentrations of TDS that range from about 10 to 1,000 mg L^{-1} (approximately 16 to 1,563 µS cm^{-1}) (Pennak, 1989; Hart and others, 1991). Salinity levels in inland lakes and wetlands, however, can vary considerably, and the few species that can tolerate extremely high salt concentrations require highly specialized and efficient osmoregulatory systems to maintain a proper internal balance of salt and water. Since water will tend to move into the hypertonic (high salt) tissues of freshwater invertebrates through permeable surfaces such as epithelia, cuticle, chitin, and gills (Pennak, 1989), these species have developed various adaptations such as contractile vacuoles, flame bulb systems, nephridia, and various glandular structures that are capable of forming highly dilute urine (hypotonic to body fluids) that is excreted in great quantities. As a result, concentrations of internal salts and water remain somewhat constant.

Similar to that of plants, the salinity tolerance of aquatic invertebrates often varies by life stage, with immature organisms often exhibiting less tolerance to salts than do adults (Euliss and others, 1999; Brock and others, 2005; Pinder and others, 2005). Many species of Coleoptera and Hemiptera are able to exist in prairie wetlands in spite of highly variable salinities because their adult stages are capable of flying to suitable habitats. Conversely, many nonflying aquatic invertebrates and immature stages of flying insects must rely on various adaptations that allow them to endure highly saline habitats, including burrowing into substrates or producing ephippia (resting eggs), cysts, or waterproof secretions (Euliss and others, 1999). For example, cladocerans such as *Daphnia* sp. produce ephippia that remain viable in the substrate until conditions are favorable for hatching. Because of the high mobility of some adult invertebrates and the inability of many immature aquatic invertebrates to cope with high salinities, the presence of adults in highly saline wetlands does not necessarily indicate the presence of a persistent population (Pinder and others, 2005).

Database Summary Statistics

Plants

The plant database (*http://pubs.usgs.gov/sir/2009/5098/downloads/databases_21april2009.xls*) contains information on 411 taxa obtained from 17 studies conducted in 9 States and 3 Canadian Provinces, as well as literature that did not specify a location (apps. 4 and 5). Figure 10 is a graphic portrayal of the compiled data by the number of plant taxa in relation to source (fig. 10*A*), location (fig. 10*B*), wetland classification (fig. 10*C*), wetland indicator category (fig. 10*D*), plant physiognomy/life-span (fig. 10*E*), and salinity categories (fig. 10*F*). We used this database to compute the minimum and maximum reported specific conductance and pH by substrate (soil, water) for each plant taxon (app. 5).

Invertebrates

The invertebrate database (*http://pubs.usgs.gov/sir/2009/5098/downloads/databases_21april2009.xls*) contains 330 taxa obtained from 7 sources (apps. 4 and 6) that represent studies from 3 States, 2 Canadian Provinces, and Australia. Figure 11 provides a summary of the number of invertebrate taxa by source (fig. 11*A*), location (fig. 11*B*), wetland classification (fig. 11*C*), taxonomic classification (fig. 11*D*), and salinity maxima (fig. 11*E*). Appendix 6 contains the minimum and maximum specific conductance and pH for invertebrate taxa included in the database.

Considerations in Using Information from the Plant and Invertebrate Databases

The plant and invertebrate databases represent information obtained from an extensive search of the scientific literature and unpublished data; however, it is not considered comprehensive. Data are derived primarily from field studies conducted in natural wetland ecosystems rather than from experimentally derived tolerance values. Users should consider the following aspects and limitations when creating summaries or conducting analyses:

1. The data represent information from numerous geographic locations (for example, Iowa, North Dakota, Prairie Pothole Region, Manitoba) and wetland types (for example, palustrine, lacustrine, salt-marsh); users may want to focus on, or exclude data from, a certain region or wetland type.

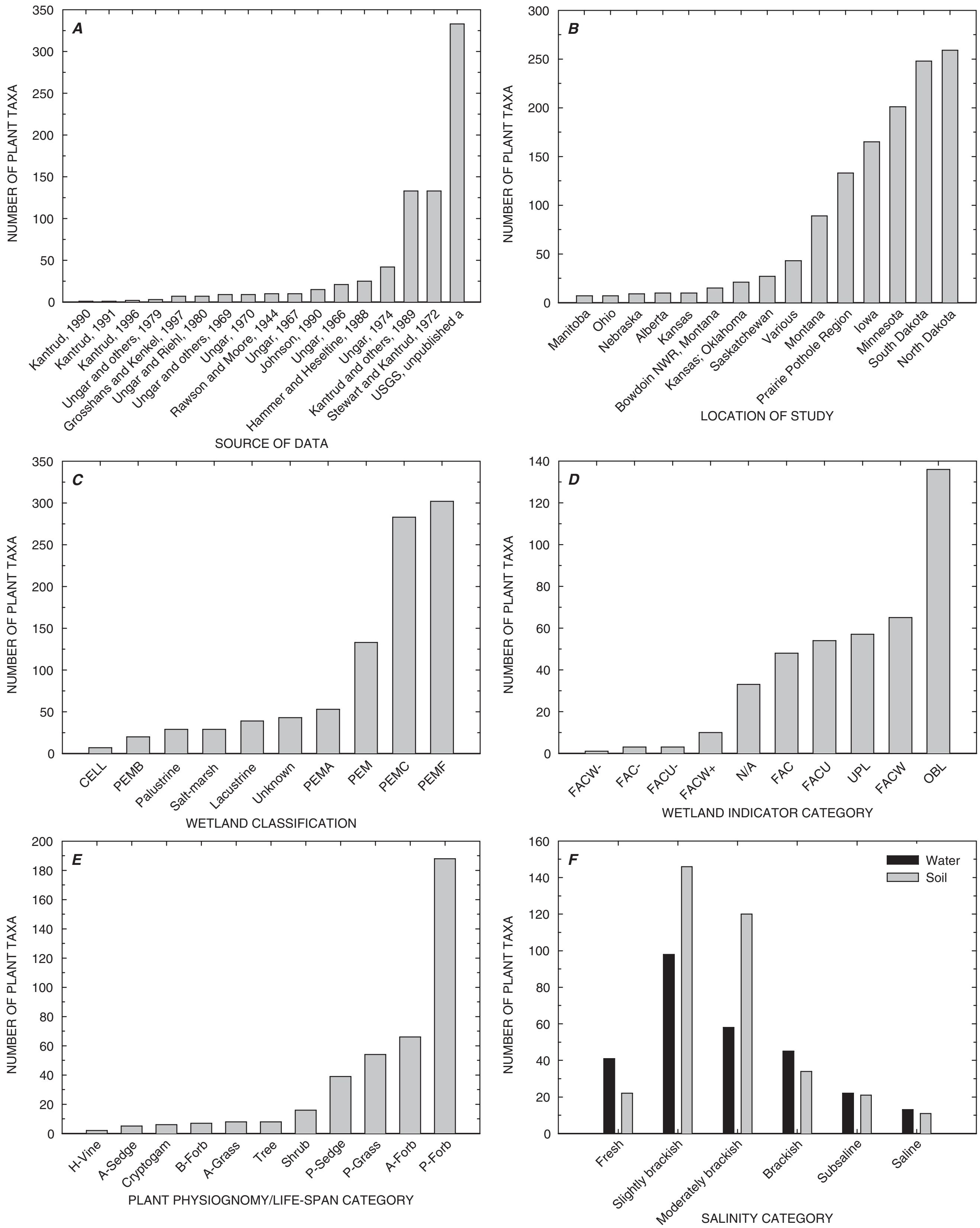
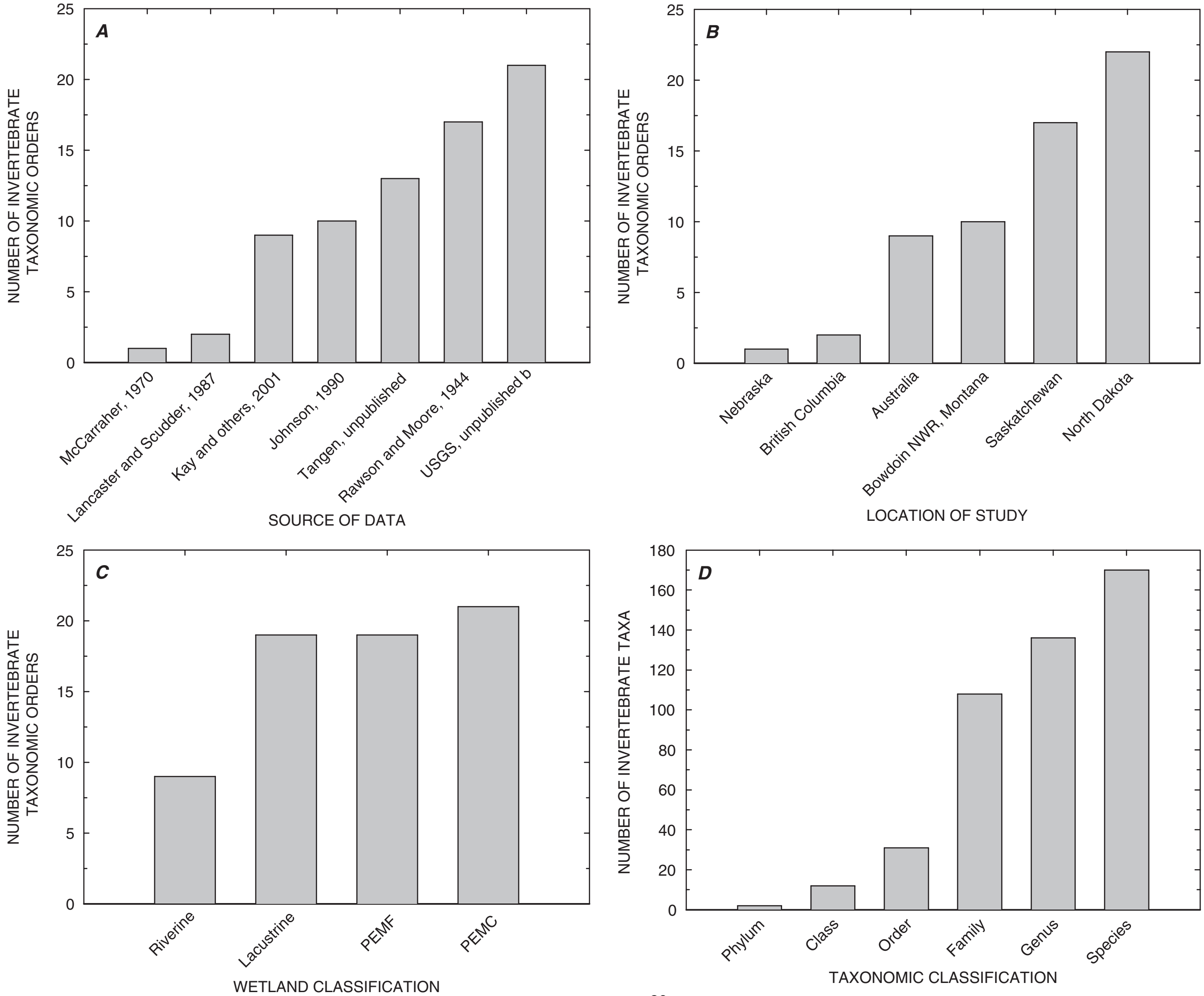


Figure 10. Number of taxa from the plant database by various categories. *A*, Data source. *B*, Location. *C*, Classification. *D*, Wetland indicator category. *E*, Plant physiognomy/life-span category. See appendix 3 for definitions of variables within each category. *F*, The number of taxa from the plant database in relation to plant community salinity categories presented in table 2. Plant taxa were included in each category on the basis of the maximum reported salinity of soil and water.



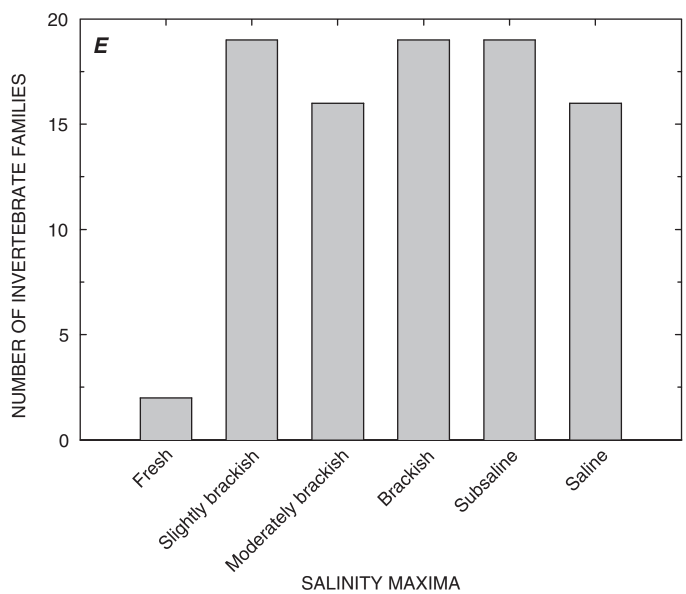


Figure 11. Number of taxonomic orders from the invertebrate database for each category. *A*, Data source. *B*, Location. *C*, Classification. See appendix 3 for definitions of variables within each category. *D*, Depiction of the number of taxa that were reported at each level of taxonomic classification. *E*, The number of taxa from the invertebrate database in relation to plant community salinity categories presented in table 2. Invertebrate taxa were included in each category on the basis of the maximum reported salinity of water.

2. To avoid misinterpretation, users should always consider the database variables DATA_TYPE and CONDUCTIVITY_CODE. DATA_TYPE defines whether the water-quality value (for example, specific conductance) was reported as a single measurement or as a summarized value such as a mean, median, minimum, or maximum. For consistency, salinity units were converted to microsiemens in the databases. The variable CONDUCTIVITY_CODE identifies whether the original study reported the value as microsiemens, or if it was converted (see Methods, above).
3. For consistency, taxonomic and common names for plants were based on The Great Plains Flora Association (1986) when possible. Therefore, the variables GENUS and SPECIES do not necessarily represent the scientific names reported by the original source; the variables GENUS_R and SPECIES_R present the scientific name reported by the original study.
4. Users of the invertebrate database must first determine which taxonomic classification is most appropriate since individual studies report invertebrate occurrences at varying degrees of resolution (for example, Order, Family, Genus, Species). Resolution will be lost when using a higher taxonomic classification such as Order, whereas using a lower taxonomic classification such as Genus may result in the loss of some information on occurrence.
5. Certain taxa in both databases may have only been reported in a single or small number of studies. Therefore, salinity values for specific taxa may be limited by a paucity of data. Additionally, many studies that report salinity values are conducted in highly saline systems and focus only on salt-tolerant taxa; therefore, many common freshwater taxa may not be well represented.
6. It is important to consider that many abiotic factors that control wetland plant and invertebrate community composition are highly dynamic and exhibit seasonal and annual fluctuations. Therefore, salinity or other measurements recorded on a given day or year may not be representative of the site during other time periods. Consequently, the occurrence of plant and invertebrate taxa recorded at a site may be influenced by factors, or values of factors, other than those occurring at the time of sampling.
7. For both plants and invertebrates, tolerance to salinity can vary significantly depending on life stage. Mature plants may be able to survive in saline conditions as long as the proper conditions existed during the period of germination, which is often earlier in the year when snowmelt and spring rains dilute waters and result in lower salinities. Similarly, presence of mobile adult invertebrates does not necessarily indicate the presence of a persistent population.

Application to Bowdoin National Wildlife Refuge

Plants

There are about 210 plant species documented on Bowdoin NWR according to a vegetation survey conducted in the late 1980s and early 1990s (app. 1). Of these plants, the database compiled for this report includes information for 110 species that was obtained from 13 known locations distributed among 9 types of aquatic systems, 8 wetland indicator categories, and 11 plant physiognomy/life-span categories (table 6). On the basis of this information, at least some taxa in each plant physiognomy and wetland indicator category can tolerate fresh to moderately brackish habitats (fig. 12; based on 10th and 90th percentile ranges); however, most taxa within each category (based on mean and median as measures of central tendency) tolerate only slightly brackish

Table 6. Summary information from the plant database (210 total species) for 110 species documented on Bowdoin National Wildlife Refuge (app. 1).

[Data were obtained from 13 known locations and represent 9 types of aquatic systems (classification), 8 wetland indicator categories, and 11 plant physiognomy/life-span categories]

Location	Alberta, Iowa, Kansas, Manitoba, Minnesota, Montana, Nebraska, North Dakota, Ohio, Oklahoma, Prairie Pothole Region, Saskatchewan, South Dakota, "unknown"
Classification[1]	CELL, LACUSTRINE, PALUSTRINE, PEM, PEMA, PEMB, PEMC, PEMF, SALT-MARSH, "unknown"
Wetland indicator category[2] (number of taxa)	FAC (10), FAC- (1), FACU (26), FACU- (2), FACW (9), FACW+ (1), OBL (30), UPL (24), n/a (7)
Plant physiognomy/life-span[3] category (number of taxa)	A-forb (19), A-grass (6), A/P-forb (3), B-forb (1), cryptogam (2), H-vine (1), P-forb (45), P-grass (17), P-sedge (7), shrub (5), tree (4)

[1]See variable "CLASSIFICATION" in app. 3 for definitions.

[2]See variable "WIC" in app. 3 for definitions.

[3]See variable "PHYSIOGNOMY" in app. 3 for definitions.

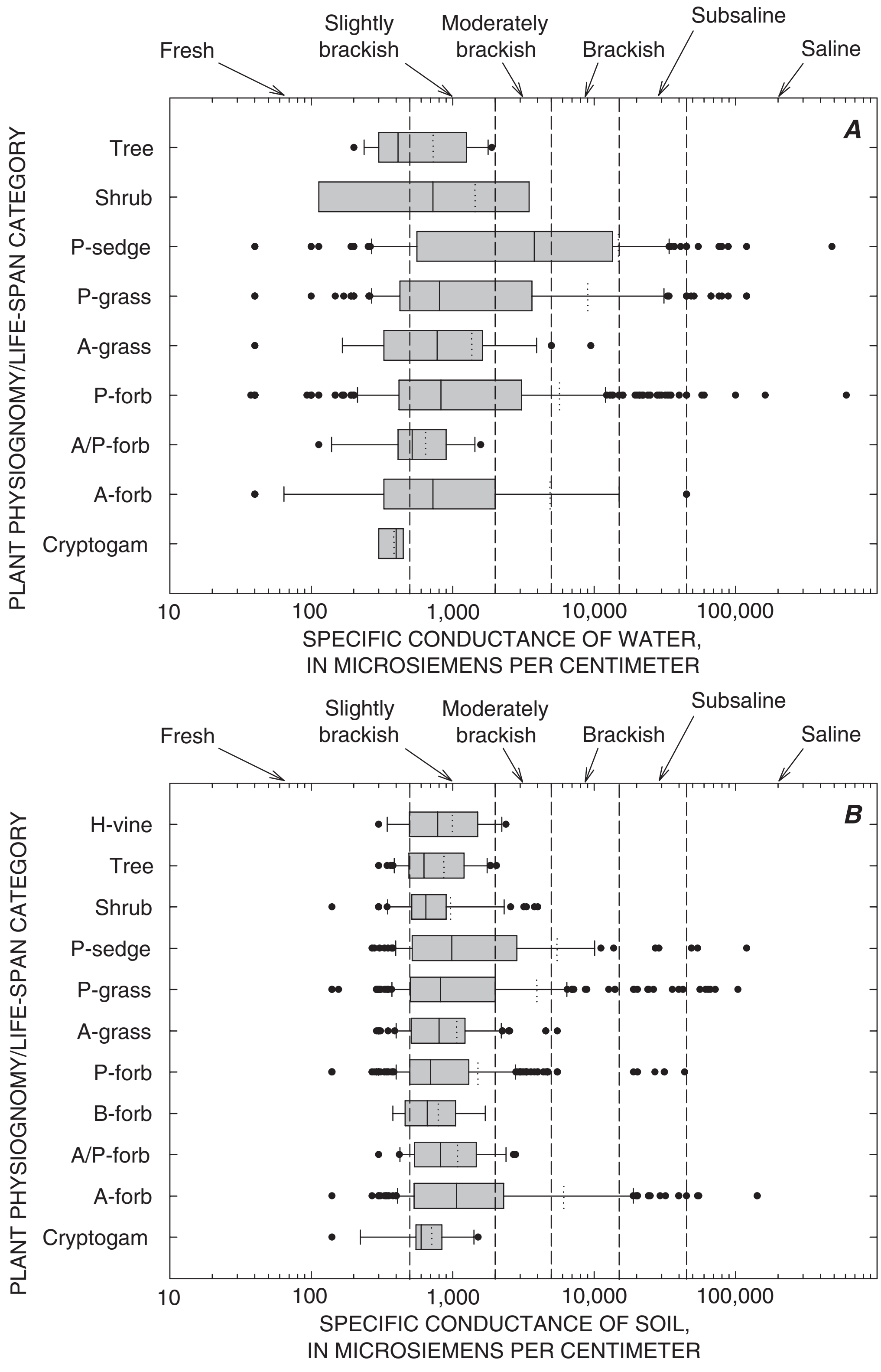


Figure 12. Specific conductance of water and soil for each plant physiognomy/life-span category and each wetland indicator category (see variables "PHYSIOGNOMY" and "WIC" in app. 3). *A*, Specific conductance of water for each plant physiognomy/life-span category. *B*, Specific conductance of soil for each plant physiognomy/life-span category. *C*, Specific conductance of water for each wetland indicator category. *D*, Specific conductance of soil for each wetland indicator category. The data represent taxa identified at Bowdoin National Wildlife Refuge (app. 1) that are found in the plant database. The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles (horizontal boxes with error bars); and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).

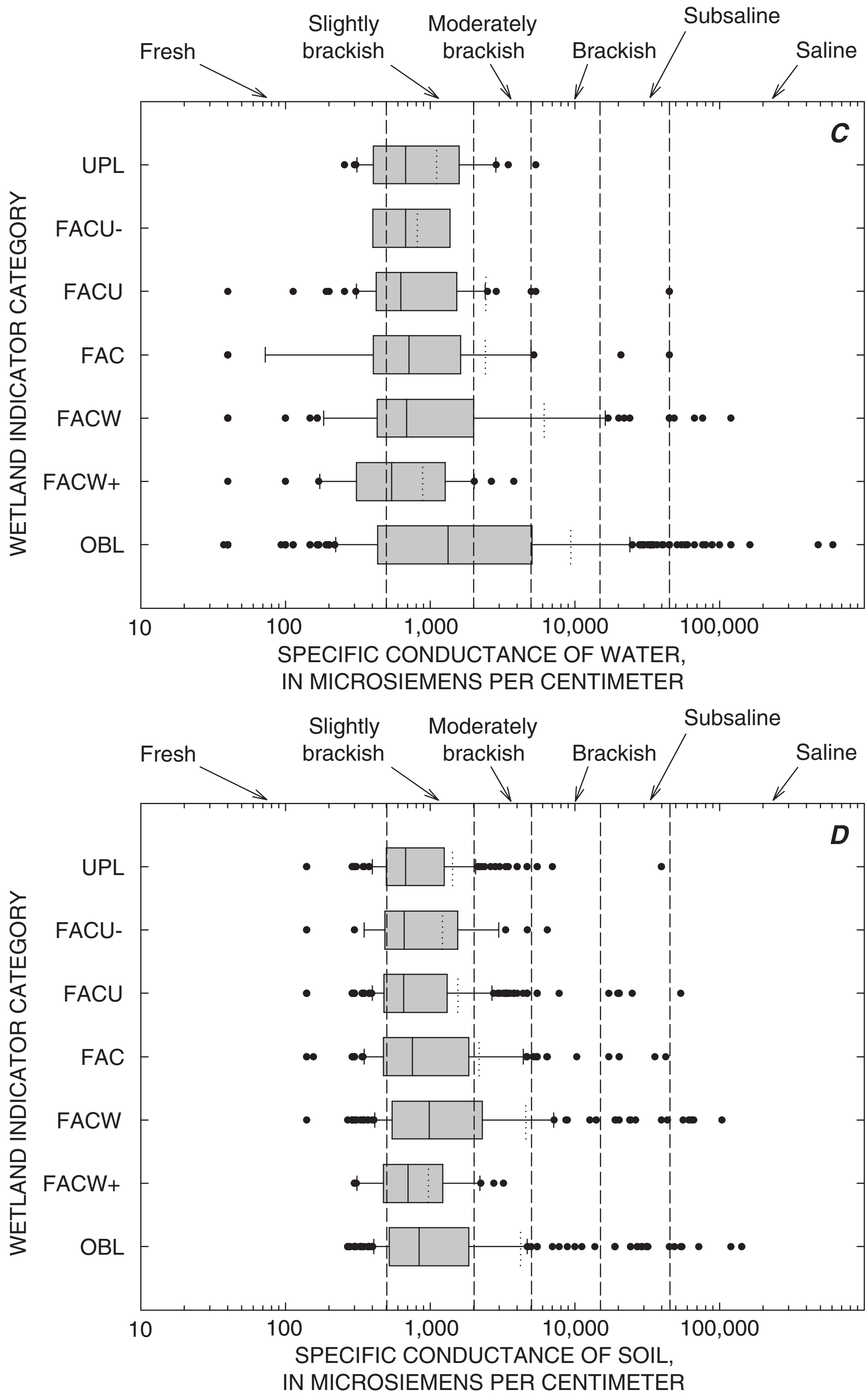


Figure 12. Specific conductance of water and soil for each plant physiognomy/life-span category and each wetland indicator category (see variables "PHYSIOGNOMY" and "WIC" in app. 3). *A*, Specific conductance of water for each plant physiognomy/life-span category. *B*, Specific conductance of soil for each plant physiognomy/life-span category. *C*, Specific conductance of water for each wetland indicator category. *D*, Specific conductance of soil for each wetland indicator category. The data represent taxa identified at Bowdoin National Wildlife Refuge (app. 1) that are found in the plant database. The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles (horizontal boxes with error bars); and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).—Continued

conditions (figs. 13, 14). Most of the dominant plant species found on the refuge (see *Description of Bowdoin National Wildlife Refuge*) exhibited the greatest tolerance to salinity. Examples include hardstem bulrush (*Scirpus acutus*), alkali bulrush (*S. paludosus*), common threesquare (*S. americanus*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia rubra*), sago pondweed (*Potomogeton pectinatus*), and widgeon-grass (*Ruppia maritima*). Few of these species, however, appear to tolerate salinities above brackish (approximately 15,000 µS cm^{-1}).

Invertebrates

Most of the taxonomic orders and families of aquatic invertebrates known to occur on the refuge (app. 2) are represented in the database (figs. 15, 16). Examination of invertebrates at the taxonomic level of family (fig. 16) indicates that most families can occur in fresh to brackish habitats; however, the greatest diversity tends to occur within slightly to moderately brackish habitats. Similar to that of plants, information on invertebrates compiled in the database suggests that few taxa appear capable of tolerating salinities above brackish (approximately 15,000 µS cm^{-1}).

Summary

We reviewed and summarized relevant literature to assess the relation between salinity and composition of biotic communities associated with freshwater ecosystems. This is not a comprehensive literature review and should not be considered exhaustive. Further, we do not report experimentally derived threshold values (for example, minimum or maximum salt tolerance) for individual plant or invertebrate species; instead, we present data obtained from field surveys that describe species occurrences across naturally fluctuating ranges of salinity and other environmental factors (for example, salt composition, temperature, pH). This approach allows for the prediction of broad species assemblages that have the potential to occur in wetlands with varying ranges of salinity that should facilitate evaluation of various management practices and strategies aimed at enhancing wildlife habitat. As an example, wetlands on Bowdoin NWR are characterized by elevated salinity levels that have been exacerbated by changes in land use and past management activities that enhance water inputs into a closed basin. The high salinity levels have had a negative impact on the ability of wetlands to support waterfowl, which is one of the primary objectives of the refuge. Refuge staff can use the information presented in this report to evaluate various management strategies designed to remove salts from wetlands and create environmental conditions that favor establishment of plant and invertebrate communities that are highly attractive to waterfowl. In addition, refuge staff can use this information to help establish specific (for example, obtain a specific range of salinity levels) rather than general (for example, reduce salinity levels) management goals. A primary focus of this report was to provide information to address the salinity problem at Bowdoin NWR, but information in the database, as well as concepts and information discussed, is intended to be applicable to other areas or refuges. Ideally, information in the database will be augmented with additional field studies by resource managers (for example, salinity monitoring, vegetation inventories) to facilitate a better understanding of the ecological relations between salinity and flora and fauna when developing management strategies.

Acknowledgments

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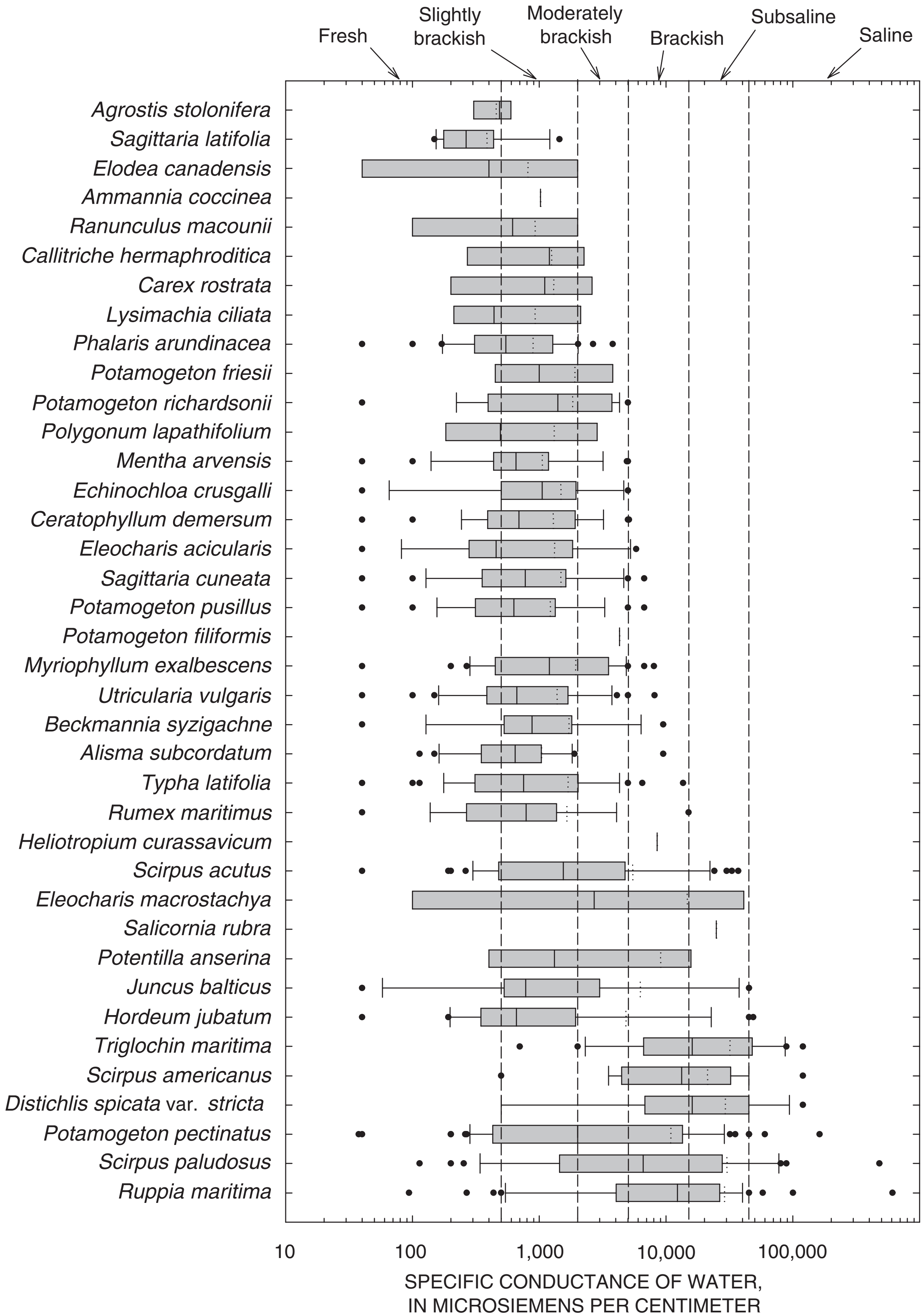

Figure 13. Specific conductance of water for common plant species at Bowdoin National Wildlife Refuge that are associated with wetlands (FACW, FACW+, OBL; see variable "WIC" in app. 3). The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles (horizontal boxes with error bars); and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).

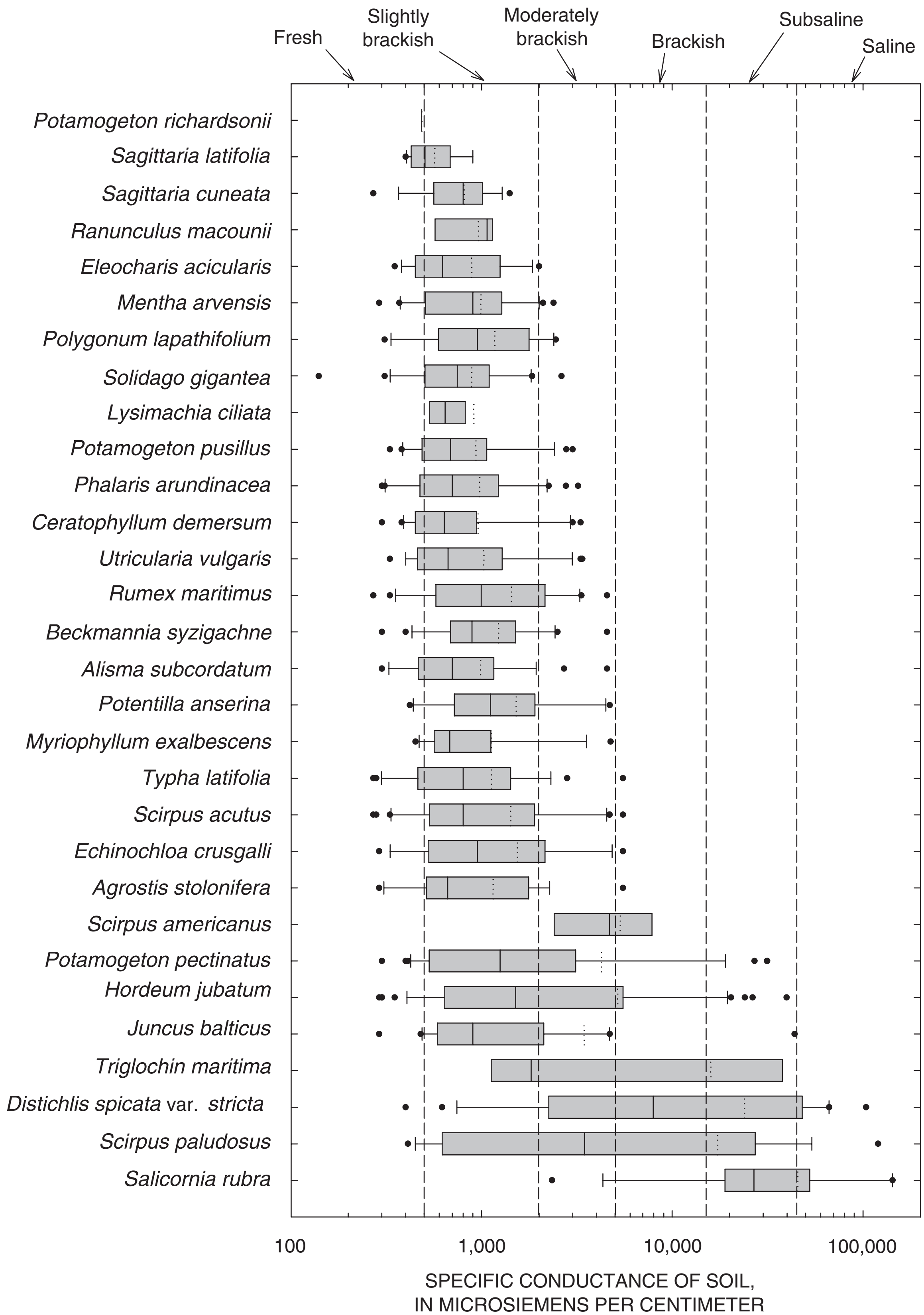

Figure 14. Specific conductance of soil for common plant species at Bowdoin National Wildlife Refuge that are associated with wetlands (FACW, FACW+, OBL; see variable "WIC" in app. 3). The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles (horizontal boxes with error bars); and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).

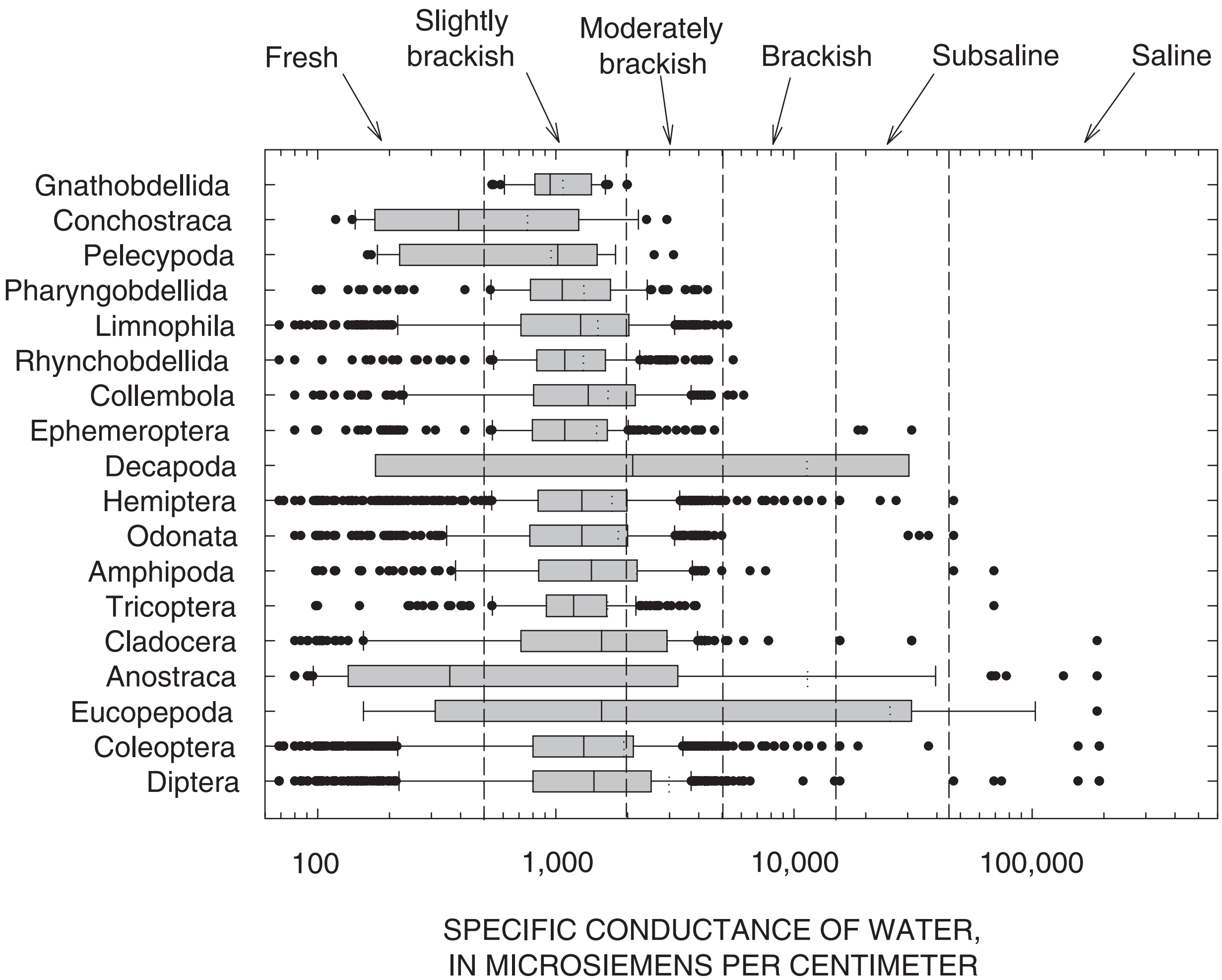

Figure 15. Specific conductance of water for representative taxa in the invertebrate database that could occur at Bowdoin National Wildlife Refuge. The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles as horizontal boxes with error bars; and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).

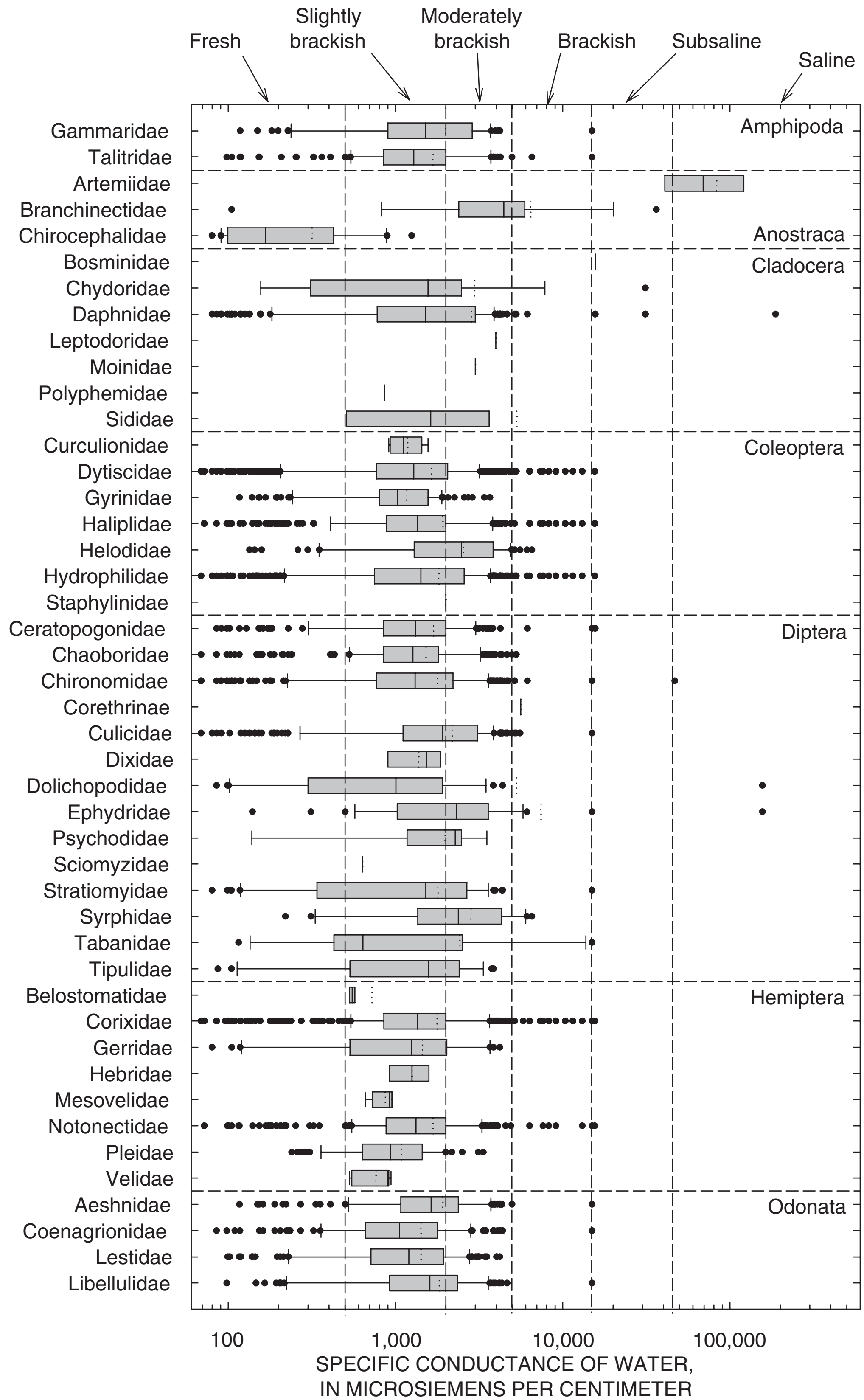

Figure 16. Specific conductance of water for invertebrate families from representative taxonomic orders in the invertebrate database. The box plots show the median (solid line); mean (dotted line); 10th, 25th, 75th, and 90th percentiles (horizontal boxes with error bars); and outliers (dots). Vertical dashed lines delineate boundaries for plant community salinity categories (table 2).

References

Baskin, C.C., and Baskin, J.M., 1998, Seeds—ecology, biogeography, and evolution of dormancy and germination: San Diego, Calif., Academic Press, 666 p.

Bauder, J.W., Hershberger, K., and Sessom, H., 2007, Bowdoin National Wildlife Refuge salt mitigation impact review: Bozeman, Montana State University, Department of Land Resources and Environmental Sciences, Open-file report to Montana Reserve Water Rights Compact Commission, Technical Advisory Team, April 2007, 81 p.

Brock, M.A., Nielsen, D.L., and Crossle, K., 2005, Changes in biotic communities developing from freshwater wetland sediments under experimental salinity and water regimes: Freshwater Biology, v. 50, p. 1376–1390.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Fish and Wildlife Service, 131 p.

DuBois, K.L., Palawski, D.U., and Malloy, J.C., 1992, Bowdoin National Wildlife Refuge contaminants biomonitoring study: Helena, Mont., U.S. Fish and Wildlife Service, Contaminant Report R6/207H/92, 53 p.

Euliss, N.H., Jr., Jarvis, R.L., and Gilmer, D.S., 1991, Standing crops and ecology of aquatic invertebrates in agricultural drainwater ponds in California: Wetlands, v. 11, p. 179–190.

Euliss, N.H., Jr., Wrubleski, D.A., and Mushet, D.M., 1999, Wetlands of the Prairie Pothole Region—invertebrate species composition, ecology, and management, *in* Batzer, D.P., Rader, R.B., and Wissinger, S.A., eds., Invertebrates in freshwater wetlands of North America—ecology and management: New York, N.Y., John Wiley & Sons, Inc., p. 471–514.

Fredrickson, L.H., and Laubhan, M.K., 1994, Managing wetlands for wildlife, *in* Bookhout, T.A., ed., Research and management techniques for wildlife and habitats: Bethesda, Md., The Wildlife Society, p. 623–647.

Grosshans, R.E., and Kenkel, N.C., 1997, Dynamics of emergent vegetation along natural gradients of water depth and salinity in a prairie marsh—delayed influences of competition, *in* Goldsborough, L.G., and Hann, B.J., eds., University of Manitoba Field Station (Delta Marsh) thirty-second annual report: Portage la Prairie, Manitoba, Canada, p. 83–93.

Hamilton, D.B., Roelle, J.E., and Schafer, W.M., 1989, A simulation model of water and salt balance at Bowdoin National Wildlife Refuge: Fort Collins, Colo., U.S. Fish and Wildlife Service, National Ecology Research Center, NERC-89/08, 60 p.

Hammer, U.T., and Heseltine, J.M., 1988, Aquatic macrophytes in saline lakes of the Canadian prairies: Hydrobiologia, v. 158, p. 101–116.

Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C., and Swadling, K., 1991, A review of the salt sensitivity of the Australian freshwater biota: Hydrobiologia, v. 210, p. 105–144.

Havlin, J.L., Beaton, J.D., Tisdale, S.L., and Nelson, W.L., eds., 1999, Soil fertility and fertilizers (6th ed.): Upper Saddle River, N.J., Prentice Hall, 515 p.

Johnson, K.M., 1990, Aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin National Wildlife Refuge: Bozeman, Montana State University, master's thesis.

Kantrud, H.A., 1990, Sago pondweed (*Potamogeton pecinatus* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Resource Publication 176, 89 p.

Kantrud, H.A., 1991, Widgeongrass (*Ruppia maritima* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Research 10, 58 p.

Kantrud, H.A., 1996, The alkali (*Scirpus maritimus* L.) and saltmarsh (*S. robustus* Pursh) bulrushes—a literature review: Washington, D.C., National Biological Service Information and Technology Report 6, 77 p.

Kantrud, H.A., Millar, J.B., and van der Valk, A.G., 1989, Vegetation of wetlands of the prairie pothole region, *in* van der Valk, A., ed., Northern prairie wetlands: Ames, Iowa State University Press, p. 132–187.

Kay, W.R., Halse, S.A., Scanlon, M.D., and Smith, M.J., 2001, Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia: Journal of the North American Benthological Society, v. 20, p. 182–199.

Kendy, E., 1999, Simulation of water and salt budgets and effects of proposed management strategies for Bowdoin National Wildlife Refuge, northeastern Montana: Helena, Mont., U.S. Geological Survey Water-Resources Investigations Report 98–4260, 86 p.

LaBaugh, J.W., 1989, Chemical characteristics of water in northern prairie wetlands, *in* van der Valk, A., ed., Northern prairie wetlands: Ames, Iowa State University Press, p. 56–90.

LaBaugh, J.W., Winter, T.C., Swanson, G.A., Rosenberry, D.O., Nelson, R.D., and Euliss, N.H., Jr., 1996, Changes in atmospheric circulation patterns affect midcontinent wetlands sensitive to climate: Limnology and Oceanography v. 41, p. 864–870.

Lambing, J.H., Jones, W.E., and Sutphin, J.W., 1988, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in Bowdoin National Wildlife Refuge and adjacent areas of the Milk River Basin, northeastern Montana, 1986-87: Helena, Mont., U.S. Geological Survey Water-Resources Investigations Report 87–4243, 71 p.

Laubhan, M.K., Gleason, R.A., Knutsen, G.A., and Euliss, N.H., Jr., 2006, A preliminary biological assessment of Long Lake National Wildlife Refuge Complex, North Dakota: Washington, D.C., U.S. Fish and Wildlife Service Biological Technical Publication BTP R6006-2006, 66 p.

Lieffers, V.J., and Shay, J.M., 1983, Ephemeral saline lakes on the Canadian prairies—their classification and management for emergent macrophyte growth: Hydrobiologia, v. 105, p. 85–94.

Lind, O.T., 1985, Handbook of common methods in limnology (2d ed.): Dubuque, Iowa, Kendall/Hunt Publishing Company, 199 p.

Moss, B., 1998, Ecology of fresh waters—man and medium, past to future (3d ed.): Blackwell Science, Inc., 557 p.

Nimick, D.A., 1997, Hydrology and water chemistry of the Benton Lake basin with emphasis on the fate of dissolved solids at Benton Lake National Wildlife Refuge, west-central Montana: Helena, Mont., U.S. Geological Survey Water-Resources Investigations Report 97-4100, 79 p.

Parrett, C., 2005, Synthesis of monthly and annual streamflow records (water years 1950-2003) for Big Sandy, Clear, Peoples, and Beaver Creeks in the Milk River Basin, Montana: Reston, Va., U.S. Geological Survey Scientific Investigations Report 2005–5216, 29 p.

Pennak, R.W., 1989, Fresh-water invertebrates of the United States—Protozoa to Mollusca (3d ed.): New York, N.Y., John Wiley & Sons, Inc., 628 p.

Pinder, A.M., Halse, S.A., McRae, J.M., and Shiel, R.J., 2005, Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity: Hydrobiologia, v. 543, p. 1–24.

Poljakoff-Mayber, A., 1975, Morphological and anatomical changes in plants as a response to salinity stress, *in* Poljakoff-Mayber, A., and Gale, J., eds., Plants in saline environments: New York, Heidelberg, Berlin, Springer-Verlag, p. 97–117.

Rawson, D.S., and Moore, J.E., 1944, The saline lakes of Saskatchewan: Canadian Journal of Research, v. 22, p. 141–201.

Rodney, M., and Mohrman, J., 2006, Analysis of stock reservoirs in Beaver Creek Basin, Montana, for downstream effects near Bowdoin National Wildlife Refuge: Lakewood, Colo., U.S. Fish and Wildlife Service, Mountain-Prairie Region, Report dated July 5.

Stewart, R.E., and Kantrud, H.A., 1971, Classification of natural ponds and lakes in the glaciated prairie region: Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 92, 57 p.

Stewart, R.E., and Kantrud, H.A., 1972, Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors: Washington, D.C., U.S. Geological Survey Professional Paper 585-D, 36 p.

Swanson, G.A., Winter, T.C., Adomaitis, V.A., and LaBaugh, J.W., 1988, Chemical characteristics of prairie lakes in south-central North Dakota—their potential for influencing use by fish and wildlife: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Technical Report 18, 44 p.

Tchobanoglous, G., and Burton, F.L., 1991, Wastewater engineering; treatment, disposal, and reuse (3d ed.): New York, N.Y., Metcalf & Eddy, Inc., McGraw-Hill Inc., 1,024 p.

Tester, M., and Davenport, R., 2003, Na^+ tolerance and Na^+ transport in higher plants: Annals of Botany, v. 91, p. 503–527.

The Great Plains Flora Association, 1986, Flora of the Great Plains: Lawrence, University Press of Kansas, 1,402 p.

Ungar, I.A., 1966, Salt tolerance of plants growing in saline areas of Kansas and Oklahoma: Ecology, v. 47, p. 154–155.

Ungar, I.A., 1967, Vegetation-soil relationships on saline soils in northern Kansas: American Midland Naturalist, v. 78, p. 98–120.

Ungar, I.A., 1970, Species-soil relationships on sulfate dominated soils of South Dakota: American Midland Naturalist, v. 83, p. 343–357.

Ungar, I.A., 1974, Inland halophytes of the United States, *in* Reimold, R.J., and Queen, W.H., eds., Ecology of halophytes: New York, N.Y., Academic Press, Inc., p. 235–305.

Ungar, I.A., Benner, D.K., and McGraw, D.C., 1979, The distribution and growth of Salicornia Europaea on an inland salt pan: Ecology, v. 60, p. 329–336.

Ungar, I.A., Hogan, W., and McClelland, M., 1969, Plant communities of saline soils at Lincoln, Nebraska: The American Midland Naturalist, v. 82, p. 564–577.

Ungar, I.A., and Riehl, T.E., 1980, The effect of seed reserves on species composition in zonal halophyte communities: Botanical Gazette, v. 141, p. 447–452.

U.S. Department of Agriculture, 2004, Soil survey of Phillips County area, Montana, part I: Washington, D.C., U.S. Department of Agriculture, Natural Resources Conservation Service, 226 p.

van der Valk, A.G., 1981, Succession in wetlands—a Gleasonian approach: Ecology, v. 62, p. 688–696.

van der Valk, A.G., and Davis, C.B., 1978, The role of seed banks in the vegetation dynamics of prairie glacial marshes: Ecology, v. 59, p. 322–335.

Weydemeyer, W., and Marsh, V.L., 1936, The bird life of Lake Bowdoin, Montana: The Condor, v. 38, p. 185–198.

Wiederholm, T., 1980, Effects of dilution on the benthos of an alkaline lake: Hydrobiologia, v. 68, p. 199–207.

Winter, T.C., ed., 2003, Hydrological, chemical, and biological characteristics of a prairie pothole wetland complex under highly variable climate conditions—the Cottonwood Lake area, east-central North Dakota: Washington, D.C., U.S. Geological Survey Professional Paper 2003–1675, 109 p.

Woods, A.J., Omernik, J., Nesser, M., Shelden, J.A., Comstock, J., Azevedo, J.A., and Sandra, H., 2002, Ecoregions of Montana (2d ed.), (color poster with map, descriptive text, summary tables, and photographs): Corvallis, Oreg., U.S. Environmental Protection Agency, Western Ecology Division, map scale 1:1,500,000.

Appendix 1. Plant Taxa Identified at Bowdoin National Wildlife Refuge

Plant taxa (genus and species; common name) identified at Bowdoin National Wildlife Refuge during a preliminary vegetation survey conducted from 1987 to 1993 by researchers from the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and the Southeastern Wisconsin Regional Planning Commission. Taxa followed by an asterisk (*) are in the plant/salinity database. Nomenclature follows The Great Plains Flora Association (1986).

Acer negundo; box elder
Achillea millefolium; yarrow*
Agropyron cristatum; crested wheatgrass*
Agropyron repens; quackgrass*
Agropyron smithii; western wheatgrass*
Agropyron spicatum; bluebunch wheatgrass
Agrostis stolonifera; redtop*
Alisma subcordatum; common water plantain*
Allium textile; onion
Amaranthus retroflexus; rough pigweed*
Ambrosia artemisiifolia; common ragweed, short ragweed*
Ammannia coccinea; toothcup*
Anemone patens; pasque flower
Apocynum androsaemifolium; spreading dogbane
Arnica fulgens; arnica
Artemisia cana; dwarf sagebrush
Artemisia dracunculus; silky wormwood*
Artemisia frigida; prairie sagewort*
Artemisia ludoviciana; white sage*
Aruncus pubescens; bride's feathers
Asclepias speciosa; showy milkweed*
Asparagus officinalis; asparagus
Aster ericoides; white aster*
Aster floralvinda; wild aster
Aster puniceus; swamp aster
Aster sp.; wild aster*
Astragalus pectinatus; tine-leaved milk-vetch, narrow-leave
Astragalus racemosus; alkali milk-vetch, creamy poison-vetch
Avena fatua; wild oats*
Beckmannia syzigachne; sloughgrass*
Betula papyrifera; paper birch, canoe birch
Bouteloua gracilis; blue grama
Brassica kaber; charlock*
Bromus inermis; smooth brome*
Bromus japonicus; Japanese brome*
Bromus porteri; nodding brome
Bromus tectorum; downy brome*
Buchloe dactyloides; buffalo grass
Callitriche hermaphroditica; northern water starwort*
Cardaria draba; hoary cress
Carex brevior; fescue sedge*
Carex deweyana; sedge
Carex hookerana; sedge
Carex rostrata; beaked sedge*
Castilleja sulphurea; Indian paintbrush
Centaurea maculosa; spotted knapweed
Cerastium arvense; prairie chickweed
Cerastium brachypodum; nodding chickweed*
Ceratophyllum demersum; hornwort, coontail*
Cheilanthes feei; lip fern
Chenopodium sp.; goosefoot, lamb's quarter*
Chrysanthemum leucanthemum; ox-eye daisy, marguerite
Chrysopsis villosa; golden aster
Chrysothamnus nauseosus; rabbit brush
Cirsium arvense; Canada thistle, field thistle*
Cirsium undulatum; wavy-leaf thistle
Cirsium vulgare; bull thistle*
Clematis pseudoalpina; virgin's bower
Clematis terniflora; virgin's bower
Cleome serrulata; rocky mountain bee plant
Collomia linearis; collomia
Convolvulus arvensis; field bindweed*
Dactylis glomerata; orchard grass*
Distichlis spicata var. *stricta*; inland saltgrass*
*Echinacea angustifo*lia; purple coneflower
Echinochloa crusgalli; barnyard grass*
Elaeagnus angustifolia; Russian olive*
Eleocharis acicularis; needle spikerush*
Eleocharis macrostachya; common spikerush*
Elodea canadensis; Canadian waterweed*
Elodea nuttallii; waterweed
Elymus canadensis; Canada wild rye*
Elymus glaucus; blue wild rye
Epilobium angustifolium; willow-herb
Equisetum arvense; field horsetail*
Equisetum fluviatile; water horsetail*
Eragrostis cilianensis; stinkgrass
Erigeron glabellus; fleabane
Erigeron sp.; fleabane
Eriogonum flavum; yellow wild buckwheat
Escobaria vivipara; spinystar
Euphorbia esula; leafy spurge*
Euphorbia glyptosperma; ridge-seeded spurge
Fraxinus pennsylvanica; green ash*
Galium boreale; northern bedstraw*
Gaura coccinea; scarlet gaura
Glycyrrhiza lepidota; wild licorice*
Grindelia squarrosa; curly-top gumweed*
Gutierrizia sarothrae; snakeweed
Helianthus laetiflorus; sunflower
Helianthus maximiliani; maximilian sunflower*
Heliotropium curassavicum; seaside heliotrope*
Hordeum jubatum; foxtail barley*
Hydrochloa carolinensis; water grass
Hystrix patula; bottlebrush grass
Iva axillaris; poverty weed
Juncus balticus; baltic rush*
Juncus sp.; rush*
Juniperus communis; common or dwarf juniper
Kochia scoparia; kochia*
Koeleria cristata; junegrass
Lactuca oblongifolia; blue lettuce
Lactuca serriola; prickly lettuce*
Lappula echinata; blue stickseed
Lappula occidentalis; flatspine stickseed
Lappula redowskii; stickseed

Lappula texana; cupseed stickseed
Lepidium perfoliatum; clasping peppergrass
Lepidium sp.; peppergrass
Liatris punctata; dotted blazing star*
Linaria vulgaris; butter-and-eggs
Lupinius flexuosus; lupine
Lygodesmia juncea; skeletonweed*
Lysimachia ciliata; fringed loosestrife*
Machaeranthera spinulosus; aster
Malva moschata; musk mallow
Malva neglecta; common mallow*
Medicago lupulina; black medick*
Medicago sativa; alfalfa*
Melilotus officinalis; yellow sweet clover*
Mentha arvensis; field mint*
Monarda spicata; horse mint, beebalm
Myriophyllum exalbescens; American milfoil*
Oenothera villosa; common evening primrose
Opuntia polyacantha; plains prickly pear
Oxytropis lambertii; purple locoweed
Oxytropis sericea; white locoweed
Panicum miliaceum; broom-corn millet
Penstemon albidus; white beardtongue
Petalostemum purpurea; purple prairie clover
Phalaris arundinacea; reed canarygrass*
Phleum pratense; timothy*
Phlox douglasii; phlox
Pinus ponderosa; ponderosa pine
Plantago lanceolata; English plantain, buckhorn
Plantago major; common plantain*
Poa pratensis; Kentucky bluegrass*
Poa sandbergii; Sandberg's bluegrass*
Polanisia dodecandra; clammy-weed
Polemonium haydeni; Jacob's-ladder
Polygonum aviculare; knotweed*
Polygonum buxiforme; knotweed
Polygonum convolvulus; climbing or wild buckwheat*
Polygonum lapathifolium; pale smartweed*
Polygonum persicaria; lady's thumb
Polygonum ramosissimum; bushy knotweed*
Populus deltoides; cotton-wood*
Potamogeton filiformis; slender pondweed*
Potamogeton friesii; Fries' pondweed*
Potamogeton pectinatus; sago pondweed*
Potamogeton pusillus; baby pondweed*
Potamogeton richardsonii; claspingleaf pondweed*
Potentilla anserina; silverweed*
Potentilla argentea; silvery cinquefoil
Potentilla arguta; tall cinquefoil*
Potentilla rivalis; brook conquefoil*
Prunus virginiana; choke cherry
Psoralea argophylla; silver-leaf scurf-pea*
Ranunculus longirostric; white water crowfoot
Ranunculus macounii; Macoun's buttercup*
Ratibida columnifera; prairie coneflower*
Rhus aromatica; fragrant sumac, polecat bush
Ribes odoratum; buffalo currant
Rosa arkansana; prairie wild rose*
Rosa woodsii; western wild rose*
Rudbeckia sp.; coneflower
Rumex maritimus; golden dock*
Rumex sp.; dock, sorrel*
Rumex venosus; wild begonia
Ruppia maritima; ditchgrass, widgeon grass*
Sagittaria cuneata; arrowhead*
Sagittaria graminea; arrowhead
Sagittaria latifolia; common arrowhead*
Salix exigua subs. *interior*; sandbar willow*
Salix sp.; willow*
Salsola iberica; russian thistle*
Sarcobatus vermiculatus; greasewood
Scirpus acutus; hardstem bulrush*
Scirpus americanus; chairmaker's bulrush*
Scirpus paludosus; cosmopolitan bulrush*
Senecio integerrimus; groundsel
Setaria sp.; foxtail*
Setaria viridis; green foxtail
Shepherdia argentea; buffaloberry
Silene cserei; smooth catchfly
Sisymbrium altissimum; tumbling mustard
Solidago gigantea; late goldenrod*
Solidago juncea; early goldenrod
Solidago missouriensis; prairie goldenrod*
Solidago rigida var. *rigida*; rigid goldenrod*
Sonchus arvensis; field sow thistle*
Sparganium emersum; bur-reed
Sphaeralcea coccinea; red false mallow
Sporobolus airoides; alkali sacaton*
Sporobolus asper; rough dropseed
Stipa comata; needle-and-thread*
Stipa spartea; porcupine-grass
Stipa viridula; green needlegrass*
Symphoricarpos occidentalis; western snowberry*
Symphoricarpos orbiculatus; coralberry, buckbrush
Taraxacum officinale; common dandelion*
Thlaspi arvense; field pennycress*
Tragopogan dubius; goat's beard, western salsify
Triglochin maritima; seaside arrowgrass*
Typha latifolia; broad-leaved cat-tail*
Utricularia vulgaris; common bladderwort*
Verbena bracteata; prostrate vervain
Vicia americana; American vetch*
Yucca glauca; soapweed, yucca
Zigadenus venenosus; death camass

References

The Great Plains Flora Association, 1986, Flora of the Great Plains: Lawrence, University Press of Kansas, 1,402 p.

Appendix 2. Invertebrate Taxa Identified at Bowdoin National Wildlife Refuge

Invertebrate taxa identified at Bowdoin National Wildlife Refuge by Johnson (1990) and DuBois and others (1992). All taxa are in the invertebrate/salinity database.

Phylum	Class	Order	Family
Annelida	Hirudinea		
Annelida	Oligochaeta		
Arthropoda	Arachnoidea	Hydracarina	
Arthropoda	Branchiopoda	Cladocera	
Arthropoda	Copepoda		
Arthropoda	Insecta	Coleoptera	
Arthropoda	Insecta	Diptera	Ceratopogonidae
Arthropoda	Insecta	Diptera	Chironomidae
Arthropoda	Insecta	Diptera	Culicidae
Arthropoda	Insecta	Diptera	Ephydridae
Arthropoda	Insecta	Diptera	Stratiomyidae
Arthropoda	Insecta	Diptera	Tabanidae
Arthropoda	Insecta	Diptera	
Arthropoda	Insecta	Ephemeroptera	Baetidae
Arthropoda	Insecta	Ephemeroptera	Caenidae
Arthropoda	Insecta	Ephemeroptera	
Arthropoda	Insecta	Hemiptera	Corixidae
Arthropoda	Insecta	Hemiptera	Notonectidae
Arthropoda	Insecta	Hemiptera	
Arthropoda	Insecta	Odonata	Aeshnidae
Arthropoda	Insecta	Odonata	Coenagrionidae
Arthropoda	Insecta	Odonata	Libellulidae
Arthropoda	Insecta	Tricoptera	Leptoceridae
Arthropoda	Insecta	Tricoptera	Phryganeidae
Arthropoda	Insecta	Tricoptera	Polycentropodidae
Arthropoda	Insecta	Tricoptera	
Arthropoda	Malacostraca	Amphipoda	Gammaridae
Arthropoda	Malacostraca	Amphipoda	Talitridae
Mollusca	Gastropoda	Limnophila	Lymnaeidae
Mollusca	Gastropoda	Limnophila	Physidae
Mollusca	Gastropoda	Limnophila	Planorbidae
Nematoda			

References

DuBois, K.L., Palawski, D.U., and Malloy, J.C., 1992, Bowdoin National Wildlife Refuge contaminants biomonitoring study: Helena, Mont., U.S. Fish and Wildlife Service, Contaminant Report R6/207H/92, 53 p.

Johnson, K.M., 1990, Aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin National Wildlife Refuge, Montana: Bozeman, Montana State University, master's thesis.

Appendix 3. Description of Variables Found in the Plant and Invertebrate Databases

Variable	Description and units
CHLORIDE	Concentration of chlorides, reported as %
CLASS	Taxonomic Class of invertebrate taxa
CLASSIFICATION	Wetland classification; in some cases this was provided, and in others the class was assigned on the basis of site descriptions provided by the authors of each data source. • LACUSTRINE = lake; classification of Cowardin and others, 1979 • PALUSTRINE = marsh or wetland; classification of Cowardin and others, 1979 • PEM = palustrine emergent; classification of Cowardin and others, 1979 • PEMA = palustrine emergent, temporarily flooded; classification of Cowardin and others, 1979 • PEMB = palustrine emergent, saturated; classification of Cowardin and others, 1979 • PEMC = palustrine emergent, seasonally flooded; classification of Cowardin and others, 1979 • PEMF = palustrine emergent, semipermanently flooded; classification of Cowardin and others, 1979 • SALT-MARSH = general term for saline wetlands commonly used in scientific literature • CELL = artificial wetland or pond • UNKNOWN = data were presented for multiple wetland classes, or the wetland class could not be determined
COMMON_NAME	Common name of plant
CONDUCTIVITY_CODE	This variable identifies conductivity measurements (µS cm^{-1}) that were reported as µS cm^{-1} or that were converted to µS cm^{-1} from other units (for example, mg L^{-1}, ppm, %). • CONVERSION = value was converted from other salinity unit. Total dissolved solids and specific conductance were related using the following forumula: mg L^{-1} = µS cm^{-1} × 0.64 (Tchobanoglous and Burton, 1991). • REPORTED = value was reported as µS cm^{-1}
DOM_SALT	Dominant salt identified for the water body
FAMILY	Taxonomic Family of invertebrate taxa
GENUS	Genus of the plant or invertebrate • Plant genus terminology following The Great Plains Flora Association (1986) when possible
GENUS_R	Genus of the plant reported by the original source
LOCATION	Location of the study from which the data were obtained (for example, State, Province, country, region)
MG_L	Salinity, reported as milligrams per liter (mg L^{-1})
OPTIMUM_MG_L	Salinity reported as optimum for the growth of the plant species, reported as milligrams per liter (mg L^{-1})
ORDER	Taxonomic Order of invertebrate taxa
PERCENT	Salinity (for example, dissolved solids, total salts), reported as %
PH	pH of the water or soil where a plant species occurred
PHYLUM	Taxonomic Phylum of invertebrate taxa
PHYSIOGNOMY	Plant physiognomy (for example, forb/herb, graminoid, shrub, tree, vine) and life span (A, annual; B, biennial; P, perennial) according to The Great Plains Flora Association (1986) and the U.S. Department of Agriculture, National Conservation Service web page, accessed September 2007, at *http://plants.nrcs.usda.gov/growth_habits_def.html*
PPM	Salinity, reported as parts per million
SODIUM	Concentration of sodium, reported as %
SOURCE	Source of the data

Variable	Description and units
SPECIES	Species of the plant or invertebrate • Terminology following The Great Plains Flora Association (1986) when possible
SPECIES_R	Species of the plant reported by the original source
SUBSTRATE	Substrate from which the variable (for example, salinity, pH) was obtained. • S = soil • W = water
SULFATE	Concentration of sulfate, reported as %
DATA TYPE: • TYPE_CHL (chloride) • TYPE_MG_L (mg L^{-1}) • TYPE_PCNT (%) • TYPE_PH (pH) • TYPE_PPM (ppm) • TYPE_SOD (sodium) • TYPE_SUL (sulfate) • TYPE_US_CM ($\mu S\ cm^{-1}$)	Data type; these variables identify whether the measurement (for example, salinity, pH) was reported as a mean, median, range, etc. For example, if TYPE_US_CM = 'MEAN,' then the value was reported as a mean value by the original source; if TYPE_PH = 'MIN,' then the value was reported as a minimum value (for example, smallest value of a range) by the original source, etc. • MAXIMUM = reported as maximum value, typically as part of a range (for example, 1–10) • MEAN = reported as a calculated mean • MEDIAN = reported as a calculated median • MINIMUM = reported as minimum value, typically as part of a range (for example, 1–10) • OCCURRENCE = a single value was reported, and it was not specified as a mean, median, etc.
US_CM	Salinity, reported as microsiemens per centimeter ($\mu S\ cm^{-1}$); if salinity was reported in other units (for example, milligrams per liter [mg L^{-1}], percent [%]), the data were converted to provide a consistency among studies. The original data/units are also provided, and the data that were converted are identified by the variable "CONDUCTIVITY_CODE" (see above).
WIC	Wetland indicator category according to the U.S. Department of Agriculture, Natural Resources Conservation Service Web page, accessed September 2007, at *http://plants.usda.gov/wetinfo.html*: • OBL = Obligate Wetland: Occurs almost always (estimated probability 99%) under natural conditions in wetlands. • FACW = Facultative Wetland: Usually occurs in wetlands (estimated probability 67%–99%), but occasionally found in nonwetlands. • FAC = Facultative: Equally likely to occur in wetlands or nonwetlands (estimated probability 34%–66%). • FACU = Facultative Upland: Usually occurs in nonwetlands (estimated probability 67%–99%), but occasionally found on wetlands (estimated probability 1%–33%). • UPL = Obligate Upland: Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in nonwetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List. • A positive (+) or negative (-) sign was used with the Facultative Indicator categories to more specifically define the regional frequency of occurrence in wetlands. The positive sign indicates a frequency toward the higher end of the category (more frequently found in wetlands), and a negative sign indicates a frequency toward the lower end of the category (less frequently found in wetlands).

References

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Fish and Wildlife Service, FWS/OBS-79/31, 131 p.

Tchobanoglous, G., and Burton, F.L., 1991, Wastewater engineering; treatment, disposal, and reuse (3d ed.): New York, N.Y., Metcalf & Eddy, Inc., McGraw-Hill Inc., 1,024 p.

The Great Plains Flora Association, 1986, Flora of the Great Plains: Lawrence, University Press of Kansas, 1,402 p.

Appendix 4. Description of Each Data Source Used to Develop the Plant and Invertebrate Databases

Grosshans and Kenkel, 1997
General description: Species composition (7 dominant plant species) and specific conductance were reported for the Marsh Ecology Research Complex (MERC) located on the southern end of Lake Manitoba, Manitoba, Canada. The MERC consists of 10 sand-diked marshes (cells) that are approximately 5–7 ha. The data were obtained from table 2.
Description of data: Mean soil conductivities were presented for each species for a range of water depths.
Specific conductance reporting units: micromhos cm^{-1} ($\mu S\ cm^{-1}$), no conversion
Description of data "type":
- Mean: reported as mean value

Hammer and Heseltine, 1988
General description: Plant species composition (aquatic macrophytes), pH, specific conductance, and makeup of the dominant salt were reported for 35 lakes located in Alberta and Saskatchewan, Canada. The data were obtained from tables 1 and 2.
Description of data: Ranges or single values of specific conductance, single values of pH, and makeup of the dominant salt were presented for all lakes. Additionally, aquatic macrophytes occurring in each lake were identified. Since specific conductance was presented as a range and as a single value, the low and high ranges are presented in this database as minimum and maximum values and the single values are presented as an occurrence (the authors do not state that the values are measures of central tendency). Plants occurring in each lake were assigned the specific conductance (single value or range), pH, and dominant salt of the lake.
Specific conductance reporting units: $mS\ cm^{-1}$
- converted to $\mu S\ cm^{-1}$ ($mS\ cm^{-1} \times 1{,}000 = \mu S\ cm^{-1}$)

Description of data "type":
- Occurrence: single value presented
- Min: lowest value presented in range
- Max: greatest value presented in range

Johnson, 1990
General description: Salinity gradients and their relation to vegetation and aquatic invertebrates were reported for habitats on Bowdoin National Wildlife Refuge, Mont.
Description of data: Table 1 provides the specific conductance values for each transect. Table 2 describes aquatic macrophytes found along 8 transects categorized as slightly brackish; table 3 describes aquatic macrophytes found along 5 transects categorized as moderately brackish; table 4 describes aquatic macrophytes found along 9 transects categorized as brackish; table 6 describes aquatic invertebrate taxa and their abundance per salinity category. Aquatic macrophytes were assigned salinity values based on sample transect data presented in table 1. Invertebrate species were assigned a range of conductivity values based on the salinity categories from table 6.
Specific conductance reporting units: $\mu S\ cm^{-1}$, no conversion
Description of data "type":
- Min: lowest conductivity value reported for each taxa
- Max: greatest conductivity value reported for each taxa

Kantrud, 1990
General description: Data were obtained from a literature review of sago pondweed (*Potamogeton pectinatus* L.) and represent information from multiple sources.
Description of data: Table 5 presents the salinity concentrations of locations where sago pondweed occurred. The data represent numerous sources and consist of ranges or single observations of salinity and optimum salinity. Table 6 presents a range of pH values that represent data from multiple sources.
Specific conductance reporting units: $mg\ L^{-1}$
- converted $mg\ L^{-1}$ to $\mu S\ cm^{-1}$ ($mg\ L^{-1}$ / 0.64)

Description of data "type":
- Min:
    - Salinity: lowest value presented in table 5, which contains ranges from multiple sources (that is, multiple minimum values)
    - pH: lowest value from single range presented in table 6, which represents data summarized from multiple sources

- Max:
  - Salinity: greatest value presented in table 5, which contains ranges from multiple sources (that is, multiple maximum values)
  - pH: greatest value from single range presented in table 6, which represents data summarized from multiple sources

Kantrud, 1991

General description: Data were obtained from a literature review of wigeongrass (*Ruppia maritima*) and represent information from multiple sources.
Description of data: Table 5 presents the salinity concentrations of locations where wigeongrass occurred. The data represent numerous sources and consist of ranges or single observations of salinity and optimum salinity. Tables 6 (water) and 7 (soil) present ranges of pH values that represent data from multiple sources.
Specific conductance reporting units: mg L^{-1}

- converted mg L^{-1} to µS cm^{-1} (mg L^{-1} / 0.64)

Description of data "type":

- Min:
  - Salinity: lowest value presented in table 5, which contains ranges from multiple sources (that is, multiple minimum values)
  - pH: lowest value from single range presented in tables 6 or 7, which represents data summarized from multiple sources
- Max:
  - Salinity: greatest value presented in table 5, which contains ranges from multiple sources (that is, multiple maximum values)
  - pH: greatest value from single range presented in tables 6 or 7, which represents data summarized from multiple sources

Kantrud, 1996

General description: Data were obtained from a literature review of the alkali (*Scirpus maritimus* L.) and saltmarsh (*Scirpus robustus* Pursh) bulrushes and represent information from multiple sources.
Description of data: Tables 6 (water) and 10 (soil) present the salinity concentrations of locations where alkali and saltmarsh bulrush occurred. The data represent numerous sources and consist of ranges or single observations of salinity and optimum salinity. Tables 8 (water) and 10 (soil) present ranges of pH values that represent data from multiple sources.
Specific conductance reporting units: g L^{-1} (water) and mS cm^{-1} (soil)

- converted g L^{-1} to µS cm^{-1} (g L^{-1} × 1,000 = mg L^{-1} / 0.64)
- converted mS cm^{-1} to µS cm^{-1} (mS cm^{-1} × 1,000)

Description of data "type":

- Min:
  - Salinity:
    - g L^{-1}: lowest value presented in table 6, which contains ranges from multiple sources (that is, multiple minimum values)
    - mS cm^{-1}: lowest value from single range presented in table 10, which contains ranges from multiple sources
    - Total salts (%): lowest value from single range presented in table 10, which contains ranges from multiple sources
  - pH: lowest value from single range presented in tables 8 or 10, which contains ranges from multiple sources
- Max:
  - Salinity:
    - g L^{-1}: greatest value presented in table 6, which contains ranges from multiple sources (that is, multiple maximum values)
    - mS cm^{-1}: greatest value from single range presented in table 10, which contains ranges from multiple sources
    - Total salts (%): greatest value from single range presented in table 10, which contains ranges from multiple sources
  - pH: greatest value from single range presented in tables 8 or 10, which contains ranges from multiple sources

Kantrud and others, 1989

General description: Vegetation occurrence (hydrophytes, submerged and floating aquatic plants) and specific conductance data were summarized for Prairie Pothole Region wetlands by combining data from relevant literature and unpublished data. The data were obtained from tables 5.10, 5.11, and 5.12.
Description of data: Mean, minimum, and maximum values for specific conductivity were presented for each plant species (when available). Additional information included wetland class and/or water regime.
Specific conductance reporting units: mS cm^{-1}

- converted to µS cm^{-1} (mS cm^{-1} × 1,000 = µS cm^{-1})

Description of data "type":

- Mean: reported as mean value
  - Values for submerged and floating aquatic plants (table 5.12) are presented as either a mean, or as a single measurement. In this report, all values are considered a mean since the authors do not specify which are mean values or single measurements.
- Min: reported as minimum value
- Max: reported as maximum value

Kay and others, 2001

General description: Aquatic macroinvertebrates were collected and conductivity and pH were measured at 176 river sites in Australia during the spring of 1997.

Description of data: Table 3 presents ranges (min/max) of specific conductance and pH for each invertebrate family.

Specific conductance reporting units: mS cm^{-1}

- converted to µS cm^{-1} (mS cm^{-1} × 1,000 = µS cm^{-1})

Description of data "type":

- Min: lowest value reported in range
- Max: greatest value reported in range

Lancaster and Scudder, 1987

General description: Communities of aquatic Coleoptera and Hemiptera were examined in eight fishless lakes of varying salinities in central British Columbia, Canada.

Description of data: Table 1 presents seasonal (monthly; May–October) measurements of specific conductance for each lake. Table 2 presents the invertebrate species composition for each lake. Invertebrate species were assigned the range of conductivity values for the lakes where they occurred.

Specific conductance reporting units: µS cm^{-1}, no conversion

Description of data "type":

- Mean: mean conductivity value for each lake from the six sample periods
- Min: lowest conductivity value for each lake from the six sample periods
- Max: greatest conductivity value for each lake from the six sample periods

McCarraher, 1970

General description: Fairy shrimps (Anostraca) were collected and specific conductance and pH were measured in 246 sites in the sandhills region of Nebraska.

Description of data: Table 1 presents specific conductance and pH values for 6 fairy shrimp species from 23 locations.

Specific conductance reporting units: µS cm^{-1}, no conversion

Description of data "type":

- Occurrence: value represents single conductivity/pH measurement from each location (the author does not state whether the values are single measurements or measures of central tendency).

Rawson and Moore, 1944 (plants)

General description: Plant species (common rooted aquatic plants) composition and salinity concentration were reported for lakes of varying salinities in Saskatchewan, Canada.

Description of data: Table VIII presents plant species occurrences and salinities (total solids) for 9 lakes. Plants occurring in each lake were assigned the salinity reported for the lake.

Specific conductance reporting units: ppm (total solids)

- ppm converted to µS cm^{-1} (ppm = mg L^{-1} / 0.64 = µS cm^{-1})

Description of data "type":

- Occurrence: single value presented

Rawson and Moore, 1944 (invertebrates)

General description: Salinity ranges were reported for invertebrate taxa inhabiting lakes of varying salinities in Saskatchewan, Canada.

Description of data: Table X reported salinity ranges for numerous species of Cladocera and Copepoda and one species of Anostraca. Data for additional invertebrates (for example, insects, snails, leeches) were obtained by estimating salinity ranges presented graphically in figure 7.

Specific conductance reporting units: ppm (total solids)

- ppm converted to µS cm^{-1} (ppm = mg L^{-1} / 0.64 = µS cm^{-1})

Description of data "type":

- Occurrence: single value presented
- Min: lowest value reported (table X) or estimated (figure 7)
- Max: greatest value reported (table X) or estimated (figure 7)

Stewart and Kantrud, 1972

General description: Plant species (primary and secondary) characteristic of Prairie Pothole Region wetlands in North Dakota were reported as (1) frequently common or abundant, (2) frequently fairly common/occasionally common or abundant, or (3) occasionally fairly common for various wetland zones (for example, wet-meadow, shallow-marsh, deep-marsh). Each plant was reported to occur in wetlands characterized as fresh, slightly brackish, moderately brackish, brackish, subsaline, or saline. Each of these salinity categories was associated with a normal range of specific conductance values. The data were obtained from figures 4, 9, 20, 27, 35, 37.

Description of data: Ranges (minimum/maximum) of salinity were assigned to each plant based on the salinity categories of the type of wetland where each species occurred.

Specific conductance reporting units: micromhos cm^{-1} (µS cm^{-1}), no conversion

Description of data "type":

- Min: lowest salinity value associated with the "most fresh" salinity category reported for the species
- Max: greatest salinity value associated with the "most saline" salinity category reported for the species

Tangen, unpublished

General description: Aquatic macroinvertebrates were collected and conductivity and pH were measured from 24 wetlands (PEMF) within the Prairie Pothole Region of North Dakota during 2000.

Description of data: Data from individual wetlands were summarized across the three sample periods (June, July, August) and include invertebrate taxa occurrence in relation to specific conductance and pH of the water. Invertebrates occurring in each wetland were assigned the specific conductance and pH of the wetland.

Specific conductance reporting units: µS cm^{-1}, no conversion

Description of data "type":

- Mean: mean value (specific conductance, pH) for each wetland (n=24) calculated from measurements collected during each sample period (n=3).
- Min: minimum value (specific conductance, pH) for each wetland (n=24) calculated from measurements collected during each sample period (n=3).
- Max: maximum value (specific conductance, pH) for each wetland (n=24) calculated from measurements collected during each sample period (n=3).

Ungar, 1966

General description: Salt tolerance of plants growing in saline areas of Kansas and Oklahoma was examined.

Description of data: Table I presents ranges of soil salt content in which plant species were found in saline areas of Kansas and Oklahoma. Values reported are for the upper 10 cm of the soil profile and are expressed as percentage total salts on a dry soil weight basis. Mean, minimum, and maximum salinity values were reported for each species.

Specific conductance reporting units: percent

- converted percent to µS cm^{-1} (% × 10,000 = ppm = mg L^{-1} / 0.64)

Description of data "type":

- Mean: reported as mean value
- Min: reported as minimum value
- Max: reported as maximum value

Ungar, 1967

General description: Vegetation-soil relationships on saline soils in northern Kansas were examined.

Description of data: Table 3 presents ranges of soil salinity and pH, as well as the concentration of chloride (%) for vegetation communities found in salt marshes of northern Kansas. Salinity values reported are for the upper 10 cm of the soil profile and are expressed as conductivity and total solids. Range (minimum and maximum) of conductivity, pH, chloride, and total solids were reported for the dominant species for each vegetation community.

Specific conductance reporting units: mmhos cm^{-1} and total solids (%)

- converted mmhos cm^{-1} to µS cm^{-1} (mmhos cm^{-1} × 1,000)

Description of data “type”:
- Min: lowest value reported in range
- Max: greatest value reported in range

Ungar, 1970
General description: Species-soil relationships on sulfate-dominated soils of South Dakota were examined.
Description of data: Plant species-soil (upper 10 cm) relationships were presented for Stink and Bitter lakes in South Dakota. Table 2 presents single and median values for pH, conductivity, total salts (%), sulfate (%), chloride (%), and sodium (%) for each plant species.
Specific conductance reporting units: mmhos cm^{-1} and total salts (%)
- converted mmhos cm^{-1} to µS cm^{-1} (mmhos cm^{-1} × 1,000)

Description of data “type”:
- Occurrence: single value reported
- Median: value reported as median

Ungar, 1974
General description: The data were acquired from a book chapter containing an extensive literature review of halophytes. Salinity and pH values were reported in the text as well as in tables.
Description of data: Salinity and pH data from numerous sources were reported for various plant species. These data were summarized for this report.
Specific conductance reporting units: mmhos cm^{-1} and/or total salts (%)
- converted mmhos cm^{-1} to µS cm^{-1} (mmhos cm^{-1} × 1,000)
- converted percent to µS cm^{-1} (% × 10,000 = ppm = mg L^{-1} / 0.64)

Description of data “type”:
- Min: lowest value reported (data summarized from entire chapter)
- Max: greatest value reported (data summarized from entire chapter)

Ungar and others, 1969
General description: Plant species-soil (upper 10 cm) relationships at salt marshes near Lincoln, Nebraska, were examined.
Description of data: Tables 1 and 2 present single values of conductivity, total salts (%), sodium (%), chloride (%), sulfate (%), and pH.
Specific conductance reporting units: mmhos cm^{-1} and total salts (%)
- converted mmhos cm^{-1} to µS cm^{-1} (mmhos cm^{-1} × 1,000)

Description of data “type”:
- Occurrence: single value reported
- Median: median value reported
- Min: lowest value reported
- Max: greatest value reported

Ungar and others, 1979
General description: The distribution and growth of *Salicornia europaea* and other halophytes along a soil salinity gradient were described for a salt marsh in Ohio.
Description of data: Ranges of specific conductance for vegetation zones (represented by dominant species) were presented.
Specific conductance reporting units: mmhos cm^{-1}
- converted mmhos cm^{-1} to µS cm^{-1} (mmhos cm^{-1} × 1,000)

Description of data “type”:
- Min: lowest value reported
- Max: greatest value reported

Ungar and Riehl, 1980
General description: Soil salinities were presented for 5 vegetation zones (represented by dominant species) from an inland saline pan in Ohio.
Description of data: Soils from the 5 vegetation zones were collected and ranges of soil salinities for the growing season were presented. Each plant species was assigned the range of soil salinities for the vegetation zone where it was present.
Specific conductance reporting units: percent
- converted percent to µS cm^{-1} (% × 10,000 = ppm = mg L^{-1} / 0.64)

Description of data “type”:
- Min: lowest value reported
- Max: greatest value reported

USGS, unpublished a
General description: Vegetation surveys were conducted and specific conductance and pH (water and soil) measurements were collected from 204 depressional wetlands (PEMC, PEMF) located in 5 States (Iowa, Minnesota, Montana, North Dakota, and South Dakota) across the Prairie Pothole Region during 1997 (USGS, Northern Prairie Wildlife Research Center, Study Plan 168.01).
Description of data: Data from individual wetlands were summarized by state and wetland class (that is, PEMC, PEMF) and include plant species occurrences in relation to specific conductance and pH of the soil and/or water. Plants occurring in each wetland were assigned the specific conductance and pH of the wetland and/or soil sample corresponding to each vegetation zone.
Specific conductance reporting units: $\mu S\ cm^{-1}$, no conversion
Description of data “type”:
- Occurrence: value represents occurrence of plant species in a single wetland basin
- Mean: mean value for the species calculated from all wetlands located in each state/wetland class combination
- Min: lowest value for the species based on data from all wetlands located in each state/wetland class combination
- Max: greatest value for the species based on data from all wetlands located in each state/wetland class combination

USGS, unpublished b
General description: Aquatic invertebrates were collected from 17 wetlands (PEMC, PEMF) located at the Cottonwood Lake long-term study area in Stutsman County, N. Dak. This database represents samples collected monthly (May–October) from 1992–2006 (USGS, Northern Prairie Wildlife Research Center, Study Plan 140.01).
Description of data:
1. Data from individual wetlands (3 transects, 3 sample methods [funnel traps, benthic core sampler, sweep net], 2–4 sampling zones [wet-meadow, shallow-marsh, deep-marsh, open-water]) were summarized by month and year.
2. Specific conductance data were summarized for individual wetlands by month and year.
3. Data for all wetlands were summarized by wetland class (PEMC, PEMF) and year.

Specific conductance reporting units: $\mu S\ cm^{-1}$, no conversion
Description of data “type”:
- Mean: mean value for the taxon calculated for each year/wetland class combination.
- Min: lowest value for the taxon for each year/wetland class combination.
- Max: lowest value for the taxon for each year/wetland class combination.

References

Grosshans, R.E., and Kenkel, N.C., 1997, Dynamics of emergent vegetation along natural gradients of water depth and salinity in a prairie marsh—delayed influences of competition, *in* Goldsborough, L.G., and Hann, B.J., eds., University of Manitoba Field Station (Delta Marsh) thirty-second annual report: Portage la Prairie, Manitoba, Canada, p. 83–93.

Hammer, U.T., and Heseltine, J.M., 1988, Aquatic macrophytes in saline lakes of the Canadian prairies: Hydrobiologia, v. 158, p. 101–116.

Johnson, K.M., 1990, Aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin National Wildlife Refuge: Bozeman, Montana State University, master’s thesis.

Kantrud, H.A., 1990, Sago pondweed (*Potamogeton pecinatus* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Resource Publication 176, 89 p.

Kantrud, H.A., 1991, Widgeongrass (*Ruppia maritima* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Research 10, 58 p.

Kantrud, H.A., 1996, The alkali (*Scirpus maritimus* L.) and saltmarsh (*S. robustus* Pursh) bulrushes—a literature review: Washington, D.C., National Biological Service Information and Technology Report 6, 77 p.

Kantrud, H.A., Millar, J.B., and van der Valk, A.G., 1989, Vegetation of wetlands of the prairie pothole region, *in* van der Valk, A., ed., Northern prairie wetlands: Ames, Iowa State University Press, p. 132–187.

Kay, W.R., Halse, S.A., Scanlon, M.D., and Smith, M.J., 2001, Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia: Journal of the North American Benthological Society, v. 20, p. 182–199.

Lancaster, J., and Scudder, G.G.E., 1987, Aquatic Coleoptera and Hemiptera in some Canadian saline lakes—patterns in community structure: Canadian Journal of Zoology, v. 65, p. 1383–1389.

McCarraher, D.B., 1970, Some ecological relations of fairy shrimps in alkaline habitats of Nebraska: American Midland Naturalist, v. 84, p. 59–68.

Rawson, D.S., and Moore, J.E., 1944, The saline lakes of Saskatchewan: Canadian Journal of Research, v. 22, p. 141–201.

Stewart, R.E., and Kantrud, H.A., 1972, Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors: Washington, D.C., U.S. Geological Survey Professional Paper 585-D, 36 p.

Ungar, I.A., 1966, Salt tolerance of plants growing in saline areas of Kansas and Oklahoma: Ecology, v. 47, p. 154–155.

Ungar, I.A., 1967, Vegetation-soil relationships on saline soils in northern Kansas: American Midland Naturalist, v. 78, p. 98–120.

Ungar, I.A., 1970, Species-soil relationships on sulfate dominated soils of South Dakota: American Midland Naturalist, v. 83, p. 343–357.

Ungar, I.A., 1974, Inland halophytes of the United States, *in* Reimold, R.J., and Queen, W.H., eds., Ecology of halophytes: New York, N.Y., Academic Press, Inc., p. 235–305.

Ungar, I.A., Benner, D.K., and McGraw, D.C., 1979, The distribution and growth of Salicornia Europaea on an inland salt pan: Ecology, v. 60, p. 329–336.

Ungar, I.A., Hogan, W., and McClelland, M., 1969, Plant communities of saline soils at Lincoln, Nebraska: The American Midland Naturalist, v. 82, p. 564–577.

Ungar, I.A., and Riehl, T.E., 1980, The effect of seed reserves on species composition in zonal halophyte communities: Botanical Gazette, v. 141, p. 447–452.

Appendix 5. Summary of plant database.

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Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Achillea	*millefolium*	yarrow	S	400	3,330			10
Acorus	*calamus*	sweet flag	S		600			10
Agropyron	*caninum*	slender wheatgrass	S	640	3,800			10
Agropyron	*cristatum*	crested wheatgrass	S	400	1,050			10
Agropyron	*dasystachyum*	thickspike wheatgrass	S		20,313			17
Agropyron	*elongatum*	tall wheatgrass	S	340	5,500			10
Agropyron	*intermedium*	intermediate wheatgrass	S	345	5,500			10
Agropyron	*intermedium*	intermediate wheatgrass	W		1,623		7.7	10
Agropyron	*repens*	quackgrass	S	140	6,460			10,13
Agropyron	*repens*	quackgrass	W	40	5,000	7.2	8.8	9,10
Agropyron	*smithii*	western wheatgrass	S	400	7,000	7.7	8.1	10,14,15,16,17
Agropyron	*smithii*	western wheatgrass	W	307	1,623	7.7	8.0	10
Agropyron	sp.	wheatgrass	S	350	2,790			10
Agrostis	*hyemalis*	ticklegrass	S		490			10
Agrostis	*scabra*	ticklegrass	S	345	4,688			10,17
Agrostis	*scabra*	ticklegrass	W		1,301		7.9	10
Agrostis	*stolonifera*	redtop	S	290	5,500			10
Agrostis	*stolonifera*	redtop	W	200	630	7.2	8.3	4,10
Alisma	*gramineum*	narrowleaf water plantain	S	400	1,850			10
Alisma	*gramineum*	narrowleaf water plantain	W	300	15,000	7.4	8.6	3,4,9,10
Alisma	*subcordatum*	common water plantain	S	300	4,550			10
Alisma	*subcordatum*	common water plantain	W	113	9,500	6.7	9.8	4,10
Alisma	*triviale*	water plantain	W	40	5,000			9
Allium	*canadense*	wild onion	S	400	620			10
Allium	*stellatum*	pink wild onion	S	650	2,200			10
Alopecurus	*aequalis*	short-awn foxtail	S	300	1,850			10
Alopecurus	*aequalis*	short-awn foxtail	W	40	5,000	7.0	9.7	4,9,10
Amaranthus	*retroflexus*	rough pigweed	S	730	2,450			10
Ambrosia	*artemisiifolia*	common ragweed, short ragweed	S	300	20,313			10,17

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Ambrosia	*artemisiifolia*	common ragweed, short ragweed	W	326	1,582	7.3	8.6	10
Ambrosia	*psilostachya*	western ragweed	S	140	4,000			10
Ambrosia	*psilostachya*	western ragweed	W	560	729	8.0	8.6	10
Ambrosia	sp.	ragweed	S		590			10
Ammannia	*coccinea*	toothcup	W	40	2,000			9
Amorpha	*canescens*	lead plant	S	400	850			10
Amorpha	*fruticosa*	false indigo	S	525	850			10
Andropogon	*gerardii*	big bluestem	S	350	2,620			10
Andropogon	*scoparius*	little bluestem	S		1,500			10
Anemone	*canadensis*	meadow anemone	S	140	2,940			10
Anemone	*canadensis*	meadow anemone	W	355	429	7.6	8.4	10
Apocynum	*cannabinum*	indian hemp dogbane, prairie dogbane	S	310	1,975			10
Apocynum	*cannabinum*	indian hemp dogbane, prairie dogbane	W	40	5,000	7.2	8.6	4,9,10
Artemisia	*absinthium*	wormwood	S	350	5,500			10
Artemisia	*absinthium*	wormwood	W		1,623		7.7	10
Artemisia	*biennis*	biennial wormwood	S	290	3,970			10
Artemisia	*biennis*	biennial wormwood	W	40	15,000		9.7	9,10
Artemisia	*dracunculus*	silky wormwood	S	290	2,380			10
Artemisia	*frigida*	prairie sagewort	S	900	3,330			10
Artemisia	*ludoviciana*	white sage	S	290	2,200			10
Asclepias	*incarnata*	swamp milkweed	S	295	1,725			10
Asclepias	*incarnata*	swamp milkweed	W	274	900	8.1	9.6	4,10
Asclepias	*ovalifolia*	ovalleaf milkweed	S	300	1,340			10
Asclepias	sp.	milkweed	S		550			10
Asclepias	*speciosa*	showy milkweed	S	300	1,730			10
Asclepias	*speciosa*	showy milkweed	W	40	2,000	8.5	8.6	9,10
Asclepias	*syriaca*	common milkweed	S	140	2,830			10
Asclepias	*syriaca*	common milkweed	W	326	774	7.2	9.5	10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm⁻¹, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm⁻¹)		pH		Source[1]
				Min	Max	Min	Max	
Asclepias	*verticillata*	whorled milkweed	S	620	700			10
Aster	*brachyactis*	rayless aster	S	620	2,930			10
Aster	*brachyactis*	rayless aster	W	500	15,000	8.2	8.4	9,10
Aster	*ericoides*	white aster	S	380	4,700			10,17
Aster	*ericoides*	white aster	W	492	630	7.8	8.1	10
Aster	*falcatus*	white prairie aster	S	400	3,970			10
Aster	*falcatus*	white prairie aster	W		630		8.1	10
Aster	*hesperius*	panicled aster	W	400	9,800			4
Aster	*novae-angliae*	new england aster	S		590			10
Aster	*sagittifolius*	arrow-leaved aster	W		1,000			4
Aster	*simplex*	panicled aster	S	295	5,500			10
Aster	*simplex*	panicled aster	W	40	16,100	6.7	9.7	4,9,10
Aster	sp.	wild aster	S	300	850			10
Aster	sp.	wild aster	W	391	590	7.4	8.3	10
Aster	*subulatus*	saltmarsh aster	S	1,875	9,844			14,17
Astragalus	*canadensis*	Canada milk-vetch	S	530	540			10
Atriplex	*argentea*	silver-scale saltbush	S	3,594	15,625			14,17
Atriplex	*subspicata*	spearscale	S	1,250	55,000	7.0	8.7	10,12,13,14,15,17
Atriplex	*subspicata*	spearscale	W	500	76,400		8.4	4,9,10
Avena	*fatua*	wild oats	S	820	1,470			10
Azolla	*mexicana*	water fern, mosquito fern	S		330			10
Azolla	*mexicana*	water fern, mosquito fern	W		471		7.3	10
Baccharis	*salicina*	willow baccharis	S	313	9,844			14
Bacopa	*rotundifolia*	water hyssop	S		410			10
Bacopa	*rotundifolia*	water hyssop	W	40	2,000		8.2	9,10
Beckmannia	*syzigachne*	sloughgrass	S	300	4,550			10
Beckmannia	*syzigachne*	sloughgrass	W	40	9,500	6.7	9.7	4,9,10
Bidens	*cernua*	nodding beggar-ticks	S	290	5,500			10
Bidens	*cernua*	nodding beggar-ticks	W	40	2,500	8.0	8.4	4,9,10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Bidens	*frondosa*	devil's beggar-ticks	S	290	3,465			10
Bidens	*frondosa*	devil's beggar-ticks	W	40	6,673	6.7	8.4	9,10
Bidens	sp.	beggar-ticks	S		820			10
Bidens	*vulgata*	big devil's beggar-ticks	W	40	2,000			9
Boltonia	*asteroides*	boltonia	S	290	3,480			10
Boltonia	*asteroides*	boltonia	W	100	6,800	7.4	8.2	4,10
Boltonia	*asteroides* var. *latisquama*	violet boltonia	W	40	2,000			9
Bouteloua	*curtipendula*	sideoats grama	S	770	1,150			10
Brassica	*kaber*	charlock	S	1,320	1,430			10
Bromus	*inermis*	smooth brome	S	140	4,000			10
Bromus	*inermis*	smooth brome	W	256	5,387	7.1	9.5	10
Bromus	*japonicus*	japanese brome	S	400	900			10
Bromus	*japonicus*	japanese brome	W		1,623		7.7	10
Bromus	*tectorum*	downy brome	S	400	650			10
Bromus	*tectorum*	downy brome	W		326		7.8	10
Calamagrostis	*canadensis*	bluejoint	S	350	3,480			10
Calamagrostis	*canadensis*	bluejoint	W	40	3,800	6.9	9.5	4,9,10
Calamagrostis	*stricta*	slimstem reedgrass	S	140	4,700			10
Calamagrostis	*stricta*	slimstem reedgrass	W	40	17,600	7.3	9.8	4,9,10
Callitriche	*hermaphroditica*	northern water starwort	W	40	2,500			4,9
Callitriche	*verna*	vernal water starwort	W	40	2,000			4,9
Calystegia	*sepium*	hedge bindweed	S	430	5,156			10,13
Carduus	*nutans*	musk thistle, nodding thistle	S		500			10
Carex	*alopecoidea*	foxtail sedge	S		400			10
Carex	*aquatilis*	water sedge	S	330	1,475			10
Carex	*aquatilis*	water sedge	W	170	3,800	6.9	9.6	4,10
Carex	*atherodes*	slough sedge	S	295	3,075			10
Carex	*atherodes*	slough sedge	W	40	8,500	6.6	9.9	4,9,10
Carex	*bebbii*	bebb's sedge	S	340	530			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1}) Min	Conductivity (µS cm^{-1}) Max	pH Min	pH Max	Source[1]
Carex	*brevior*	fescue sedge	S	400	700			10
Carex	*buxbaumii*	brown bog sedge	S		450			10
Carex	*buxbaumii*	brown bog sedge	W	391	1,400		8.0	4,10
Carex	*granularis*	meadow sedge	S	410	720			10
Carex	*granularis*	meadow sedge	W		113		6.9	10
Carex	*hallii*	deer sedge	S		630			10
Carex	*hallii*	deer sedge	W		412		7.9	10
Carex	*interior*	interior sedge	S		480			10
Carex	*lacustris*	hairy sedge	W	900	1,700			4
Carex	*laeviconica*	smoothcone sedge	W	40	3,200			4,9
Carex	*lanuginosa*	woolly sedge	S	290	2,615			10
Carex	*lanuginosa*	woolly sedge	W	40	32,600	7.2	9.5	4,9,10
Carex	*praegracilis*	clustered-field sedge	S	620	3,800			10
Carex	*praegracilis*	clustered-field sedge	W	40	5,000			4,9
Carex	*rostrata*	beaked sedge	S		305			10
Carex	*rostrata*	beaked sedge	W	200	2,600			4
Carex	*sartwellii*	sartwell's sedge	S	450	900			10
Carex	*sartwellii*	sartwell's sedge	W	40	5,000		8.0	4,9,10
Carex	sp.	sedge	S	290	4,700			10,17
Carex	sp.	sedge	W	192	1,487	6.9	9.9	10
Carex	*stipata*	sawbeak sedge	W		400			4
Carex	*stricta*	tussock sedge	W	100	9,400			4
Carex	*sychnocephala*	manyhead sedge	S		340			10
Carex	*tetanica*	rigid sedge	W	900	5,500			4
Carex	*vulpinoidea*	fox sedge	S	300	3,120			10
Carex	*vulpinoidea*	fox sedge	W	40	2,000	7.5	8.6	4,9,10
Carum	*carvi*	caraway	S		850			10
Centaurium	*pulchellum*	branched centaury	S		350			10
Cerastium	*brachypodum*	nodding chickweed	S		450			10

Appendix 5. Summary of plant database.—Continued

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Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1}) Min	Conductivity (µS cm^{-1}) Max	pH Min	pH Max	Source[1]
Ceratophyllum	*demersum*	hornwort, coontail	S	300	3,300			10
Ceratophyllum	*demersum*	hornwort, coontail	W	40	5,100	7.0	9.9	3,4,9,10
Chenopodium	*album*	lamb's quarters	S	300	4,000			10
Chenopodium	*album*	lamb's quarters	W	40	500			9
Chenopodium	*glaucum*	oak-leaved goosefoot	S		39,800			17
Chenopodium	*glaucum*	oak-leaved goosefoot	W	500	15,000			9
Chenopodium	*rubrum*	alkali blite	S	350	39,800			10,17
Chenopodium	*rubrum*	alkali blite	W	40	15,000	7.8	9.7	9,10
Chenopodium	sp.	goosefoot, lamb's quarter	S	860	1,870			10
Chenopodium	sp.	goosefoot, lamb's quarter	W		311		8.6	10
Cicuta	*maculata*	common water hemlock	S	450	1,720			10
Cicuta	*maculata*	common water hemlock	W	274	2,200	7.4	9.1	4,10
Cicuta	*maculata angustifolia*	common water hemlock	W	3,500	7,500	8.3	8.7	2
Cirsium	*arvense*	Canada thistle, field thistle	S	140	5,500			1,10
Cirsium	*arvense*	Canada thistle, field thistle	W	40	5,387	7.2	9.6	4,9,10
Cirsium	*flodmanii*	flodman's thistle	S	480	3,330			10
Cirsium	*vulgare*	bull thistle	S	380	1,700			10
Cirsium	*vulgare*	bull thistle	W		1,623		7.7	10
Convolvulus	*arvensis*	field bindweed	S	140	2,830			10
Convolvulus	*arvensis*	field bindweed	W	450	729	8.2	8.6	10
Conyza	*canadensis*	horse-weed	S	300	4,000			10
Coreopsis	*tinctoria*	plains coreopsis	S	345	615			10
Cornus	*sericea*	redosier dogwood	S	550	575			10
Cornus	*sericea*	redosier dogwood	W		537		8.5	10
Crataegus	*rotundifolia*	northern hawthorn	S		550			10
Crataegus	*rotundifolia*	northern hawthorn	W		450		8.6	10
Crepis	*runcinata*	hawk's-beard	S	140	1,260			10
Crepis	*runcinata*	hawk's-beard	W	326	1,263	7.2	8.6	10
Cyperus	*acuminatus*	tapeleaf flatsedge	S	720	850			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Cyperus	*acuminatus*	tapeleaf flatsedge	W	40	2,000			9
Cyperus	*erythrorhizos*	redrooted cyperus	S		900			10
Cyperus	*odoratus*	fragrant flatsedge	S	480	1,975			10
Cyperus	sp.	umbrella sedge	S	310	1,470			10
Cypripedium	sp.	lady's-slipper	S		1,730			10
Dactylis	*glomerata*	orchard grass	S	395	770			10
Dalea	*purpurea*	purple prairie clover	S	290	850			10
Descurainia	*sophia*	flixweed	S	560	2,380			10
Dichanthelium	*oligosanthes*	dichanthelium	S		530			10
Distichlis	*spicata* var. *stricta*	inland saltgrass	S	400	104,000	6.8	10.0	10,11,14,15,16,17
Distichlis	*spicata* var. *stricta*	inland saltgrass	W	500	120,000	7.9	9.1	2,4,9,10
Drepanocladus	sp.	drepanocladus moss	W	40	5,000			4,9
Echinochloa	*crusgalli*	barnyard grass	S	290	5,500			10
Echinochloa	*crusgalli*	barnyard grass	W	40	5,000	6.7	9.1	4,9,10
Elaeagnus	*angustifolia*	russian olive	S	550	1,150			10
Elaeagnus	*commutata*	silverberry	S	900	6,460			10
Eleocharis	*acicularis*	needle spikerush	S	350	2,000			10
Eleocharis	*acicularis*	needle spikerush	W	40	5,800	7.2	9.8	4,9,10
Eleocharis	*compressa*	flatstem spikerush	S	500	2,400			10
Eleocharis	*compressa*	flatstem spikerush	W	400	5,000		8.2	4,10
Eleocharis	*macrostachya*	common spikerush	W	100	41,000			4
Eleocharis	*obtusa* var. *ovata*	blunt spikerush	S	500	900			10
Eleocharis	*obtusa* var. *ovata*	blunt spikerush	W	40	2,000	7.8	9.1	9,10
Eleocharis	*palustris*	common spikerush	S	305	10,938			10,17
Eleocharis	*palustris*	common spikerush	W	40	15,000	6.8	9.8	2,9,10
Eleocharis	sp.	spikerush	S	290	3,160			10
Eleocharis	sp.	spikerush	W	113	2,597	6.6	9.5	10
Ellisia	*nyctelea*	waterpod	S		620			10
Elodea	*canadensis*	canadian waterweed	W	40	2,000			4,9

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Elymus	*canadensis*	Canada wild rye	S	400	3,800			10,17
Epilobium	*ciliatum*	willow-herb	S	500	2,930			10
Epilobium	*ciliatum*	willow-herb	W	40	5,000			4,9
Epilobium	*leptophyllum*	narrow-leaved willow-herb	S	290	4,000			10
Epilobium	*leptophyllum*	narrow-leaved willow-herb	W		1,232		8.5	10
Epilobium	sp.	willow-herb, fireweed	S		460			10
Equisetum	*arvense*	field horsetail	S	140	1,520			10
Equisetum	*arvense*	field horsetail	W	400	450		8.6	4,10
Equisetum	*fluviatile*	water horsetail	W		300			4
Equisetum	*hyemale*	common scouring rush	S	470	2,100			10
Equisetum	*laevigatum*	smooth scouring rush	S	140	3,800			10
Equisetum	*laevigatum*	smooth scouring rush	W	192	412	7.9	9.7	10
Erigeron	*philadelphicus*	Philadelphia fleabane	S	340	1,613			10
Erigeron	*philadelphicus*	Philadelphia fleabane	W	401	729	8.0	8.6	10
Erigeron	*strigosus*	daisy fleabane	S	300	1,260			10
Eriophorum	*polystachion*	narrowleaf cottongrass	W	500	2,200			4
Eupatorium	*maculatum*	joe-pye weed, spotted joe-pye weed	S	400	760			10
Eupatorium	*maculatum*	joe-pye weed, spotted joe-pye weed	W	148	700		7.3	4,10
Euphorbia	*esula*	leafy spurge	S	600	1,880			10
Euphorbia	*maculata*	spotted spurge	S	570	2,570			10
Euphorbia	*maculata*	spotted spurge	W		148		7.3	10
Eustoma	*grandiflorum*	showy prairie gentian	S	938	15,156			14
Euthamia	*graminifolia* var. *graminif*	flat-top goldentop	S	450	1,730			10
Euthamia	*graminifolia* var. *graminif*	flat-top goldentop	W	100	2,100		8.0	4,10
Fragaria	*virginiana*	wild strawberry	S	140	3,800			10
Fragaria	*virginiana*	wild strawberry	W		450		8.6	10
Fraxinus	*pennsylvanica*	green ash	S	345	2,050			10
Galium	*boreale*	northern bedstraw	S	400	1,270			10
Galium	sp.	bedstraw, cleavers	S		540			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Galium	sp.	bedstraw, cleavers	W		355		7.6	10
Galium	*trifidum*	small bedstraw	S	400	630			10
Galium	*trifidum*	small bedstraw	W	300	590	7.4	7.6	4,10
Glaux	*maritima*	sea milkwort	S	1,290	4,000			10
Glaux	*maritima*	sea milkwort	W	288	5,000		7.6	9,10
Glyceria	*borealis*	northern mannagrass	W	40	1,000			4,9
Glyceria	*grandis*	tall mannagrass	S	330	1,290			10
Glyceria	*grandis*	tall mannagrass	W	40	4,000	6.7	9.9	4,9,10
Glyceria	*striata*	fowl mannagrass	S	350	2,200			10
Glyceria	*striata*	fowl mannagrass	W	260	800		9.8	4,10
Glycyrrhiza	*lepidota*	wild licorice	S	300	4,000			10
Glycyrrhiza	*lepidota*	wild licorice	W	450	1,487	8.1	8.6	10
Gratiola	*neglecta*	hedge hyssop	W	40	2,000			9
Grindelia	*squarrosa*	curly-top gumweed	S	450	20,313			10,17
Hedeoma	*hispidum*	rough false pennyroyal	S	300	630			10
Helenium	*autumnale*	sneezeweed	W	40	2,500			4,9
Helianthus	*annuus*	common sunflower	S	340	3,480			10
Helianthus	*annuus*	common sunflower	W		326		7.8	10
Helianthus	*maximiliani*	maximilian sunflower	S	140	3,800			10
Helianthus	*maximiliani*	maximilian sunflower	W	450	590	7.4	8.6	10
Helianthus	*nuttallii*	nuttall's sunflower	S	400	3,800			10
Helianthus	*nuttallii*	nuttall's sunflower	W	590	856	7.4	8.1	10
Helianthus	*petiolaris*	plains sunflower	S	400	760			10
Helianthus	*rigidus*	stiff sunflower	S	400	2,200			10
Helianthus	sp.	sunflower	S	140	450			10
Heliopsis	*helianthoides*	false sunflower, ox-eye	S	500	1,730			10
Heliotropium	*curassavicum*	seaside heliotrope	W	2,000	15,000			9
Hesperis	*matronalis*	dame's rocket	S	450	2,615			10
Hesperis	*matronalis*	dame's rocket	W		355		7.6	10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Hierochloe	*odorata*	sweetgrass	S		760			10
Hierochloe	*odorata*	sweetgrass	W	40	2,000			9
Hippuris	*vulgaris*	mare's tail	S		850			10
Hippuris	*vulgaris*	mare's tail	W	267	4,100	8.1	8.6	2,4,8,9,10
Hordeum	*jubatum*	foxtail barley	S	290	39,800	6.4	9.5	10,11,12,13,14,15,16,17
Hordeum	*jubatum*	foxtail barley	W	40	48,600	7.3	9.7	4,9,10
Hypoxis	*hirsuta*	yellow stargrass	S	530	640			10
Impatiens	*capensis*	spotted touch-me-not	W		400			4
Iris	sp.	iris, flag	S	270	890			10
Iris	sp.	iris, flag	W	274	729	7.2	9.0	10
Iris	*versicolor*	blue flag	S	600	750			10
Iris	*versicolor*	blue flag	W	302	729	8.6	9.1	10
Iva	*annua*	marsh elder	S	1,875	24,000	6.9	8.2	11,14,15,17
Iva	*xanthifolia*	marsh elder	S	340	2,930			10
Iva	*xanthifolia*	marsh elder	W		1,582		7.3	10
Juncus	*alpinus*	richardson's rush	S	850	2,570			10
Juncus	*alpinus*	richardson's rush	W	964	1,947	7.3	8.2	10
Juncus	*balticus*	baltic rush	S	290	43,750			10,17
Juncus	*balticus*	baltic rush	W	40	45,000	7.8	8.1	4,9,10
Juncus	*bufonius*	toad rush	S		450			10
Juncus	*bufonius*	toad rush	W	40	2,300			4,9
Juncus	*dudleyi*	dudley rush	W	40	2,000			4,9
Juncus	*interior*	inland rush	S	380	4,000			10
Juncus	*interior*	inland rush	W	40	2,000		7.8	4,9,10
Juncus	sp.	rush	S	1,225	2,790			10
Juncus	*torreyi*	torrey's rush	S	490	5,500			10
Juncus	*torreyi*	torrey's rush	W	40	10,000		7.3	4,9,10
Kochia	*scoparia*	kochia	S	300	20,313			10,14,17
Kochia	*scoparia*	kochia	W	40	45,000			9

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Lactuca	*serriola*	prickly lettuce	S	340	2,930			10
Lactuca	*serriola*	prickly lettuce	W	2,000	45,000			9
Lactuca	*tatarica*	blue lettuce	S	290	3,970			10
Lactuca	*tatarica*	blue lettuce	W		307		7.8	10
Lathyrus	*palustris*	marsh vetchling	S	340	1,730			10
Lathyrus	*palustris*	marsh vetchling	W		590		7.4	10
Leersia	*oryzoides*	rice cutgrass	S	380	1,475			10
Leersia	*oryzoides*	rice cutgrass	W	192	326	7.8	9.7	10
Lemna	*minor*	common duckweed	S	350	4,000			10
Lemna	*minor*	common duckweed	W	40	15,000	6.6	9.9	2,4,9,10
Lemna	*trisulca*	star duckweed	S	350	4,000			10
Lemna	*trisulca*	star duckweed	W	40	13,900	7.0	9.9	4,9,10
Lepidium	*densiflorum*	peppergrass	S		300			10
Leptochloa	*fascicularis*	bearded sprangletop	S	469	7,656			10,14
Leptochloa	*fascicularis*	bearded sprangletop	W		577		7.9	10
Liatris	*ligulistylis*	rocky mountain blazing star	S	3,330	3,800			10
Liatris	*punctata*	dotted blazing star	S		650			10
Liatris	*pycnostachya*	prairie blazing star	S		1,730			10
Lilium	*philadelphicum*	wild lily	S		540			10
Limosella	*aquatica*	mudwort	W	40	2,000			9
Lindernia	*dubia*	false pimpernel	W	40	2,000			9
Linum	*perenne*	blue flax	S		450			10
Lithospermum	*canescens*	hoary puccoon	S		550			10
Lithospermum	*canescens*	hoary puccoon	W		450		8.6	10
Lobelia	*spicata*	palespike lobelia	S	770	2,620			10
Lotus	*unifoliolatus*	Amercian bird's-foot trefoil	S	670	3,330			10
Lycopus	*americanus*	Amercian bugleweed	S	300	4,000			10
Lycopus	*americanus*	Amercian bugleweed	W	274	24,000	7.2	9.6	2,4,10
Lycopus	*asper*	rough bugleweed	S	330	4,700			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Lycopus	*asper*	rough bugleweed	W	40	32,600	6.8	9.8	4,9,10
Lygodesmia	*juncea*	skeletonweed	S		690			10
Lysimachia	*ciliata*	fringed loosestrife	S	500	2,780			10
Lysimachia	*ciliata*	fringed loosestrife	W	166	2,653	6.7	8.3	10
Lysimachia	*hybrida*	loosestrife	S	330	860			10
Lysimachia	*hybrida*	loosestrife	W	40	2,000	7.7	9.0	4,9,10
Lysimachia	*thyrsiflora*	tufted loosestrife	S	370	735			10
Lysimachia	*thyrsiflora*	tufted loosestrife	W	192	3,800	7.4	9.7	4,10
Malva	*neglecta*	common mallow	S		1,320			10
Marsilea	*vestita*	western water clover	W	40	2,000			9
Medicago	*lupulina*	black medick	S	300	2,500			10
Medicago	*sativa*	alfalfa	S	300	5,500			10
Medicago	*sativa*	alfalfa	W		629		7.2	10
Melilotus	*officinalis*	yellow sweet clover	S	140	6,460			10
Melilotus	*officinalis*	yellow sweet clover	W	326	1,582	7.3	8.6	10
Melilotus	sp.	sweet clover	S	375	5,500			10
Melilotus	sp.	sweet clover	W		362		7.0	10
Mentha	*arvensis*	field mint	S	290	2,380			10
Mentha	*arvensis*	field mint	W	40	5,000	6.7	9.0	4,9,10
Mentha	*arvensis villosa*	field mint	W	3,500	4,100		8.3	2
Mimulus	*ringens*	alleghany monkey-flower	W		600			4
Monarda	*fistulosa*	wild bergamot	S	450	550			10
Muhlenbergia	*asperifolia*	scratchgrass	S	880	4,688			10,17
Muhlenbergia	*asperifolia*	scratchgrass	W	700	45,000			4,9
Muhlenbergia	*racemosa*	marsh muhly	S		1,725			10
Muhlenbergia	*richardsonis*	mat muhly	S	400	3,800			10
Myriophyllum	*exalbescens*	American milfoil	S	450	4,740			10
Myriophyllum	*exalbescens*	American milfoil	W	40	8,000	7.2	9.8	2,3,4,8,9,10
Myriophyllum	*heterophyllum*	water milfoil	W	40	2,000			9

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Myriophyllum	*pinnatum*	green parrot's feather	W		100			4
Myriophyllum	*verticillatum*	whorl-leaf watermilfoil	W	400	5,000			3,4,9
Najas	*flexilis*	naiad	W	300	700			4
Nepeta	*cataria*	catnip	S		380			10
Nuphar	*lutea* var. *variegatum*	yellow water lily	W		400			4
Oxalis	*stricta*	yellow wood sorrel	S	140	1,700			10
Oxalis	*stricta*	yellow wood sorrel	W		450		8.6	10
Oxalis	*violacea*	violet wood sorrel	S	450	620			10
Panicum	*americanum*	pearl millet	S	290	5,500			10
Panicum	*americanum*	pearl millet	W		275		7.9	10
Panicum	*capillare*	common witchgrass	S	290	2,500			10
Panicum	*capillare*	common witchgrass	W	40	15,000			9
Panicum	*virgatum*	switchgrass	S	300	2,750			10
Panicum	*virgatum*	switchgrass	W	260	856	7.8	9.8	10
Parietaria	*pensylvanica*	Pennsylvania pellitory	S		900			10
Parnassia	*glauca*	grass-of-parnassus	W		900			4
Pedicularis	*canadensis*	common lousewort, wood betony	S	500	1,730			10
Phalaris	*arundinacea*	reed canarygrass	S	300	3,210			10
Phalaris	*arundinacea*	reed canarygrass	W	40	3,800	6.9	9.9	4,9,10
Phleum	*pratense*	timothy	S	400	2,050			10
Phleum	*pratense*	timothy	W	600	729	8.3	8.6	10
Phragmites	*australis*	common reed	S	580	4,660		7.3	1,10,16
Phragmites	*australis*	common reed	W	100	32,600	7.6	9.0	2,4,9,10
Physalis	*virginiana*	Virginia ground cherry	S	350	1,700			10
Plagiobothrys	*scouleri*	popcorn-flower	W	40	2,000			9
Plantago	*eriopoda*	alkali plantain	W	500	20,100			4,9
Plantago	*major*	common plantain	S	400	5,500			10
Plantago	*major*	common plantain	W	40	5,000		7.8	4,9,10
Poa	*arida*	plains bluegrass	S	1,094	20,313			14,17

Appendix 5. Summary of plant database.—Continued

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Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Poa	*compressa*	Canada bluegrass	S	1,250	5,156			13
Poa	*palustris*	fowl bluegrass	S	140	5,500			10
Poa	*palustris*	fowl bluegrass	W	40	5,000	7.4	9.7	4,9,10
Poa	*pratensis*	Kentucky bluegrass	S	140	5,500			10
Poa	*pratensis*	Kentucky bluegrass	W	192	1,623	7.4	9.7	10
Poa	*sandbergii*	Sandberg's bluegrass	S		400			10
Poa	sp.	bluegrass	S		550			10
Poa	sp.	bluegrass	W		632		7.4	10
Polygonum	*amphibium*	water smartweed	S	270	3,020			10
Polygonum	*amphibium*	water smartweed	W	40	5,000	6.6	9.9	3,4,9,10
Polygonum	*amphibium* var. *emersum*	swamp smartweed	W	40	5,000			4,9
Polygonum	*aviculare*	knotweed	S		630			10
Polygonum	*aviculare*	knotweed	W		355		7.6	10
Polygonum	*convolvulus*	climbing or wild buckwheat	S	300	2,380			10
Polygonum	*erectum*	erect knotweed	S	380	1,560			10
Polygonum	*lapathifolium*	pale smartweed	S	310	2,450			10
Polygonum	*lapathifolium*	pale smartweed	W	40	5,000	7.8	8.6	9,10
Polygonum	*pensylvanicum*	Pennsylvania smartweed	S	1,145	2,450			10
Polygonum	*pensylvanicum*	Pennsylvania smartweed	W		629		7.2	10
Polygonum	*ramosissimum*	bushy knotweed	S	410	54,063			10,14,17
Polygonum	*ramosissimum*	bushy knotweed	W	2,000	45,000			9
Populus	*deltoides*	cotton-wood	S	300	1,850			10
Populus	*deltoides*	cotton-wood	W	362	1,385	7.0	7.9	10
Populus	*tremuloides*	quaking aspen	S	300	2,620			10
Populus	*tremuloides*	quaking aspen	W	192	429	7.8	9.7	10
Potamogeton	*diversifolius*	waterthread pondweed	W	40	500			9
Potamogeton	*filiformis*	slender pondweed	W	560	8,000			3
Potamogeton	*friesii*	Fries' pondweed	W	300	4,100		8.3	2,4
Potamogeton	*gramineus*	variable pondweed	S	430	660			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Potamogeton	*gramineus*	variable pondweed	W	40	2,000	6.7	8.3	4,9,10
Potamogeton	*natans*	floatingleaf pondweed	S		500			10
Potamogeton	*natans*	floatingleaf pondweed	W		777		7.7	10
Potamogeton	*nodosus*	longleaf pondweed	S	410	535			10
Potamogeton	*nodosus*	longleaf pondweed	W	401	496	8.0	8.2	10
Potamogeton	*pectinatus*	sago pondweed	S	300	31,406	8.4	8.9	1,5,10,16,17
Potamogeton	*pectinatus*	sago pondweed	W	38	162,500	6.3	10.8	2,3,4,5,8,9,10,11,17
Potamogeton	*pusillus*	baby pondweed	S	330	3,000			10
Potamogeton	*pusillus*	baby pondweed	W	40	6,700	6.9	9.9	4,9,10
Potamogeton	*richardsonii*	claspingleaf pondweed	S	450	520			10
Potamogeton	*richardsonii*	claspingleaf pondweed	W	40	5,000	8.0	9.5	2,3,4,8,9,10
Potamogeton	sp.	pondweed	W		148		7.3	10
Potamogeton	*strictifolius*	narrowleaf pondweed	W		267			8
Potamogeton	*vaginatus*	sheathed pondweed	W	267	15,000		8.9	2,4,8,9
Potamogeton	*zosteriformis*	flatstem pondweed	S	380	630			10
Potamogeton	*zosteriformis*	flatstem pondweed	W	260	5,000	7.3	9.9	3,4,8,9,10
Potentilla	*anserina*	silverweed	S	420	4,700			10
Potentilla	*anserina*	silverweed	W	100	45,000		7.2	4,9,10
Potentilla	*arguta*	tall cinquefoil	S	530	1,520			10
Potentilla	*norvegica*	Norwegian cinquefoil	S	400	2,940			10
Potentilla	*norvegica*	Norwegian cinquefoil	W	40	2,000		8.6	4,9,10
Potentilla	*pensylvanica*	Pennsylvania cinquefoil	S	400	1,990			10
Potentilla	*rivalis*	brook conquefoil	W		300			4
Psoralea	*argophylla*	silver-leaf scurf-pea	S	290	1,870			10
Puccinellia	*nuttalliana*	nuttall's alkaligrass	S	880	39,800	7.7	8.6	10,16,17
Puccinellia	*nuttalliana*	nuttall's alkaligrass	W	700	120,000	7.9	9.6	2,4,9
Ranunculus	*cymbalaria*	shore buttercup	S	760	4,688			10,17
Ranunculus	*cymbalaria*	shore buttercup	W	500	34,000	8.0	9.6	2,4,9,10
Ranunculus	*flabellaris*	threadleaf buttercup	S	450	890			10

Appendix 5. Summary of plant database.—Continued

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Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Ranunculus	*flabellaris*	threadleaf buttercup	W	40	2,500	7.4	9.6	4,9,10
Ranunculus	*gmelinii*	small yellow buttercup	S	410	2,100			10
Ranunculus	*gmelinii*	small yellow buttercup	W	113	2,867	6.9	9.9	4,9,10
Ranunculus	*longirostris*	white water crowfoot	S	530	1,520			10
Ranunculus	*longirostris*	white water crowfoot	W	40	5,000	7.5	9.7	3,9,10
Ranunculus	*macounii*	macoun's buttercup	S	450	1,530			10
Ranunculus	*macounii*	macoun's buttercup	W	40	2,100	7.4	7.8	4,9,10
Ranunculus	*pensylvanicus*	bristly crowfoot	S	1,005	1,440			10
Ranunculus	*pensylvanicus*	bristly crowfoot	W		1,263		8.6	10
Ranunculus	*sceleratus*	cursed crowfoot	S		550			10
Ranunculus	*sceleratus*	cursed crowfoot	W	40	8,500			4,9
Ranunculus	sp.	buttercup, crowfoot	S	1,130	2,790			10
Ranunculus	sp.	buttercup, crowfoot	W		729		8.7	10
Ranunculus	*subrigidus*	white water crowfoot	W	200	4,500			4
Ratibida	*columnifera*	prairie coneflower	S	400	2,270			10
Rhus	*glabra*	smooth sumac	S		550			10
Ribes	*americanum*	wild black currant	S	535	630			10
Ribes	*americanum*	wild black currant	W	355	391	7.6	8.0	10
Riccia	*fluitans*	slender riccia	S	400	740			10
Riccia	*fluitans*	slender riccia	W	40	4,700	6.9	7.9	4,9,10
Riccia	sp.	liverwort	S	375	4,000			10
Riccia	sp.	liverwort	W	307	6,673	7.0	8.4	10
Ricciocarpus	*natans*	purple-fringed riccia	S		1,120			10
Ricciocarpus	*natans*	purple-fringed riccia	W	40	3,200		7.9	4,9,10
Rorippa	*palustris*	bog yellow cress	S	290	2,930			10
Rorippa	*palustris*	bog yellow cress	W	40	3,200	7.6	9.0	4,9,10
Rosa	*arkansana*	prairie wild rose	S	300	3,800			10
Rosa	*blanda*	smooth wild rose	S	500	740			10
Rosa	*woodsii*	western wild rose	S	140	900			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Rosa	*woodsii*	western wild rose	W		113		6.9	10
Rudbeckia	*hirta*	black-eyed susan	S	400	3,800			10
Rudbeckia	*hirta*	black-eyed susan	W		1,623		7.7	10
Rumex	*crispus*	curly dock	S	290	11,250			10,14,17
Rumex	*crispus*	curly dock	W	326	1,623	7.2	9.7	10
Rumex	*maritimus*	golden dock	S	270	4,550			10
Rumex	*maritimus*	golden dock	W	40	15,000	7.1	9.9	9,10
Rumex	*mexicanus*	willow-leaved dock	W	40	5,000			4,9
Rumex	*occidentalis*	western dock	S	300	2,930			10
Rumex	*occidentalis*	western dock	W	40	5,000	7.9	8.8	9,10
Rumex	*orbiculatus*	great water dock	S		885			10
Rumex	*salicifolius*	willow dock	S	300	5,500			10
Rumex	*salicifolius*	willow dock	W	307	6,673	7.2	9.5	10
Rumex	sp.	dock, sorrel	S	420	2,700			10
Rumex	sp.	dock, sorrel	W	113	1,582	6.7	8.5	10
Rumex	*stenophyllus*	Eurasian dock	S		700			10
Ruppia	*maritima*	ditchgrass, widgeon grass	S		31,406	3.1	8.8	6,17
Ruppia	*maritima*	ditchgrass, widgeon grass	W	94	609,375	6.0	10.8	2,3,6,8,9,11,17
Ruppia	*maritima* var. *occidentalis*	ditchgrass, widgeon grass	W	600	14,200			4
Ruppia	*maritima* var. *rostrata*	ditchgrass, widgeon grass	W	5,500	66,000			4
Sagittaria	*cuneata*	arrowhead	S	270	1,400			10
Sagittaria	*cuneata*	arrowhead	W	40	6,700	6.8	9.5	2,4,8,9,10
Sagittaria	*latifolia*	common arrowhead	S	400	900			10
Sagittaria	*latifolia*	common arrowhead	W	148	1,444	6.7	9.8	10
Sagittaria	sp.	arrowhead	S	400	650			10
Sagittaria	sp.	arrowhead	W	256	782	7.2	8.6	10
Salicornia	*rubra*	saltwort	S	2,344	142,813	7.0	9.0	11,12,13,16,17
Salicornia	*rubra*	saltwort	W	5,000	45,000			9
Salix	*amygdaloides*	peachleaf willow	S	350	2,620			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Salix	*amygdaloides*	peachleaf willow	W	192	1,385	7.4	9.7	10
Salix	*exigua*	sandbar willow, coyote willow	S	300	1,655			10
Salix	*exigua*	sandbar willow, coyote willow	W	192	600	8.3	9.7	10
Salix	*exigua* subs. *interior*	sandbar willow	W	300	1,700			4
Salix	*nigra*	black willow	S		620			10
Salix	sp.	willow	S	410	1,850			10
Salix	sp.	willow	W	201	1,896	7.7	9.8	10
Salsola	*iberica*	Russian thistle	S		39,800			17
Scirpus	*acutus*	hardstem bulrush	S	270	5,500			10,17
Scirpus	*acutus*	hardstem bulrush	W	40	37,000	6.6	9.9	2,3,4,9,10
Scirpus	*americanus*	chairmaker's bulrush	S	1,719	11,200	7.9	8.5	14,15,17
Scirpus	*americanus*	chairmaker's bulrush	W	500	120,000	8.3	9.6	2,9
Scirpus	*atrovirens*	darkgreen bulrush	S	580	2,270			10
Scirpus	*atrovirens*	darkgreen bulrush	W	500	2,200		7.5	4,10
Scirpus	*fluviatilis*	river bulrush	S	330	4,550			10
Scirpus	*fluviatilis*	river bulrush	W	40	6,700	6.6	9.9	4,9,10
Scirpus	*heterochaetus*	slender bulrush	S	300	2,470			10
Scirpus	*heterochaetus*	slender bulrush	W	40	4,200	6.9	9.8	4,9,10
Scirpus	*microcarpus*	panicled bulrush	W	300	900			4
Scirpus	*nevadensis*	Nevada bulrush	W	12,000	45,000			4,9
Scirpus	*pallidus*	cloaked bulrush	S	340	2,050			10
Scirpus	*pallidus*	cloaked bulrush	W	565	1,809	7.2	8.6	10
Scirpus	*paludosus*	cosmopolitan bulrush	S	410	120,000	5.2	8.9	7,10,11,14,15,16,17
Scirpus	*paludosus*	cosmopolitan bulrush	W	113	481,250	6.4	9.8	2,3,4,7,9,10,17
Scirpus	*pungens*	common threesquare	S	465	5,500			10
Scirpus	*pungens*	common threesquare	W	100	70,000	7.2	8.4	4,10
Scirpus	*robustus*	sturdy bulrush	S	2,600	111,000	3.1	6.6	7
Scirpus	*robustus*	sturdy bulrush	W	313	60,938	4.0	8.3	7
Scirpus	sp.	bulrush	S	450	975			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Scirpus	sp.	bulrush	W	192	629	7.2	9.7	10
Scirpus	*validus*	softstem bulrush	S	280	4,550			10
Scirpus	*validus*	softstem bulrush	W	40	6,673	7.0	9.7	4,9,10
Scolochloa	*festucacea*	sprangletop	S	400	4,660			1,10
Scolochloa	*festucacea*	sprangletop	W	40	15,000	6.8	9.8	2,4,9,10
Scrophularia	*lanceolata*	figwort	S		340			10
Scutellaria	*galericulata*	marsh skullcap	W		300			4
Scutellaria	sp.	skullcap	S	380	760			10
Scutellaria	sp.	skullcap	W	256	661	7.2	9.1	10
Senecio	*congestus*	swamp ragwort	S	620	2,450			10
Senecio	*congestus*	swamp ragwort	W	40	5,000			9
Senecio	*pseudaureus*	falsegold groundsel	S	610	1,260			10
Sesuvium	*verrucosum*	sea purslane	S	3,594	81,500	7.0	9.7	14,17
Setaria	sp.	foxtail	S	300	2,500			10
Setaria	sp.	foxtail	W	192	964	7.3	9.7	10
Silene	sp.	catchfly, campion	S	340	500			10
Sisyrinchium	*campestre*	white-eyed grass	S		530			10
Sium	*suave*	water parsnip	S	400	3,800			10
Sium	*suave*	water parsnip	W	40	5,000	7.2	9.9	4,9,10
Solidago	*canadensis*	Canada goldenrod	S	140	4,700			1,10
Solidago	*canadensis*	Canada goldenrod	W	590	725	7.4	8.6	10
Solidago	*gigantea*	late goldenrod	S	140	2,620			10
Solidago	*gigantea*	late goldenrod	W		629		7.2	10
Solidago	*missouriensis*	prairie goldenrod	S	140	1,220			10
Solidago	*mollis*	soft goldenrod	S	500	6,460			10
Solidago	*rigida* var. *rigida*	rigid goldenrod	S	140	4,700			10
Sonchus	*arvensis*	field sow thistle	S	290	20,313			1,10,17
Sonchus	*arvensis*	field sow thistle	W	40	20,800	7.2	9.6	4,9,10
Sonchus	*asper*	prickly sow thistle	S	490	800			10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Sorghastrum	*nutans*	Indian grass	S		530			10
Sparganium	*eurycarpum*	giant burreed	S	270	4,550			10
Sparganium	*eurycarpum*	giant burreed	W	40	5,000	6.6	9.6	4,9,10
Spartina	*gracilis*	alkali cordgrass	S	4,688	7,813			17
Spartina	*gracilis*	alkali cordgrass	W	700	45,000			4,9
Spartina	*pectinata*	prairie cordgrass	S	290	20,313			10,17
Spartina	*pectinata*	prairie cordgrass	W	40	33,500	6.6	9.5	4,9,10
Spergularia	*marina*	salt-marsh sand spurry	S	2,344	39,800			13,17
Spergularia	*marina*	salt-marsh sand spurry	W	2,000	15,000			9
Sphenopholis	*obtusa*	wedgegrass	S	17,188	20,313			17
Sphenopholis	*obtusata*	prairie wedgegrass	S		1,900			10
Spiraea	*alba*	meadow-sweet	S	525	740			10
Spiraea	*alba*	meadow-sweet	W	588	774	8.9	9.6	10
Spirodela	*polyrhiza*	duckmeat, greater duckweed	S	330	730			10
Spirodela	*polyrhiza*	duckmeat, greater duckweed	W	40	3,000	6.9	9.0	4,9,10
Sporobolus	*airoides*	alkali sacaton	S	156	42,656	6.5	10.0	14,17
Sporobolus	*texanus*	Texas dropseed	S	1,875	72,000	7.4	8.3	14,15
Stachys	*palustris*	hedge-nettle, marsh betony	S	290	3,480			10
Stachys	*palustris*	hedge-nettle, marsh betony	W	40	5,000	6.9	9.8	4,9,10
Stipa	*comata*	needle-and-thread	S	620	1,150			10
Stipa	*viridula*	green needlegrass	S	400	1,500			10
Stipa	*viridula*	green needlegrass	W		725		8.6	10
Suaeda	*depressa*	sea blite	S	5,781	110,400	6.8	10.0	11,14,15,16,17
Suaeda	*depressa*	sea blite	W	5,000	66,000			4,9
Symphoricarpos	*occidentalis*	western snowberry	S	350	4,000			10
Symphoricarpos	*occidentalis*	western snowberry	W	725	3,480	8.1	8.6	10
Tamarix	*ramosissima*	salt cedar	S	2,188	96,000	7.4	8.7	14,15
Taraxacum	*officinale*	common dandelion	S	300	4,688			10,17
Taraxacum	*officinale*	common dandelion	W	326	630	7.8	8.4	10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Teucrium	*canadense*	wood sage	S	450	1,720			10
Teucrium	*canadense*	wood sage	W	391	856	7.4	9.5	10
Teucrium	*canadense* var. *boreale*	wood sage	W	40	9,100			4,9
Thalictrum	*dasycarpum*	purple meadow rue	S	550	860			10
Thalictrum	*dasycarpum*	purple meadow rue	W		450		8.6	10
Thalictrum	*venulosum*	early meadow rue	S	525	1,730			10
Thalictrum	*venulosum*	early meadow rue	W		590		7.4	10
Thlaspi	*arvense*	field pennycress	S	470	2,380			10
Tradescantia	*bracteata*	spiderwort	S	400	740			10
Tragopogon	*dubius*	goat's beard	S	380	2,000			10
Trifolium	*hybridum*	alsike clover	S	450	520			10
Trifolium	*pratense*	red clover	S	400	930			10
Trifolium	*pratense*	red clover	W		326		7.8	10
Trifolium	*repens*	white clover	S	520	640			10
Triglochin	*maritima*	seaside arrowgrass	S	900	72,000	8.1	8.2	10,17
Triglochin	*maritima*	seaside arrowgrass	W	700	120,000	7.9	9.6	2,4,9
Triglochin	*palustris*	marsh arrowgrass	W				9.6	2
Typha	*angustifolia*	narrow-leaved cat-tail	S	280	4,550			10
Typha	*angustifolia*	narrow-leaved cat-tail	W	192	15,000	7.0	9.9	4,9,10
Typha	*latifolia*	broad-leaved cat-tail	S	270	5,500			10
Typha	*latifolia*	broad-leaved cat-tail	W	40	13,600	6.2	9.9	2,4,9,10,11
Typha	sp.	cat-tail	S	420	4,660			1,10
Typha	sp.	cat-tail	W	195	5,387	6.9	8.5	3,10
Typha	x *glauca*	hybrid cat-tail	S	330	4,550			10
Typha	x *glauca*	hybrid cat-tail	W	100	6,600	6.7	9.9	4,9,10
Urtica	*dioica*	stinging nettle	S	400	3,800			10
Urtica	*dioica*	stinging nettle	W	274	5,387	7.1	9.0	10
Utricularia	*vulgaris*	common bladderwort	S	330	3,370			10
Utricularia	*vulgaris*	common bladderwort	W	40	8,100	6.8	9.9	2,4,8,9,10

Appendix 5. Summary of plant database.—Continued

[Scientific and common names primarily follow The Great Plains Flora Association (1986), and the minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). S, soil; W, water; µS cm^{-1}, microsiemens per centimeter]

Genus	Species	Common name	Substrate	Conductivity (µS cm^{-1})		pH		Source[1]
				Min	Max	Min	Max	
Vallisneria	*americana*	tapegrass	S	410	880			10
Vallisneria	*americana*	tapegrass	W	192	852	7.6	9.8	10
Verbena	*hastata*	blue vervain	S	415	1,690			10
Verbena	*hastata*	blue vervain	W	355	632	7.4	7.6	10
Verbena	sp.	vervain	S		590			10
Vernonia	*fasciculata*	ironweed	S	310	1,400			10
Vernonia	*fasciculata*	ironweed	W	40	500	7.2	7.8	4,9,10
Veronica	*anagallis-aquatica*	water speedwell	S		500			10
Veronica	*peregrina*	purslane speedwell	S		4,000			10
Veronica	*peregrina*	purslane speedwell	W	40	2,000			9
Vicia	*americana*	American vetch	S	400	1,720			10
Vicia	sp.	vetch	S	140	770			10
Vicia	sp.	vetch	W		450		8.6	10
Viola	*nuttallii*	yellow prairie violet	S	580	650			10
Viola	*sororia*	downy blue violet	S	535	860			10
Viola	*sororia*	downy blue violet	W	391	590	7.4	8.6	10
Xanthium	*strumarium*	cocklebur	S	300	5,500			10
Xanthium	*strumarium*	cocklebur	W	40	5,000	7.7	9.7	9,10
Zannichellia	*palustris*	horned pondweed	W	300	45,000			3,4,9
Zigadenus	*elegans*	white camass	S	530	760			10
Zizia	*aptera*	meadow parsnip	S	400	620			10
Zizia	*aptera*	meadow parsnip	W	192	450	8.6	9.7	10
Zizia	*aurea*	golden alexanders	S	400	1,725			10
Zizia	*aurea*	golden alexanders	W	590	856	7.4	8.1	10

[1]Source: 1, Grosshans and Kenkel, 1997; 2, Hammer and Heseltine, 1988; 3, Johnson, 1990; 4, Kantrud and others, 1989; 5, Kantrud, 1990; 6, Kantrud, 1991; 7, Kantrud, 1996; 8, Rawson and Moore, 1944; 9, Stewart and Kantrud, 1972; 10, USGS unpublished a; 11, Ungar and others, 1969; 12, Ungar and others, 1979; 13, Ungar and Riehl, 1980; 14, Ungar, 1966; 15, Ungar, 1967; 16, Ungar, 1970; 17, Ungar, 1974.

References

Grosshans, R.E., and Kenkel, N.C., 1997, Dynamics of emergent vegetation along natural gradients of water depth and salinity in a prairie marsh—delayed influences of competition, *in* Goldsborough, L.G., and Hann, B.J., eds., University of Manitoba Field Station (Delta Marsh) thirty-second annual report: Portage la Prairie, Manitoba, Canada, p. 83–93.

Hammer, U.T., and Heseltine, J.M., 1988, Aquatic macrophytes in saline lakes of the Canadian prairies: Hydrobiologia, v. 158, p. 101–116.

Johnson, K.M., 1990, Aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin National Wildlife Refuge: Bozeman, Montana State University, master's thesis.

Kantrud, H.A., 1990, Sago pondweed (*Potamogeton pecinatus* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Resource Publication 176, 89 p.

Kantrud, H.A., 1991, Widgeongrass (*Ruppia maritima* L.)—a literature review: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Research 10, 58 p.

Kantrud, H.A., 1996, The alkali (*Scirpus maritimus* L.) and saltmarsh (*S. robustus* Pursh) bulrushes—a literature review: Washington, D.C., National Biological Service Information and Technology Report 6, 77 p.

Kantrud, H.A., Millar, J.B., and van der Valk, A.G., 1989, Vegetation of wetlands of the prairie pothole region, *in* van der Valk, A., ed., Northern prairie wetlands: Ames, Iowa State University Press, p. 132–187.

Rawson, D.S., and Moore, J.E., 1944, The saline lakes of Saskatchewan: Canadian Journal of Research, v. 22, p. 141–201.

Stewart, R.E., and Kantrud, H.A., 1972, Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors: Washington, D.C., U.S. Geological Survey Professional Paper 585-D, 36 p.

Ungar, I.A., 1966, Salt tolerance of plants growing in saline areas of Kansas and Oklahoma: Ecology, v. 47, p. 154–155.

Ungar, I.A., 1967, Vegetation-soil relationships on saline soils in northern Kansas: American Midland Naturalist, v. 78, p. 98–120.

Ungar, I.A., 1970, Species-soil relationships on sulfate dominated soils of South Dakota: American Midland Naturalist, v. 83, p. 343–357.

Ungar, I.A., 1974, Inland halophytes of the United States, *in* Reimold, R.J., and Queen, W.H., eds., Ecology of halophytes: New York, N.Y., Academic Press, Inc., p. 235–305.

Ungar, I.A., Benner, D.K., and McGraw, D.C., 1979, The distribution and growth of Salicornia Europaea on an inland salt pan: Ecology, v. 60, p. 329–336.

Ungar, I.A., Hogan, W., and McClelland, M., 1969, Plant communities of saline soils at Lincoln, Nebraska: The American Midland Naturalist, v. 82, p. 564–577.

Ungar, I.A., and Riehl, T.E., 1980, The effect of seed reserves on species composition in zonal halophyte communities: Botanical Gazette, v. 141, p. 447–452.

Appendix 6. Summary of invertebrate database.

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Annelida	Hirudinea					270	15,625	7.1	9.3	1,5,6,7
Annelida	Hirudinea	Gnathobdellida	Hirudinidae			540	1,997	7.1	9.4	6
Annelida	Hirudinea	Pharyngobdellida	Erpobdellidae			531	2,000	7.1	9.7	6
Annelida	Hirudinea	Pharyngobdellida	Erpobdellidae	*Erpobdella*		99	4,340			7
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae			531	2,000	7.3	9.7	6
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Glossiphonia*		105	2,930			7
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Helobdella*		69	5,554	7.1	10.0	6,7
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Helobdella*	*stagnalis*		2,644			7
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Placobdella*		168	1,243			7
Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	*Theromyzon*		217	4,378			7
Annelida	Oligochaeta					57	69,100	5.4	12.9	1,2,5,7
Arthropoda	Arachnida	Acarina				100	33,600	4.6	12.9	2
Arthropoda	Arachnoidea	Hydracarina				57	15,625	7.1	10.0	1,5,6,7
Arthropoda	Branchiopoda	Anastraca	Streptocephalidae	*Streptucephalus*	*texanus*	101	982			7
Arthropoda	Branchiopoda	Anostraca				80	2,178			7
Arthropoda	Branchiopoda	Anostraca	Artemiidae	*Artemia*	*salina*	26,622	187,500	10.0	10.6	4,5
Arthropoda	Branchiopoda	Anostraca	Branchinectidae	*Branchinecta*	*campestris*	5,130	5,557	9.8	9.9	4
Arthropoda	Branchiopoda	Anostraca	Branchinectidae	*Branchinecta*	*lindahli*	1,312	36,342	9.3	10.3	4
Arthropoda	Branchiopoda	Anostraca	Branchinectidae	*Branchinecta*	*mackini*		2,394		9.3	4
Arthropoda	Branchiopoda	Anostraca	Chirocephalidae	*Chirocephalopsis*	*bundyi*	680	1,250	8.8	9.0	4
Arthropoda	Branchiopoda	Anostraca	Chirocephalidae	*Eubranchipus*		188	892			7
Arthropoda	Branchiopoda	Anostraca	Chirocephalidae	*Eubranchipus*	*bundyi*	91	388			7
Arthropoda	Branchiopoda	Anostraca	Chirocephalidae	*Eubranchipus*	*ornatus*	80	892			7
Arthropoda	Branchiopoda	Anostraca	Streptocephalidae	*Streptocephalus*	*seali*		136		7.8	4
Arthropoda	Branchiopoda	Cladocera				99	15,000			1,7
Arthropoda	Branchiopoda	Cladocera	Bosminidae	*Bosmina*	*obtusirostris*	156	31,250			5
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Alona*	*costata*	156	7,813			5
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Alona*	*rectangula*	313	1,563			5
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Alonella*			1,879			7
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Chydorus*		185	3,658			7
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Chydorus*	*gibbus*	313	1,563			5

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1}) Min	Conductivity (µS cm^{-1}) Max	pH Min	pH Max	Source[1]
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Chydorus*	*sphaericus*	156	31,250			5
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Eurycercus*	*lamellatus*	156	2,497			5,7
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Graptoleberis*	*testudinaria*	313	1,563			5
Arthropoda	Branchiopoda	Cladocera	Chydoridae	*Pleuroxus*	*denticulatus*	156	7,813			5
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Ceriodaphnia*		91	4,650			7
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Ceriodaphnia*	*quadrangula*	313	15,625			5
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Daphnia*		80	6,150			7
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Daphnia*	*longispina*	156	187,500			5
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Daphnia*	*pulex*	313	31,250			5
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Scapholeberis*		196	3,698			7
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Scapholeberis*	*mucronata*	156	31,250			5
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Simocephalus*		57	5,266			7
Arthropoda	Branchiopoda	Cladocera	Daphnidae	*Simocephalus*	*vetulus*	156	15,625			5
Arthropoda	Branchiopoda	Cladocera	Leptodoridae	*Leptodora*	*kindtii*	156	7,813			5
Arthropoda	Branchiopoda	Cladocera	Moinidae	*Moina*			2,295			7
Arthropoda	Branchiopoda	Cladocera	Moinidae	*Moina*	*macrocopa*		3,706			7
Arthropoda	Branchiopoda	Cladocera	Polyphemidae	*Polyphemus*	*pediculus*	156	1,563			5
Arthropoda	Branchiopoda	Cladocera	Sididae	*Diaphanosoma*		1,104	4,073			7
Arthropoda	Branchiopoda	Cladocera	Sididae	*Diaphanosoma*	*leuchtenbergianum*	156	31,250			5
Arthropoda	Branchiopoda	Cladocera	Sididae	*Sida*	*crystallina*	313	1,563			5
Arthropoda	Branchiopoda	Conchostraca				119	2,407			7
Arthropoda	Branchiopoda	Conchostraca	Lynceidae	*Lynceus*		140	2,930			7
Arthropoda	Copepoda					500	15,000			1,7
Arthropoda	Copepoda	Calanoida				105	6,150			7
Arthropoda	Copepoda	Cyclopoida				69	6,543			7
Arthropoda	Copepoda	Eucopepoda	Canthocamptidae	*Cletocamptus*	*albuquerquensis*	31,250	187,500			5
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*albidus*	313	7,813			5
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*bicuspidatus*	313	15,625			5
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*fimbriatus*	313	1,563			5
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*leuckarti*	313	3,125			5
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*serrulatus*	313	31,250			5

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Copepoda	Eucopepoda	Cyclopidae	*Cyclops*	*viridis*	156	46,875			5
Arthropoda	Copepoda	Eucopepoda	Diaptomidae	*Diaptomus*	*oregonensis*	156	1,094			5
Arthropoda	Copepoda	Eucopepoda	Diaptomidae	*Diaptomus*	*shoshone*	3,125	31,250			5
Arthropoda	Copepoda	Eucopepoda	Diaptomidae	*Diaptomus*	*siciloides*	1,563	187,500			5
Arthropoda	Copepoda	Eucopepoda	Diaptomidae	*Diaptomus*	*tenuicaudatus*	156	46,875			5
Arthropoda	Copepoda	Eucopepoda	Ergasilidae	*Ergasilus*			1,493			7
Arthropoda	Copepoda	Eucopepoda	Laophontidae	*Laophonte*	*mohammed*	1,094	31,250			5
Arthropoda	Eubranchiopoda	Anostraca	Branchinectidae	*Branchinecta*	*lindahli*	105	5,800			7
Arthropoda	Eubranchiopoda	Conchostraca	Caenestheriidae	*Caenestheriella*			960			7
Arthropoda	Insecta	Coleoptera				313	156,250	7.8	7.9	1,5,6
Arthropoda	Insecta	Coleoptera	Curculionidae	*Litodactylus*	*griseomicans*	913	1,568			3
Arthropoda	Insecta	Coleoptera	Curculionidae	*Lixellus*	*filiformis*	913	1,568			3
Arthropoda	Insecta	Coleoptera	Dytiscidae			69	192,000	4.9	12.9	2,6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Acilius*		650	1,492			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Acilius*	*semisulcatus*		811			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*		57	4,378	7.5	9.4	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*	*ajax*	45	9,106			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*	*antennatus*	45	9,106			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*	*bifarius*	107	811			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*	*falli*		3,850			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Agabus*	*griseipennis*	6,335	15,524			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Colymbetes*		85	5,266			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Colymbetes*	*sculptilis*	190	3,310			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Coptotomus*		57	4,030	8.0	9.4	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Coptotomus*	*longulus*	107	3,019			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Dytiscus*		80	4,030	7.5	9.7	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*alaskanus*	99	4,892			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*circumcinctus*	1,651	1,771			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*cordieri*	45	3,430			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*hybridus*	179	3,850			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Graphoderus*		57	4,030	7.1	9.2	6,7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Graphoderus*	*liberus*	45	72			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Graphoderus*	*occidentalis*	140	3,955			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Graphoderus*	*perplexus*	45	4,340			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydaticus*		105	3,385		8.0	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydaticus*	*modestus*	279	2,670			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*		91	4,210	8.2	8.7	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*criniticoxis*		324			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*notabilis*		1,602			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*pervicinus*	228	951			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*superioris*	153	2,575			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*tenebrosus*	183	2,253			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hydroporus*	*undulatus*		1,936			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*		57	5,266	7.5	9.7	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*canadensis*	168	2,046			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*impressopunctatus*	153	3,310			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*lutescens*	45	4,892			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*masculinus*	6,335	15,524			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*patruelis*	153	4,078			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*picatus*	324	1,791			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*sayi*	45	9,106			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*sellatus*	190	3,130			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*turbidus*	238	2,819			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Hygrotus*	*unguicularis*	45	9,106			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Ilybius*		101	4,378	7.1	9.4	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Ilybius*	*fraterculus*	45	3,883			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Ilybius*	*subaenus*	45	4,892			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Laccophilus*		57	3,822	7.1	10.0	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Laccophilus*	*biguttatus*	45	3,808			3,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Laccophilus*	*maculosus*	217	4,098			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Laccornis*			171			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Liodessus*		100	4,973			7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Liodessus*	*affinis*	140	4,744			7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Potamonectes*	*griseostriatus*	45	72			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Potamonectes*	*spenceri*	6,335	15,524			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Potamonectes*	*striatellus*	6,335	9,106			3
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Rhantus*		57	4,210	7.3	9.4	6,7
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Rhantus*	*frontalis*	45	15,524			3,7
Arthropoda	Insecta	Coleoptera	Gyrinidae			153	18,600	6.4	9.0	2,7
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus*		117	3,405	7.6	8.4	6,7
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus*	*maculiventris*	363	2,888			7
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus*	*minutus*		1,682			7
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus*	*pectoralis*		1,782			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*		57	5,160	7.5	10.0	6,7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*connexus*	947	1,048			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*hoppingi*	217	3,883			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*immaculicollis*	45	15,524			3,7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*leechi*	45	72			3
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*salinarius*	1,209	3,356			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*stagninus*	913	11,532			3,7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*strigatus*	45	15,524			3,7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus*	*subguttatus*	986	3,720			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes*		153	4,210	7.5	9.7	6,7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes*	*edentulus*	140	3,883			7
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes*	*tortulosis*		1,714			7
Arthropoda	Insecta	Coleoptera	Helodidae			134	6,543			7
Arthropoda	Insecta	Coleoptera	Hydraenidae			400	192,000	5.3	9.0	2
Arthropoda	Insecta	Coleoptera	Hydrophilidae			100	192,000	6.1	12.9	2,7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*		91	4,720	7.8	8.6	6,7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*	*fraternus*	99	3,083			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*	*hatchi*	991	3,430			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*	*striatus*	99	3,706			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Cercyon*		1,015	4,210			7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Cymbiodyta*	*dorsalis*		2,888			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Enochrus*		80	5,266		8.4	6,7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Enochrus*	*diffusus*	3,706	15,524			3
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Helophorus*		57	4,973			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Helophorus*	*linearis*	179	2,123			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Helophorus*	*lineatus*		205			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Helophorus*	*oblongus*	811	1,080			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Hydrobius*		69	2,930			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Hydrobius*	*fuscipes*		107			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Hydrochara*		134	4,210			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Hydrochara*	*obtusatus*		273			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Hydrochus*		99	4,210			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Laccobius*	sp.	6,335	11,532			3
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Paracymus*		205	6,120			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Paracymus*	*subcupreus*	1,682	2,323			7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Tropisternus*		123	3,946		7.9	6,7
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Tropisternus*	*lateralis*	148	3,850			7
Arthropoda	Insecta	Coleoptera	Scirtidae			100	36,700	5.9	12.9	2
Arthropoda	Insecta	Coleoptera	Staphylinidae	*Micralymma*			2,000		8.2	6
Arthropoda	Insecta	Collembola				272	2,384	8.1	9.2	6,7
Arthropoda	Insecta	Collembola	Entomobryidae			118	5,554			7
Arthropoda	Insecta	Collembola	Isotomidae			80	6,150			7
Arthropoda	Insecta	Collembola	Poduridae			455	1,466			7
Arthropoda	Insecta	Collembola	Sminthuridae			134	4,378			7
Arthropoda	Insecta	Diptera				57	15,000		8.8	1,6,7
Arthropoda	Insecta	Diptera	Ceratopogonidae			57	192,000	4.6	12.9	1,2,5,6,7
Arthropoda	Insecta	Diptera	Ceratopogonidae	*Bezzia*		540	2,000	7.5	8.7	6
Arthropoda	Insecta	Diptera	Chaoboridae			544	2,000	7.6	8.9	6
Arthropoda	Insecta	Diptera	Chaoboridae	*Chaoborus*		57	5,266	7.1	9.7	6,7
Arthropoda	Insecta	Diptera	Chironomidae			57	192,000	4.6	12.9	1,2,5,6,7
Arthropoda	Insecta	Diptera	Corethrinae			313	10,938			5

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1}) Min	Conductivity (µS cm^{-1}) Max	pH Min	pH Max	Source[1]
Arthropoda	Insecta	Diptera	Culicidae			91	192,000	4.6	9.3	1,2,6,7
Arthropoda	Insecta	Diptera	Culicidae	*Aedes*		69	4,210			7
Arthropoda	Insecta	Diptera	Culicidae	*Culex*		159	5,554			7
Arthropoda	Insecta	Diptera	Culicidae	*Culiseta*		126	5,554			7
Arthropoda	Insecta	Diptera	Culicidae	*Mansonia*	*perturbans*	1,512	2,013			7
Arthropoda	Insecta	Diptera	Dixidae			153	2,123			7
Arthropoda	Insecta	Diptera	Dolichopodidae			85	192,000	4.6	9.1	2,5,7
Arthropoda	Insecta	Diptera	Ephydridae			140	156,250	4.6	9.3	1,2,5,7
Arthropoda	Insecta	Diptera	Psychodidae			139	3,536			7
Arthropoda	Insecta	Diptera	Psychodidae	*Pericoma*		2,283	2,294			7
Arthropoda	Insecta	Diptera	Ptychopteridae				3,698			7
Arthropoda	Insecta	Diptera	Sciomyzidae				637		9.2	6
Arthropoda	Insecta	Diptera	Simuliidae			200	14,800	5.9	12.9	2
Arthropoda	Insecta	Diptera	Stratiomyidae			80	15,000			1,7
Arthropoda	Insecta	Diptera	Stratiomyidae	*Odontomyia*		105	2,927			7
Arthropoda	Insecta	Diptera	Syrphidae			220	6,543			5,7
Arthropoda	Insecta	Diptera	Tabanidae			115	15,000			1,5,7
Arthropoda	Insecta	Diptera	Tipulidae			57	192,000	5.4	12.9	2,7
Arthropoda	Insecta	Ephemeroptera				313	31,250			1,5
Arthropoda	Insecta	Ephemeroptera	Baetidae			185	19,600	6.9	8.7	1,2,7
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Baetis*		286	2,930			7
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Callibaetis*		132	4,098	7.1	10.0	6,7
Arthropoda	Insecta	Ephemeroptera	Caenidae			100	18,600	6.4	9.0	1,2
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis*		80	2,381	7.1	9.7	6,7
Arthropoda	Insecta	Ephemeroptera	Ephemeroptera			185	4,650			7
Arthropoda	Insecta	Hemiptera				313	46,875			1,5
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Belostoma*			531		9.7	6
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Lethocerus*			572		9.4	6
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Lethocerus*	*americanus*	210	2,245			7
Arthropoda	Insecta	Hemiptera	Corixidae			69	23,100	6.1	12.9	1,2,6,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Callicorixa*		57	4,378	7.6	10.0	6,7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Hemiptera	Corixidae	*Callicorixa*	*audeni*	45	4,892			3
Arthropoda	Insecta	Hemiptera	Corixidae	*Cenocorixa*		57	4,098	7.8	10.0	6,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Cenocorixa*	*bifida*	45	15,524			3
Arthropoda	Insecta	Hemiptera	Corixidae	*Cenocorixa*	*expleta*	6,335	15,524			3
Arthropoda	Insecta	Hemiptera	Corixidae	*Corisella*			3,018			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Corisella*	*tarsalis*	1,628	1,679			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Cymatia*		98	3,350	7.5	10.0	6,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Cymatia*	*americana*	45	4,892			3
Arthropoda	Insecta	Hemiptera	Corixidae	*Dasycorixa*	*rawsoni*	858	15,524			3,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Hespercorixa*		531	2,000	7.5	9.7	6
Arthropoda	Insecta	Hemiptera	Corixidae	*Hesperocorixa*		57	4,030			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Hesperocorixa*	*atopodonta*	107	811			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Hesperocorixa*	*laevigata*	45	9,106			3
Arthropoda	Insecta	Hemiptera	Corixidae	*Hesperocorixa*	*vulgaris*		811			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Sigara*		57	5,800	7.5	10.0	6,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Sigara*	*solensis*	99	1,940			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Trichocorixa*		274	4,210	7.6	9.7	6,7
Arthropoda	Insecta	Hemiptera	Corixidae	*Trichocorixa*	*borealis*	1,608	4,098			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Trichocorixa*	*naias*	1,782	4,098			7
Arthropoda	Insecta	Hemiptera	Corixidae	*Trichocorixa*	*verticalis interiores*	2,014	3,755			7
Arthropoda	Insecta	Hemiptera	Gerridae			105	3,650			7
Arthropoda	Insecta	Hemiptera	Gerridae	*Gerris*		80	4,210			7
Arthropoda	Insecta	Hemiptera	Gerridae	*Rheumatobates*		194	2,030			7
Arthropoda	Insecta	Hemiptera	Hebridae	*Hebridae*		925	1,583	8.5	8.7	6
Arthropoda	Insecta	Hemiptera	Mesovelidae	*Mesovelia*		665	959	7.3	9.4	6
Arthropoda	Insecta	Hemiptera	Nepidae	*Ranatra*	*fusca*		1,682			7
Arthropoda	Insecta	Hemiptera	Notonectidae			100	26,900	5.3	10.0	1,2,6,7
Arthropoda	Insecta	Hemiptera	Notonectidae	*Buenoa*		308	2,745	7.5	10.0	6,7
Arthropoda	Insecta	Hemiptera	Notonectidae	*Buenoa*	*margaritacea*	1,064	4,098			7
Arthropoda	Insecta	Hemiptera	Notonectidae	*Notonecta*		101	3,850	7.5	10.0	6,7
Arthropoda	Insecta	Hemiptera	Notonectidae	*Notonecta*	*kirbyi*	45	15,524			3,7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Hemiptera	Notonectidae	*Notonecta*	*undulata*	45	4,098			3,7
Arthropoda	Insecta	Hemiptera	Pleidae			240	978			7
Arthropoda	Insecta	Hemiptera	Pleidae	*Neoplea*		286	2,000	7.1	9.7	6,7
Arthropoda	Insecta	Hemiptera	Pleidae	*Plea*		270	3,350			7
Arthropoda	Insecta	Hemiptera	Velidae			531	942	7.3	9.7	6
Arthropoda	Insecta	Odonata				80	46,875	7.1	10.0	5,6,7
Arthropoda	Insecta	Odonata	Aeshnidae			117	30,200	5.9	9.3	1,2,7
Arthropoda	Insecta	Odonata	Aeshnidae	*Aeshna*		57	4,973	7.8	8.8	6,7
Arthropoda	Insecta	Odonata	Aeshnidae	*Anax*		150	4,340			7
Arthropoda	Insecta	Odonata	Coenagrionidae			200	30,200	6.7	9.3	1,2,7
Arthropoda	Insecta	Odonata	Coenagrionidae	*Amphiagrion*			223			7
Arthropoda	Insecta	Odonata	Coenagrionidae	*Coenagrion*		680	1,890			7
Arthropoda	Insecta	Odonata	Coenagrionidae	*Enallagma*		57	4,378	7.3	10.0	6,7
Arthropoda	Insecta	Odonata	Coenagrionidae	*Ischnura*		85	2,710			7
Arthropoda	Insecta	Odonata	Corduliidae			100	33,600	5.3	12.9	2
Arthropoda	Insecta	Odonata	Lestidae			117	36,700	5.3	9.3	2,7
Arthropoda	Insecta	Odonata	Lestidae	*Lestes*		100	4,210	7.1	9.2	6,7
Arthropoda	Insecta	Odonata	Libellulidae			194	30,200	6.4	9.3	1,2,7
Arthropoda	Insecta	Odonata	Libellulidae	*Leucorrhinia*		147	2,470			7
Arthropoda	Insecta	Odonata	Libellulidae	*Libellula*		147	4,340			7
Arthropoda	Insecta	Odonata	Libellulidae	*Sympetrum*		98	4,210	7.5	8.3	6,7
Arthropoda	Insecta	Trichoptera				313	31,250			5
Arthropoda	Insecta	Tricoptera				98	15,000		9.0	1,6,7
Arthropoda	Insecta	Tricoptera	Brachycentridae	*Brachycentrus*		1,454	2,012			7
Arthropoda	Insecta	Tricoptera	Leptoceridae			100	69,100	4.9	12.9	1,2,7
Arthropoda	Insecta	Tricoptera	Leptoceridae	*Nectopsyche*			1,421			7
Arthropoda	Insecta	Tricoptera	Leptoceridae	*Oecetis*		826	1,030	7.5	9.2	6
Arthropoda	Insecta	Tricoptera	Leptoceridae	*Triaenodes*		845	1,640	8.1	8.6	6
Arthropoda	Insecta	Tricoptera	Limnephilidae			245	2,725			7
Arthropoda	Insecta	Tricoptera	Limnephilidae	*Anabolia*			873			7
Arthropoda	Insecta	Tricoptera	Limnephilidae	*Limnephilus*		240	2,407			7

Appendix 6. Summary of invertebrate database.—Continued

[The minimum and maximum values represent all data types (that is, values reported as minimum, maximum, mean, median, or single occurrence). µS cm^{-1}, microsiemens per centimeter]

Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Arthropoda	Insecta	Tricoptera	Molannidae	*Molanna*	*flavicornis*	911	3,808			7
Arthropoda	Insecta	Tricoptera	Phryganeidae			150	15,000			1,7
Arthropoda	Insecta	Tricoptera	Phryganeidae	*Fabria*		910	1,640	7.3	9.4	6
Arthropoda	Insecta	Tricoptera	Polycentropodidae			363	15,000			1,7
Arthropoda	Insecta	Tricoptera	Polycentropodidae	*Cernotina*		540	1,542	7.6	8.8	6,7
Arthropoda	Malacostraca	Amphipoda				313	46,875			5
Arthropoda	Malacostraca	Amphipoda	Ceinidae			100	69,100	4.9	12.9	2
Arthropoda	Malacostraca	Amphipoda	Gammaridae			500	15,000			1
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus*		118	4,214		8.0	6,7
Arthropoda	Malacostraca	Amphipoda	Perthiidae			200	7,600	5.4	9.0	2
Arthropoda	Malacostraca	Amphipoda	Talitridae			500	15,000			1
Arthropoda	Malacostraca	Amphipoda	Talitridae	*Hyalella*		98	6,543	7.1	10.0	6,7
Arthropoda	Malacostraca	Amphipoda	Talitridae	*Hyalella*	*azteca*	254	4,098			7
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Cambarus*		313	3,906			5
Arthropoda	Malacostraca	Decapoda	Palaemonidae			200	34,100	6.1	8.8	2
Arthropoda	Malacostraca	Decapoda	Parastacidae			100	29,200	5.9	8.8	2
Arthropoda	Ostracoda					101	6,150			7
Bryozoa	Phylactolaemata	Plumatellida	Plumatellidae	*Plumatella*		313	1,563			5
Cnidaria	Hydrozoa	Hydroida	Hydridae	*Hydra*		313	1,875			5
Mollusca	Bivalvia	Pelecypoda	Sphaeriidae			162	3,125			5,7
Mollusca	Bivalvia	Pelecypoda	Sphaeriidae	*Pisidium*	*casertanum*		185			7
Mollusca	Bivalvia	Pelecypoda	Sphaeriidae	*Pisidium*	*nitidum*	168	2,594			7
Mollusca	Bivalvia	Pelecypoda	Sphaeriidae	*Sphaerium*	*lacustre*	217	1,608			7
Mollusca	Bivalvia	Pelecypoda	Unionidae	*Anodonta*		313	469			5
Mollusca	Gastropoda					313	15,625			5
Mollusca	Gastropoda	Limnophila	Lymnaeidae			119	15,000			1,7
Mollusca	Gastropoda	Limnophila	Lymnaeidae	*Lymnaea*		196	3,658			7
Mollusca	Gastropoda	Limnophila	Lymnaeidae	*Lymnaea*	*caparata*	510	1,618			7
Mollusca	Gastropoda	Limnophila	Lymnaeidae	*Lymnaea*	*elodes*	57	4,214			7
Mollusca	Gastropoda	Limnophila	Lymnaeidae	*Lymnaea*	*reflexa*	324	1,416			7
Mollusca	Gastropoda	Limnophila	Lymnaeidae	*Lymnaea*	*stagnalis*	767	1,985			7

Appendix 6. Summary of invertebrate database.—Continued

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Phylum	Class	Order	Family	Genus	Species	Conductivity (µS cm^{-1})		pH		Source[1]
						Min	Max	Min	Max	
Mollusca	Gastropoda	Limnophila	Lymnaidae			540	1,579	7.9	9.4	6
Mollusca	Gastropoda	Limnophila	Physidae			500	15,000	7.1	10.0	1,6,7
Mollusca	Gastropoda	Limnophila	Physidae	*Aplexa*	*hypnorum*	188	3,480			7
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*		119	286			7
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*	*gyrina*	351	3,880			7
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*	*jennessi*	98	5,266			7
Mollusca	Gastropoda	Limnophila	Planorbidae			105	15,000	7.1	10.0	1,6,7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Armiger*	*crista*	57	4,250			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Gyralus*		168	2,407			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Gyralus*	*parvus*	85	4,378			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Gyraulus*	*circumstriatus*	57	4,650			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Helisoma*	*anceps*	334	1,264			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Helisoma*	*trivolvis*	98	3,456			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Planorbula*	*campestris*	220	261			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Promenetus*	*exacuous*	98	4,340			7
Mollusca	Gastropoda	Limnophila	Planorbidae	*Promenetus*	*umbilicatellus*	69	3,680			7
Mollusca	Gastropoda	Mesogastropoda	Valvatidae	*Valvata*	*lewesi*	122	1,985			7
Nematoda						313	156,250			1,5
Nemato-morpha	Gordioida	Gordea	Gordiidae	*Gordius*		313	1,094			5
Platyhel-minthes	Turbellaria	Tricladida	Planariidae	*Planaria*		313	469			5

[1]Source: 1, Johnson, 1990; 2, Kay and others, 2001; 3, Lancaster and Scudder, 1987; 4, McCarraher, 1970; 5, Rawson and Moore, 1944; 6, Tangen, unpublished; 7, USGS, unpublished b.

References

Johnson, K.M., 1990, Aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin National Wildlife Refuge: Bozeman, Montana State University, master's thesis.

Kay, W.R., Halse, S.A., Scanlon, M.D., and Smith, M.J., 2001, Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia: Journal of the North American Benthological Society, v. 20, p. 182–199.

Lancaster, J, and Scudder, G.G.E., 1987, Aquatic Coleoptera and Hemiptera in some Canadian saline lakes—patterns in community structure: Canadian Journal of Zoology, v. 65, p. 1383–1389.

McCarraher, D.B., 1970, Some ecological relations of fairy shrimps in alkaline habitats of Nebraska: American Midland Naturalist, v. 84, p. 59–68.

Rawson, D.S., and Moore, J.E., 1944, The saline lakes of Saskatchewan: Canadian Journal of Research, v. 22, p. 141–201.

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