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ODONATA AS INDICATORS OF HABITAT QUALITY AT LAKES IN LOUISIANA, UNITED STATES

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Larval Zygoptera and Anisoptera were sampled at 3 lakes. Environmental variables such as chemical composition, water current, turbidity, and vegetation cover were measured. Cross Lake had the most spp. and greater diversity of spp. than Chaplin's and Sibley lakes. Most Zygoptera spp. were found at Cross Lake where carbon availability was highest. Classification and ordination analysis produced similar species groups, providing strong evidence for species assemblages being determined by the measured environmental variables. Tolerant spp. included *Enallagma civile, Erythemis simplicicollis* and *Plathemis lydia*. Spp. only present at Cross Lake (incl. *Argia sedula, Enallagma basidens, Ischnura hastata, I. kellicotti, Celithemis eponina, Erpetogomphus designatus, Libellula luctuosa, L. pulchella, Nasiaeschna pentacantha*) were associated with lower levels of ammonia, conductivity, pH, and higher levels of oxygen and increased vegetation. Cross Lake provided habitat that could support more spp. and was important for spp. that were less tolerant of ammonia and anoxia. This study provides baseline data for future monitoring and conservation management of these lakes.

INTRODUCTION

Aquatic insects are good indicators of changes in water quality. Information on indicator species and water chemistry can enable the development of a habitat suitability index. Much research has been done on using macroinvertebrates for assessing ecological condition (e.g. RESH & JACKSON, 1993; BARBOSA et al., 2001; PALLER, 2001; USSEGLIO-POLATERA et al., 2001) Invertebrates are good indicator species because they tend to accumulate substances in their tissues (BRYAN, 1976).

There is little information available on the use of aquatic invertebrates for monitoring freshwater systems in Louisiana. Small water bodies are very valuable resources for fisheries in the southeastern United States (MUDRE et al., 2000).

Odonates are also valuable as sources of food for fish in these fisheries (WILSON, 1921). They can be used as good indicators of habitat quality (OSBORN & SAMWAYS, 1996; SAMWAYS et al., 1996; VON ELLENRIEDER, 2000). They are useful as indicators because the larvae are long-lived, sedentary, constrained to the water, and relatively easy to identify (CARLE, 1979). Changes in water quality and landscape disturbance can be monitored using dragonfly species (WATSON et al., 1982; BROWN, 1991), since odonate larvae occur within a range of water chemistry variables (KAY et al., 2001). Disturbance to habitat has been shown to be detrimental to dragonfly species (e.g. WILSON, 1997). Assessing habitat has become important and is being completed for rare species of dragonflies, for example *Williamsonia lintneri* (BIBER, 2002) and the endangered *Somatochlora hineana* (SOLUK, 1997). Baseline data on odonate communities is thus essential for future monitoring of lakes.

The aim of the study was to determine the species assemblage of larval odonates at three different lakes in Louisiana, and to assess if certain chemical and physical parameters of the habitat could be important in determining the presence of specific species at sites.

MATERIAL AND METHODS

Three sites were selected from central and northwest Louisiana. The sites were Cross Lake in Caddo Parish (32°30'30" N, 93°50'00" W), Chaplin's Lake and Sibley Lake, both in Natchitoches Parish (31°44' N, 93°06' W). Sibley Lake has an area of 8 km^2, 70 km shoreline and maximum depth of 6 m. Chaplin's Lake has an area of 0.18 km^2, and maximum depth of 7.6 m. Cross Lake has a maximum area of 86 km^2 and maximum depth of 8 m. These lakes were selected because two of them provide municipal water to the cities of Natchitoches (Sibley Lake) and Shreveport (Cross Lake) (SMITH, 1973; CARLSON et al., 1987). These three sites were also subject to different types and amounts of anthropogenic disturbance. Sites were sampled on hot, sunny days between 11:00 and 14:00 h. Five transects of 10×2 m were selected at each site. Sites were sampled weekly from 2 August to 15 September 2000. Larvae were sampled since the presence of adults does not always indicate residency of a species at a site. Larval odonates are also useful indicators of water quality since they are constrained to the water environment. Water variables that were measured included: temperature, pH, REDOX (reduction-oxidation potential), dissolved oxygen, conductivity, water current, and turbidity. Chemicals that were measured included: Ca, NH_3 (including toxic ammonia), Cu, Pb, Triazine pesticides, Fe, Mg, Mn, PO_4, K, SO_4, Cl, Al, NO_2, NO_3 available C, Free CO_2 O_2, and Hardness. There were 10 replicates of variables measured on site, in each transect (Tab. I). Measurements were made 5 cm below the surface. Water samples had to be collected and taken to the laboratory for analysis of some of the other chemicals (Tab. I). Percentage cover was estimated for floating, emergent and submerged vegetation within each transect. Values given are percentage of the transect area covered by vegetation. Dissolved oxygen, conductivity, temperature and pH were measured using a YSI Model 85 portable meter, REDOX with a Hanna portable meter, and water current measured with a MJP Flowmeter for Stream Velocity. Turbidity was indirectly measured by measuring transparency using a Secchi disk, such that higher values indicate lower turbidities. Chemicals were measured according to methods suggested by GREENBERG et al. (1992), and using a Flinn Spectrophotometer.

PATTERNS OF SPECIES RICHNESS AND DIVERSITY

A total of 24 species were recorded, 8 Zygoptera and 16 Anisoptera, viz. Coenagrionidae: *Argia sedula* (Hagen), *Enallagma basidens* Calvert, *E. civile* (Hagen), *E. signatum* (Hagen), *Ischnura hastata* (Say), *I. kellicotti* Williamson, *I. posita* (Hagen), *I. ramburii* (Selys); – Aeshnidae: *Anax junius* (Drury), *Nasiaeschna pentacantha* (Ramb.); – Gomphidae: *Erpetogomphus designatus* Hagen; – Corduliidae: *Didymops transversa* (Say); – Libellulidae: *Celithemis eponina* (Drury), *Erythemis simplicicollis* (Say), *Libellula incesta* Hagen, *L. luctuosa* Burm, *L. pulchella* Drury, *Orthemis ferruginea* Fabricius, *Pachydiplax longipennis* Burm., *Pantala hymenaea* (Say), *Perithemis tenera* (Say), *Plathemis lydia* (Drury), *Sympetrum corruptum* (Hagen), *Tramea lacerata* Hagen.

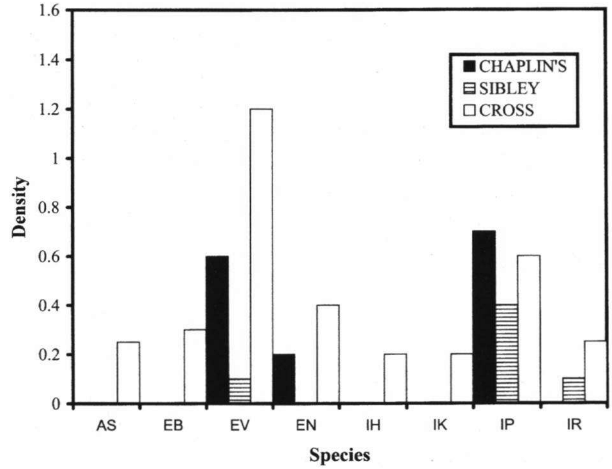

Fig. 1. Density (number of individuals per m^2) of Zygoptera at Chaplin's, Sibley and Cross Lake. Species abbreviations: AS = *Argia sedula*; – EB = *Enallagma basidens*; – EV = *E. civile*; – EN = *E. signatum*; – IH = *Ischnura hastata*; – IK = *I. kellicotti*; – IP = *I. posita*; – IR = *I. ramburii*.

The most abundant Zygoptera, which were present at all sites, were *Enallagma civile*, and then *Ischnura posita*. The most species of Zygoptera were present at Cross Lake (n = 8), while Sibley Lake and Chaplin's Lake had few present (n = 3 in both cases) (Fig. 1). The most abundant species of Anisoptera was *Erythemis simplicicollis* followed by *Perithemis tenera* (Fig. 2). Anisoptera found only at Cross Lake were: *Nasiaeschna pentacantha, Celithemis eponina, Libellula incesta, L. luctuosa, L. pulchella.* Two species only found at Chaplin's Lake were: *Orthemis ferruginea* and *Sympetrum corruptum.* The greatest diversity of species was at Cross Lake (Shannon's diversity index = 1.174), then Chaplin's Lake (Shannon's diversity index = 1.011), then Sibley Lake (Shannon's diversity index = 0.930).

WATER QUALITY AND ENVIRONMENTAL VARIABLES

Cross Lake had the least amount of metals detected compared with Chaplin's Lake and Sibley Lake (Tab. I). There were no detectable levels of ammo-

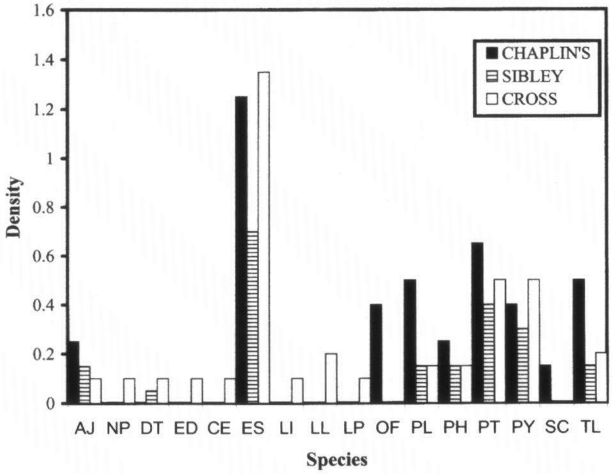

Fig. 2. Density (number of individuals per m²) of Anisoptera at Chaplin's, Sibley and Cross lake. Species abbreviations: AJ = *Anax junius*; – NP = *Nasiaeschna pentacantha*; – DT = *Didymops transversa*; – ED = *Erpetogomphus pentacantha*; – CE = *Celithemis eponina*; – ES = *Erythemis simplicicollis*; – LI = *Libellula incesta*; – LL = *L. luctuosa*; – LP = *L. pulchella*; – OF = *Orthemis ferruginea*; – PL = *Pachydiplax longipennis*; – PH = *Pantala hymenaea*; – PT = *Perithemis tenera*; – PY = *Plathemis lydia*; – SC = *Sympetrum corruptum*; – TL = *Tramea lacerata*.

nia, copper or lead at Cross Lake, although some aluminum was detected. Chaplin's Lake was the only lake with measurable levels of lead of 1.33 mg/L, and it had the highest levels of toxic ammonia at 0.253 mg/L. This lake also had the highest conductivity and hardness levels, and highest readings for aluminum, nitrates, pH and temperature (Tab. I). BERG (1982) found that Chaplin's Lake had levels of dissolved aluminum as high as 0.1 mg/L. Aluminum was also found in tissues of fish from Chaplin's Lake (BERG, 1982). Cross Lake had the greatest percentage cover and more types of vegetation than the other lakes. It also had the highest oxygen levels and lowest temperature and pH readings.

CLASSIFICATION OF SITES

The UPGMA (Unpaired Group Method, Arithmetic) analysis using Jaccards coefficient, grouped Sibley and Chaplin's Lake together based on species composition. The UPGMA classification of species based on sites produced groups of species that shared particular environmental preferences (Fig. 3). Two of the species groups contained species, such as *Enallagma civile*, *Erythemis simplicicollis* and *Plathemis lydia*, which are tolerant of various water conditions and are of widespread distribution in Louisiana. *Orthetrum ferruginea* and *Sympetrum corruptum* are both common in muddy conditions. *Anax junius* and *Pantala hymenaea*, were grouped together in the classification. These species are both migrants that rapidly colonize new habitats. *Argia sedula*, *Enallagma basidens*, *Ischnura hastata*, *I. kellicotti*, *Nasiaeschna pentacantha*, *Erpetogomphus designatus*, *Celithemis eponina*, *Libellula incesta*, *L. luctuosa* and *L. pulchella* were only found at Cross

Lake. These species were associated with ecological conditions at Cross Lake.

CANOCO ordination

A canonical correspondence ordination analysis (CANOCO) was done on natural log transformed data [y = ln(y + 1)]. The CANOCA is an eigenvalue ordination technique that uses multiple regression analysis to find the best linear combination of variables in a multidimensional matrix. Axis 2 of the ordination was responsible for 79.804% of the variation. Interset correlations indicated that several of the environmental variables were strongly correlated with axis 2. These variables were: ammonia, hardness, manganese, conductivity, pH, available C, floating veg-

Table I

Environmental variables measured at the lakes. Given are the mean and (standard error), n = 100 except for vegetation where n = 10. Units are mg/L unless otherwise indicated

Variable	Chaplin's	Sibley	Cross
Calcium	24.000 (0.12)	56.000 (0.03)	70.000 (0.01)
Ammonia	0.430 (0.04)	0.400 (0.03)	0.000 (0)
Toxic Ammonia	0.253 (0.04)	0.015 (0.01)	0.000 (0)
Copper	0.000 (0)	0.000 (0)	0.000 (0)
Lead	1.330 (0.01)	0.000 (0)	0.000 (0)
Pesticides	0.000 (0)	0.000 (0)	0.000 (0)
Iron (μg/L)	0.431 (0.01)	0.290 (0.03)	0.520 (0.01)
Magnesium	0.003 (0.12)	0.001 (0.09)	0.003 (0.15)
Manganese	0.009 (0.02)	0.007 (0.02)	0.006 (0.01)
Phosphate	0.037 (0.04)	0.025 (0.01)	0.040 (0.01)
Potassium	0.211 (0.01)	0.135 (0.03)	0.234 (0.02)
Sulfate	10.840 (0.12)	5.030 (0.10)	5.190 (0.11)
Chloride (μg/L)	0.500 (0.01)	0.400 (0.02)	0.200 (0.1)
Aluminum	0.135 (0.10)	0.006 (0.07)	0.019 (0.09)
Nitrites	0.000 (0)	0.000 (0)	0.000 (0)
Nitrates	20.000 (0.10)	0.000 (0)	0.000 (0)
C available	9.600 (0.04)	8.700 (0.04)	12.400 (0.02)
REDOX (mV)	0.690 (0.02)	0.740 (0.04)	1.093 (0.02)
Free Carbon Dioxide	2.400 (0.01)	4.760 (0.01)	9.565 (0.01)
Dissolved Oxygen	6.700 (0.02)	7.400 (0.01)	8.400 (0.01)
Hardness (Mg and Ca)	300.000 (0.01)	225.000 (0.01)	125.00 (0.02)
Conductivity (μ'/cm)	436.100 (0.02)	321.000 (0.02)	256.680 (0.01)
Temperature (°C)	21.000 (0.03)	17.000 (0.02)	256.68 (0.03)
pH	8.650 (0.01)	7.540 (0.01)	7.04 (0.01)
$CaCO_3$ Alkalinity	40.000 (0.01)	30.000 (0.02)	40.000 (0.01)
Transparency (cm)	12.000 (0.05)	23.000 (0.06)	40.000 (0.04)
Current rate (m/sec)	8.000 (0.04)	3.000 (0.02)	4.000 (0.04)
Submerged Vegetation (%)	18.000 (0.01)	4.000 (0)	20.000 (0)
Emergent Vegetation (%)	4.000 (0)	8.000 (0.01)	22.000 (0.01)
Floating Vegetation (%)	0.000 (0)	0.000 (0)	17.000 (0.02)

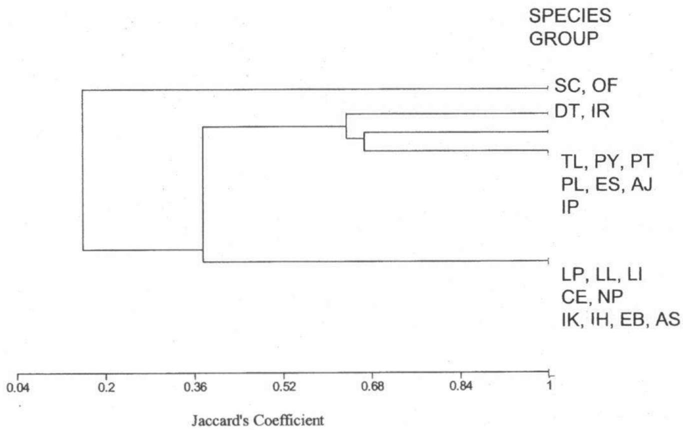

Fig. 3. UPGMA species classification based upon site characteristics. Species abbreviations are as for Figures 1 and 2.

etation, emergent vegetation, oxygen, turbidity (recorded as transparency), and calcium. The ordination diagram produced from the analysis indicated similar clusters of species, placed along these environmental gradients (Fig. 4).

The only species not similarly grouped as those of the UPGMA classification, were *Didymops transversa* and *Ischnura ramburii*. These two species were still closest to a group of species, grouped as GR1 on the ordination plot. The GR1 species included three *Libellula* species, two *Ischnura* species, *Nasiaeschna pentacantha*, *Erpetogomphus designatus*, *Argia sedula* and *Enallagma basidens*. These species preferred the lower pH, the increased emergent and floating vegetation, available carbon, and calcium of Cross Lake. Species such as *Anax junius, Perithemis tenera,* and *Plathemis lydia* could tolerate higher levels of ammonia, manganese, hardness, conductivity and pH than GR1 species. These variables and species were typical of Chaplin's Lake. Some species can occur in diverse habitats, even in brackish waters (PRITCHARD & SMITH, 1963). Sibley Lake was not located near any of the environmental variables measured in this study.

DISCUSSION

WATER QUALITY VARIABLES

The strong concordance in species assemblage classifications produced by both UPGMA and CCA ordination analyses provide evidence for the species assemblage patterns being influenced by the environmental variables that were measured. Oxygen levels are important in influencing Zygoptera survival. Some species of Zygoptera are susceptible to hypoxia (CORBET, 1999). This could explain why most of the species of damselflies were found at Cross Lake. Chemical parameters including, water hardness are important in influencing the distribution and abundance of larval odonates (ROBACK & WESTFALL, 1967). The water at Chaplin's Lake was a much higher hardness (General Hardness, GH = 300 mg/L), than Cross Lake (GH = 125 mg/L). Cross Lake also had lower conductivity (256.68 μ^s/cm) than Chaplin's Lake (436.10 μ^s /cm). Anisoptera larvae are more abundant in hard water than Zygoptera (ROBACK & WESTFALL, 1967). In this study, Anisoptera were more abundant in the harder water of Chaplin's Lake than Cross Lake. Zygoptera are more abundant where organic loading is higher (ROBACK & WESTFALL, 1967). The higher numbers of Zygoptera at Cross Lake could also be due to this, since the available C was higher here than in Chaplin's Lake.

Lentic waters with higher oxygen levels and lower temperatures have been found to have more species of odonates present (OSBORN & SAMWAYS, 1996). Certain species such as *Didymops transversa* prefer lakes with moderate wave action and well-aerated, clear water (WALKER & CORBET, 1975), which describes Cross Lake. Higher water temperatures could cause water to become anoxic in summer. The lethal limit for odonates was established by GARTEN & GENTRY (1976) to be 40°C.

The higher levels of ammonia, nitrates and lead at Chaplin's Lake could have

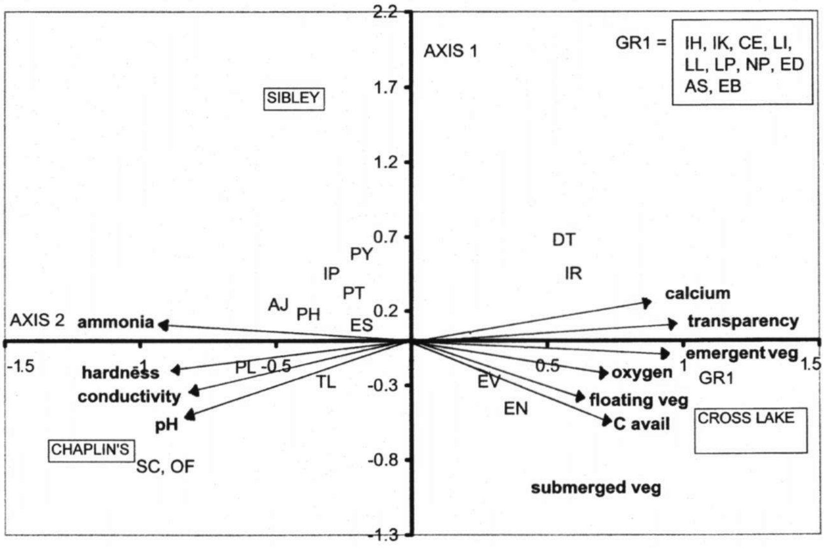

Fig. 4. CANOCO triplot ordination of sites, species and environmental variables. Species abbreviations are as for Figures 1 and 2. GR1 represents one group of species which were placed in the same position on the ordination plot, hence they are represented near the corresponding environmental variables, using the abbreviation GR1. Only environmental variables that were associated with axis 2 are represented. Lakes are given in boxes. Arrows indicate increasing trends, e.g. increasing dissolved oxygen.

been responsible for excluding some of the odonate species. For example, ammonia was found to be toxic to larvae of *Erythromma najas* (BEKETOV, 2002).

The absence of *Enallagma basidens*, *E. signatum*, *Ischnura posita* and *Erpetogomphus designatus*, at Sibley Lake may have been partly due to the high nitrate levels (20 mg/L). ROBACK & WESTFALL (1967) for instance only found these species at nitrate levels of less than 1.58 mg/L. The higher ammonia levels at Chaplin's and Sibley Lake (Tab. I), may have excluded some of the species, since ammonia can be toxic to dragonflies particularly at higher pH values (BEKETOV, 2002). Odonates can be influenced by acidity and heavy metals (BRYAN, 1976). Decreased pH can also alter feeding rates in some species (CORBET, 1999). *Enallagma civile* has been found in temporary ponds where maximum pH was 7.7, and dissolved oxygen ranged from 5.4 to 8.0 mg/L (KENK, 1949). This species was found at all the lakes in this study.

Accumulations of heavy metals in invertebrates can negatively impact fish, which depend on these for a food source (BARWICK & WILDA, 1999). Larval dragonflies are tolerant of solute levels (ROBACK & WESTFALL, 1967). Some species such as *P. lydia* are tolerant of moderate levels of organic pollution (DUNKLE, 1989). This could explain why it was present at all three lakes in the study.

AQUATIC VEGETATION

Zygoptera species are more dependent on vegetation than most anisopteran species, due to their endophytic oviposition habits. Larval zygopterans are also more dependent on vegetation for feeding and concealment from predators than anisopteran larvae are (CORBET, 1999). Lower oxygen levels can be tolerated more easily if there is vegetation present. For instance, HYNES (1970) found that species of *"Agrion"* and *Ischnura* were able to survive in fairly anoxic water because they were able to climb up weeds to where oxygen saturation was higher.

At Cross Lake the increased aquatic vegetation (59% covered) versus Sibley Lake (12% covered), and Chaplin's Lake (22% covered) influenced how many species and individuals could survive in the habitat. Species richness and abundance was associated with percentage vegetation cover. Floating vegetation and emergent vegetation provide supports for larval damselflies (PRITCHARD & SMITH, 1963). The highest densities of *Enallagma civile* have been found in fields with an abundance of submerged macrophytes (CORBET, 1999). *Ischnura kellicotti* is a species that is restricted to waterlilies of the genera *Nuphar* and *Nymphaea* (JOHNSON & WESTFALL, 1970). MAUFFRAY (1997) did not find *I. kellicotti* in Louisiana, but predicted that it would occur in lentic, acidic waters, which describes Cross Lake. *I. kellicotti* was collected from the undersides of *Nuphar* leaves at Cross Lake. Other species such as *Enallagma laterale* have been found to have similar specific associations with vegetation such as *Nuphar* (GIBBONS et al., 2002). Some of the anisopterans may also be more closely related to vegetation. KENK (1949) for instance, only found *Libellula pulchella* in ponds that were heavily vegetated. Related to vegetation, sedimentation can impact odonate densities (MARTIN & NEELY, 2001). Riparian vegetation can also impact invertebrate production and abundance, for example BEHMER & HAWKINS (1986) found that mayfly and midge abundance increased in water that was not shaded by canopy vegetation. Although not measured, Cross Lake did have more woodland and riparian vegetation that provided shading of the water. Some of the species found only at Cross Lake are known to prefer wooded areas (BICK, 1975). *Libellula incesta* is also often found near forests (DUNKLE, 1989). Others, such as *Orthemis ferruginea* are found and can breed in more temporary, muddy conditions (DUNKLE, 1989).

IMPLICATIONS FOR CONSERVATION MANAGEMENT

Human disturbance can impact insects, for example WORTHEN (2002) found that streams with the most recent disturbance had the lowest abundance, richness and diversity of Odonata. This could have been due to decreased habitat heterogeneity and increased sediment load (WORTHEN, 2002). Chaplin's Lake is the most disturbed being completely accessible to the public. Much of the Cross Lake shoreline is privately-owned and not open to the public. Sibley Lake falls between these two in how accessible the shoreline is to the public.

Odonate species diversity and richness can be reduced by certain types of aquatic pollution (WATSON et al., 1982). Although some larvae are tolerant of levels of solutes (CARCHINI & ROTA, 1985), others can be as sensitive as other invertebrates (HAVENS, 1993). Environmental factors and pollutants can indirectly influence aquatic insects like dragonflies, by influencing other components of the habitat on which their survival depends (WIEDERHOLM, 1984). Odonates are sensitive to habitat disturbance, and there are species that are threatened or rare, and need to be monitored and managed (SOLUK, 1997; CORBET, 1999; BIBER, 2002). Some species are already being managed and monitored, for example, *Megalagrion xanthomelas* (ENGLUND, 2001). Although many of the dragonflies in my study appeared to be tolerant to most of the conditions that were measured, some of the species did appear to be more common under certain conditions. Some species can have very specific habitat requirements (GIBBONS et al., 2002). Increasing habitat complexity may be another way to increase species diversity in general, in part because of increased prey diversity associated with increased macrophytes (LOMBARDO, 1997). My study provides data for future monitoring and studies at these lakes. This study is part of a larger ongoing aquatic research project examining all the invertebrates at these lakes for use as potential indicators.

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