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**PATTERNS OF HABITAT USE OF BREEDING DUCKS AND GREBES IN
THE WESTERN BOREAL FOREST**

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Bachelor of Science, University of Lethbridge, 2002

A Thesis
Submitted to the School of Graduate Studies
of the University of Lethbridge
in Partial Fulfillment of the
Requirements for the Degree

MASTER OF BIOLOGICAL SCIENCE

Department of Biology
University of Lethbridge
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APPROVAL/SIGNATURE

ABSTRACT

Canada's boreal forest provides important breeding habitat for 12 to 14 million migratory birds annually. Nonetheless the ecology of boreal wetlands remains poorly understood. Over the last 40 years, rapid industrial development with little attention to conservation has been ongoing in the region. Apparent population declines of species, such as that of lesser scaup have raised concerns about the quality of western boreal wetlands. This is one of very few studies demonstrating patterns in brood-rearing habitat use by ducks and grebes in the Canadian western boreal forest. In this study, wetland characteristics associated with brood-rearing wetlands of American wigeon (*Anas Americana*), green-winged teal (*Anas crecca*), mallard (*Anas platyrhynchos*), lesser scaup (*Aythya affinis*), ring-necked duck (*Aythya collaris*), horned grebe (*Podiceps auritus*), and red-necked grebe (*Podiceps grisegena*) were investigated on 75 wetlands near Yellowknife, NT, Canada.

I used Principle Components and regression analyses to delineate patterns of habitat use by breeding water birds. Results indicate that physical characteristics of wetlands, area in particular, had stronger correlations with brood-rearing habitat than did invertebrate abundance. Invertebrate groups positively associated with brood-rearing wetlands included: Amphipoda, Pelecypoda, and or Ephemeroptera. Breeding diving ducks had negative

associations with Dipteran abundance. Diving ducks and red-necked grebes were more strongly correlated with habitat variables than were dabbling ducks and horned grebes. Brood-rearing wetlands of the smallest birds in the study, green-winged teal and horned grebe, had the fewest and weakest associations with habitat variables.

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Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect.

~Chief Seattle, 1855

1. INTRODUCTION

The survival and reproductive success of waterfowl and other aquatic birds are directly linked to habitat selection (Greene and Stamps 2001, Martin 1998). Therefore, key to developing sound conservation initiatives and meeting conservation objectives pertaining to waterfowl and other aquatic birds is identifying and understanding what factors influence their habitat selection. Predictions regarding wildlife-habitat associations are only possible after patterns of association are identified.

Factors influencing habitat selection by waterfowl and other aquatic birds include food availability (Pöysä 2000), vegetation composition (Martin 1987, Sjöberg et al. 2000), abundance of predators and competitors (Martin 1993, Petit and Petit 1996), intraspecific attraction (Danchin et al. 1998, Forsman et al. 1998, Pöysä 1998), and philopatry to natal or previously successful breeding areas (Greenwood 1980). Because behaviour (breeding, non-breeding), location (wintering, summering), and needs (habitat for nesting, brood-rearing, migration stops, wintering) change substantially throughout the year, migratory birds provide interesting and challenging subjects with respect to identifying habitat requirements. This study used variables thought to influence wetland suitability for brood-rearing by five duck and two grebe species that breed on northwestern boreal wetlands near Yellowknife, Northwest Territories, Canada. American

wigeon (*Anas americana*), green-winged teal (*Anas crecca*), mallard (*Anas platyrhynchos*), lesser scaup (*Aythya affinis*), ring-necked duck (*Aythya collaris*), red-necked grebe (*Podiceps grisigena*), and horned grebe (*Podiceps auritus*) are the seven most abundant nesters on the study wetlands (Canadian Wildlife Service, unpublished data).

Canada's boreal forest is an important aquatic bird breeding ground with over a third of the region covered by water and wetlands critical to migratory birds (Ducks Unlimited 2000). Certain waterfowl populations are declining in the region; annual waterfowl breeding surveys indicate that the population of lesser scaup has declined by 50% or more since the early 1980's (Austin et al. 2000). Much of the dramatic decline of scaup has occurred in the northwestern boreal forest (WBF). Recent studies indicate that the portions of the population most affected are those of female and young birds (G.T. Allen, D.F. Caithamer, and M. Otto, United States Fish and Wildlife Service, 1999, unpublished report, A.D. Afton, United States Geological Survey, unpublished data, Anderson, Ducks Unlimited, unpublished data in Austin et al. 2000). A number of potential causes for scaup declines have been suggested, including: poor recovery from drought during the 1980's in Prairie Pothole Region (PPR) breeding grounds, contaminants, and or habitat changes in migration and/or wintering areas, and

disturbance, such as logging impacts, fires, and acid rain. Scaup declines may be indicative of deteriorating quality of WBF wetlands (Austin et al. 2000).

WBF wetlands provide brood-rearing habitat for 12 to 14 million ducks and, in North America, are second only to the PPR of Canada in this capacity (Ducks Unlimited 2000). Northern wetlands become of even greater importance to waterfowl during periods of extended drought (Johnson and Grier 1988, Hodges et al. 1996, Dubovsky et al. 1997, and Niemuth and Solberg 2003). For example, over the past 40 years, Canadian Wildlife Service waterfowl surveys have found that decreased breeding mallard numbers in the PPR have been offset by stable or increasing numbers in the WBF (Canadian Wildlife Service Waterfowl Committee 2004).

Historically, research activities by wetland and aquatic bird scientists have been limited in the WBF, and aquatic bird habitat associations derived from studies performed in other regions, such as the PPR of North America and the Fennoscandian boreal region, have been extrapolated, perhaps questionably, to include the boreal area. Knowledge derived from other regions regarding the habitat requirements of aquatic birds may not be unequivocally applicable to the habitat of the WBF (Hornung 2005, Simpson 2005). For instance, seasonal drought is not an issue in the WBF, and although seasonal or age related changes in duckling mortality occur in the boreal and Great Lakes regions, within season

temporal variation in duckling mortality is linked to seasonal drought in the PPR (Simpson 2005). In addition, while previous studies have suggested a link between mallard duckling success and chironomid abundance (Danell and Sjöberg 1980, Dzus and Clark 1997, King and Wrubleski 1998), Hornung (2005) proposed that coleopterans, specifically Dytiscidae, and not dipterans, specifically Chironomidae (Danell and Sjöberg 1980; Sjöberg and Dannell 1982; Swanson et al. 1985; Batzer et al. 1993) are the dominant food source in mallard duckling diets in WBF wetlands in northern Alberta. Finally, given the northern latitude and recent glacial history of the region, WBF wetlands assuredly have low overall species diversity (Pianka 1966, Schindler 1998), in contrast to species-rich wetlands of the PPR (Swanson and Duebbert 1989 in Cox 1998). Resource use commonly changes with availability (Manly et al. 1993), thus aquatic birds dependent on invertebrates may utilize resources in WBF wetlands differently if the nature and structure of invertebrate communities differ in WBF and PPR wetlands (Hornung 2005). Low species diversity leads to low functional redundancy and increased susceptibility to change (MacArthur 1955, Rosenzweig 1995, Jacobsen 1997). Nonetheless, across the WBF region, expanding industrial developments continue to outpace conservation efforts. Given the pace of natural resource development in the region and since little work has been conducted towards understanding the ecology of WBF wetlands,

habitat selection studies (fundamentally linked to functional ecology) from the area are quickly becoming increasingly urgent (Caughley 1994).

Aquatic invertebrates play a central role in all wetland food webs, providing an essential trophic link between wetland primary producers (Murkin and Wrubleski 1988 in Zimmer et al. 2000), macrophytes (Pieczynska et al. 1999), and top predators, like insectivorous fish and aquatic birds. Although outside of the breeding season species such as the American wigeon, mallard, and ring-necked duck are predominantly or exclusively vegetarian, breeding females and ducklings of all aquatic bird species are insectivorous, relying heavily on invertebrates (Chura 1961, Perret 1962, Bartonek and Hickey 1969, Sugden, 1973, Krapu 1974, Pehrsson 1979, Swanson 1984) during the breeding season and earliest weeks of life. The protein necessary for growth and development is obtained primarily from aquatic invertebrates. Fat reserves acquired prior to arrival on breeding grounds are depleted during rapid ovarian follicle growth, and the protein required for egg production must be obtained from food eaten during the laying period (Hohman 1986, Alisauskas et al. 1992). Efficient foraging in the earliest weeks of life results in increased duckling survival (Cox 1998). In turn, duckling survival is a key factor affecting aquatic bird population dynamics (Johnson et al. 1992).

Patterns of distribution and abundance can be framed at different scales (Johnson 1980), therefore, consideration of the scale from which habitat associations have been identified is important when those data are to be applied in resource management. Given the large area of the WBF with its relatively contiguous habitat and abundant wetland complexes, the scale dilemma is only accentuated in a study such as this. Specifically, used habitat may not necessarily be optimal habitat if individuals are in some way prevented from occupying or identifying optimal sites (Van Horne 1983, Pulliam 1988, Martin 1992, Jones 2001). For instance, in consecutive years apparent nest-success (a plausible surrogate for reproductive success (Greenwood et al. 1987)) was 38% and 68% greater for Great Slave Lake island-nesting lesser scaup compared to mainland (YKSA) wetland nesters (Fournier and Hines 2001), which may indicate that on a large scale, nest-sites and brood-rearing habitat on the islands of Great Slave Lake are preferable to those on the mainland (YKSA). (Reproductive success is a measurable response to habitat selection.) Once capacity on the islands of Great Slave Lake is reached, nest-site and brood rearing habitat suitability choices made on a smaller scale may form the basis of habitat selection from amongst the mosaic of wetlands on the mainland adjacent to the lake. Studies specific to this region, which lend a better understanding to the unique qualities and ecology of

its wetlands may lead to a better understanding of water bird habitat associations therein.

1.1. *The ducks and grebes of YKSA*

Species of the genus *Anas* are referred to as dabbling ducks or dabblers, whereas those of *Aythya* are known as diving ducks or divers. In order of size, from the smallest to the largest, the dabbling ducks in this study are the green-winged teal (length 30-41 cm), American wigeon (length 46-58 cm), and mallard (length 51-71 cm) (Fisher 1998). Nesting habitat preferences overlap greatly in the boreal region; all of the dabbling ducks included in this study are typically upland nesters. In 2002, over 40% of the population estimate of American wigeon occurred in the northern portion of the boreal forest (U.S. Fish and Wildlife 2004). Breeding population trends in the short, medium, and long terms all indicate declining American wigeon populations in the Canadian Prairies and a long term declining trend in the WBF (Canadian Wildlife Service Waterfowl Committee 2005). According to long term trends, abundance of Green-winged teal is stable or increasing in the WBF (Canadian Wildlife Service Waterfowl Committee 2005). Although there was no significant trend in the WBF, 5- and 10-year breeding mallard population trends show declines (Canadian Wildlife Service Waterfowl Committee 2005). The western Canadian boreal forest is a core breeding area for ring-necked ducks and lesser scaup; both species are diving ducks and are

similar in size (length 36-46 cm and 38-46 cm, respectively) (Fisher 1998). Ring-necked ducks and lesser scaup typically build nests near water with ring-necked ducks perhaps showing a greater inclination to construct nests over water in emergent vegetation or on a floating sedge mat. Breeding population estimates for ring-necked ducks have been stable or increasing in the long term in the WBF (Hohman 1998, Canadian Wildlife Service Waterfowl Committee 2005), whereas that of lesser scaup has declined dramatically since the 1980's (Austin et al. 2002, Canadian Wildlife Service Waterfowl Committee 2005).

Toft et al. (1982) identified two patterns of breeding chronology among the five dominant duck species on the YKSA. On average, the dabblers arrived earlier, initiated nests earlier, and fledged young much earlier than the divers did.

Grebes are not closely related to ducks. Morphologic constraints confine grebe broods to a single wetland until fledged, whereas, among the species studied, diving ducks may move their broods among wetlands and dabbling ducks frequently move broods among wetlands. Horned grebes are smaller than red-necked grebes (length 30-38 cm and 43-56 cm, respectively) (Fisher 1998). Less precocial than ducklings, which follow the hen to a water body and begin feeding themselves within 24 hours after hatching, red-necked grebe chicks travel on their mother's back and horned grebe chicks are fed by a parent for at

least 9 days after hatching. Although isolated population declines have been reported, red-necked grebe populations are most likely stable (Stout and Nuechterlein 1999), whereas 1966-1996 horned grebe populations (except Manitoba) showed negative trends (Stedman 2000). Both grebe species build their nests over water in emergent vegetation, such as willows, cattails, and sedges.

1.2. Thesis objectives

1.2.1. Relationships between physical wetland characteristics and use by breeding water birds

One of the main objectives of this thesis is to determine the effects of abiotic wetland characteristics on wetland selection by broods of each of the seven aquatic bird species of interest in the study. Based on existing size dependent theory, that larger habitats attract greater numbers of individuals (Abbott 1978, Williamson 1981, Price 1984, Blake and Karr 1987), I expect that area will demonstrate a positive influence on wetland-use by broods. Because shoreline irregularity increases habitat diversity, I also suspect that increasing shoreline irregularity will positively influence wetland-use by broods. I test six other potentially influential abiotic parameters as well including conductivity, depth, pH, water transparency, water temperature, and distance to the roadway.

The ability to move broods between wetlands differs among the water birds studied. As a consequence, I expect that associations between brood-rearing wetlands and habitat variables will be stronger for species less likely to or unable to move broods between wetlands.

1.2.2. Relationships between aquatic invertebrates and wetland use

Quantitative analysis of the invertebrate community and its effect on wetland-use by broods was another fundamental facet of this study. I evaluate the status of whether a wetland is used or unused by broods relative to invertebrate abundance and biomass.

Because it is typical for the abundances of certain invertebrate taxa to rise and fall throughout the summer, before analyzing the effect of invertebrate abundance on wetland selection by broods, I determine whether temporal changes to invertebrate abundances occurred on YKSA wetlands during my sampling period, identify which taxonomic groups behaved dynamically, and qualify the pattern(s) of temporal change. I completed sampling in as short a time as possible and hypothesized that within taxa, invertebrate abundance would be static. Although among the aquatic birds in my study, chronology of hatching may occur, field season sampling was timed to coincide with the time during which the majority of broods hatch. Additionally, I look for correlations between invertebrate abundances and the eight abiotic wetland characteristics.

1.2.3. Interspecific associations and interactions among aquatic bird species in wetland use

In this thesis I also investigate interspecific associations between the seven aquatic bird species. I also expect that since grebes are highly territorial, wetlands used by grebe broods would not be shared with broods of other species. Toft et al. (1982) identified two patterns of breeding chronology among the five dominant duck species on YKSA, one early and the other late. Differences in chronology of breeding among species may result from interspecific competition for habitat or some other resource; consequently I hypothesized that wetlands would be shared among species whose patterns of breeding chronology were opposed, specifically I expect more sharing of wetlands between dabblers and divers, and more negative interactions within these groups.

1.2.4. Unused wetlands

Finally, I hypothesize that although a fraction of the over 500 YKSA wetlands were not used by broods of any of the five duck species for the duration of CWS survey years, this proportion of unused wetlands is not greater than what would be expected to occur by chance.

1.3. *Study area*

Field work was conducted on a 38-km² study area (Figure 1), west of Yellowknife, Northwest Territories (62°27'N, 114°22'W). The Yellowknife Study Area (YKSA) is an approximately 48-km roadside transect dissected by Northwest Territories Highway 3. Wetlands included in the study area are located within 0.4-km of either side of the road. The Canadian Wildlife Service (CWS) has monitored waterfowl pair and brood use of wetlands on the YKSA since 1985 and that of grebes since 1991.

There are over 500 wetlands in the YKSA; 262 are natural wetlands and approximately 300 are borrow pits, which were established during the construction of Highway 3. The YKSA wetlands have been surveyed several times each year between May and August. At each wetland, the aquatic bird species present are identified and wetland-use by pairs and/or broods is recorded. At the time this study was conducted, a notable number of YKSA wetlands had never been used by a brood of any of the duck species included in this study for the duration of the CWS survey years.

The YKSA falls within the Tazin Lake Upland ecoregion of the Western Taiga Shield ecozone, (Ecological Stratification Working Group 1995). The area is characterized by many poorly drained fens and bogs and small lakes. Bog-fen vegetation includes dwarf black spruce (*Picea mariana*), Labrador tea (*Ledum*

groenlandicum), ericaceous shrubs, and mosses. Common trees in the region are black and white spruce (*Picea glauca* and *Picea mariana*), white birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*). Permafrost is discontinuous and localized. Elevated areas of exposed bedrock commonly occur (National Wetlands Working Group, 1988). YKSA runs approximately parallel to the North Arm shore of Great Slave Lake between Yellowknife and Rae, NT.

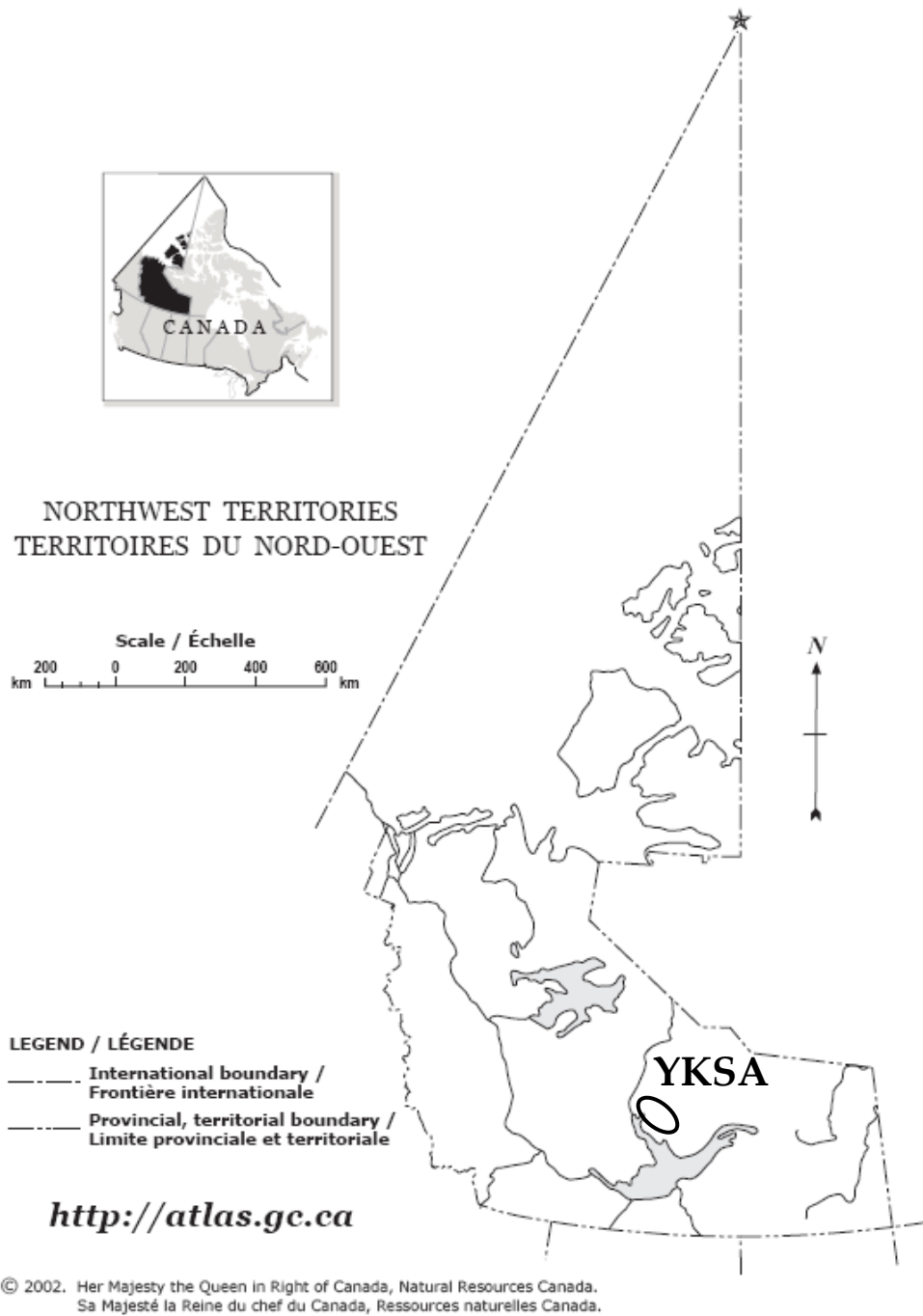


Figure 1 - Map showing the approximate location of the Yellowknife Study Area in the boreal forest region of the Northwest Territories.

2. METHODS

All analyses were executed using JMP IN® software (SAS Institute Inc. 2001).

2.1. *Wetland Selection*

A total of 75 natural wetlands were chosen so to reflect the physical ranges of size and shape of wetlands available and the different levels of brood use. The frequency of brood use of a wetland was calculated as the total number of broods observed on a given wetland over all of the survey years (1985-2003 for ducks, 1991-2003 for grebes) and was calculated for each of the seven aquatic bird species in the study. Brood use data were acquired from CWS survey records for YKSA wetlands. The choice of wetlands to be sampled was also determined by their accessibility for sampling, either by canoe or on foot with a small inflatable boat.

2.2. *Limnological characteristics*

Sampling was conducted via canoe or inflatable boat, and took place between June 24 and July 24, 2004. At the centre of each wetland conductivity (μ/s), pH, temperature, depth, and Secchi disc transparency were measured and a surface water sample was collected from approximately 15 cm below the surface. Water samples were transferred to a freezer at the end of each day and

kept frozen until concentrations of total phosphorus (mg/L) were analyzed at Norwest Labs, Lethbridge, AB, approximately one year later. Area, perimeter, and distance to the road were measured from maps (scale 100 mm = 75 m) using ArcView GIS software. Distance to the road was measured from the center of each pond to the edge of the road. An index of shoreline irregularity (SI: Ried 1961: 34, in Haszard 2004) was calculated using the equation:

$$SI = p / 2\sqrt{a} ,$$

where p = perimeter (m) and a = area (m²). For perfectly round wetlands $SI = 1.0$ and as shoreline irregularity increases, $SI \gg 1.0$.

2.3. *Invertebrate sampling*

Invertebrate sampling of the 75 study wetlands took place between 24 June and 24 July, 2004. Samples were taken from 4 randomly-selected sites on each wetland. Sweep samples were conducted 0.5 to 1.5 m from shore by pushing the flat net-opening down through the water column to a depth of 0.5 to 1.0 m, sweeping through the water parallel to the surface for 1.0 to 1.5 m, then drawing the net to the surface. The net bag was dipped into the water and shaken to sieve fine silts out through the mesh. This method of sampling invertebrates well reflects the availability of potential food items for dabbling ducks and some diving ducks, but may less accurately capture the preferred food

of grebes (Elmberg et al. 1994). Sample material and invertebrates were placed in Zip-loc™ freezer bags and frozen at the end of each day. The first 12 wetlands sampled were sampled again after 30 days in order to ascertain if changes in invertebrate community composition or sampling effort had occurred. I used a two-sample t-test ($P < 0.05$) to determine if abundances of 13 taxonomic groups of invertebrates changed over time. This analysis was carried out subsequent to Levene's Test for homogeneity of variances (> 0.5). A value of Levene's Test < 0.5 , indicated that variances of two samples being compared were not equal; in such instances a Welsh Anova F-test was used to test for significant differences.

Temporal changes in the abundance of 5 of 13 invertebrate groups collected from YKSA wetlands were detected (Table 1). Anisoptera, Zygoptera, Crustacea, Gastropoda, and Hemiptera all increased in abundance in shoreline samples during the first four weeks of summer, which may reflect offshore shifts in distribution during the winter months when near shore areas are at risk of freezing to the bottom. In June 2004, when I began sampling YKSA wetlands, the substrate in areas of some wetlands was still frozen. Break-up on YKSA wetlands traditionally begins in-mid-May and freeze-up has usually occurred by the end of October (Toft et al. 1982). Surviving long cold winters poses an obvious dilemma for aquatic insects many of which have developed elaborate mechanisms to deal with freezing and over-wintering. In wetlands that do not

freeze solid, some invertebrates will move to deeper water to avoid freezing (Moon 1940, Davies and Everett 1977). Many benthic invertebrates are able to resist freezing by means of supercooling and may produce antifreeze agents. Daborn (1971) and Sawchyn and Gillott (1975) have described damselflies (*coenagrion sp.*) collected, encased in ice, but not frozen. Crustaceans, *Daphnia* in particular are well studied in regards to life cycles and general ecology. Diurnal variation and cyclic seasonal patterns in abundances are characteristic in some species and may explain the temporal variation observed for Crustacea in this study. Nonetheless, in this study, I believe that the populations of late emergent taxa had become established by the time the second set of samples were taken, thus an accurate measure of invertebrate abundance during the brood-rearing period on these wetland was captured.

In the lab, frozen samples were thawed and aquatic organism were identified to general taxonomic group (described below), and counted. Organisms from each taxonomic group were then pooled and weighed (wet-weight).

2.4. *Data treatment and analysis*

Measurements of wetland area and depth were transformed using Box-Cox statistical methods to improve normality. Because shoreline details may be

lost due to map scale, wetland periphery, used in determining shoreline irregularity, may have been underestimated. Underestimated measurements of periphery would be consistent among wetlands of similar size. To investigate the degree to which my measurements of periphery might be biased due to deriving them from maps with too coarse a scale, I determined the correlation between the shoreline irregularity indices I calculated with wetland area. A second issue regarding SI was that some wetlands consisted of a series of small water bodies. In these cases, I calculated SI for the individual water bodies, took the highest estimate only of SI, and added 0.2 to it for each additional water body in the wetland complex. Total phosphorus measurements were categorized into one of five categories: high, high-moderate, moderate, moderate-low and low. The counts and weights of sorted invertebrate data were skewed and contained zeros. Where numbers and weights of organisms were extremely low, the raw data for related taxa were pooled into broader taxonomic groups and then transformed using a $\log_{10}(x+10)$ transformation.

Principal Components Analysis (PCA) was used to examine relationships among aquatic bird community structure and the (1) environmental variables and (2) invertebrate community structure. I explored relationships between principal component scores for axis 1, 2, 3, and 4 of the bird species by correlating those with (1) environmental variables and (2) principal component

scores of the invertebrate community structure. The strength of the relationship between the avian responses to particular variables was assessed using linear regressions on the eigenvectors of the principal components. I also tested the relationships between and among abiotic variables and invertebrate groups using Pearson correlations (r), when one or both variables were not normally distributed Spearman's Rho was used to evaluate the correlation between variables.

Associations of each aquatic bird species with environmental and invertebrate abundances were further evaluated using logistic regression analyses. Variables significant in predicting brood-rearing wetlands are identified by the logistic regressions. Subsequent linear regressions identify variables significant to increases in the numbers of broods of each species on a wetland.

In the logistic regression analysis, for the more abundant aquatic bird species on the YKSA (American wigeon, green-winged teal, lesser scaup, and red-necked grebe,) wetlands were defined as "used" if a brood or broods had been observed on the wetland for more than 2 of the survey years. For the less abundant species (mallard, ring-necked duck, and horned grebe) wetlands were defined as "used" if a brood or broods had been observed on the wetland for more than 1 of the survey years. Logit models were also meant to provide insight

into the type and strength of relationships between habitat characteristics and brood presence or absence, while controlling for interactions between variables. Normality is not a requirement in logit modelling. However where the untransformed data were not normally distributed, transformation may have improved the fit of a model, therefore data both before and after transformation were used as separate parameters in this study. Likelihood ratio chi-square test was used to test for significant differences between used and unused wetlands for each aquatic bird species resulting from the categorized total phosphorus data.

Variables with no significant effect in univariate logistic regression were excluded from multivariate logistic regression analysis. Otherwise, multivariate logit analysis proceeded in a stepwise manner, whereby the most significant variable from the among the univariate models was incorporated first, followed by the next most significant and so on. A variable was removed and excluded from the multivariate model if it was not significant ($p > 0.05$). Two-way interactions between terms in the model were tested as additional variables were added and retained.

Using the wetland-use by brood data for all 262 natural YKSA wetlands, I predicted the number of wetlands expected to be unused by any duck broods by chance alone, as well as the number of wetlands expected to be used by all 5

species, by chance alone. Predictions are derived using probabilities; the percentage of used and unused wetlands is determined for each of the 5 duck species (N = 262) (all survey years combined); I dealt with correlations in the patterns of wetland-use between species ($R^2 > 0.20$) by excluding one of the correlated species. The product of the percentages of unused wetlands by each waterfowl species is the probability that a wetland will be unused by broods of any of the 5 waterfowl species. The product of the percentages of used wetlands by each duck species is the probability that a wetland will be used by broods of all 5 duck species.

3. RESULTS

The most abundant species breeding and raising broods on the YKSA are lesser scaup and red-necked grebes, and fewest broods are recorded for ring-necked ducks (Table 2).

Twenty-year trends in duck brood abundances on YKSA wetlands (Figure 2) show increased numbers of American wigeon broods during the later half of the 1990's and increasing numbers of green-winged teal broods throughout the 1990's. Mallard brood numbers indicate a weak negative trend across the survey years. Of all species surveyed, lesser scaup brood counts have demonstrated the greatest variation across the survey years and suggest a declining trend in numbers of lesser scaup broods on YKSA ($P = 0.046$; $R^2 = 0.21$; Figure 2).

Conversely, brood counts of the other main diver, ring-necked duck, indicate a weak, but positive trend across the survey years ($P = 0.011$; $R^2 = 0.33$; Figure 2).

There are fewer years of grebe brood abundance data for YKSA wetlands. Brood abundances of both grebe species are highly variable possibly showing a cyclical pattern (Figure 3). Numbers of red-necked grebe broods counted each year on the YKSA wetlands were less variable than numbers of horned grebe broods.

3.1. Physical and chemical characteristics and invertebrate composition of 75 Yellowknife Study Area wetlands

Surface area among the study wetlands ranged from 0.03 ha to 12.8 ha. The majority of wetlands included in the study were relatively small, mean 2 ha, SE 0.3 (Table 3). Wetland depth ranged from less than 1 m to 6.4 m, however a thick peat substrate, which was relatively consistent among wetlands, may have hindered detection of the maximum depth of some ponds. Conductivity among wetlands ranged from 48 $\mu\text{/cm}$ to 1764 $\mu\text{/cm}$; only the two highest values were greater than 920 $\mu\text{/cm}$. Water pH ranged from 5.4 to 8.7. Total phosphorus levels indicated that the ponds are meso-eutrophic (Vollenweider and Kerekes 1980, from Walsh et al. 2006).

Pairwise correlations showed that a few of the environmental variables were correlated (Table 4). Wetland area was positively correlated with shoreline

irregularity ($R^2=0.31$, $P<0.0001$, $N=75$). Weaker correlations were present between area and depth, distance to the road, pH, water transparency, and water temperature (all $R^2<0.13$ and $P<0.002$, $N=75$). Water transparency was positively correlated with depth ($R^2=0.33$, $P<0.0001$, $N=75$) and also with shoreline irregularity ($R^2=0.14$, $P<0.0011$, $N=75$). Temperature was positively correlated with distance to the road ($R^2=0.18$, $P<0.0002$, $N=75$). Conductivity was negatively correlated with distance to the road ($R^2=0.15$, $P<0.0005$, $N=75$), that is wetlands further from the road had lower conductivities. Other correlations among environmental variables were weak to negligible: shoreline irregularity with temperature ($R^2=0.06$, $P<0.0330$, $N=75$) and pH with water transparency ($R^2=0.05$, $P<0.0513$, $N=75$), shoreline irregularity ($R^2=0.05$, $P<0.0457$, $N=75$), and temperature ($R^2=0.05$, $P<0.0524$, $N=75$) and, thus likely to have occurred by chance alone.

The aquatic invertebrate community contained 18 taxonomic orders. Thirty-three species, genera, or families were identified. A few samples contained specimens that were unidentifiable beyond the classification of order due the integrity of the specimen. Thus a few more species than reported may have been present in the samples (Appendix A). Larvae of damselflies and dragonflies (Odonata) made up the largest part (21.5%) of the overall biomass. "Miscellaneous Crustacea" including Conchostraca, Cladocera, Copepoda, and

Ostracoda contributed 17% to overall biomass. Other major contributors to biomass included snails (Gastropoda) (16%), clams (Pelecypoda) (15.8%), *Hyalella azteca* (Amphipoda) (9.2%), true bugs (Hemiptera) (9%), beetles (Coleoptera) (2.8%), and mayflies (Ephemeroptera) (2.2%). The mean number of taxa collected from a wetland in the study was 18, with a range of 12 to 24. The highest biomass collected was 93.7 g/m², the lowest was 4.9 g/m², mean 24.7 g/m², median 19.1 g/m². Pairwise correlations between the invertebrate taxa and environmental variables revealed a number of significant correlations (Table 5). Amphipoda were positively correlated with all the environmental variables, but most strongly so with wetland area ($R^2=0.25$, $P<0.0001$, $N=75$). Pelecypoda were positively correlated with shoreline irregularity ($R^2=0.16$, $P<0.0004$, $N=75$). Hemiptera were positively correlated with temperature ($R^2=0.16$, $P<0.0005$, $N=75$). Total invertebrate biomass (log-transformed) was positively correlated with shoreline irregularity ($R^2=0.16$, $P<0.0005$, $N=75$, Figure 4), and weakly correlated with transparency ($R^2=0.07$, $P<0.0259$, $N=75$), but apparently not related to wetland area, conductivity, depth, pH, total phosphorus, or temperature. Total invertebrate abundance (log-transformed) was weakly correlated with pH ($R^2=0.07$, $P<0.0234$, $N=75$). Correlations among invertebrate groups were also present (Table 6). The strongest correlations were between Ephemeroptera and Pelecypoda ($R^2=0.25$, $P<0.0001$, $N=75$), Pelecypoda and

Gastropoda ($R^2=0.19$, $P<0.0001$, $N=75$), Amphipoda and Ephemeroptera ($R^2=0.18$, $P<0.0002$, $N=75$), Anisoptera with Zygoptera ($R^2=0.16$, $P<0.0005$, $N=75$) and Pelecypoda ($R^2=0.19$, $P<0.0001$, $N=75$), and Coleoptera and Hemiptera ($R^2=0.14$, $P<0.0008$, $N=75$). All significant correlations among taxa were positive.

In all but one wetland, I saw no evidence of the presence of fish. I did see a pike (*Esox lucius*) in a tributary (creek) that flowed into one of the larger YKSA wetlands in the study. Most YKSA wetlands are not proximate to a colonization source and likely freeze to the bottom in the winter, and are therefore unlikely to contain fish (J. Hines, CWS, pers. comm.).

3.2. Brood-rearing habitat characteristics of aquatic birds on the Yellowknife Study Area

The distribution of broods of each of the seven aquatic bird species, by the total brood abundances over the CWS survey years lay on the positive side of Axis-1 of the PCA (Figure 5). Thus the gradient reflected by Axis-1 is some characteristic, which benefits all species. Axis-1 explains 51% of the variation in brood distribution. The total number of broods on a wetland over all the survey years is clearly influenced by wetland area (ha) (Figure 6), so to interpret the gradient represented by Axis-1 in the PCA, I began by fitting Factor-1 of the PCA by the slope derived by regression equations predicting brood abundance from wetland area (Table 7). A strong correlation exists between Factor-1 of the PCA

with the slopes derived from the relationships of brood abundances with wetland area (Figure 7), which indicates that the gradient reflected by Axis-1 in the PCA is wetland area. Axis-2 explains an additional 18% of the variation in brood distribution; it describes a gradient that separates the abundances of horned grebe, American wigeon, green-winged teal and mallard broods from the abundances of red-necked grebe, ring-necked duck, and lesser scaup broods. Although I investigated components 1 and 2 of a PCA of the invertebrate community structure, none of the relationships provided a satisfactory interpretation of the gradient reflected by Axis-2, 3, or 4 of the distribution of broods. However, two possible explanations emerged from my exploration of what other variables might explain Axis-2 of the brood abundance PCA. Predicting the distribution of broods by (1) mean lake area that broods were recorded on (weighted by the number of broods of that species) (Figure 8) and (2) water transparency (Figure 9) both provide plausible explanations for Axis-2 of the brood abundance PCA. The data presented in Table 7 indicate that brood abundances on the YKSA wetlands in the study are, with the exception of horned grebe broods, affected by wetland area (Axis-1 reflects the association between brood abundance and wetland area). The data in Table 7 also indicate that the predictive power of area on brood abundance varies among the bird species. Mean lake area that broods were recorded on, (weighted by the number of

broods of that species) (Table 7) provides an estimation of the relative importance of wetland area to breeding habitat selection by each of the aquatic bird species in the study and could explain the distribution of brood abundance on Axis-2. Although the predictive power of water transparency as measured by Secchi disc depth (Table 7) on Factor-2 is not as strong as that of mean lake area (weighted by brood abundance) ($R^2=0.67$ and $R^2=0.93$, respectively), it is a significant variable on the brood-rearing habitats of some species, thereby providing a second possible explanation for Axis-2. Thirteen-percent of the variation in the PCA remained unexplained; however Eigen Values for all factors, except Factor-1 and 2, were <1 , which makes it unlikely that they contribute any relevant or interpretable information to the distribution of brood abundances in the PCA (Manly 1990).

Results of the logistic regressions are summarized in Table 8. With the exception of horned grebe broods, wetland area was a significant explanatory variable of brood-rearing wetland selection by all the aquatic bird species included in the study. In all models, the estimate for wetland area was positive, indicating that larger wetlands supported more broods overall.

With the exception of green-winged teal broods, shoreline irregularity contributed significantly to the univariate logit model for all aquatic bird species. Wetland distance to the road was a significant variable on brood-rearing wetland

selection by mallards, lesser scaup, and red-necked grebes. That water transparency was significant with the diving ducks and red-neck grebes in the univariate logistic regressions, provides support for my impression that transparency could explain the gradient reflected by Axis-2 of the brood abundance PCA. Little or no effect of other physical or chemical variables, such as depth, conductivity, pH, temperature, or total phosphorus on brood-rearing wetland selection was evident.

Three invertebrate groups had significant associations with brood-rearing wetlands: Amphipoda, Pelecypoda, and Ephemeroptera. The strength and direction of associations between brood-rearing wetlands and the habitat variables I measured are discussed in further detail for each aquatic bird species below. Although the effect of invertebrate abundance, log-transformed invertebrate abundance, and invertebrate biomass were all investigated in the regression analyses of brood-use, log-transformed invertebrate abundance provides the best fit to most models and was thus retained as the single parameter from which association between broods and invertebrates were estimated in this study. (Logit regression results from all measures are reported in Appendix B.)

3.3. *American wigeon brood associations*

Thirty-seven percent of the studied wetlands were used by American wigeon broods for more than 2 survey years and were thus considered consistently used wetlands. Univariate logit regression analysis indicated that wetland area, shoreline irregularity, and abundance of Amphipoda, Pelecypoda, and Ephemeroptera were positively correlated with American wigeon brood-rearing wetlands (Table 9). The best logit model with a reduction in deviance of 17.36 from 32.19 ($R^2 = 0.35$) for a loss of 2 *d.f.* indicated American wigeon broods were most strongly correlated with wetland area and the abundance of Ephemeroptera (Table 10). The average size of wetlands used by American wigeon broods in this study was 2.63 ha, SE 0.27, median 1.4 ha (derived from all wetlands ever used). The total number of American wigeon broods on these wetlands was positively correlated with wetland area, shoreline irregularity, and abundance of Pelecypoda, and Ostracoda (Table 11).

3.4. *Green-winged teal brood associations*

Forty percent of the studied wetlands were considered used consistently by green-winged teal broods. Univariate logit regression analysis indicated that wetland area alone was correlated with brood-rearing wetlands (Table 12). Model fit was not improved by the addition of other variables. The average size

of wetlands used by green-winged teal broods in this study was 2.28 ha, SE 0.28, median 1.4 ha (derived from all wetlands ever used). The total number of green-winged teal broods on these wetlands was positively correlated with wetland area, shoreline irregularity, and abundance of Gastropoda (Table 13).

3.5. *Mallard brood associations*

Forty-four percent of the studied wetlands were considered used consistently by mallard broods. Univariate logit regression analysis indicated that wetland area, shoreline irregularity, pH, and abundance of Amphipoda, Pelecypoda, and Conchostraca were positively correlated with brood-rearing wetlands (Table 14). Model fit was not improved by the addition of other variables. The average size of wetlands used by mallard broods in this study was 2.53 ha, SE 0.27, median 1.8 ha (derived from all wetlands ever used). The total number of mallard broods on these wetlands was positively correlated with wetland area, pH, shoreline irregularity, and abundance of Amphipoda, Gastropoda, and Pelecypoda (Table 15).

3.6. *Lesser scaup brood associations*

Fifty-three percent of the studied wetlands were considered used consistently by lesser scaup broods. Univariate logit regression analysis indicated that wetland area, shoreline irregularity, pH, temperature, water

transparency, and abundance of Pelecypoda, Amphipoda, Ephemeroptera, and Ostracoda were positively correlated with brood-rearing wetlands, while Diptera had a negative correlation (Table 16). Model fit was not improved by the addition of other variables. The average size of wetlands used by lesser scaup broods in this study was 2.57 ha, SE 0.27, median 1.8 ha (derived from all wetlands ever used). The total number of lesser scaup broods on these wetlands was positively correlated with wetland area, transparency, shoreline irregularity, abundance of Amphipoda and Ostracoda, and Hirudinea biomass (g) (Table 17).

3.7. *Ring-necked duck brood associations*

Thirty-two percent of the studied wetlands were considered used consistently by ring-necked duck broods. Univariate logit regression analysis indicated that that wetland area, shoreline irregularity, transparency, water depth (m), and abundance of Pelecypoda, Amphipoda, and Ephemeroptera were positively correlated with brood-rearing wetlands, while Diptera had a negative correlation (Table 18). The best logit model with a reduction in deviance of 23.83 from 47.02 ($R^2 = 0.51$) for 2 *d.f.* indicated ring-necked duck broods were most strongly correlated with wetland area and abundance of Pelecypoda (Table 19). The average size of wetlands used by ring-necked duck broods in this study was 3.21, SE 0.33, median 2.4 ha (derived from all wetlands ever used). The total number of ring-necked duck broods on these wetlands was positively correlated

with wetland area, transparency, shoreline irregularity, and abundance of Amphipoda, and Ostracoda (Table 20).

3.8. *Horned grebe brood associations*

Forty percent of the studied wetlands were considered used consistently by horned grebe broods. Univariate logit regression analysis indicated that abundance of Pelecypoda, Zygoptera, and Cyclopoida, and shoreline irregularity were positively correlated with horned grebe brood-rearing wetlands, while abundance of Trichoptera had a strong negative correlation (Table 21). Model fit was not improved by the addition of any of the other variables. The average size of wetlands used by horned grebe broods in this study was 2.4, SE 0.40, median 1.4 ha (derived from all wetlands ever used). The total number of horned grebe broods on these wetlands was positively correlated with abundance of Cyclopoida and Pelecypoda and negatively by abundance of Trichoptera (Table 22).

3.9. *Red-necked grebe brood associations*

Forty-six percent of the studied wetlands were considered used consistently by red-necked grebe broods. Univariate logit regression analysis indicated that wetland area, shoreline irregularity, transparency, temperature, and abundance of Amphipoda and Pelecypoda were positively correlated with

brood-rearing wetlands (Table 23). The average size of wetlands used by red-necked grebe broods in this study was 2.86, SE 0.28, median 2.06 ha (derived from all wetlands ever used). The total number of red-necked grebe broods on these wetlands was positively correlated with wetland area, pH, transparency, shoreline irregularity, and abundance of Amphipoda, Ostracoda, and Trichoptera (Table 24).

3.10. *Interspecific brood associations*

Green-winged teals and especially horned grebes stood out as having the fewest associations with the brood-rearing wetlands of the other species in the study (Table 25). Wetland area was not strongly correlated with the brood-rearing wetlands of these two small species, which could explain the lack of association between these and the brood-rearing wetlands of the other species. All other species were associated with larger YKSA wetlands, which were less abundant in the study. The predictive power of the association, assessed by the R^2 values derived by the logistic regressions (Table 25) indicate better fitting models among the diving ducks, between the diving ducks and red-necked grebe, and between the diving ducks and red-necked grebe with the largest dabbling duck, the mallard. The affinity for larger wetlands is a likely explanation for the brood-rearing wetland associations that were derived among these four YKSA breeders.

3.11. *Unused wetlands*

The probability that a natural YKSA wetland would *not* be used by a brood of any of the 5 dominant duck species on YKSA is 0.099. Thus, by chance alone, approximately 25 of 262 wetlands would be expected to be unused, if the use probabilities were independent. The actual number of ponds unused by any duck species was only slightly higher than this with 34 (12.9%) wetlands were unused by any of the duck species. Similarly, if use probabilities were independent, we would expect only 9 of 262 (3.4%) wetlands to be used by all of the duck species studied on YKSA. The observed number of wetlands used by all species was 41 (15%), which was much greater than the number expected based on the assumption of independent probabilities. Thus the positive associations that were detected between brood-use by several of the most abundant species lead to many wetlands being used by all species.

4. DISCUSSION

4.1. *Relationships between physical wetland characteristics and use by breeding water birds*

As expected, wetland area is associated with brood-rearing wetlands on the 75 YKSA wetlands studied. Two patterns in the association are apparent (1) in general, brood-rearing wetlands of diving ducks and the red-neck grebe are

larger than those of dabbling ducks and the horned grebe and (2) brood-rearing wetlands of the bigger aquatic birds in the study (American wigeon, mallard, ring-necked duck, lesser scaup, and red-necked grebe) are larger than those of the smallest species studied (green-winged teal and horned grebe).

Although, horned grebe broods were an exception, associations between the physical characteristics of wetlands and brood-rearing habitat characteristics are stronger for species that are unable to or less likely to make frequent movements between wetlands (red-necked grebes and diving ducks). Ducks with ducklings that are able to move between wetlands (the dabbling ducks in this study) may subsidize an inadequacy of some resource by acquiring the resource elsewhere (Dzus 1997). In agreement with Möller (1987) and Elmberg (1994) my data indicate that wetland area is the more significant determinant of species number the more functionally dependant the species is on the wetland.

The lack of any significant pattern of association between horned grebes and wetland size is interesting. That horned grebes are distinct from all the other species may be a reflection of the territorial nature of this species. Horned grebes are highly territorial with a preference for small ponds from which they aggressively defend a territory using visual cues (Faaborg 1975). The strongest negative influence of an invertebrate group on brood-rearing habitat was that of Trichoptera on horned grebes. A possible explanation for the strong negative

association is that some habitat characteristic, which is favourable to Trichoptera, is undesirable to horned grebe broods. Trichoptera larvae and pupae are often associated with logs hanging into or sitting under the waters surface (Hoffmann 2000). Perhaps, in the case of horned grebes, the presence of protruding logs visually restricts an environment and decreases its suitability for brood-rearing; however I was unable to test this hypothesis.

My results also indicate that, as hypothesised, shoreline irregularity is associated with brood-rearing wetland selection. Shoreline irregularity may (1) cue pairs in search of a suitable wetland based on potential food availability or (2) indicate areas with a greater abundance of suitable protective plant cover for brood rearing. While shoreline irregularity is likely a wetland characteristic associated with wetland selection during the breeding season for some species, in this study, shoreline irregularity was correlated with wetland area and the significance of SI as a regressor could be reflective of the strong association between brood-rearing wetlands and wetland area. Undoubtedly, shoreline details of small wetlands were lost by measuring wetland perimeters from coarse scale maps. Thereby, the shoreline irregularity of small wetlands is underestimated. As a result, the association between shoreline irregularity and brood-rearing wetland selection remains somewhat unresolved. Interestingly, the only case where SI was not significant on wetland selection was in that of

green-winged teal, a small species associated with smaller wetlands. Consequently, I think my results may be at least partially driven by the association between wetland area and habitat suitability. Nevertheless, shoreline irregularity is likely an important characteristic of brood-rearing wetlands for aquatic birds and I think that if wetland perimeter were measured on a finer scale, its association with brood-rearing habitat would (1) include green-winged teal and (2) increase in the strengths of its associations with brood-rearing habitat of the other water birds studied.

The water transparency of wetlands, as measured by Secchi disc depth, is positively associated with brood-rearing wetlands of diving ducks and red-necked grebes. In laboratory studies Sugden (1973) observed, ducklings making attempts to retrieve larger food items, while avoiding smaller, but more abundant items such as *Daphnia sp.*, an indication that visual recognition affects the detection of food items in ducklings. The positive association between brood-rearing wetlands and water transparency may occur because water transparency affects foraging success, especially in diving duck species and red-necked grebes.

On many wetlands the Secchi disc was visible to the bottom, so a strong correlation between wetland depth and water transparency was not surprising. However, that wetland depth appeared to have little or no influence on brood-rearing wetland selection by water birds in the study was somewhat surprising.

Walsh et al. (2006) found a strong correlation between wetland depth and lesser scaup broods on 24 YKSA wetlands. The median and range of depths in the 24 wetlands sampled by Walsh et al. (2006) were similar to those in this study; in Walsh et al. (2006) median wetland depth was 2.0 m, minimum 0.3 m, and maximum 4.6 m and in this study median depth was 1.6 m, minimum 0.5 m, and maximum 6.4 m.

Wetlands on the study area had relatively low conductivity levels and were well below levels shown to be fatal to young ducklings ($>20,000\text{ms/cm}$) or known to affect growth (Mitcham and Wobeser 1998, Swanson et al. 1984). Conductivity had no association with brood-rearing habitat on these YKSA wetlands. Wetlands further from the road had lower conductivities. Elevated conductivities near the road could possibly be attributed to former dust-suppression practices on the highway.

Although my results indicate wetland area is correlated with distance to the road and shoreline irregularity, I think it is unlikely that an actual cause and effect relationship exists between the variables. I think the correlation between wetland area and distance to the road exists because the study area is long and narrow and large wetlands often encompass a large portion of the 400m stretch from the road to the boundary of the study area, thus the distance from the edge of the road to the center of a large wetland implies that large wetlands are far

from the road. In actuality, the shorelines of large wetlands may be situated very near the road. Therefore, although distance to the road was a significant variable on brood-rearing wetland selection by mallards, lesser scaup, and red-necked grebes, interpreting the reason for the association is not straightforward; in fact the association may be spurious.

Most studies that have correlated wetland-use by waterfowl with wetland productivity have been conducted in the PPR, the Great Lakes region, or Fennoscandia (eg. Merendino et al. 1993, Merendino and Ankney 1994, Staicer 1994, Paquette and Ankney 1996, and Sjöberg et al. 2000 in Haszard 2004). The nutrient states of wetlands differ among regions and in comparison to wetlands in the WBF (Hornung 2005), making comparisons among regions difficult. I found no evidence to support associations between wetland-use by broods or invertebrate food abundance and wetland productivity on YKSA wetlands. One possible explanation for this is that levels used to detect phosphorus concentration from the samples were too high and did not provide the resolution necessary to detect a correlation. However, a more likely explanation is that no correlations with phosphorus concentrations were found since productivity was uniformly low across this series of wetlands.

4.2. Relationships between aquatic invertebrates and brood-rearing habitats of aquatic birds on the YKSA

Numerous studies have linked waterfowl abundance and distribution to the availability of invertebrate prey. Nummi et al. (1994), Pöysä et al. (2000), and Elmberg et al. (2003) linked mallard and green-winged teal (Nummi and Pöysä 1995) density to food abundance in Fennoscandian wetlands, and Lindeman and Clark (1999) linked wetland-use by lesser scaup to amphipod abundance in Saskatchewan wetlands.

Three invertebrate groups had significant associations with brood-rearing wetlands: Amphipoda, Pelecypoda, and Ephemeroptera. Brood associations with Pelecypoda may reflect the nutritive requirements of egg production. Egg production is associated with high calcium requirements, and egg-laying female ducks often eat empty snail and clam shells (Krapu and Swanson 1975), which are high in calcium. In contrast, postlaying females sometimes remove shells and ingest only the soft parts of the animal (Hohman 1985). Fat reserves acquired prior to arrival on breeding grounds are depleted during rapid ovarian follicle growth and the protein required for egg production must be obtained from ambient dietary items ingested during laying (Hohman 1986, Alisauskas et al. 1992). Swanson (1984) reported that only trace amounts of Gastropoda were consumed by mallards in the PPR during April; one month later, they accounted

for 25% of the foods consumed. Although the bill morphology of the green-winged teal limit it to prey items smaller than those selected by other dabbling ducks (Pöysä 1983, Nudds and Bowlby 1984, Nummi 1993), even when its diet shifted to one higher in animal content during the breeding season, 11.3% of the 17% total animal consumption was mainly Ostracoda, a small, but calcium-rich food item (Hughes and Young 1982). (Although not always a factor favouring occupancy alone, Ostracoda directly influenced the total numbers of American wigeon, lesser scaup, ring-necked duck, and red-necked grebe broods on wetlands.) Thus, female nutritive requirements during egg-production might drive the association between Pelecypoda with brood-rearing wetland habitat.

Ducklings are precocial. They leave the nest and follow the hen to water within 24 hours of hatching and begin feeding themselves immediately. For the first few days of life their bills are unspecialized and they are too light to tip-up or dive to retrieve food items, thus ducklings are restricted to food items on the waters surface (Sugden 1973). Scaup ducklings begin making short dives within a day or so of being in the water and, as do the ducklings of other species, begin to emulate adult foraging behaviour within 4-5 days. However, mature foraging behaviour may not be effectual for several weeks (Sugden 1973). Thus, although invertebrate sampling was better suited to invertebrates available to dabbling ducks, as ducklings, most species are restricted to capturing similar invertebrate

prey. Although the youngest ducklings are bound by morphologic constraints to a generalist diet for the first few days of life, bill specialization occurs in conjunction with increased duckling body mass, which affords some broods with the ability to move to a new wetland in search of food if the original brood pond is insufficient in that capacity. Hens in the PPR and Fennoscandia are known to move their broods to a new wetland for rearing within a short time (Talent et al. 1982, Dzus and Clark 1997). Similarly hens may move young broods to alternate wetlands on YKSA (J. Hines, Canadian Wildlife Service, pers. comm.). Talent et al. (1982) hypothesized that the brood movements are conducted due to poor food availability in natal ponds. Thus there is evidence for the existence of food limitation on these wetlands. However, my findings demonstrate that, overall the associations between invertebrate taxa and brood-rearing wetlands are weak in comparison to brood-rearing habitat associations with the physical parameters of these wetlands. This could indicate that other factors, such as predation, cool weather, and late frosts may be more important at the population level than food limitation is in this area.

My findings provide some support for geographic variation in the invertebrate groups associated with brood-rearing habitat for certain aquatic bird species in the study. Diptera, especially chironomid larvae have been considered an important dietary item for mallard and other ducklings (Danell and Sjöberg

1980, Sjöberg and Danell 1982, Talent et al. 1982, Batzer et al. 1993, Gardarsson and Einarsson 1994), Dzus and Clark 1997, King and Wrubleski 1998, Ashley et al. 2000, in Hornung 2005). However, in my study, Dipteran abundance was not associated with brood-rearing wetlands of any species. In fact, Dipteran abundance had a negative correlation with the brood-rearing habitats of lesser scaup and ring-necked ducks. My findings are consistent with those of Hornung (2005) who found no association between mallard duckling diet and the abundance of dipterans in northern Alberta wetlands. Hornung (2005) identifies Dytiscids as important to mallard duckling diets in northern Alberta, however, I found no association between Dytiscids and mallard brood-rearing habitat on these wetlands.

Diets of duckling and juvenile lesser scaup are dominated by Amphipoda, Gastropoda, and Diptera in Manitoba (Bartonek and Hickey 1969) and Diptera and Conchostraca in the Northwest Territories (Bartonek and Murdy 1970). In my study, Amphipoda, Pelecypoda, Ephemeroptera, and Ostracoda were positively correlated with brood-rearing wetlands of lesser scaup, while the association with Diptera was a negative one.

In Maine and Minnesota, Hohman (1985) and McAuley and Longcore (1988) identified Trichoptera, Diptera, Conchostraca, Gastropoda and Pelecypoda as important food items for ring-necked ducklings. Trichoptera had

no association with the brood-rearing wetlands of ring-necked ducks, Pelecypoda may be a potential prey item, and Diptera had a negative association with brood-rearing wetlands of ring-necked ducks on the YKSA.

In breeding lakes in Alberta and British Columbia, Odonata are important food items for adult and young red-necked grebes (Kevan 1970, Riske 1976, Ohanjanian 1986, in Stout and Nuechterlein 1999). However, Odonata were not significantly associated with red-necked grebe brood-rearing wetlands in my study.

4.3. *Interspecific associations among aquatic bird species on the YKSA*

Interspecific association (+ or -) results from one of two general factors: (1) species select or avoid the same habitat or components of the same habitat or (2) species have an affinity for another species that is manifested in an attraction or repulsion.

Since variables that were significant on brood-rearing wetlands were similar among species, with the exception of horned grebes, it is not surprising that associations among species were common in this study. Support for my predictions regarding the effect of breeding chronology patterns on interspecific associations found little support in the results of evaluations of interspecific affinities (Table 23). While numerous associations are significant, the R^2 values

do not indicate that, in any of the instances, breeding chronology predicts well that wetlands used by early breeders will be shared with late breeders.

My predictions regarding the effect of grebe territoriality on brood-use of wetlands also found little support. Both grebe species are territorial (Garner 1991 and Fjeldså 1973), but red-necked grebes appear to be tolerant of other species on these wetlands. Garner (1991) indicated territoriality increased in red-necked grebes in response to limits to food availability. Determining whether broods of other species occur more often on wetlands during the years when red-necked grebes are absent would provide a better test of the degree of territoriality exercised by breeding red-necked grebes in this area. Nonetheless, I interpreted my findings regarding interspecific associations of red-necked grebes on these wetlands as partial, yet further support suggesting that food limitation is not the foremost factor affecting brood-rearing wetland selection on the YKSA wetlands studied.

4.4. *Unused wetlands*

Slightly more natural YKSA wetlands were unused for brood-rearing by all ducks than what I predicted would have occurred by chance (12.9% and 9% respectively). Two-hundred and sixty-two YKSA wetlands are natural water bodies and 313 are borrow pits. A possible explanation for why more wetlands were unused than what I expected is that breeding ducks use both natural water

bodies and borrow-pits, thus the number of unused natural wetlands on YKSA is inflated. I predicted fewer wetlands would be used by all broods (3.4%) than what was observed (15.6%). These findings suggest that, in general, YKSA wetlands do not lack brood rearing resources.

4.5. *Invertebrate community patterns and environmental relationships*

Aside from shoreline irregularity total invertebrate abundance was not significantly correlated with any other abiotic variable. Shoreline irregularity affords a wetland with wind-protected bays, which promote macrophyte colonization, increase the number of hiding places and ultimately habitat suitability for many aquatic invertebrates (Kalff 2001), which probably explains the correlation.

Some studies have reported that predation pressure from fish presence has reduced the abundances of Crustacea (Zimmer et al. 2000, Bartonek and Hickey 1969) and Anisoptera (Henrikson 1988, Bendell and McNicol 1995 in Sotiropoulos 2002) in wetlands. The fact that Crustacea and Odonata are the two highest contributors to invertebrate biomass in study wetlands is therefore consistent with the observation that fish are absent from these wetlands. In terms of food availability, the absence of fish in YKSA wetlands may increase the suitability of these wetlands for broods. Hill et al. (1987) reported that mallard ducklings feeding in lakes with high densities of fish (and low densities of

aquatic invertebrates) survived at lower rates than those feeding in habitats with low densities of fish.

5. CONCLUSION

The western boreal forest provides important breeding habitat for 12 to 14 million aquatic birds annually. Across the region, industrial developments are quickly outpacing conservation efforts. This is one of very few studies demonstrating patterns in brood-rearing habitat use by ducks and grebes in the boreal region.

With the exception of horned grebes, in my study area, the most significant variable in determining brood-rearing habitat was wetland area. Shoreline irregularity was also an important variable in determining wetland suitability. Admittedly the indices of shoreline irregularity in my study were correlated with wetland area, which may have biased those results. In general, associations between physical wetland characteristics and brood-rearing habitat were greater than associations between invertebrate taxa and brood-rearing habitat. Among the aquatic birds studied, associations with habitat variables were also stronger with the diving ducks and red-necked grebes than they were with the dabbling ducks and horned grebes. The ability or tendency of dabbling ducks to use several wetlands during the brood-rearing period may explain why correlations between wetland variables and breeding dabbling ducks were

weaker than the associations with breeding birds that are less likely to or unable to move between wetlands.

Developing sound conservation initiatives for aquatic bird communities like this one is complicated by the range of life history traits, such as the ability to move broods, present in the assemblage. In the assemblage I have studied, a few species are reliant on a single wetland for the duration of the brood-rearing period, whereas other species use numerous wetlands for brood-rearing. Therefore, successful management strategies will require the conservation of a variety of features to meet the requirements of this assembly of aquatic birds during the breeding season. My findings indicate that an appropriate target for management would include wetland complexes, within which there are large wetlands characterized by irregular shorelines, as well as smaller wetlands characterized by sparsely vegetated shorelines.

Invertebrate sampling was better suited to invertebrates available to dabbling ducks, but the ducklings of most species are restricted to similar invertebrate prey while young. In general this study shows weak links between invertebrate abundance and brood-rearing wetland selection by all 7 aquatic bird species. This finding may indicate that factors, other than food limitation, such as predation, cool weather, and late frosts may be more important at the population level in this area. Additionally, some of my findings demonstrate intraspecific

variation along geographic lines with regard to the biotic variables that influence wetland suitability for certain waterfowl broods; however further research is needed to learn more about the relationships between ducklings and invertebrate prey.

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Table 1 - Temporal changes to invertebrate abundance (transformed) on YKSA wetlands between mid-June and mid-July 2004. Asterisks denote significant differences by 2-sample t-tests ($P < 0.05$, $n = 13$).

Taxa		mean	SE
Amphipoda	June	1.95	0.165
	July	2.18	0.162
*Anisoptera	June	1.36	0.064
	July	1.58	0.073
Coleoptera	June	1.18	0.043
	July	1.26	0.026
*Crustacea	June	2.28	0.144
	July	2.73	0.101
Diptera	June	1.75	0.080
	July	2.04	0.144
Ephemoptera ^{1,2}	June	1.65	0.179
	July	1.36	0.053
*Gastropoda	June	1.53	0.127
	July	1.86	0.090
*Hemiptera ^{1,2}	June	1.29	0.040
	July	1.82	0.090
Hiudinea ¹	June	1.14	0.064
	July	1.17	0.067
Hydrachnidia ¹	June	1.17	0.041
	July	1.19	0.037
Pelecypoda ¹	June	1.89	0.168
	July	1.90	0.121
Trichoptera ^{1,2}	June	1.13	0.040
	July	1.06	0.019
*Zygoptera	June	1.34	0.060
	July	1.71	0.075

¹ data not normally distributed

² significant differences tested using Welsh Anova F-test

Table 2 - Total number of broods counted on wetlands on the Yellowknife Study Area. Counts for ducks are based on the years 1985-2003 and counts for grebes are based on the years 1991-2003. The percentage of wetlands (N=75) used by broods is reported for each aquatic bird species. Medians, ranges, and means \pm SE, are the median, range, and mean \pm SE broods counted per "used wetland".

Species	Total broods counted	% wetlands used by broods (N=75)	Number of broods per "used wetland"		
			Median	Range	Mean (\pm SE)
<i>dabbling ducks</i>					
American wigeon	218	69.3%	3	1 to 23	4.2 (\pm 0.59)
Green-winged teal	211	76.0%	3	1 to 20	3.7 (\pm 0.42)
Mallard	162	73.3%	2	1 to 8	2.9 (\pm 0.29)
<i>diving ducks</i>					
Lesser scaup	406	73.3%	4	1 to 62	7.4 (\pm 1.33)
Ring-necked duck	140	45.3%	2	1 to 24	4.1 (\pm 0.97)
<i>grebes</i>					
Horned grebe	161	61.3%	3	1 to 11	3.6 (\pm 0.42)
Red-necked grebe	453	60.0%	7	1 to 48	9.8 (\pm 1.37)

Table 3 - Means standard errors, medians, and ranges of environmental and chemical characteristics of 75 natural wetlands near Yellowknife, Northwest Territories, Canada (2004).

Variable	Mean	SE	Median	Min	Max
Area (ha)	2.0	0.3	1.2	0.03	12.8
Conductivity (u/cm)	296	29	229	48	1764
Depth (m)	2.1	0.2	1.6	0.5	6.4
Distance to road (m)	21.8	1.5	20.0	2.5	54.0
pH	7.4	0.1	7.5	5.4	8.7
Shoreline irregularity	1.7	0.1	1.7	0.4	3.8
Secchi disc depth (m)	1.2	0.0	1.2	0.4	2.5
Temp (C°)	20.9	0.3	20.8	14.4	26.7
Total P (mg/L)	<0.02	0.002	<0.02	<0.02	0.1

Table 4 – Simple correlation coefficients between environmental variables of 75 Yellowknife Study Area wetlands (2004).

	Area (ha) ^a	Conductivity (μ /cm) ¹	Depth (m) ^b	pH	Transparency (m) ^c	SI ^d	Temperature (°C)
Conductivity (μ /cm) ¹	-						
Depth (m) ^b	0.2383 P=0.0395	-					
pH	0.2884 P=0.0121	0.2432 P=0.0355	-				
Transparency (m) ^c	0.3444 P=0.0025	-	0.5725 P=0.0000	0.2259 P=0.0513			
SI ^d	0.5600 P=0.0000	-	-	0.2315 P=0.0457	0.3705 P=0.0011		
Temperature (°C)	0.2677 P=0.0203	-	-	0.2249 P=0.0524	-	0.2465 P=0.0330	
Distance to road (m) ¹	0.4257 P=0.0002	-0.3934 P=0.0005	-	-	-	0.3078 P=0.0076	0.4183 P=0.0002

¹ Data not normally distributed. Correlation is measured using Spearman's Rho.

^a Area data are Box-Cox transformed (Area^{0.2})

^b Depth data are Box-Cox transformed (Log(Depth))

^c Transparency as measured by Secchi disc depth (m)

^d SI = shoreline irregularity

Table 5 - Simple correlation coefficients between environmental variables and invertebrate taxa of 75 Yellowknife Study Area wetlands (2004). Invertebrate data have been $\log_{10}(x+10)$ transformed.

	Area (ha) ^a	Cond. (μ/cm) ¹	Depth (m) ^b	pH	SD (m) ^c	SI ^d	Temp. (°C)	Dist. to road (m) ¹
Amphipoda ¹	0.4124 P=0.0002	-	0.2645 P=0.0219	0.2447 P=0.0344	0.2595 P=0.0246	0.2812 P=0.0145	0.2490 P=0.0345	-
Coleoptera ¹	-	-	-	-	-	-	-	-
Crustacea	-	-	-	0.2729 P=0.0178	-	-	-	-
Diptera ¹	-0.3030 P=0.0082	0.2774 P=0.0160	-0.3299 P=0.0038	-	-	-	-	-
Ephemeroptera ¹	0.3415 P=0.0027	-	-	-	0.3310 P=0.0037	0.2461 P=0.0333	-	-
Gastropoda	-	-	-	0.3232 P=0.0047	-	-	-	-
Hemiptera ¹	-	-	-	-	-	-	0.3846 P=0.0007	-
Hirudinea ¹	0.2663 P=0.0209	-	-	0.2599 P=0.0243	-	-	-	-
Hydrachnidae & Araneae ¹	-	0.2730 P=0.0178	-	-	-	-	-	-
Anisoptera	-	-	-	-	-	-	-	-
Zygoptera ¹	-	-	-	-	-	0.2997 P=0.0090	0.2322 P=0.0450	-
Pelecypoda	0.3678 P=0.0012	-	-	-	0.2824 P=0.0141	0.4010 P=0.0004	-	-
Trichoptera ¹	-	-	-	-	-	-	-	0.2555 P=0.0280

¹ Data not normally distributed. Correlation is measured using Spearman's Rho.

^a Area data are Box-Cox transformed (Area^{0.2})

^b Depth data are Box-Cox transformed (Log(Depth))

^c Transparency as measured by Secchi disc depth (m)

^d SI = shoreline irregularity

Table 6 - Simple correlation coefficients between invertebrate taxa from 75 Yellowknife Study Area wetlands (2004).).

Invertebrate data have been $\log_{10}(x+10)$ transformed.

	Amphipoda ¹	Coleoptera ¹	Crustacea	Diptera ¹	Ephemeroptera ¹	Gastropoda	Hemiptera ¹	Hirudinea ¹	Hydrachnidae & Araneae ¹	Anisoptera	Zygoptera ¹	Pelecypoda
Coleoptera ¹	-											
Crustacea	-	-										
Diptera ¹		-	0.2793 P=0.0152									
Ephemeroptera ¹	0.3749 P=0.0009	-	0.2488 P=0.0314	-								
Gastropoda	0.3170 P=0.0056	-	0.2328 P=0.0444	0.3159 P=0.0058	0.3577 P=0.0016							
Hemiptera ¹	-	0.4051 P=0.0003	-	-	-0.3077 P=0.0072	-						
Hirudinea ¹	0.3971 P=0.0004	0.2404 P=0.0378	-	-	0.2287 P=0.0484	0.2350 P=0.0424	-					
Hydrachnidae & Araneae ¹	0.2481 P=0.0319	0.3455 P=0.0024	0.3412 P=0.0027	-	-	-	0.2828 P=0.0139	-				
Anisoptera	-	-0.2604 P=0.0241	-	-	0.3427 P=0.0026	0.3248 P=0.0045	-	-0.2340 P=0.0433	-			
Zygoptera ¹	-	-	-	-	-	0.3699 P=0.0011	-	-	-	0.3791 P=0.0008		
Pelecypoda	0.2294 P=0.0477	-	-	-	0.5125 P<0.0000	0.4324 P<0.0001	-	-	-	0.4334 P=0.0001	0.2992 P=0.0091	
Trichoptera ¹	0.2665 P=0.0208	-	-	-	-	-	-	0.3704 P=0.0011	-	-	-	-

¹ Data not normally distributed. Correlation is measured using Spearman's Rho.

Table 7 – Regression equations predicting brood abundance by wetland area (ha) and Secchi disc depth (m) are derived from 75 wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Mean-pond size (weighted by brood abundance, calculated by: ((area*brood abundance)/brood abundance) is also reported.

Species	Regression equation predicting brood abundance by wetland area	Mean-pond size (weighted by brood abundance) (ha) ³	Regression equation predicting brood abundance by wetland area
¹ American wigeon	y=0.53+1.21x; P<0.0001; R²=0.45	4.03	y=1.42+1.2x; P<0.2888; R ² =0.02
¹ Green-winged teal	y=1.76+0.54x; P<0.0009; R²=0.14	2.9	y=2.65+1.4x; P<0.8813; R ² =0.00
¹ Mallard	y=1.26+0.46x; P<0.0001; R²=0.21	3.02	y=1.4+0.6x; P<0.3346; R ² =0.01
¹ Lesser scaup	y=-1.61+3.57x; P<0.0001; R²=0.79	5.25	y=-1.64+5.7x; P<0.0224; R²=0.07
¹ Ring-necked duck	y=-1.39+1.65x; P<0.0001; R²=0.74	6.37	y=-1.83+2.9x; P<0.0121; R²=0.08
² Horned grebe	y=2.11+0.02x; P<0.9006; R ² =0.00	2	y=1.39+0.6x; P<0.4360; R ² =0.01
² Red-necked grebe	y=-0.69+3.42x; P<0.0001; R²=0.77	4.78	y=-2.29+6.8x; P<0.0048; R²=0.10

¹ Brood abundance is the total number of broods observed by Canadian Wildlife Service survey 1985-2003.

² Brood abundance is the total number of broods observed by Canadian Wildlife Service survey 1991-2003.

³ Mean pond size (weighted by the number of broods of that species) =
$$\frac{\sum_{i=1}^L N_i \cdot A_i}{\sum_{i=1}^L N_i},$$

where N_i represents the number of broods of a given species in the i th lake, L is the number of lakes, and A_i is the surface area of the i th lake

Table 8 – Summary results of logistic regressions for the habitat characteristics and invertebrate groups associated with brood-rearing wetlands for 7 aquatic bird species on 75 Yellowknife Study Area wetlands, near Yellowknife, NT, 2004. Only variables that were significant to two or more species are listed.

<i>Variable</i>	American wigeon	Green-winged teal	Mallard	Lesser scaup	Ring-necked duck	Horned grebe	Red-neck grebe
<i>Environmental variable</i>							
Area (ha) ^a	●	○	●	●	●		●
Area (ha)	□	•	●	●	●		●
Distance to road (m) ^b			○	○			○
pH			•	•			
Secchi disc depth (m)				•	○		•
Shoreline irregularity	○		□	□	○	•	○
<i>Invertebrate group</i>							
Log_Amphipoda	○		•	•	•		○
Log-Diptera				•	•		
Log-Ephemeroptera	○			•	•		
Log-Pelecypoda	○		•	•	○	○	•

● P<0.05, ○ P<0.01, □ P<0.001, • P<0.0001.

^a Area is Box-Cox transformed ($Area = Area^{0.02}$).

^b Distance to the road is measured from the center of a wetland to the edge of the road.

Table 9 - Univariate logit regression indicating habitat features associated with American wigeon brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	7.0763	1.7301	16.7298	0.0000	0.3037
Shoreline irregularity	1.5570	0.5019	9.6237	0.0019	0.1244
Log_Amphipoda	1.8699	0.6313	8.7731	0.0031	0.1140
Log-Ephemeroptera	2.2212	0.7840	8.0269	0.0046	0.0943
Log-Pelecypoda	1.7148	0.6125	7.8379	0.0051	0.0963

Table 10 - Multivariate logit regression indicating habitat associated with American wigeon brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	7.1731	1.8846	14.4868	0.0001	0.35
Log-Ephemeroptera	1.9023	0.9204	4.2717	0.0388	

Table 11 - Linear regressions indicating habitat features associated with the total number of American wigeon broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	9.6987	1.4160	6.85	<.0001	0.3829
Shoreline irregularity	2.8488	0.7016	4.06	0.0001	0.1731
Log-Pelecypoda	2.0948	0.9582	2.19	0.0320	0.0486
Log-Ostracoda	5.0084	2.2988	2.18	0.0326	0.0482

Table 12 - Univariate logit regression indicating habitat features associated with green-winged teal brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	3.0191	1.0847	7.7500	0.0054	0.0908

Table 13 - Linear regressions indicating habitat features associated with the total number of green-winged teal broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	5.1145	1.3177	3.8800	0.0002	0.1711
Shoreline irregularity	1.7409	0.5850	2.9800	0.0040	0.1082
Log-Gastropoda	2.2681	1.0400	2.1800	0.0324	0.0486

Table 14 - Univariate logit regression indicating habitat features associated with mallard brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	9.2326	2.1589	18.2900	<.0001	0.3982
Shoreline irregularity	1.8653	0.5435	11.7800	0.0006	0.1586
pH	1.2486	0.5200	5.7700	0.0163	0.0710
Log_Amphipoda	1.2423	0.5334	5.4300	0.0198	0.0597
Log-Pelecypoda	1.1409	0.5417	4.4400	0.0352	0.0476
Log-Conchostraca	0.6829	0.3419	3.9900	0.0458	0.0409

Table 15 - Linear regressions indicating habitat features associated with the total number of mallard broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	5.2242	0.8179	6.39	<.0001	0.3497
Shoreline irregularity	1.5954	0.3952	4.04	0.0001	0.1713
Log-Gastropoda	2.0577	0.7181	2.87	0.0054	0.0888
Log-Amphipoda	1.2717	0.5095	2.50	0.0148	0.0660
Log-Pelecypoda	1.2660	0.5365	2.36	0.0210	0.0582
pH	0.9981	0.4365	2.29	0.0251	0.0540

Table 16 - Univariate logit regression indicating habitat features associated with lesser scaup brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	9.1552	2.1389	18.3200	<.0001	0.3982
Shoreline irregularity	1.9821	0.5683	12.1700	0.0005	0.1657
Log-Pelecypoda	1.4469	0.5720	6.4000	0.0114	0.0720
pH	1.1346	0.4934	5.2900	0.0215	0.0631
Log_Amphipoda	1.1495	0.5117	5.0500	0.0247	0.0535
Temperature (°C)	0.1971	0.0912	4.6700	0.0306	0.0488
Log-Diptera	-1.2292	0.5712	4.6300	0.0314	0.0495
Log-Ephemeroptera	1.5583	0.7413	4.4200	0.0355	0.0472
Log-Ostracoda	3.2510	1.5983	4.1400	0.0420	0.0536
Secchi disc depth (m)	1.2326	0.6187	3.9700	0.0463	0.0421

Table 17 - Linear regressions indicating habitat features associated with the total number of lesser scaup broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	23.7609	2.9675	8.01	<.0001	0.4603
Hirudinea (wt) (g)	3.6299	1.0486	3.46	0.0009	0.1292
Shoreline irregularity	4.9817	1.6403	3.04	0.0033	0.1000
Log-Ostracoda	12.2793	5.1185	2.40	0.0190	0.0604
Secchi disc depth (m)	5.7119	2.4484	2.33	0.0224	0.0566
Log-Amphipoda	4.2948	2.0534	2.09	0.0400	0.0436

Table 18 - Univariate logit regression indicating habitat features associated with ring-necked duck brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	10.8327	2.6066	17.2700	<.0001	0.4553
Shoreline irregularity	1.5074	0.5009	9.0600	0.0026	0.1207
Log-Pelecypoda	1.7596	0.6312	7.7700	0.0053	0.1002
Secchi disc depth (m)	1.8078	0.6746	7.1800	0.0074	0.0880
Log-Diptera	-1.4993	0.6666	5.0600	0.0245	0.0628
Log_Amphipoda	1.2469	0.5794	4.6300	0.0314	0.0564
Log-depth (m)	0.9459	0.4528	4.3600	0.0367	0.0501
Log-Ephemeroptera	1.4298	0.7305	3.8300	0.0503	0.0427

Table 19 - Multivariate logit regression indicating habitat associated with ring-necked duck brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	11.6381	2.8912	16.2038	0.0001	0.51
Log-Pelecypoda	1.7696	0.8655	4.1801	0.0409	

Table 20 - Linear regressions indicating habitat features associated with the total number of ring-necked duck broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	10.2473	1.5311	6.69	<.0001	0.3718
Shoreline irregularity	2.5756	0.7760	3.32	0.0014	0.1192
Log-Ostracoda	6.8629	2.4123	2.84	0.0058	0.0875
Hirudinea (wt) (g)	1.3522	0.5174	2.61	0.0109	0.0730
Secchi disc depth (m)	2.9912	1.1622	2.57	0.0121	0.0706
Log-Amphipoda	2.0814	0.9812	2.12	0.0373	0.0452

Table 21 - Univariate logit regression indicating habitat features associated with horned grebe brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Log-Trichoptera	-24.6855	7.6937	10.2900	0.0013	0.1798
Log-Pelecypoda	1.9268	0.6364	9.1700	0.0025	0.1161
Shoreline irregularity	1.0455	0.4407	5.6300	0.0177	0.0635
Log-Zygoptera	2.1136	0.9571	4.8800	0.0272	0.0538
Log-Cyclopoida	0.6802	0.3257	4.3600	0.0368	0.0453

Table 22 - Linear regressions indicating habitat features associated with the total number of horned grebe broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Log Trichoptera	-17.2617	5.0838	-3.40	0.0011	0.1246
Log-Pelecypoda	1.8461	0.6523	2.83	0.0060	0.0865
Log-Cyclopoida	0.8360	0.4223	1.98	0.0515	0.0380

Table 23 - Univariate logit regression indicating habitat features associated with red-necked grebe brood-rearing wetlands on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Area (ha) ^ 0.2	12.6504	2.9969	17.8200	<.0001	0.5096
Shoreline irregularity	1.7229	0.5246	10.7800	0.0010	0.1395
Log_Amphipoda	1.4347	0.5469	6.8800	0.0087	0.0775
Secchi disc depth (m)	1.5283	0.6359	5.7800	0.0163	0.0633
Log-Pelecypoda	1.1320	0.5394	4.4000	0.0358	0.0469
Temperature (°C)	0.1734	0.0897	3.7300	0.0533	0.0384

Table 24 - Linear regressions indicating habitat features associated with the total number of red-necked grebe broods on the Yellowknife Study Area, near Yellowknife, NT, 2004. Variables are listed in order of significance.

<i>variable</i>	estimate	SE	t Ratio	P	R²
Area (ha) ^ 0.2	25.0854	2.6134	9.60	<.0001	0.5519
Shoreline irregularity	6.1937	1.5183	4.08	0.0001	0.1745
Secchi disc depth (m)	6.7548	2.3220	2.91	0.0048	0.0916
Log-Amphipoda	4.7896	1.9648	2.44	0.0172	0.0626
Log-Ostracoda	11.1862	4.9686	2.25	0.0274	0.0521
pH	3.6403	1.6864	2.16	0.0342	0.0471
Log Trichoptera	34.6940	16.5639	2.09	0.0397	0.0438

Table 25 - Interspecific affinity for coexistence between brood species on YKSA wetlands, near Yellowknife, NT as evaluated using logit regression analysis.

Significant associations are highlighted in bold lettering and listed in order of significance.

interspecific association (Y by X)						
Y	X	estimate	SE	Walds X2	P	R ²
American wigeon	Mallard	0.4531	0.1299	12.1700	0.0005	0.1555
	Lesser scaup	0.2601	0.0781	11.0900	0.0009	0.2398
	Red-necked grebe	0.1157	0.0394	8.6200	0.0033	0.1220
	Green-winged teal	0.2941	0.1046	7.9000	0.0049	0.1063
	Ring-necked duck	0.4407	0.2020	4.7600	0.0291	0.1483
	Horned grebe	0.1146	0.0855	1.8000	0.1801	0.0184
Green-winged teal	American wigeon	0.2524	0.0959	6.9300	0.0085	0.1089
	Mallard	0.2855	0.1134	6.3300	0.0118	0.0693
	Lesser scaup	0.0853	0.0415	4.2300	0.0396	0.0618
	Red-necked grebe	0.0593	0.0314	3.5700	0.0587	0.0417
	Horned grebe	0.1559	0.0879	3.1400	0.0762	0.0330
	Ring-necked duck	0.1049	0.0667	2.4700	0.1158	0.0311
Mallard	Red-necked grebe	0.2508	0.0612	16.7900	<.0001	0.2991
	Lesser scaup	0.3852	0.1066	13.0500	0.0003	0.2994
	Green-winged teal	0.4049	0.1207	11.2500	0.0008	0.1577
	American wigeon	0.3180	0.1130	7.9200	0.0049	0.1344
	Ring-necked duck	0.7326	0.2766	7.0100	0.0081	0.1786
	Horned grebe	0.0290	0.0834	0.1200	0.7280	0.0012
Lesser scaup	Mallard	0.7902	0.2058	14.7400	0.0001	0.2673
	Ring-necked duck	1.5577	0.4039	14.8700	0.0001	0.3030
	Red-necked grebe	0.3232	0.0839	14.8600	0.0001	0.3275
	American wigeon	0.7624	0.2037	14.0100	0.0002	0.2871
	Green-winged teal	0.3311	0.1170	8.0000	0.0047	0.1071
	Horned grebe	0.0502	0.0847	0.3500	0.5539	0.0034
Ring-necked duck	Red-necked grebe	0.2167	0.0529	16.8000	<.0001	0.2991
	Lesser scaup	0.4219	0.1108	14.5100	0.0001	0.4025
	Mallard	0.3684	0.1199	9.4300	0.0021	0.1147
	American wigeon	0.2752	0.0962	8.1800	0.0042	0.1400
	Green-winged teal	0.1697	0.0881	3.7100	0.0540	0.0472
	Horned grebe	-0.0721	0.0957	0.5700	0.4510	0.0064
Horned Grebe	Green-winged teal	0.2674	0.1019	6.8800	0.0087	0.0896
	American wigeon	0.1368	0.0714	3.6700	0.0553	0.0452
	Mallard	0.0998	0.1043	0.9200	0.3385	0.0091
	Red-necked grebe	-0.0250	0.0299	0.7000	0.4028	0.0075
	Ring-necked duck	-0.0476	0.0634	0.5600	0.4528	0.0063
	Lesser scaup	-0.0017	0.0265	0.0000	0.9497	0.0000
Red-necked grebe	Mallard	0.9385	0.2231	17.6900	<.0001	0.3517
	Ring-necked duck	1.5046	0.3696	16.5700	<.0001	0.3272
	Lesser scaup	0.4817	0.1271	14.3700	0.0002	0.3444
	American wigeon	0.4237	0.1367	9.6000	0.0019	0.1763
	Green-winged teal	0.3257	0.1117	8.5100	0.0035	0.1124
	Horned grebe	-0.0502	0.0847	0.3500	0.5539	0.0034

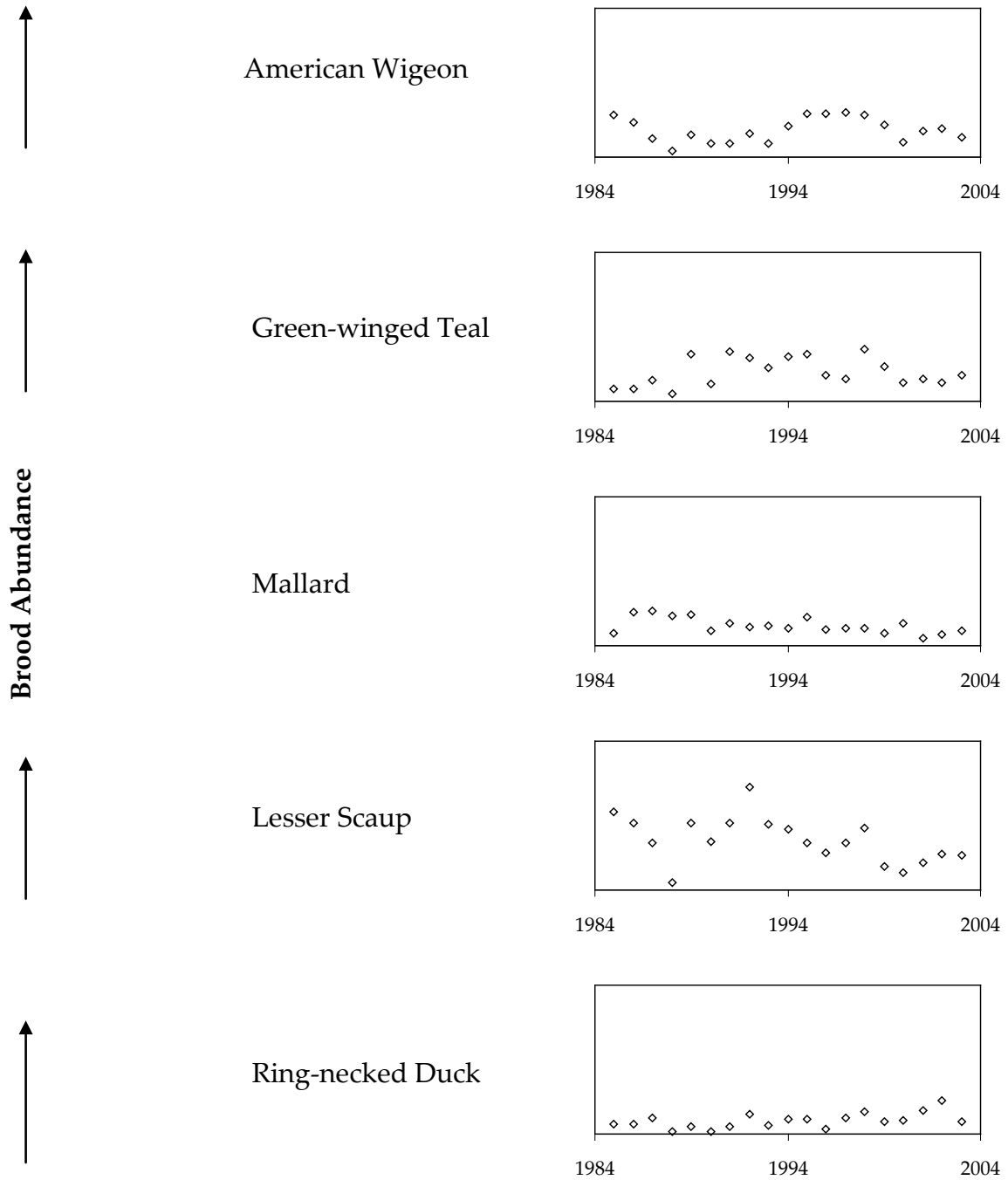


Figure 2 – Brood abundance of five species of ducks on the 38 km² Yellowknife Study Area. Broods were counted during Canadian Wildlife Service surveys from 1985 to 2003 (Canadian Wildlife Service, unpublished data). The scale of the y-axis is the same for all species and ranges from 0 to 150 broods.

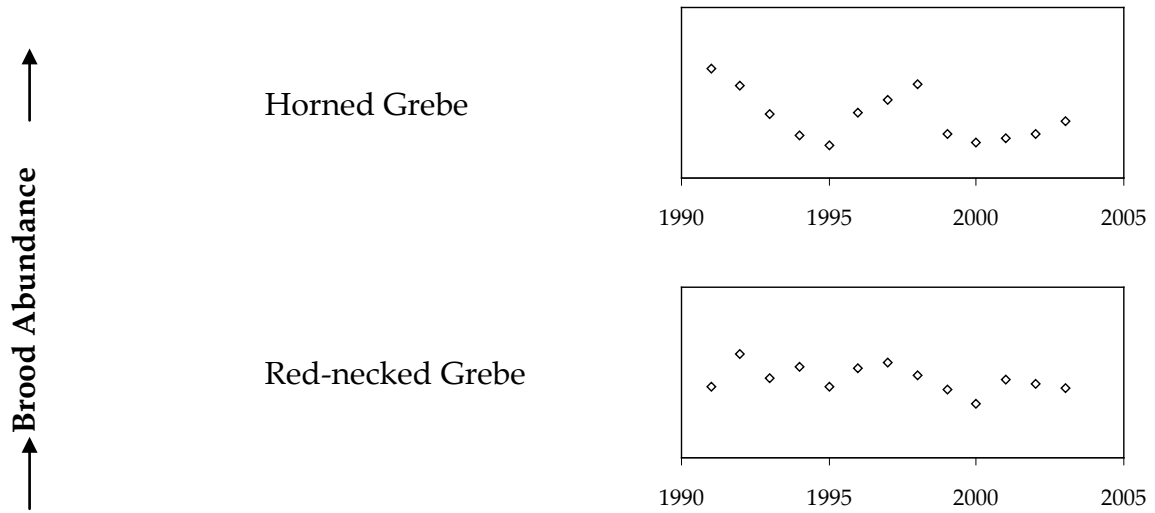


Figure 3 – Brood abundance of two species of grebes on the 38 km² Yellowknife Study Area. Broods were counted during Canadian Wildlife Service surveys from 1991 to 2003 (Canadian Wildlife Service, unpublished data). The scale of the y-axis is the same for both species and ranges from 0 to 150 broods.

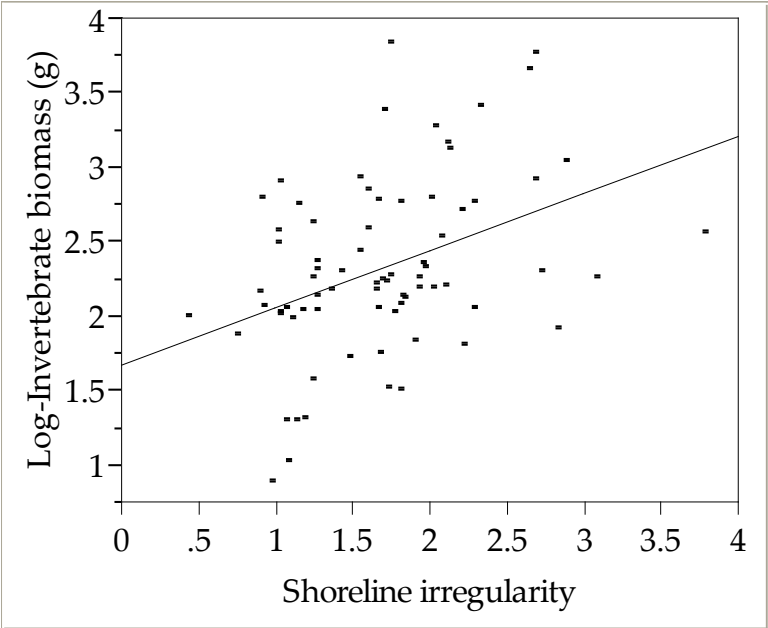
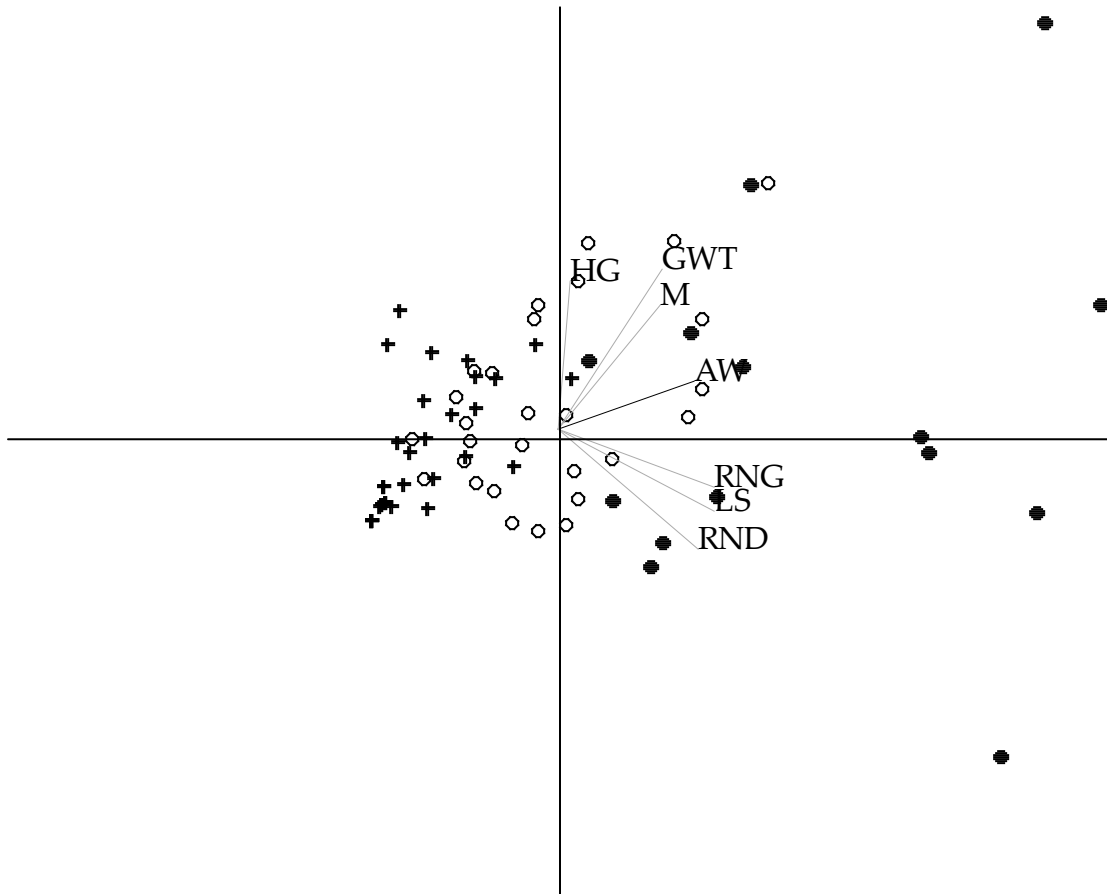


Figure 4 - Relationship of total invertebrate biomass (g) to shoreline irregularity on 75 Yellowknife Study Area wetlands (2004) ($R^2 = 0.16$, $P < 0.0005$).



- Wetland area > 3ha
- Wetland area > 1 ha < 3ha
- + Wetland area < 1 ha

Figure 5 - PCA on brood abundances of seven species of aquatic birds that breed on Yellowknife Study Area wetlands. Waterfowl broods were counted during Canadian Wildlife Service surveys from 1985 to 2003 and grebe broods were counted on the same surveys from 1991 to 2003 (Canadian Wildlife Service, unpublished data). Axis-1 explains 51% of the variation and Axis-2 explains an additional 18%.

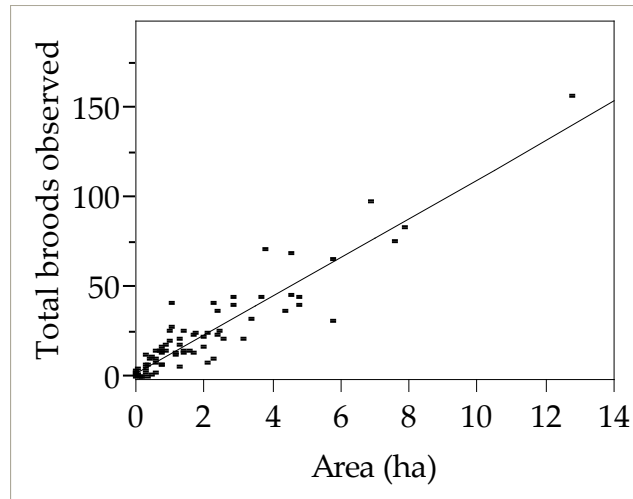


Figure 6 - Relationship of total water bird broods counted by Canadian Wildlife Service annual survey on 75 Yellowknife Study Area wetlands, near Yellowknife, NT, to wetland area (ha), ($R^2 = 0.86$, $P < 0.0001$). Duck broods were counted from 1985 to 2003 and grebe broods were counted from 1991 to 2003.

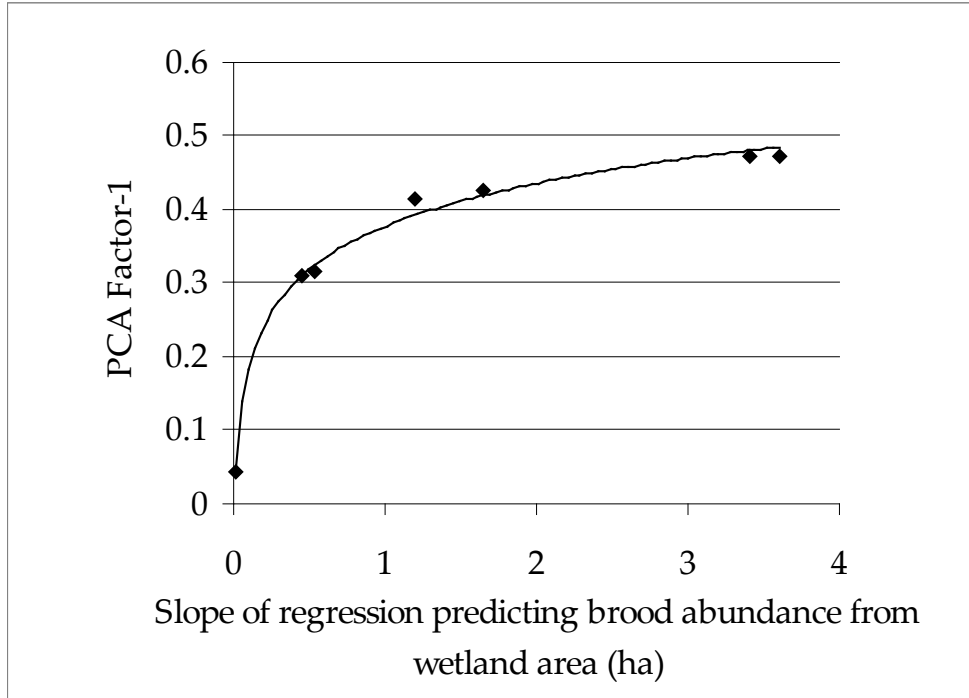


Figure 7 – Fit of Factor-1 from the PCA of the distribution of broods on Yellowknife Study Area wetlands by the slopes of the regression equations predicting brood abundance from wetland area. Regression equation: $y=0.38+0.09\ln(x)$; $R^2 = 0.99$.

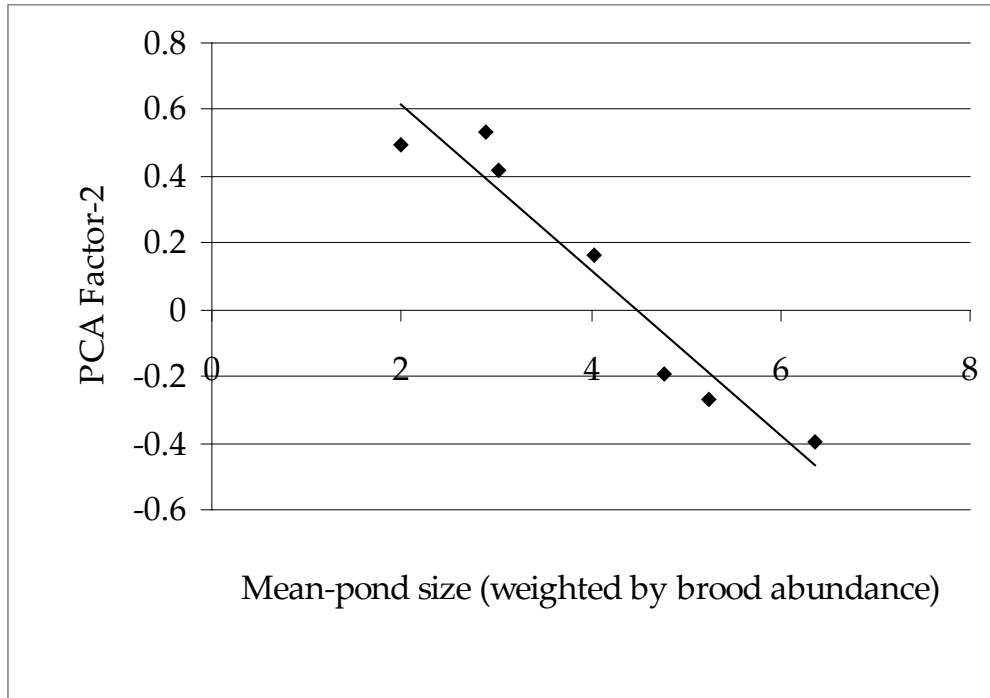


Figure 8 - Fit of Factor-2 from the PCA of the distribution of broods on Yellowknife Study Area wetlands by mean-pond size (weighted by brood abundance). Regression equation: $y=1.12+0.25x$; $R^2 = 0.93$. Mean-pond size (weighted by brood abundance) is calculated by: $((\text{area} \times \text{brood abundance}) / \text{brood abundance})$.

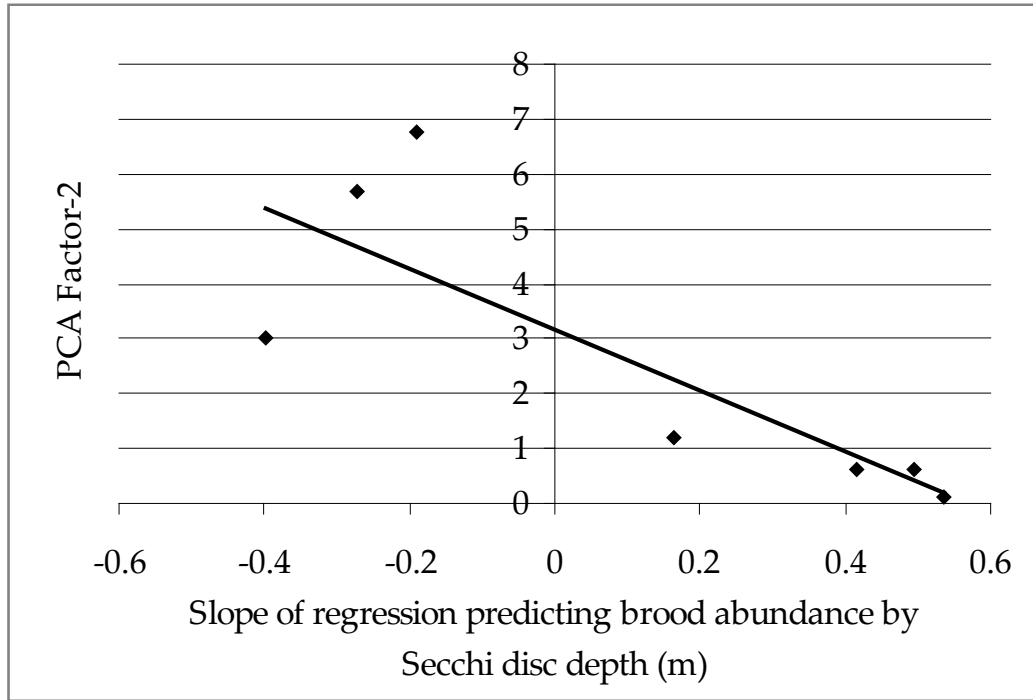


Figure 9 - Fit of Factor-2 from the PCA of the distribution of broods on Yellowknife Study Area wetlands by the slopes of the regression equations predicting brood abundance from Secchi disc depth (m). Regression equation: $y = -3.17 - 5.59x$; $R^2 = 0.67$.

Appendix A - Aquatic invertebrate taxa belonging to the invertebrate groups used in analyses of 75 wetlands near Yellowknife, NT (2004).

Invertebrate Grouping	Families or Genera in Grouping
Anostraca†	
Amphipoda	<i>Hyalella azteca</i> , <i>Gammarus lacustris</i>
Coleoptera	Chrysomelidae, Curculionidae, Dytiscidae, Elmidae, Gyrinidae,
Crustacea	Cladocera, Conchostraca, Cyclopoida, Ostracoda
Diptera	Chaoboridae, Chironomidae, Culicidae, Ceratopogonidae
Ephemeroptera*	Caenidae, Ephemerellidae, Siphonuridae
Gastropoda	Planorbidae, Lymnaeidae
Hemiptera	Corixidae, Gerridae, Notonectidae
Hirudinea	Glossiphoniidae, Hirudinidae
Hydrachnidae & Araneae	Hydrachnidia & <i>Hydrachna</i>
Odonata	Anisoptera, Zygoptera
Plecoptera†	
Pelecypoda	Sphaeriidae
Trichoptera*	Limnephilidae

† occurrence on YKSA wetlands extremely rare

* taxonomic resolution to order only

Appendix B - Univariate logit regression indicating the influence of habitat features on wetland-use by broods of seven aquatic bird species on YKSA wetlands near Yellowknife, NT (2004).

American Wigeon					
<i>abiotic variable</i>	estimate	SE	Walds X2	P	R²
Area (ha)	0.8367	0.2228	14.1000	0.0002	0.2665
Area (ha) (Box-Cox transformed)	7.0763	1.7301	16.7300	<.0001	0.3037
Conductivity	-0.0017	0.0014	1.5100	0.2196	0.0207
Depth (m)	-0.0753	0.1875	0.1600	0.6879	0.0017
Log-depth (m)	0.0002	0.4057	0.0000	0.9997	0.0000
pH	0.8743	0.4823	3.2900	0.0698	0.0382
Secchi disc depth (m)	0.6427	0.5822	1.2200	0.2696	0.0125
Shoreline irregularity	1.5570	0.5019	9.6200	0.0019	0.1244
Temperature (°C)	0.1100	0.0893	1.5200	0.2176	0.0157
<i>biotic variable</i>					
Amphipoda	0.0016	0.0012	1.6500	0.1994	0.0196
Log_Amphipoda	1.8699	0.6313	8.7700	0.0031	0.1140
Amphipoda biomass (g)	0.5229	0.2533	4.2600	0.0390	0.0544
Coleoptera	0.0416	0.0292	2.0300	0.1539	0.0234
Log_Coleoptera	2.4780	1.6606	2.2300	0.1356	0.0235
Coleoptera biomass (g)	-0.1241	0.6322	0.0400	0.8444	0.0004
Dytiscidae	0.0197	0.0353	0.3100	0.5759	0.0031
Dytiscidae biomass (g)	-0.1330	0.6518	0.0400	0.8383	0.0004
Crustacea	-0.0002	0.0002	0.5800	0.4457	0.0067
Log-Crustacea	-0.0501	0.3726	0.0200	0.8929	0.0002
Crustacea biomass (g)	-0.0336	0.0591	0.3200	0.5705	0.0037
Cladocera	-0.0017	0.0012	2.1800	0.1397	0.0383
Log-Cladocera	-0.5377	0.3811	1.9900	0.1583	0.0209
Cladocera biomass (g)	-1.6501	1.2241	1.8200	0.1777	0.0325
Conchostraca	0.0000	0.0005	0.0000	0.9561	0.0000
Log-Conchostraca	0.3578	0.3331	1.1500	0.2828	0.0117
Conchostraca biomass (g)	-0.0241	0.0605	0.1600	0.6898	0.0018
Cyclopoida	0.0001	0.0004	0.0500	0.8313	0.0005
Log-Cyclopoida	0.0791	0.3167	0.0600	0.8028	0.0006
Cyclopoida biomass (g)	0.0664	0.3396	0.0400	0.8450	0.0004
Ostracoda	0.0285	0.0226	1.5900	0.2080	0.0166
Log-Ostracoda	1.7054	1.2060	2.0000	0.1573	0.0207
Ostracoda biomass (g)	8.6044	7.1560	1.4500	0.2292	0.0151
Diptera	-0.0037	0.0030	1.5500	0.2127	0.0308
Log-Diptera	-0.5117	0.5530	0.8600	0.3548	0.0089
Diptera biomass (g)	-0.9382	0.9223	1.0300	0.3090	0.0196
Chaoboridae	-0.0059	0.0073	0.6500	0.4185	0.0159
Chaoboridae biomass (g)	-0.5526	0.8491	0.4200	0.5151	0.0068
Chironomidae	-0.0055	0.0047	1.3300	0.2490	0.0249
Chironomidae biomass (g)	-5.5288	3.9569	1.9500	0.1623	0.0371
Culicidae	0.0092	0.0227	0.1700	0.6837	0.0017
Culicidae biomass (g)	-1.2523	7.9991	0.0200	0.8756	0.0002
Ceratopogonidae	-0.0262	0.0397	0.4400	0.5092	0.0056
Ceratopogonidae biomass (g)	-52.9148	69.6691	0.5800	0.4475	0.0081

American Wigeon cont.

<i>variable</i>					
Ephemeroptera	0.0101	0.0052	3.7200	0.0538	0.0469
Log-Ephemeroptera	2.2212	0.7840	8.0300	0.0046	0.0943
Ephemeroptera biomass (g)	0.2752	0.5902	0.2200	0.6410	0.0022
Gastropoda	0.0074	0.0042	3.0500	0.0808	0.0387
Log-Gastropoda	1.3565	0.7233	3.5200	0.0607	0.0376
Gastropoda biomass (g)	0.1043	0.0857	1.4800	0.2236	0.0244
Planorbidae	0.0066	0.0053	1.5400	0.2149	0.0158
Planorbidae biomass (g)	-0.1777	0.2368	0.5600	0.4529	0.0071
Lymnaeidae	0.0138	0.0141	0.9500	0.3292	0.0274
Lymnaeidae biomass (g)	0.3796	0.2268	2.8000	0.0942	0.0578
Hemiptera	-0.0027	0.0034	0.6200	0.4301	0.0105
Log-Hemiptera	-0.7102	0.7040	1.0200	0.3131	0.0108
Hemiptera biomass (g)	0.0668	0.1103	0.3700	0.5450	0.0037
Corixidae	-0.0146	0.0098	2.2300	0.1358	0.0438
Corixidae biomass (g)	-5.6848	3.2445	3.0700	0.0797	0.0620
Gerridae	-0.4584	0.4298	1.1400	0.2862	0.0165
Gerridae biomass (g)	-80.2623	72.9259	1.2100	0.2711	0.0197
Notonectidae	0.0067	0.0063	1.1500	0.2837	0.0127
Notonectidae biomass (g)	0.1036	0.1150	0.8100	0.3677	0.0086
Hirudinea	-0.0147	0.0270	0.3000	0.5865	0.0034
Log_Hirudinea	0.5452	1.4705	0.1400	0.7108	0.0014
Hirudinea biomass (g)	0.1882	0.2532	0.5500	0.4572	0.0056
Hydrachnidae & Araneae	-0.0167	0.0266	0.4000	0.5289	0.0043
Log_Hydrachnidae & Araneae	-1.1253	1.4192	0.6300	0.4278	0.0066
Hydrachnidae & Araneae biomass (g)	-6.9413	8.1155	0.7300	0.3924	0.0082
Odonata	0.0006	0.0043	0.0200	0.8867	0.0002
Odonata biomass (g)	0.0230	0.0972	0.0600	0.8130	0.0006
Anisoptera	0.0018	0.0063	0.0800	0.7756	0.0008
Log-Anisoptera	0.5864	0.9172	0.4100	0.5226	0.0041
Anisoptera Biomass (g)	0.0206	0.1008	0.0400	0.8377	0.0004
Zygoptera	-0.0006	0.0071	0.0100	0.9352	0.0001
Log-Zygoptera	-0.0120	0.8640	0.0000	0.9889	0.0000
Zygoptera biomass (g)	0.2046	0.7153	0.0800	0.7748	0.0008
Pelecypoda	0.0022	0.0011	3.9100	0.0480	0.0551
Log-Pelecypoda	1.7148	0.6125	7.8400	0.0051	0.0963
Pelecypoda biomass (g)	0.1288	0.0901	2.0400	0.1530	0.0245
Trichoptera	0.1434	0.1402	1.0500	0.3062	0.0106
Log-Trichoptera	4.3218	3.9699	1.1900	0.2763	0.0120
Trichoptera biomass (g)	1.0544	2.9936	0.1200	0.7247	0.0012

Green-winged Teal

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	0.2892	0.1299	4.9600	0.0260	0.0612
Area (ha) (Box-Cox transformed)	3.0191	1.0847	7.7500	0.0054	0.0908
Conductivity	-0.0010	0.0011	0.8200	0.3639	0.0097
Depth (m)	-0.0352	0.1822	0.0400	0.8467	0.0004
Log-depth (m)	0.1825	0.4014	0.2100	0.6493	0.0021
pH	0.3584	0.4216	0.7200	0.3953	0.0074
Secchi disc depth (m)	-0.0130	0.5703	0.0000	0.9818	0.0000
Shoreline irregularity	0.4413	0.3963	1.2400	0.2655	0.0125
Temperature (°C)	0.0673	0.0867	0.6000	0.4372	0.0060
<i>biotic variable</i>					
Amphipoda	-0.0002	0.0011	0.0200	0.8896	0.0002
Log_Amphipoda	0.0858	0.4759	0.0300	0.8569	0.0003
Amphipoda biomass (g)	0.1505	0.2013	0.5600	0.4547	0.0057
Coleoptera	0.0015	0.0261	0.0000	0.9541	0.0000
Log_Coleoptera	0.6977	1.5864	0.1900	0.6601	0.0019
Coleoptera biomass (g)	0.1135	0.6092	0.0300	0.8523	0.0003
Dytiscidae	-0.0131	0.0363	0.1300	0.7184	0.0013
Dytiscidae biomass (g)	-0.1174	0.6401	0.0300	0.8544	0.0003
Crustacea	0.0000	0.0002	0.0100	0.9231	0.0001
Log-Crustacea	0.2901	0.3743	0.6000	0.4384	0.0060
Crustacea biomass (g)	0.0337	0.0506	0.4400	0.5047	0.0046
Cladocera	-0.0003	0.0004	0.4100	0.5198	0.0068
Log-Cladocera	0.0654	0.3609	0.0300	0.8561	0.0003
Cladocera biomass (g)	-0.2781	0.4389	0.4000	0.5263	0.0072
Conchostraca	0.0006	0.0006	1.2100	0.2712	0.0156
Log-Conchostraca	0.3366	0.3302	1.0400	0.3080	0.0103
Conchostraca biomass (g)	0.0495	0.0580	0.7300	0.3933	0.0081
Cyclopoida	0.0000	0.0004	0.0100	0.9390	0.0001
Log-Cyclopoida	0.2133	0.3127	0.4700	0.4952	0.0046
Cyclopoida biomass (g)	0.0125	0.3399	0.0000	0.9706	0.0000
Ostracoda	0.0084	0.0220	0.1500	0.7016	0.0014
Log-Ostracoda	0.7729	1.1778	0.4300	0.5117	0.0043
Ostracoda biomass (g)	2.5544	6.9507	0.1400	0.7132	0.0013
Diptera	-0.0010	0.0014	0.4500	0.5008	0.0053
Log-Diptera	-0.6039	0.5496	1.2100	0.2719	0.0124
Diptera biomass (g)	0.0695	0.4171	0.0300	0.8677	0.0003
Chaoboridae	0.0016	0.0024	0.4300	0.5144	0.0047
Chaoboridae biomass (g)	0.5053	0.6031	0.7000	0.4021	0.0090
Chironomidae	-0.0065	0.0049	1.7900	0.1815	0.0317
Chironomidae biomass (g)	-5.4672	3.8178	2.0500	0.1521	0.0384
Culicidae	-0.0118	0.0233	0.2600	0.6123	0.0026
Culicidae biomass (g)	-10.2501	8.7308	1.3800	0.2404	0.0150
Ceratopogonidae	-0.0409	0.0474	0.7400	0.3885	0.0112
Ceratopogonidae biomass (g)	-74.7443	81.4129	0.8400	0.3586	0.0135
Ephemeroptera	0.0075	0.0048	2.4300	0.1191	0.0275
Log-Ephemeroptera	0.4922	0.6766	0.5300	0.4670	0.0053
Ephemeroptera biomass (g)	1.4234	1.0125	1.9800	0.1598	0.0328
Gastropoda	0.0071	0.0042	2.8500	0.0913	0.0355
Log-Gastropoda	0.9278	0.6941	1.7900	0.1813	0.0182
Gastropoda biomass (g)	0.1334	0.1021	1.7100	0.1913	0.0306
Planorbidae	0.0048	0.0052	0.8500	0.3562	0.0085
Planorbidae biomass (g)	0.0225	0.1766	0.0200	0.8986	0.0002
Lymnaeidae	0.0273	0.0170	2.5700	0.1086	0.0471
Lymnaeidae biomass (g)	0.3098	0.2122	2.1300	0.1443	0.0448

Green-winged Teal cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0021	0.0028	0.5500	0.4602	0.0080
Log-Hemiptera	-0.1790	0.6586	0.0700	0.7857	0.0007
Hemiptera biomass (g)	-0.1004	0.1317	0.5800	0.4458	0.0066
Corixidae	-0.0013	0.0025	0.2900	0.5894	0.0037
Corixidae biomass (g)	-0.1972	0.5619	0.1200	0.7257	0.0013
Gerridae	0.1561	0.2689	0.3400	0.5617	0.0034
Gerridae biomass (g)	61.5356	48.4187	1.6200	0.2038	0.0200
Notonectidae	-0.0062	0.0074	0.7000	0.4040	0.0084
Notonectidae biomass (g)	-0.0914	0.1311	0.4900	0.4860	0.0055
Hirudinea	-0.0282	0.0328	0.7400	0.3901	0.0101
Log_Hirudinea	-1.3606	1.7122	0.6300	0.4268	0.0070
Hirudinea biomass (g)	0.2385	0.2606	0.8400	0.3601	0.0088
Hydrachnidae & Araneae	0.0202	0.0241	0.7100	0.4008	0.0071
Log_Hydrachnidae & Araneae	1.4520	1.3385	1.1800	0.2780	0.0118
Hydrachnidae & Araneae biomass (g)	8.9679	7.2576	1.5300	0.2166	0.0160
Odonata	0.0066	0.0045	2.1600	0.1413	0.0227
Odonata biomass (g)	0.1475	0.1186	1.5500	0.2134	0.0191
Anisoptera	0.0060	0.0067	0.8200	0.3644	0.0088
Log-Anisoptera	0.7759	0.9120	0.7200	0.3949	0.0073
Anisoptera Biomass (g)	0.1387	0.1219	1.3000	0.2550	0.0159
Zygoptera	0.0100	0.0071	1.9600	0.1613	0.0201
Log-Zygoptera	1.2837	0.8958	2.0500	0.1519	0.0213
Zygoptera biomass (g)	0.8302	0.7195	1.3300	0.2486	0.0135
Pelecypoda	0.0006	0.0008	0.4700	0.4917	0.0048
Log-Pelecypoda	0.6118	0.5111	1.4300	0.2313	0.0146
Pelecypoda biomass (g)	0.0003	0.0790	0.0000	0.9968	0.0000
Trichoptera	-0.0851	0.1449	0.3400	0.5572	0.0035
Log-Trichoptera	-2.2151	4.0616	0.3000	0.5855	0.0030
Trichoptera biomass (g)	-2.1222	3.2172	0.4400	0.5095	0.0046

Mallard

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	1.2259	0.3120	15.4300	<.0001	0.3454
Area (ha) (Box-Cox transformed)	9.2326	2.1589	18.2900	<.0001	0.3982
Conductivity	-0.0009	0.0011	0.7300	0.3919	0.0081
Depth (m)	-0.0709	0.1808	0.1500	0.6950	0.0015
Log-depth (m)	-0.0868	0.3958	0.0500	0.8265	0.0005
pH	1.2486	0.5200	5.7700	0.0163	0.0710
Secchi disc depth (m)	0.6740	0.5746	1.3800	0.2408	0.0137
Shoreline irregularity	1.8653	0.5435	11.7800	0.0006	0.1586
Temperature (°C)	0.1128	0.0871	1.6800	0.1950	0.0168
<i>biotic variable</i>					
Amphipoda	0.0026	0.0015	2.9500	0.0857	0.0394
Log-Amphipoda	1.2423	0.5334	5.4300	0.0198	0.0597
Amphipoda biomass (g)	0.5143	0.2573	4.0000	0.0456	0.0493
Coleoptera	-0.0506	0.0340	2.2100	0.1369	0.0269
Log_Coleoptera	-2.3732	1.6928	1.9700	0.1609	0.0204
Coleoptera biomass (g)	-0.4151	0.6368	0.4300	0.5144	0.0043
Dytiscidae	-0.0718	0.0434	2.7400	0.0982	0.0320
Dytiscidae biomass (g)	-0.3771	0.6526	0.3300	0.5634	0.0034
Crustacea	-0.0001	0.0002	0.3200	0.5734	0.0033
Log-Crustacea	0.2762	0.3684	0.5600	0.4535	0.0055
Crustacea biomass (g)	0.0665	0.0605	1.2100	0.2712	0.0147
Cladocera	-0.0018	0.0011	2.7500	0.0973	0.0464
Log-Cladocera	-0.4755	0.3678	1.6700	0.1961	0.0167
Cladocera biomass (g)	-2.0669	1.2366	2.7900	0.0946	0.0470
Conchostraca	0.0008	0.0007	1.4700	0.2260	0.0209
Log-Conchostraca	0.6829	0.3419	3.9900	0.0458	0.0409
Conchostraca biomass (g)	0.1264	0.0919	1.8900	0.1690	0.0305
Cyclopoida	-0.0001	0.0004	0.0600	0.8094	0.0006
Log-Cyclopoida	0.0756	0.3095	0.0600	0.8070	0.0006
Cyclopoida biomass (g)	-0.0697	0.3414	0.0400	0.8383	0.0004
Ostracoda	-0.0064	0.0224	0.0800	0.7768	0.0008
Log-Ostracoda	0.4031	1.1727	0.1200	0.7311	0.0011
Ostracoda biomass (g)	-1.9510	7.0781	0.0800	0.7828	0.0007
Diptera	-0.0028	0.0023	1.5000	0.2199	0.0259
Log-Diptera	-0.6625	0.5427	1.4900	0.2222	0.0151
Diptera biomass (g)	-0.7996	0.7480	1.1400	0.2851	0.0186
Chaoboridae	-0.0029	0.0039	0.5700	0.4509	0.0092
Chaoboridae biomass (g)	-0.5545	0.7721	0.5200	0.4726	0.0077
Chironomidae	-0.0035	0.0037	0.9200	0.3373	0.0179
Chironomidae biomass (g)	-2.2807	2.4569	0.8600	0.3533	0.0173
Culicidae	-0.0261	0.0237	1.2100	0.2722	0.0123
Culicidae biomass (g)	-8.9921	8.3209	1.1700	0.2798	0.0121
Ceratopogonidae	-0.0441	0.0470	0.8800	0.3483	0.0132
Ceratopogonidae biomass (g)	-60.8798	68.4905	0.7900	0.3741	0.0110
Ephemeroptera	0.0041	0.0044	0.8500	0.3579	0.0086
Log-Ephemeroptera	0.8902	0.6835	1.7000	0.1928	0.0169
Ephemeroptera biomass (g)	1.9850	1.2369	2.5800	0.1085	0.0445
Gastropoda	0.0053	0.0039	1.8000	0.1794	0.0206
Log-Gastropoda	0.8424	0.6841	1.5200	0.2181	0.0151
Gastropoda biomass (g)	0.1060	0.0919	1.3300	0.2490	0.0217
Planorbidae	0.0006	0.0052	0.0100	0.9136	0.0001
Planorbidae biomass (g)	-0.0824	0.1894	0.1900	0.6637	0.0020
Lymnaeidae	0.0484	0.0222	4.7500	0.0293	0.0834
Lymnaeidae biomass (g)	0.3423	0.2274	2.2600	0.1324	0.0453

Mallard cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0078	0.0051	2.3400	0.1263	0.0392
Log-Hemiptera	-1.2426	0.7258	2.9300	0.0869	0.0317
Hemiptera biomass (g)	-0.0537	0.1160	0.2100	0.6433	0.0022
Corixidae	-0.0175	0.0100	3.0600	0.0802	0.0594
Corixidae biomass (g)	-3.6374	2.5351	2.0600	0.1514	0.0463
Gerridae	-0.6281	0.4619	1.8500	0.1739	0.0280
Gerridae biomass (g)	-131.1624	92.6057	2.0100	0.1567	0.0388
Notonectidae	-0.0010	0.0059	0.0300	0.8633	0.0003
Notonectidae biomass (g)	-0.0155	0.1116	0.0200	0.8893	0.0002
Hirudinea	0.0193	0.0242	0.6400	0.4238	0.0069
Log_Hirudinea	1.8652	1.6139	1.3400	0.2478	0.0145
Hirudinea biomass (g)	0.2263	0.2638	0.7400	0.3910	0.0076
Hydrachnidae & Araneae	-0.0205	0.0258	0.6300	0.4260	0.0066
Log_Hydrachnidae & Araneae	-0.8141	1.3438	0.3700	0.5447	0.0036
Hydrachnidae & Araneae biomass (g)	-7.0333	7.6605	0.8400	0.3586	0.0089
Odonata	0.0030	0.0042	0.4900	0.4861	0.0048
Odonata biomass (g)	0.1749	0.1286	1.8500	0.1740	0.0237
Anisoptera	0.0080	0.0072	1.2400	0.2664	0.0139
Log-Anisoptera	0.9263	0.9083	1.0400	0.3079	0.0103
Anisoptera Biomass (g)	0.1744	0.1365	1.6300	0.2014	0.0215
Zygoptera	-0.0010	0.0069	0.0200	0.8792	0.0002
Log-Zygoptera	-0.1807	0.8418	0.0500	0.8301	0.0004
Zygoptera biomass (g)	0.6473	0.7106	0.8300	0.3624	0.0082
Pelecypoda	0.0026	0.0013	4.0100	0.0452	0.0598
Log-Pelecypoda	1.1409	0.5417	4.4400	0.0352	0.0476
Pelecypoda biomass (g)	0.3020	0.1565	3.7200	0.0536	0.0681
Trichoptera	0.1356	0.1397	0.9400	0.3316	0.0093
Log-Trichoptera	3.8478	3.9377	0.9500	0.3285	0.0094
Trichoptera biomass (g)	1.5126	2.9695	0.2600	0.6105	0.0025

Lesser Scaup

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	1.6076	0.4105	15.3400	<.0001	0.3752
Area (ha) (Box-Cox transformed)	9.1552	2.1389	18.3200	<.0001	0.3982
Conductivity	-0.0012	0.0011	1.3600	0.2440	0.0154
Depth (m)	0.0228	0.1778	0.0200	0.8979	0.0002
Log-depth (m)	0.2300	0.3959	0.3400	0.5613	0.0033
pH	1.1346	0.4934	5.2900	0.0215	0.0631
Secchi disc depth (m)	1.2326	0.6187	3.9700	0.0463	0.0421
Shoreline irregularity	1.9821	0.5683	12.1700	0.0005	0.1657
Temperature (°C)	0.1971	0.0912	4.6700	0.0306	0.0488
<i>biotic variable</i>					
Amphipoda	0.0007	0.0011	0.3600	0.5469	0.0037
Log-Amphipoda	1.1495	0.5117	5.0500	0.0247	0.0535
Amphipoda biomass (g)	0.4813	0.2652	3.2900	0.0695	0.0403
Coleoptera	0.0157	0.0269	0.3400	0.5597	0.0034
Log_Coleoptera	0.9391	1.5862	0.3500	0.5538	0.0034
Coleoptera biomass (g)	-0.2232	0.6042	0.1400	0.7118	0.0013
Dytiscidae	-0.0056	0.0348	0.0300	0.8729	0.0002
Dytiscidae biomass (g)	-0.4198	0.6321	0.4400	0.5066	0.0044
Crustacea	-0.0003	0.0002	1.6600	0.1971	0.0194
Log-Crustacea	-0.0367	0.3616	0.0100	0.9191	0.0001
Crustacea biomass (g)	-0.0860	0.0689	1.5600	0.2117	0.0209
Cladocera	-0.0007	0.0008	0.8200	0.3651	0.0215
Log-Cladocera	-0.5357	0.3674	2.1300	0.1449	0.0213
Cladocera biomass (g)	-0.8064	0.9035	0.8000	0.3721	0.0222
Conchostraca	-0.0005	0.0005	0.8600	0.3540	0.0103
Log-Conchostraca	0.2690	0.3300	0.6600	0.4149	0.0065
Conchostraca biomass (g)	-0.0744	0.0709	1.1000	0.2939	0.0143
Cyclopoida	-0.0001	0.0004	0.0300	0.8547	0.0003
Log-Cyclopoida	-0.2232	0.3097	0.5200	0.4711	0.0050
Cyclopoida biomass (g)	-0.1025	0.3353	0.0900	0.7599	0.0009
Ostracoda	0.0433	0.0282	2.3600	0.1248	0.0288
Log-Ostracoda	3.2510	1.5983	4.1400	0.0420	0.0536
Ostracoda biomass (g)	13.6754	9.0385	2.2900	0.1303	0.0283
Diptera	-0.0074	0.0037	4.0100	0.0453	0.0813
Log-Diptera	-1.2292	0.5712	4.6300	0.0314	0.0495
Diptera biomass (g)	-1.8010	1.2196	2.1800	0.1397	0.0503
Chaoboridae	-0.0109	0.0086	1.6200	0.2035	0.0373
Chaoboridae biomass (g)	-1.0896	1.1642	0.8800	0.3493	0.0193
Chironomidae	-0.0094	0.0050	3.5900	0.0580	0.0599
Chironomidae biomass (g)	-7.4029	3.8546	3.6900	0.0548	0.0670
Culicidae	-0.0226	0.0227	0.9900	0.3185	0.0098
Culicidae biomass (g)	-8.7437	7.9357	1.2100	0.2705	0.0122
Ceratopogonidae	-0.0551	0.0485	1.2900	0.2560	0.0208
Ceratopogonidae biomass (g)	-104.8881	86.4484	1.4700	0.2250	0.0258
Ephemeroptera	0.0041	0.0047	0.7600	0.3826	0.0079
Log-Ephemeroptera	1.5583	0.7413	4.4200	0.0355	0.0472
Ephemeroptera biomass (g)	1.4029	1.1242	1.5600	0.2121	0.0253
Gastropoda	0.0072	0.0046	2.4500	0.1178	0.0308
Log-Gastropoda	1.1167	0.6997	2.5500	0.1105	0.0258
Gastropoda biomass (g)	0.1393	0.1180	1.3900	0.2378	0.0248
Planorbidae	0.0044	0.0053	0.6700	0.4130	0.0067
Planorbidae biomass (g)	-0.0271	0.1752	0.0200	0.8772	0.0002
Lymnaeidae	0.0433	0.0230	3.5300	0.0602	0.0617
Lymnaeidae biomass (g)	0.4915	0.2910	2.8500	0.0913	0.0542

Lesser Scaup cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0031	0.0031	1.0100	0.3158	0.0169
Log-Hemiptera	-0.4747	0.6489	0.5400	0.4644	0.0052
Hemiptera biomass (g)	0.0962	0.1228	0.6100	0.4338	0.0066
Corixidae	-0.0132	0.0078	2.8700	0.0901	0.0531
Corixidae biomass (g)	-3.0603	2.1135	2.1000	0.1476	0.0483
Gerridae	-0.3845	0.3347	1.3200	0.2506	0.0161
Gerridae biomass (g)	-38.7691	44.2114	0.7700	0.3805	0.0083
Notonectidae	0.0088	0.0079	1.2600	0.2623	0.0161
Notonectidae biomass (g)	0.1601	0.1454	1.2100	0.2706	0.0151
Hirudinea	-0.0017	0.0222	0.0100	0.9375	0.0001
Log_Hirudinea	0.7252	1.5125	0.2300	0.6316	0.0023
Hirudinea biomass (g)	0.4615	0.3608	1.6400	0.2009	0.0222
Hydrachnidae & Araneae	-0.0042	0.0237	0.0300	0.8596	0.0003
Log_Hydrachnidae & Araneae	-0.2269	1.3070	0.0300	0.8622	0.0003
Hydrachnidae & Araneae biomass (g)	0.4859	6.9403	0.0000	0.9442	0.0000
Odonata	0.0018	0.0042	0.1800	0.6734	0.0017
Odonata biomass (g)	0.1855	0.1382	1.8000	0.1794	0.0233
Anisoptera	0.0079	0.0076	1.0800	0.2994	0.0124
Log-Anisoptera	0.8165	0.9047	0.8100	0.3668	0.0080
Anisoptera Biomass (g)	0.1996	0.1520	1.7200	0.1893	0.0232
Zygoptera	-0.0034	0.0068	0.2500	0.6154	0.0024
Log-Zygoptera	0.1472	0.8378	0.0300	0.8606	0.0003
Zygoptera biomass (g)	0.3611	0.7083	0.2600	0.6102	0.0025
Pelecypoda	0.0021	0.0013	2.8000	0.0943	0.0401
Log-Pelecypoda	1.4469	0.5720	6.4000	0.0114	0.0720
Pelecypoda biomass (g)	0.1137	0.0992	1.3100	0.2515	0.0159
Trichoptera	0.0076	0.1379	0.0000	0.9561	0.0000
Trichoptera biomass (g)	-2.5026	3.0494	0.6700	0.4118	0.0067
Log-Trichoptera	0.5461	3.8995	0.0200	0.8886	0.0002

Ring-necked Duck

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	1.1232	0.2774	16.4000	<0.0001	0.3899
Area (ha) (Box-Cox transformed)	10.8327	2.6066	17.2700	<.0001	0.4553
Conductivity	-0.0018	0.0015	1.4100	0.2345	0.0211
Depth (m)	0.2857	0.1866	2.3400	0.1258	0.0253
Log-depth (m)	0.9459	0.4528	4.3600	0.0367	0.0501
pH	0.2979	0.4417	0.4500	0.5000	0.0050
Secchi disc depth (m)	1.8078	0.6746	7.1800	0.0074	0.0880
Shoreline irregularity	1.5074	0.5009	9.0600	0.0026	0.1207
Temperature (°C)	0.1481	0.0944	2.4600	0.1168	0.0274
<i>biotic variable</i>					
Amphipoda	0.0009	0.0011	0.6600	0.4165	0.0071
Log-Amphipoda	1.2469	0.5794	4.6300	0.0314	0.0564
Amphipoda biomass (g)	0.6111	0.2647	5.3300	0.0210	0.0737
Coleoptera	-0.0248	0.0322	0.5900	0.4414	0.0071
Log_Coleoptera	-1.3531	1.7549	0.5900	0.4407	0.0066
Coleoptera biomass (g)	-0.5333	0.7262	0.5400	0.4627	0.0063
Dytiscidae	-0.0384	0.0426	0.8100	0.3677	0.0096
Dytiscidae biomass (g)	-0.5152	0.7492	0.4700	0.4917	0.0055
Crustacea	-0.0005	0.0004	1.9800	0.1599	0.0366
Log-Crustacea	-0.3498	0.3892	0.8100	0.3687	0.0087
Crustacea biomass (g)	-0.0503	0.0707	0.5100	0.4767	0.0068
Cladocera	-0.0024	0.0014	2.7700	0.0961	0.0510
Log-Cladocera	-0.7326	0.4068	3.2400	0.0717	0.0368
Cladocera biomass (g)	-2.6142	1.5849	2.7200	0.0990	0.0505
Conchostraca	-0.0005	0.0007	0.5400	0.4629	0.0078
Log-Conchostraca	0.2072	0.3423	0.3700	0.5450	0.0039
Conchostraca biomass (g)	-0.0256	0.0649	0.1600	0.6931	0.0018
Cyclopoida	-0.0005	0.0005	0.7400	0.3892	0.0101
Log-Cyclopoida	-0.4931	0.3598	1.8800	0.1705	0.0214
Cyclopoida biomass (g)	-0.4045	0.4734	0.7300	0.3928	0.0097
Ostracoda	0.0147	0.0223	0.4300	0.5097	0.0045
Log-Ostracoda	1.2045	1.1967	1.0100	0.3142	0.0106
Ostracoda biomass (g)	4.4182	7.0571	0.3900	0.5313	0.0041
Diptera	-0.0132	0.0060	4.8200	0.0281	0.0997
Log-Diptera	-1.4993	0.6666	5.0600	0.0245	0.0628
Diptera biomass (g)	-5.9272	3.1845	3.4600	0.0627	0.0833
Chaoboridae	-0.0135	0.0139	0.9400	0.3310	0.0275
Chaoboridae biomass (g)	-3.1430	3.2445	0.9400	0.3327	0.0282
Chironomidae	-0.0180	0.0084	4.6200	0.0316	0.0888
Chironomidae biomass (g)	-15.5244	6.9332	5.0100	0.0251	0.1020
Culicidae	-0.0370	0.0279	1.7600	0.1850	0.0212
Culicidae biomass (g)	-9.5749	9.3832	1.0400	0.3075	0.0123
Ceratopogonidae	-0.1251	0.1110	1.2700	0.2597	0.0307
Ceratopogonidae biomass (g)	-208.0348	180.8723	1.3200	0.2501	0.0324
Ephemeroptera	0.0057	0.0045	1.6400	0.2006	0.0178
Log-Ephemeroptera	1.4298	0.7305	3.8300	0.0503	0.0427
Ephemeroptera biomass (g)	1.5485	1.0063	2.3700	0.1239	0.0429
Gastropoda	-0.0007	0.0037	0.0300	0.8577	0.0003
Log-Gastropoda	0.0228	0.7113	0.0000	0.9744	0.0000
Gastropoda biomass (g)	-0.0893	0.1107	0.6500	0.4199	0.0115
Planorbidae	0.0020	0.0054	0.1300	0.7170	0.0014
Planorbidae biomass (g)	-0.0750	0.2094	0.1300	0.7202	0.0015
Lymnaeidae	-0.0039	0.0076	0.2600	0.6075	0.0041
Lymnaeidae biomass (g)	-0.1218	0.1794	0.4600	0.4970	0.0113

Ring-necked Duck cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0038	0.0045	0.7400	0.3913	0.0143
Log-Hemiptera	-0.8335	0.7486	1.2400	0.2655	0.0141
Hemiptera biomass (g)	-0.0106	0.1186	0.0100	0.9289	0.0001
Corixidae	-0.0140	0.0103	1.8400	0.1749	0.0381
Corixidae biomass (g)	-2.7139	2.4974	1.1800	0.2772	0.0285
Gerridae	-10.0157	72.0700	0.0200	0.8895	0.1095
Gerridae biomass (g)	-7167.7747	78352	0.0100	0.9271	0.1095
Notonectidae	0.0031	0.0059	0.2900	0.5932	0.0030
Notonectidae biomass (g)	0.0185	0.1146	0.0300	0.8721	0.0003
Hirudinea	-0.0321	0.0400	0.6400	0.4219	0.0106
Log_Hirudinea	-0.9391	1.7559	0.2900	0.5928	0.0033
Hirudinea Biomass (g)	0.2294	0.2542	0.8100	0.3669	0.0087
Hydrachnidae & Araneae	-0.0059	0.0261	0.0500	0.8221	0.0005
Log-Hydrachnidae & Araneae	-0.0196	1.4000	0.0000	0.9888	0.0000
Hydrachnidae & Araneae biomass (g)	1.6653	7.2478	0.0500	0.8183	0.0006
Odonata	0.0081	0.0046	3.0400	0.0812	0.0346
Odonata biomass (g)	0.2711	0.1483	3.3400	0.0675	0.0522
Anisoptera	0.0150	0.0085	3.0900	0.0785	0.0445
Log-Anisoptera	1.4982	0.9835	2.3200	0.1277	0.0258
Anisoptera Biomass (g)	0.2875	0.1621	3.1500	0.0761	0.0512
Zygoptera	0.0051	0.0072	0.5100	0.4743	0.0054
Log-Zygoptera	1.0486	0.9344	1.2600	0.2618	0.0139
Zygoptera biomass (g)	0.5850	0.7314	0.6400	0.4239	0.0068
Pelecypoda	0.0035	0.0014	6.4200	0.0113	0.1126
Log-Pelecypoda	1.7596	0.6312	7.7700	0.0053	0.1002
Pelecypoda biomass (g)	0.3751	0.1622	5.3400	0.0208	0.1121
Trichoptera	0.0477	0.1447	0.1100	0.7417	0.0011
Log-Trichoptera	1.6003	4.0894	0.1500	0.6956	0.0016
Trichoptera biomass (g)	-2.1502	3.4699	0.3800	0.5355	0.0044

Horned Grebe

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	-0.0131	0.1065	0.0200	0.9021	0.0002
Area (ha) (Box-Cox transformed)	1.4333	0.9541	2.2600	0.1331	0.0233
Conductivity	-0.0009	0.0011	0.6500	0.4216	0.0073
Depth (m)	0.1074	0.1792	0.3600	0.5489	0.0036
Log-depth (m)	0.4616	0.4084	1.2800	0.2584	0.0129
pH	-0.1270	0.4032	0.1000	0.7528	0.0010
Secchi disc depth (m)	0.3598	0.5703	0.4000	0.5281	0.0040
Shoreline irregularity	1.0455	0.4407	5.6300	0.0177	0.0635
Temperature (°C)	-0.0115	0.0858	0.0200	0.8936	0.0002
<i>biotic variable</i>					
Amphipoda	-0.0009	0.0012	0.5700	0.4520	0.0064
Log-Amphipoda	0.4472	0.4866	0.8400	0.3581	0.0085
Amphipoda biomass (g)	-0.0750	0.2072	0.1300	0.7175	0.0013
Coleoptera	0.0163	0.0261	0.3900	0.5317	0.0039
Log_Coleoptera	0.7249	1.5866	0.2100	0.6477	0.0021
Coleoptera biomass (g)	-0.3320	0.6433	0.2700	0.6057	0.0027
Dytiscidae	-0.0092	0.0360	0.0600	0.7989	0.0007
Dytiscidae biomass (g)	-0.3314	0.6636	0.2500	0.6175	0.0026
Crustacea	0.0001	0.0002	0.1600	0.6902	0.0016
Log-Crustacea	0.1915	0.3712	0.2700	0.6060	0.0027
Crustacea biomass (g)	0.0718	0.0604	1.4100	0.2345	0.0176
Cladocera	-0.0005	0.0007	0.5100	0.4772	0.0124
Log-Cladocera	-0.2812	0.3658	0.5900	0.4420	0.0059
Cladocera biomass (g)	-0.5101	0.7752	0.4300	0.5105	0.0123
Conchostraca	0.0006	0.0006	1.1800	0.2776	0.0150
Log-Conchostraca	0.3789	0.3310	1.3100	0.2523	0.0131
Conchostraca biomass (g)	0.0915	0.0740	1.5300	0.2165	0.0217
Cyclopoida	0.0005	0.0004	1.5400	0.2139	0.0175
Log-Cyclopoida	0.6802	0.3257	4.3600	0.0368	0.0453
Cyclopoida biomass (g)	0.4279	0.3630	1.3900	0.2385	0.0152
Ostracoda	-0.0045	0.0227	0.0400	0.8443	0.0004
Log-Ostracoda	-0.5083	1.2283	0.1700	0.6790	0.0017
Ostracoda biomass (g)	-2.8445	7.3273	0.1500	0.6979	0.0015
Diptera	-0.0040	0.0030	1.7600	0.1851	0.0348
Log-Diptera	-0.7598	0.5601	1.8400	0.1749	0.0193
Diptera biomass (g)	-0.9524	0.8963	1.1300	0.2880	0.0210
Chaoboridae	-0.0108	0.0102	1.1100	0.2911	0.0276
Chaoboridae biomass (g)	-0.8174	1.0916	0.5600	0.4540	0.0111
Chironomidae	-0.0058	0.0047	1.5200	0.2172	0.0278
Chironomidae biomass (g)	-4.3111	3.4641	1.5500	0.2133	0.0299
Culicidae	0.0293	0.0228	1.6500	0.1984	0.0167
Culicidae biomass (g)	9.5269	7.8822	1.4600	0.2268	0.0148
Ceratopogonidae	-0.0099	0.0313	0.1000	0.7513	0.0011
Ceratopogonidae biomass (g)	-23.1030	52.0870	0.2000	0.6574	0.0022
Ephemeroptera	0.0081	0.0049	2.6900	0.1007	0.0312
Ephemeroptera biomass (g)	1.2474	0.9389	1.7700	0.1840	0.0279
Log-Gastropoda	1.3508	0.7164	3.5500	0.0594	0.0374
Gastropoda biomass (g)	0.3991	0.1900	4.4100	0.0357	0.0951
Planorbidae	0.0057	0.0053	1.1800	0.2781	0.0118
Planorbidae biomass (g)	0.4236	0.2779	2.3200	0.1274	0.0349
Lymnaeidae	0.0150	0.0148	1.0200	0.3118	0.0273
Lymnaeidae biomass (g)	0.5668	0.2773	4.1800	0.0410	0.0815

Horned Grebe cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0027	0.0033	0.6800	0.4098	0.0113
Log-Hemiptera	-0.4392	0.6721	0.4300	0.5135	0.0043
Hemiptera biomass (g)	-0.0865	0.1276	0.4600	0.4978	0.0051
Corixidae	-0.0021	0.0032	0.4400	0.5085	0.0070
Corixidae biomass (g)	-0.4759	0.7374	0.4200	0.5187	0.0058
Gerridae	-0.0596	0.2775	0.0500	0.8301	0.0005
Gerridae biomass (g)	8.6450	40	0.0500	0.8282	0.0005
Notonectidae	-0.0045	0.0068	0.4300	0.5127	0.0048
Notonectidae biomass (g)	-0.0663	0.1239	0.2900	0.5928	0.0031
Hirudinea	0.0078	0.0222	0.1200	0.7264	0.0012
Log_Hirudinea	0.7172	1.4651	0.2400	0.6245	0.0024
Hirudinea biomass (g)	0.3637	0.2852	1.6300	0.2023	0.0188
Hydrachnidae & Araneae	0.0134	0.0238	0.3100	0.5751	0.0031
Log_Hydrachnidae & Araneae	0.7599	1.3231	0.3300	0.5657	0.0033
Hydrachnidae & Araneae biomass (g)	3.7044	6.9613	0.2800	0.5946	0.0028
Odonata	0.0098	0.0048	4.1900	0.0407	0.0469
Odonata biomass (g)	0.1631	0.1231	1.7600	0.1852	0.0224
Anisoptera	0.0060	0.0067	0.8200	0.3644	0.0088
Log-Anisoptera	1.0389	0.9221	1.2700	0.2599	0.0129
Anisoptera Biomass (g)	0.1331	0.1201	1.2300	0.2674	0.0149
Log-Zygoptera	2.1136	0.9571	4.8800	0.0272	0.0538
Zygoptera biomass (g)	1.6353	0.7815	4.3800	0.0364	0.0485
Pelecypoda	0.0022	0.0012	3.7800	0.0519	0.0532
Log-Pelecypoda	1.9268	0.6364	9.1700	0.0025	0.1161
Trichoptera	-0.9633	0.3113	9.5800	0.0020	0.1830
Log-Trichoptera	-24.6855	7.6937	10.2900	0.0013	0.1798
Trichoptera biomass (g)	-19.2012	6.5060	8.7100	0.0032	0.1511

Red-necked Grebe

<i>abiotic variable</i>	estimate	SE	Walds X2	P	R ²
Area (ha)	2.0209	0.4875	17.1800	<.0001	0.4881
Area (ha) (Box-Cox transformed)	12.6504	2.9969	17.8200	<.0001	0.5096
Conductivity	-0.0023	0.0015	2.5700	0.1092	0.0365
Depth (m)	0.1288	0.1791	0.5200	0.4719	0.0051
Log-depth (m)	0.4780	0.4028	1.4100	0.2354	0.0139
pH	0.7712	0.4501	2.9400	0.0866	0.0319
Secchi disc depth (m)	1.5283	0.6359	5.7800	0.0163	0.0633
Shoreline irregularity	1.7229	0.5246	10.7800	0.0010	0.1395
Temperature (°C)	0.1734	0.0897	3.7300	0.0533	0.0384
<i>biotic variable</i>					
Amphipoda	0.0024	0.0015	2.5600	0.1097	0.0334
Log-Amphipoda	1.4347	0.5469	6.8800	0.0087	0.0775
Amphipoda biomass (g)	0.4077	0.2431	2.8100	0.0934	0.0330
Coleoptera	-0.0248	0.0283	0.7700	0.3804	0.0081
Log_Coleoptera	-0.8669	1.5834	0.3000	0.5840	0.0029
Coleoptera biomass (g)	-0.1435	0.6077	0.0600	0.8134	0.0005
Dytiscidae	-0.0509	0.0392	1.6800	0.1949	0.0181
Dytiscidae biomass (g)	-0.1637	0.6264	0.0700	0.7938	0.0007
Crustacea	-0.0002	0.0002	1.3000	0.2549	0.0152
Log-Crustacea	-0.1309	0.3622	0.1300	0.7178	0.0013
Crustacea biomass (g)	0.0291	0.0511	0.3200	0.5694	0.0033
Cladocera	-0.0009	0.0009	1.0500	0.3063	0.0229
Log-Cladocera	-0.3445	0.3605	0.9100	0.3393	0.0090
Cladocera biomass (g)	-1.1788	1.0201	1.3400	0.2479	0.0267
Conchostraca	0.0004	0.0005	0.7100	0.3996	0.0081
Log-Conchostraca	0.3128	0.3277	0.9100	0.3399	0.0089
Conchostraca biomass (g)	0.0719	0.0697	1.0600	0.3028	0.0136
Cyclopoida	-0.0007	0.0005	1.7900	0.1807	0.0246
Log-Cyclopoida	-0.3130	0.3152	0.9900	0.3206	0.0097
Cyclopoida biomass (g)	-0.6553	0.4781	1.8800	0.1705	0.0252
Ostracoda	0.0164	0.0224	0.5400	0.4644	0.0053
Log-Ostracoda	1.6791	1.2447	1.8200	0.1773	0.0188
Ostracoda biomass (g)	4.2426	7.0158	0.3700	0.5454	0.0036
Diptera	-0.0033	0.0025	1.7800	0.1819	0.0323
Log-Diptera	-0.7709	0.5443	2.0100	0.1567	0.0204
Diptera biomass (g)	-0.8405	0.7476	1.2600	0.2609	0.0208
Chaoboridae	-0.0029	0.0037	0.6100	0.4353	0.0096
Chaoboridae biomass (g)	-0.5559	0.7461	0.5600	0.4562	0.0081
Chironomidae	-0.0050	0.0042	1.4100	0.2351	0.0265
Chironomidae biomass (g)	-2.9377	2.7553	1.1400	0.2863	0.0232
Culicidae	-0.0262	0.0234	1.2500	0.2637	0.0126
Culicidae biomass (g)	-7.6565	8.0661	0.9000	0.3425	0.0091
Ceratopogonidae	-0.0345	0.0398	0.7500	0.3857	0.0099
Ceratopogonidae biomass (g)	-48.7738	59.6836	0.6700	0.4138	0.0083
Ephemeroptera	0.0019	0.0043	0.1900	0.6633	0.0018
Log-Ephemeroptera	0.9362	0.6860	1.8600	0.1724	0.0186
Ephemeroptera biomass (g)	-0.2596	0.6219	0.1700	0.6764	0.0018
Gastropoda	0.0035	0.0036	0.9100	0.3393	0.0096
Log-Gastropoda	0.9930	0.6889	2.0800	0.1495	0.0208
Gastropoda biomass (g)	0.0468	0.0626	0.5600	0.4549	0.0064
Planorbidae	0.0000	0.0052	0.0000	0.9995	0.0000
Planorbidae biomass (g)	-0.1419	0.2028	0.4900	0.4841	0.0054
Lymnaeidae	0.0160	0.0156	1.0500	0.3055	0.0248
Lymnaeidae biomass (g)	0.0903	0.1053	0.7300	0.3915	0.0132

Red-necked Grebe cont.

<i>variable</i>	estimate	SE	Walds X2	P	R²
Hemiptera	-0.0041	0.0039	1.1000	0.2932	0.0201
Log-Hemiptera	-0.4860	0.6563	0.5500	0.4590	0.0054
Hemiptera biomass (g)	-0.0409	0.1123	0.1300	0.7156	0.0013
Corixidae	-0.0078	0.0067	1.3600	0.2431	0.0276
Corixidae biomass (g)	-1.7605	1.6306	1.1700	0.2803	0.0262
Gerridae	-0.9693	0.5679	2.9100	0.0878	0.0496
Gerridae biomass (g)	-94.1632	71	1.7500	0.1858	0.0284
Notonectidae	0.0004	0.0058	0.0000	0.9515	0.0000
Notonectidae biomass (g)	-0.0079	0.1102	0.0100	0.9426	0.0001
Hirudinea	0.0173	0.0241	0.5100	0.4732	0.0054
Log_Hirudinea	1.8374	1.6367	1.2600	0.2616	0.0138
Hirudinea biomass (g)	0.2830	0.2800	1.0200	0.3122	0.0112
Hydrachnidae & Araneae	-0.0236	0.0258	0.8400	0.3590	0.0088
Log_Hydrachnidae & Araneae	-0.9117	1.3357	0.4700	0.4949	0.0046
Hydrachnidae & Araneae biomass (g)	-4.4548	7.1975	0.3800	0.5360	0.0038
Odonata	0.0017	0.0042	0.1600	0.6893	0.0015
Odonata biomass (g)	-0.0060	0.0962	0.0000	0.9502	0.0000
Anisoptera	-0.0027	0.0065	0.1700	0.6811	0.0017
Log-Anisoptera	0.1996	0.8870	0.0500	0.8220	0.0005
Anisoptera Biomass (g)	-0.0295	0.1022	0.0800	0.7728	0.0008
Zygoptera	0.0076	0.0070	1.1900	0.2749	0.0118
Log-Zygoptera	1.0938	0.8637	1.6000	0.2054	0.0159
Zygoptera biomass (g)	1.1503	0.7459	2.3800	0.1230	0.0246
Pelecypoda	0.0015	0.0010	2.2200	0.1359	0.0274
Log-Pelecypoda	1.1320	0.5394	4.4000	0.0358	0.0469
Pelecypoda biomass (g)	0.1700	0.1115	2.3200	0.1274	0.0322
Trichoptera	0.2278	0.1463	2.4300	0.1193	0.0250
Log-Trichoptera	6.2966	4.0777	2.3800	0.1225	0.0242
Trichoptera biomass (g)	2.7537	3.0737	0.8000	0.3703	0.0081