BREEDING WATERFOWL AS INDICATORS OF AQUATIC ECOSYSTEM ACIDIFICATION IN WETLANDS OF NORTHEASTERN ONTARIO

by

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ABSTRACT

The effects on waterfowl of ecological changes in aquatic ecosystems associated with acidification were studied in an acid-stressed and an unstressed area of northeastern Ontario. The availability of food for some species has been influenced by acidification. In the stressed area, acid-sensitive organisms, such as certain fish, Ephemeroptera and Gastropoda, occurred infrequently at moderately high pH levels. Acid-tolerant organisms, including certain Odonata and nektonic taxa (Notonectidae, Corixidae and Dytiscidae), were common at low pH, the latter group proliferating in the absence of fish predation. Both resident piscivores (Common Loon and Common Merganser) had lower brood production in the stressed area, presumably due to the loss of fish in many lakes. Only minor reductions in brood production were observed for non-piscivores (Common Goldeneye, Hooded Merganser, Ring-necked Duck and Black Duck). Diets of non-piscivores converged in acidic habitats, due to a reliance on a few, abundant insect taxa, particularly libellulid dragonflies.

Because the Common Loon has been linked closely to the fisheries resource, the breeding success of this species would be an ideal early indicator of the effects of aquatic ecosystem acidification on fish at moderately high pH levels (pH > 5.5). Other non-piscivorous waterfowl, for example Black Duck and Common Goldeneye, integrate the combined effects of fish predation and pH/metal tolerance on major invertebrate prey taxa under more acidic conditions (pH < 5.5). In view of their economic and symbolic importance in North America and their value as

indicators of biological response to lake acidification, the reproductive success of Common Loons and selected duck species should be an integral part of a long-term biological monitoring program. With volunteer assistance, a monitoring network could be implemented to generate the trend-through-time data required to assess the long-term effects of acidification on waterfowl productivity and freshwater ecosystem quality.

INTRODUCTION

Acid Precipitation and Aquatic Biota

Acid precipitation has become a serious environmental threat to aquatic and terrestrial ecosystems in eastern North America, Scandinavia and Europe (MOI 1983). The deposition of atmospheric pollutants, such as sulphur and nitrous oxides, and their interaction with natural hydrological and soil processes in watersheds, result in significant alterations to surface water (lake/stream) chemistry including decreased pH, increased trace metal concentrations and modified base cation, organic anion and nutrient relationships (Fig. 1). These chemical changes have been linked to biologial responses (Kelso et al. 1986), manifested both as lethal (toxicological) effects, leading to direct mortality of biota (Nyholm 1981, Magnuson et al. 1984, Campbell and Stokes 1985), or as sub-lethal effects, represented by a deterioration in habitat quality often resulting in reproductive impairment, reduced growth and condition of adults and young, or behavioural changes (Ormerod et al. 1985). Both lethal and sub-lethal processes may lead to significant ecological change as manifested by disruptions in food chain relationships, including altered predator-prey interactions (Eriksson et al. 1980, Haines 1981).

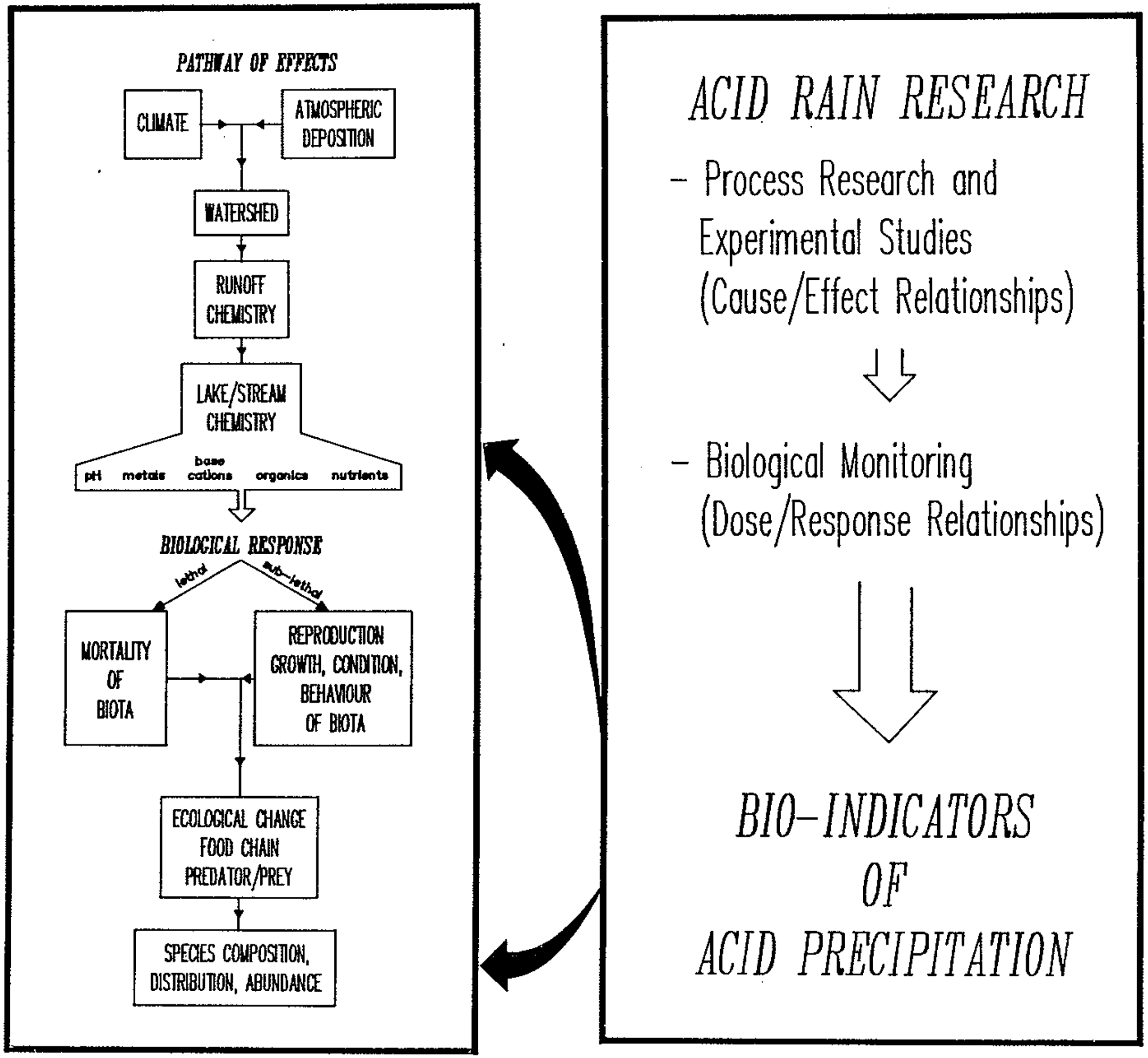


Figure 1. Diagram illustrating the probable pathway of effects and biological response to acidification of surface waters.

Ultimately, these biological responses to acid stress involve changes in the composition, distribution and abundance of species at several levels of the food chain.

Biological Monitoring

In the past decade, most acid rain research has been process-oriented. Cause/effect relationships have been examined at various stages along the 'pathway of effects' (Fig. 1), by means of field and laboratory studies. Current and possibly increased levels of acid deposition will be observed in most regions of eastern North America until at least the mid-1990's. Proposed emission reduction standards (target sulphate loadings of 20 kg $ha^{-1}yr^{-1}$) may continue to cause environmental degradation, so that acidification of sensitive waters in eastern Canada will progress further before improvements in water quality are observed.

Due to the shortage of long-term temporal data sets, the rates of acidification and changes in water quality over time for many aquatic ecosystems in eastern Canada cannot be assessed adequately at present. Therefore, it is necessary to develop long-term atmospheric, chemical and biological monitoring programs which will reliably measure changes through time in the chemistry and biota of aquatic systems. Bio-monitoring will consist of synoptic surveys of selected biota over time in waters with varying sensitivities to acidification and which receive different rates of atmospheric deposition. Since biological response time varies from days to years, a bio-monitoring program must extend through at least several life cycles of the bio-indicator organism

(Aquatic Effects Task Group 1984), some 15-20 years in the case of waterfowl. In this way, an empirical dose/response relationship can be developed which reliably links changes in biological parameters to water quality and thereby to the adequacy of emission reduction strategies implemented over the next two decades in eastern North America.

Waterfowl as Bio-Indicators of Lake Acidification

The effectiveness of bio-monitoring will depend largely on the reliability of the indicator species selected. While most process-oriented research has emphasized lower trophic levels (such as phytoplankton, zooplankton and decomposers) or fish, there is general agreement that bio-monitoring should include higher trophic levels, most notably fish and aquatic wildfowl, which rely on the integrity of various components of the food chain. However, little is known about the effects of acidification on organisms that are not wholly aquatic, including aquatic mammals and birds. Due to their dependence on the aquatic environment for nest sites, brood protection and food, waterfowl may be seriously affected by acid precipitation (Haines and Hunter 1982, Eriksson 1984). The availability of prey during the brood-rearing period and the long-term impact of low-level heavy metal exposure on the survival and reproductive success of adults and young are of particular importance. The selection of an appropriate indicator species must be based on an understanding of the mechanisms by which individual species respond to changes in the chemical and biological status of their habitat arising from acidification. Each species may not be equally at risk from the long-term effects of acidification, and thus equally valuable as a bio-indicator.

Since 1980, the Ontario Region of the Canadian Wildlife Service has studied the effects of acid precipitation on waterfowl populations breeding in northeastern Ontario. With little historical information available, these studies have been designed to provide spatial comparisons of waterfowl breeding success and food chain relationships between areas of differing sensitivities and rates of acid deposition, but in which species distribution and breeding densities are comparable. This paper summarizes current information on waterfowl-acid rain relationships in Ontario, identifies the advantages of using breeding waterfowl as potential bio-indicators of lake acidification and provides recommendations (species selectivity) for long-term bio-monitoring needs.

STUDY DESIGN AND METHODOLOGY

At the outset of this study, we hypothesized that the success of waterfowl breeding in small, headwater lakes undergoing acidification depends directly on food resources that could be lost by toxic effects or by trophic structure changes as follows:

i) Piscivorous waterbirds, such as Common Mergansers (*Mergus merganser*) and including the Common Loon (*Gavia immer*), would be adversely affected at moderately high pH levels, due to a reduction in overall fish stocks.

ii) Local extinctions of sensitive fish species would permit the proliferation of acid-tolerant invertebrates, previously regulated by fish predation.

iii) Waterfowl which rely on aquatic insects during the brood-rearing period, such as Common Goldeneye (Bucephala clangula), Hooded Merganser (Lophodytes cucullatus) and to a lesser extent Ring-necked Duck (Aythya collaris) and Black Duck (Anas rubripes), would benefit initially from such a situation.

iv) As lake pH continued to decline, invertebrates would ultimately suffer, posing potential problems for these ducks as well.

To test these predictions, waterfowl habitat selection and food chain studies were conducted on 124 lakes in two areas of northeastern Ontario receiving different acid-loading levels (Fig. 2). Ranger Lake, northeast of Sault Ste. Marie, Ontario, receives moderate levels of sulphate deposition (20kg $ha^{-1}yr^{-1}$) (Semkin et al. 1984) and represents a largely unaffected but sensitive area. Wanapitei, northeast of Sudbury, Ontario, receives high acid loading levels (> 30kg $ha^{-1}yr^{-1}$) and represents a heavily stressed area which has undergone considerable lake acidification (Pitblado et al. 1980) and loss of aquatic biota (Yan and Miller 1984) as a result of nickel smelting operations near Sudbury.

Small, headwater lakes, ranging in size from 1 to 25 hectares were studied. While not all habitats are vulnerable to acidification, headwater lakes and streams are particularly sensitive, with little or no capacity to buffer acidic precipitation and runoff (Minns 1981). Such wetlands also represent preferred nesting and brood-rearing habitat for many waterfowl species in the Precambrian Shield (McNicol et al. in prep).

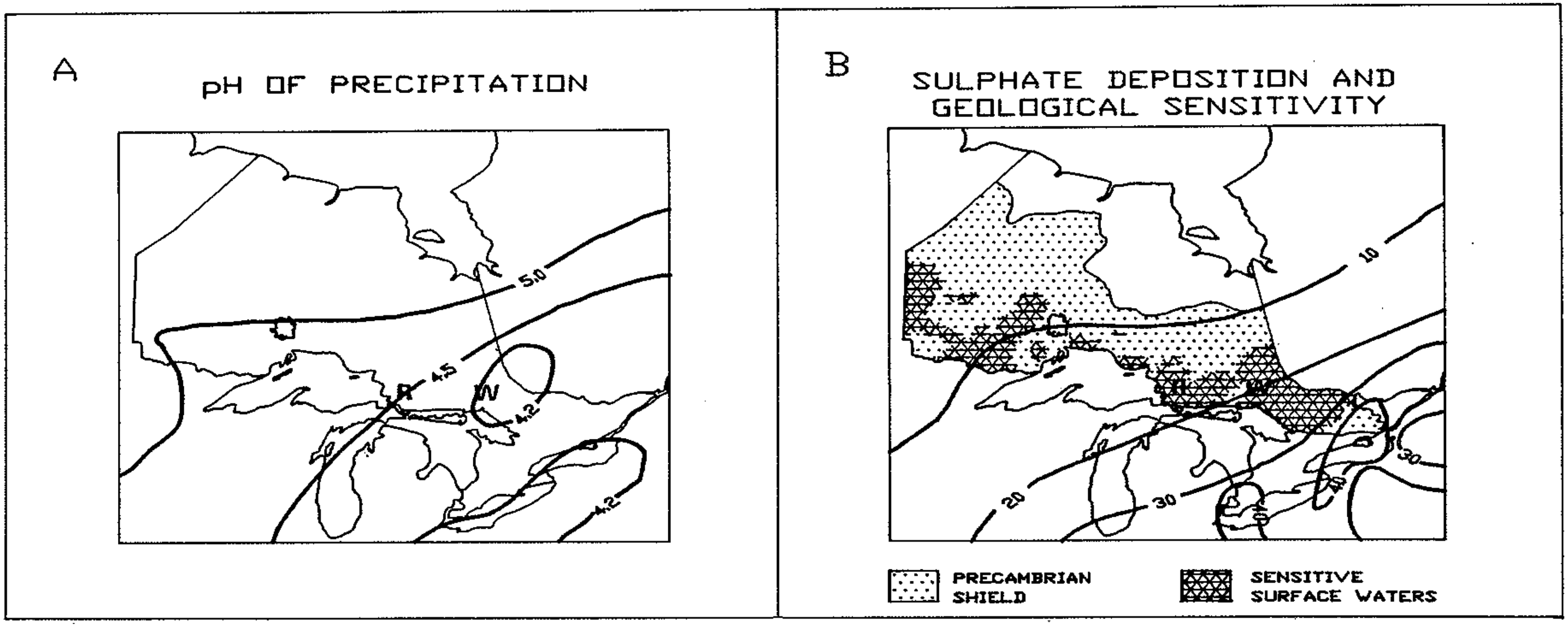


Figure 1. Maps of Ontario showing location of Ranger Lake (R) and Wanapitei (W) study areas in relation to:
A - precipitation amount - weighted mean annual pH in 1980 (from MOI 1983);
B - Mean annual wet sulphate deposition (kg SO_4/ha.yr) (from MOI 1983), showing outline of Precambrian Shield and sensitive surface waters (from NRC 1981).

A systematic survey design, using 2X2 km plots located at 20km intervals in standard 100km per side blocks, was instituted throughout much of northeastern and central Ontario (Ross 1985). The location and number of indicated pairs of waterfowl nesting in each plot was determined using helicopter surveys conducted during the nest initiation period in May. Selective surveys of plots and individual wetlands were also conducted at Ranger Lake and Wanapitei (McNicol et al. in prep). Ground surveys were conducted in June and July to assess adult and brood utilization patterns. Along with data on water quality and lake morphometry, other biological data were collected, including fish and aquatic invertebrate sampling (see McNicol et al. in prep).

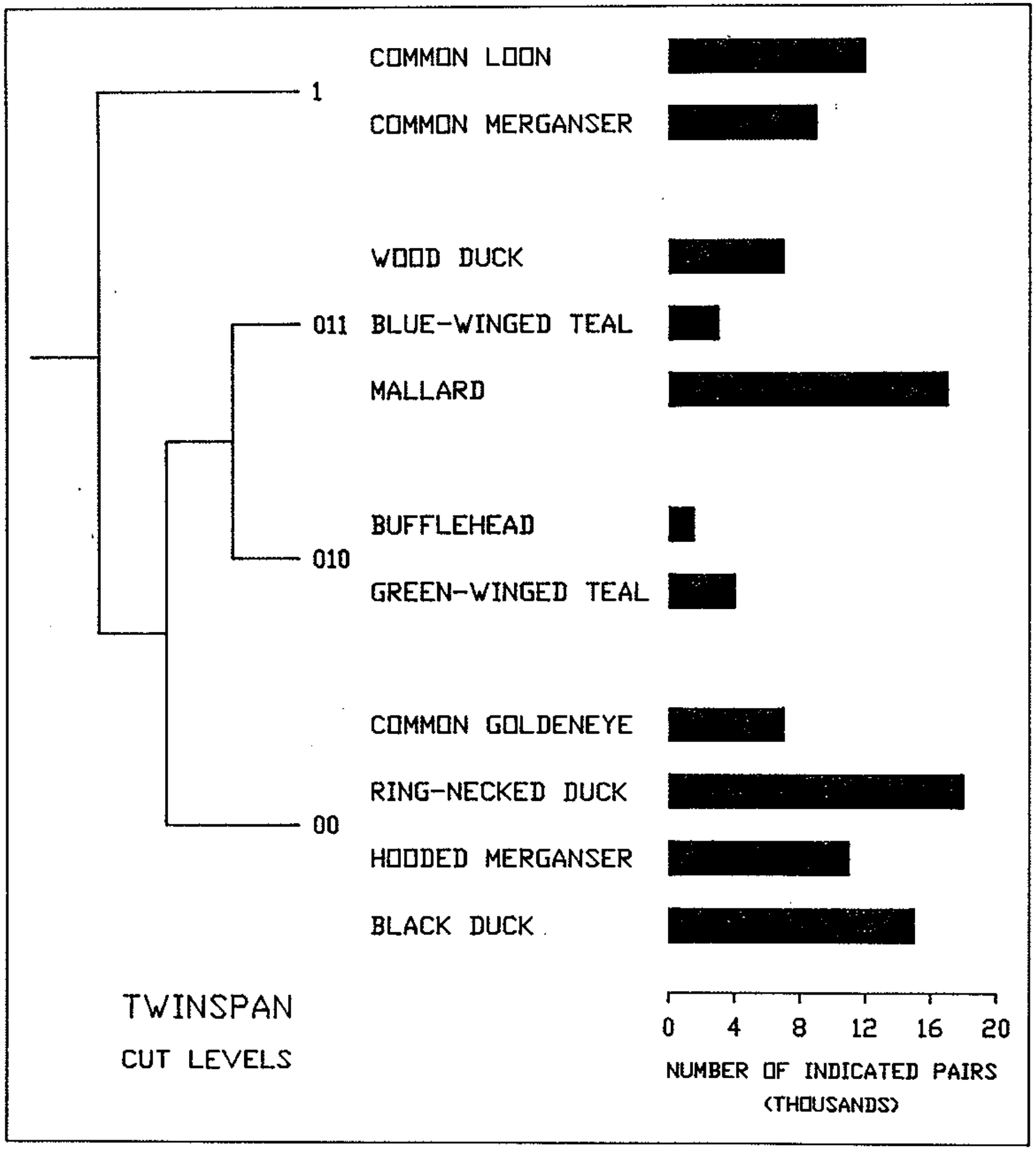
Since 1984, dietary habits of ducklings of several species have been examined on both acid (pH < 5.5) and non-acid (pH > 5.5) lakes in the two study areas. Foraging birds were collected using a 12 gauge shotgun and gut conents examined. The number of items of each major prey type consumed has been estimated from the combined contents of the esophagus, proventriculus and gizzard of each duckling. At the same time, the availability and abundance of major prey taxa were determined using several sampling techniques. Benthic macroinvertebrates were examined in 20 lakes at Wanapitei (ranging in pH from 4.2 to 7.5) using random, multiple one metre benthic drags with a sweep net. Free-swimming (nektonic) invertebrates were examined using a water column sampler on 15 lakes at Wanapitei, including those with and without fish, and across a range of pH (Bendell and McNicol in prep a,b). Small, non-game fish species were sampled with wire minnow traps in all 124 lakes in both study areas (Bendell and McNicol in prep c).

RESULTS

The distribution, density and habitat preferences of waterfowl (including Common Loons) were examined throughout much of northeastern and central Ontario using aerial survey counts of indicated nesting pairs. The number of waterfowl breeding in unbuffered areas receiving significant inputs of acid deposition was estimated at 105,000 breeding pairs (McNicol et al. in prep). While a substantial waterfowl resource is threatened by acid precipitation, overall breeding densities were relatively low (c. 1 indicated pair per km^2), and no significant trends in population levels have been noted since 1980. Based on co-occurrences of species within systematic survey plots, broad ecological associations were noted (Fig. 3). Boreal-lake species, including Common Goldeneye, Hooded Merganser, Ring-necked Duck and Black Duck, comprise nearly 47% of the waterfowl resource and commonly breed on small lakes and wetlands (< 4.0 ha in size)(McNicol et al. in prep). Piscivorous waterbirds, including Common Merganser and Common Loon utilize larger lakes (> 4.0 ha) and river habitat. More southerly breeding dabblers, including Wood Duck (Aix sponsa), Blue-winged Teal (Anas discors) and Mallard Duck (Anas platyrhynchos), utilize well-buffered aquatic habitat associated with agricultural land (McNicol et al. in prep). Green-winged Teal (Anas crecca carolinensis) and Bufflehead (Bucephala albeola) nest infrequently in the region.

Spatial comparisons between the Ranger Lake and Wanapitei study areas indicated major differences in water quality, with lake acidity (Fig. 4) and trace metal concentrations significantly higher at Wanapitei

Figure 3. Dendrogram produced by the TWINSPAN reciprocal averaging ordination technique (Hill 1970) illustrating associations of major waterfowl species from systematic aerial surveys conducted throughout northeastern Ontario, and depicting relative numbers of indicated breeding pairs in acid-sensitive areas.



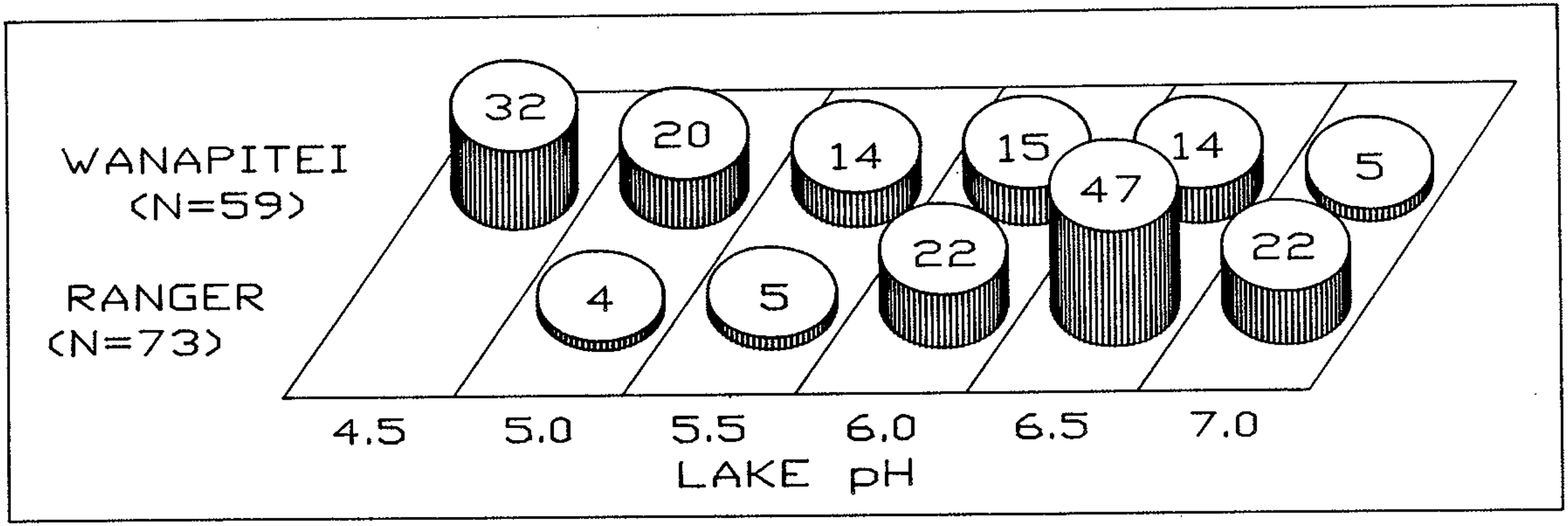


Figure 4. Comparison between lake pH distributions in the Ranger Lake and Lake Wanapitei study areas.

(McNicol et al. in prep). While a broad range of lake pH's occurred across both areas, more than two/thirds of Wanapitei study lakes were acidic (pH < 5.5), compared to less than 10% at Ranger Lake.

Despite these pronounced chemical differences, no significant difference in the proportion of lakes occupied by indicated nesting pairs, as determined by spring aerial surveys, was observed between the two study areas. On average, slightly fewer study lakes were occupied by waterfowl at Ranger Lake (59%) than at Wanapitei (76%) during the nest-initiation period.

However, the percentage of lakes occupied by broods, in relation to those occupied by indicated breeding pairs, indicated substantial differences in waterfowl productivity between the two study areas (Fig. 5). At Ranger Lake, the ratios of occupancy rates were nearly one brood:two pairs for piscivores (Common Loon and Common Merganser combined) and omnivores (Ring-necked Duck, Black Duck and Mallard) and nearly one:one for insectivores (Common Goldeneye and Hooded Merganser). At Wanapitei, the brood:pair ratio was generally lower for all groups, and particularly for piscivores (1:17).

Two questions arise from these results. Firstly, is the reproductive failure observed in piscivorous species at Wanapitei linked to declining food availability? Secondly, are the differences in brood to indicated pair ratios observed for non-piscivores linked to acidification or are they merely a reflection of natural variability between the two study areas attributable to other regulatory parameters such as predation?

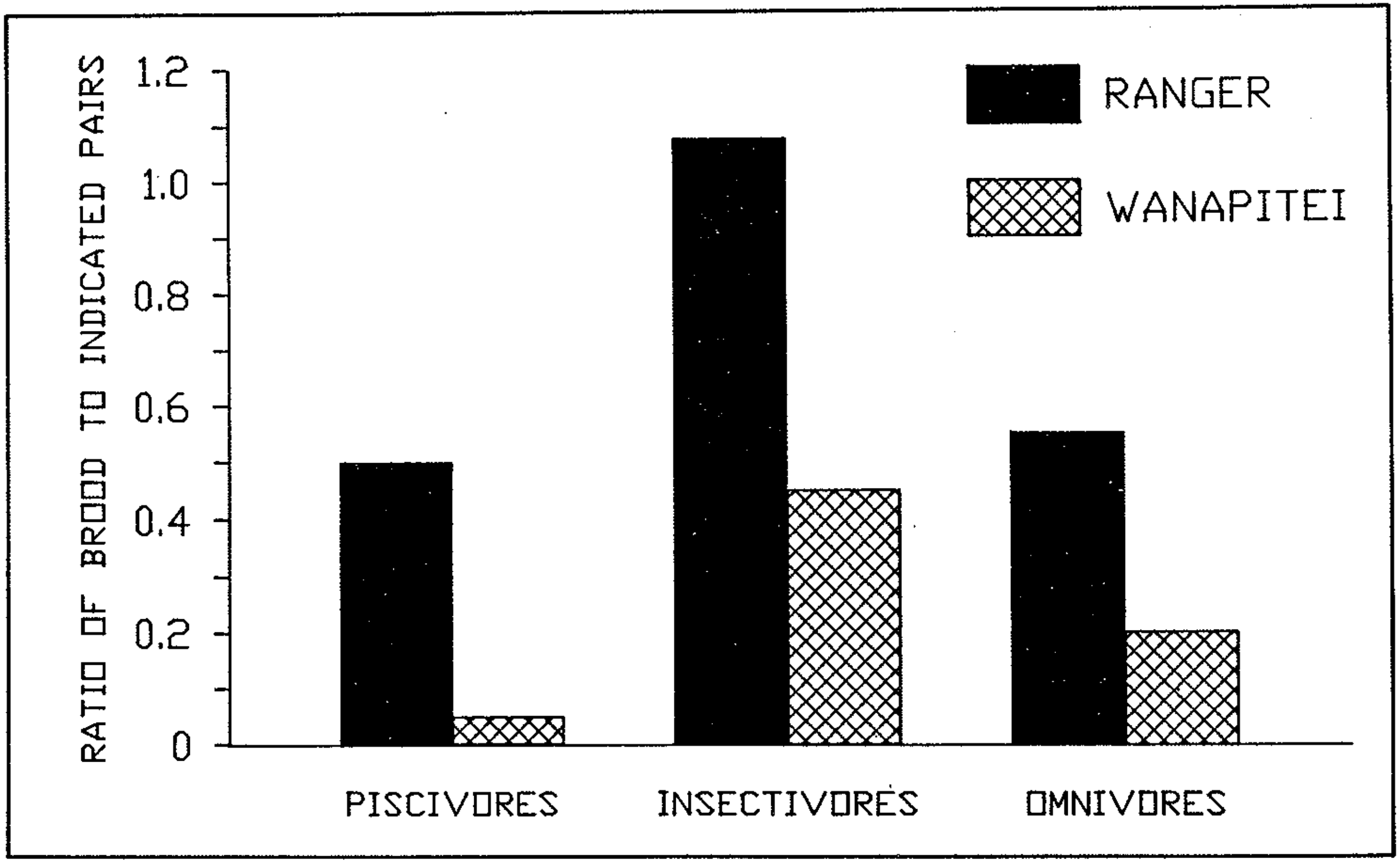


Figure 5. Ratios of broods to indicated pairs for 3 major waterfowl groups (piscivores - Common Loon + Common Merganser, insectivores - Common Goldeneye + Hooded Merganser, omnivores - Ring-necked Duck + Black Duck + Mallard) in the two study areas.

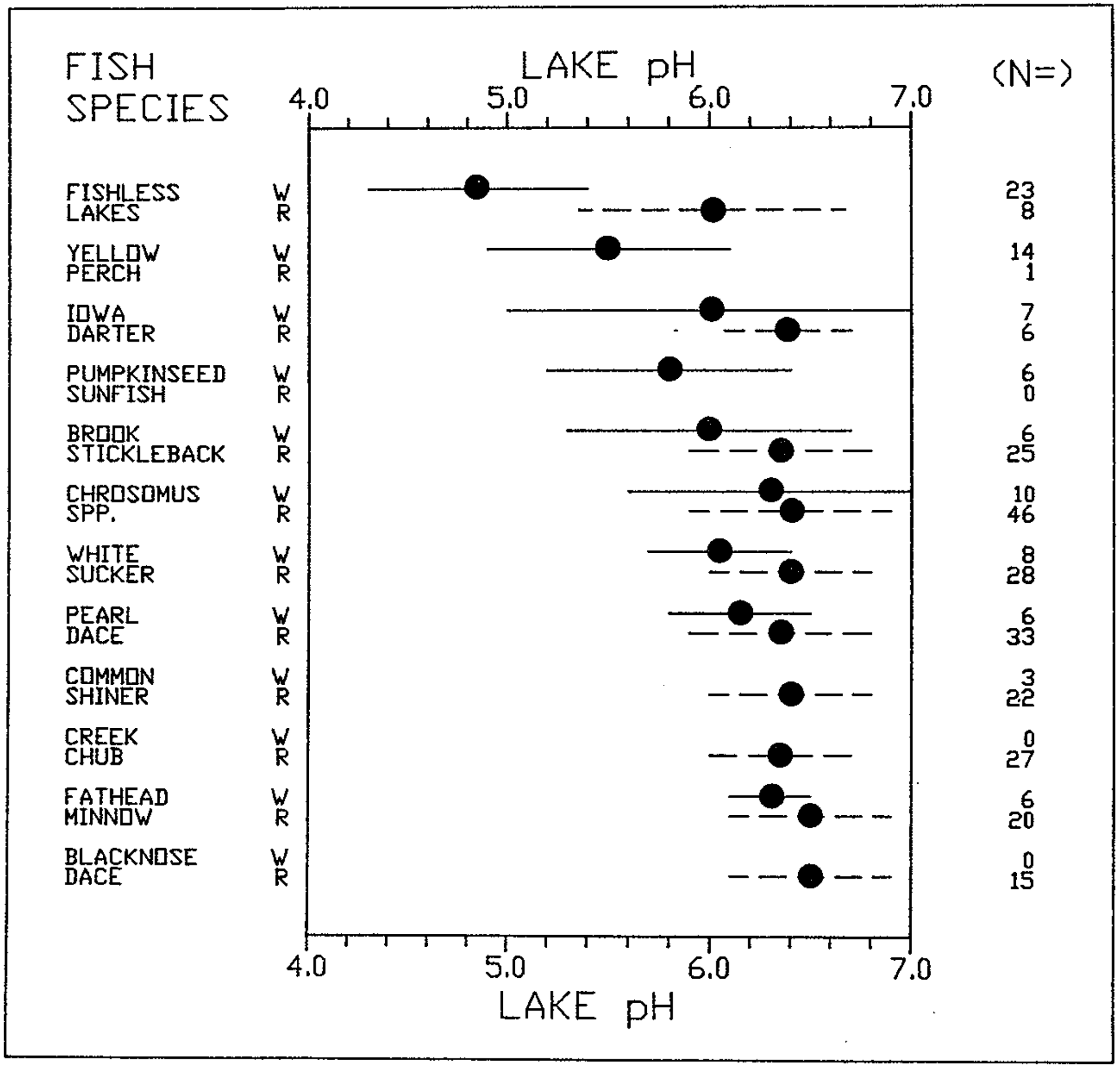


Figure 6. Distribution of individual fish species tolerances (mean ± S.D.) in relation to lake pH in the two study areas, Ranger Lake (R) and Wanapitei (W).

As predicted, lake acidity in the Wanapitei area was correlated with an overall reduction in fish stocks and simplification of fish communities (Fig. 6). Non-game fish assemblages were found to shift from diverse cyprinid populations, common at pH > 6 in both areas, to a very simple community dominated by the acid-tolerant yellow perch (Perca flavescens), commonly found between pH 5-6 at Wanapitei (McNicol et al. in prep). As lake pH declined below 5.5, lakes without fish became increasingly common. Of the 30 acidic lakes (pH < 5.5) examined at Wanapitei, more than two/thirds were fishless. At Ranger Lake, the occurrence of 8 fishless lakes was unrelated to lake pH. As noted elsewhere, both chemical (winter anoxia) and bio-geographic factors (isolation from other waterbodies) may restrict fish faunas in shallow headwater lakes (Rahel 1986).

The results of brood surveys underline the importance of fish in headwater lakes to their ultimate use by waterfowl (Fig. 7). As was expected, fish-eating species, including both Common Merganser and particularly Common Loon, preferred lakes with fish. Conversely, Common Goldeneye and Hooded Merganser showed a distinct preference for fishless lakes. More generalized feeders, including Ring-necked Duck and Black Duck, showed little preference for either condition.

While no attempt was made to examine Common Loon food habits, Common Merganser ducklings were sampled. Due to the scarcity of broods on acid lakes, a comparison of diets between acid/fishless and non-acid/fish situations could not be undertaken. Reliance by Common Merganser ducklings on fish in non-acid lakes was unmistakable (Fig. 8),

Figure 7. Summary of waterfowl survey results for adults and/or young observed during the brood-rearing period, in relation to the presence or absence of fish (Fisher Exact Test, * $p < 0.01$, ** $p < 0.0001$).

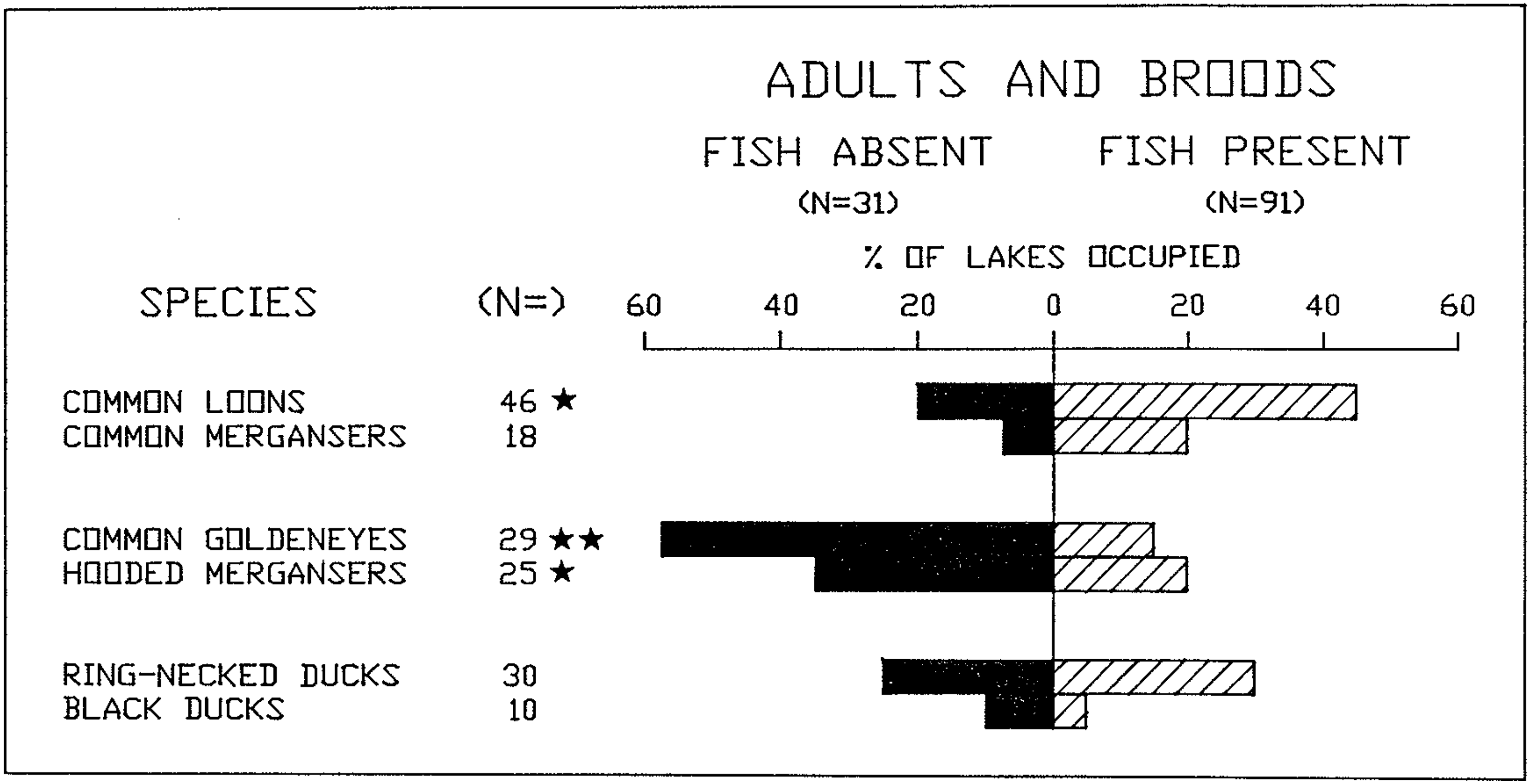
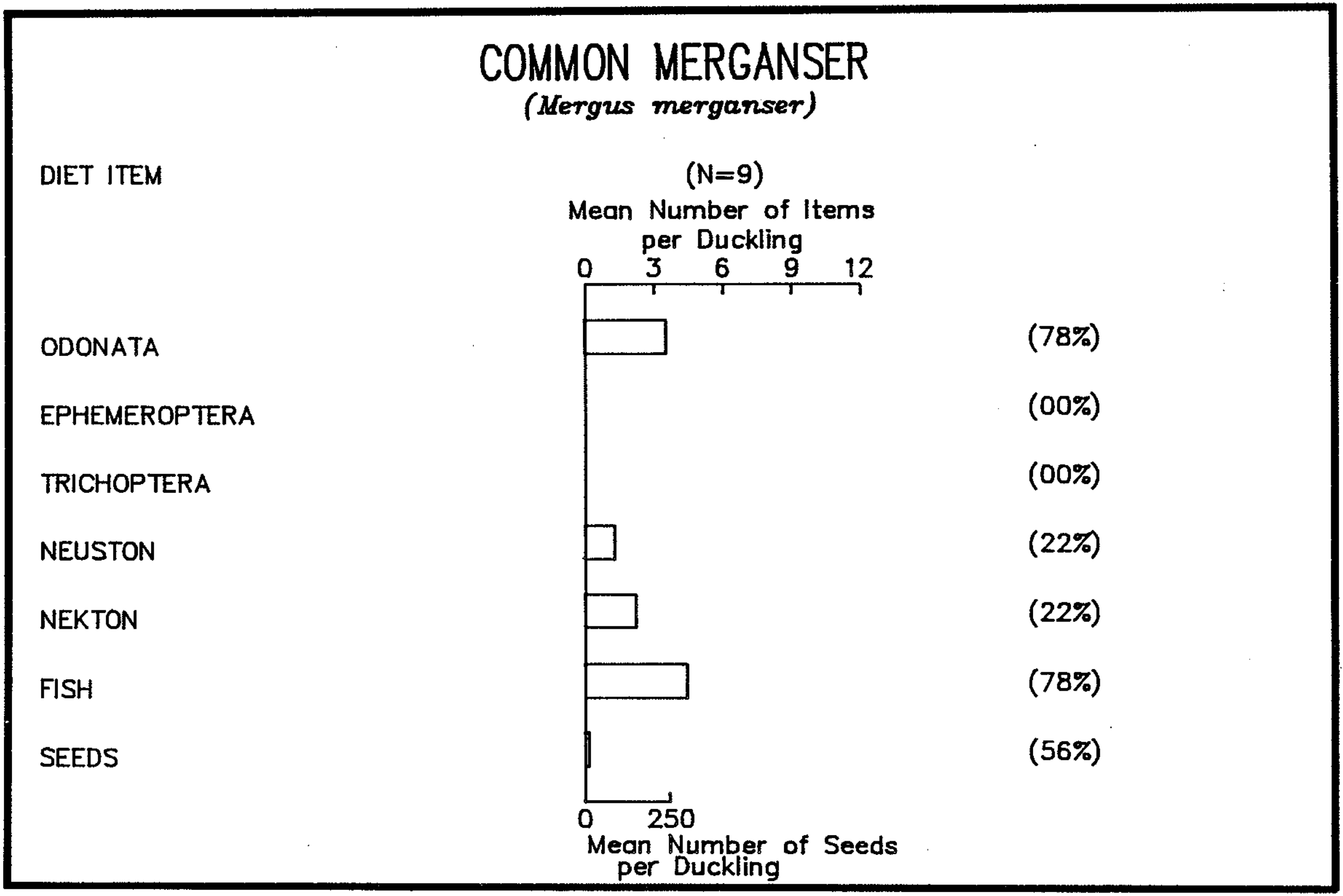


Figure 8. Use of major aquatic insect prey, fish and seeds (expressed as mean number of items per duckling) by Common Merganser ducklings (N = 9, 1 from an acid lake) collected in 1984 and 1985.



although augmented to some extent by an assortment of aquatic insects taken from the nekton, neuston and benthos (immature Odonata).

These results suggest that poor reproductive performance by obligate piscivores, such as Common Merganser and Common Loon, was linked to the reduced fish stocks found in the acid-stressed area. As predicted, both species are immediately at risk from the combined effects of reduced pH and increased trace metal levels on fish. Clearly, reduced breeding success of either species would be a valuable early indicator of the effects of lake acidification at moderately high pH levels (pH > 5.5).

For non-piscivores, the relationship between lake acidification and reproductive success was much more complex. The preference by insectivores, including Common Goldeneye and to a lesser extent Hooded Merganser, for fishless lakes during the brood-rearing period suggests that fish may act as competitors for insect prey of ducklings. Such macroinvertebrates are potential prey for waterfowl as well as many fish species (Eriksson 1979, Eadie and Keast 1982). As predicted, aquatic invertebrate composition and abundance was closely linked to the presence or absence of fish. Insect assemblages from fishless lakes in both areas, regardless of lake pH, along with lakes containing only a few fish, shared many more taxa in common than with lakes containing large numbers of fish (Bendell and McNicol in prep a). These differences in insect community structure are largely explained by the increased occurrence and abundance of large, free-swimming organisms, primarily backswimmers (Notonectidae) and water boatmen (Corixidae)(Fig. 9), but also including the diving beetle (*Graphoderus liberus*) and the phantom midge larvae (*Chaoborus americanus*). These nektonic taxa proliferate in

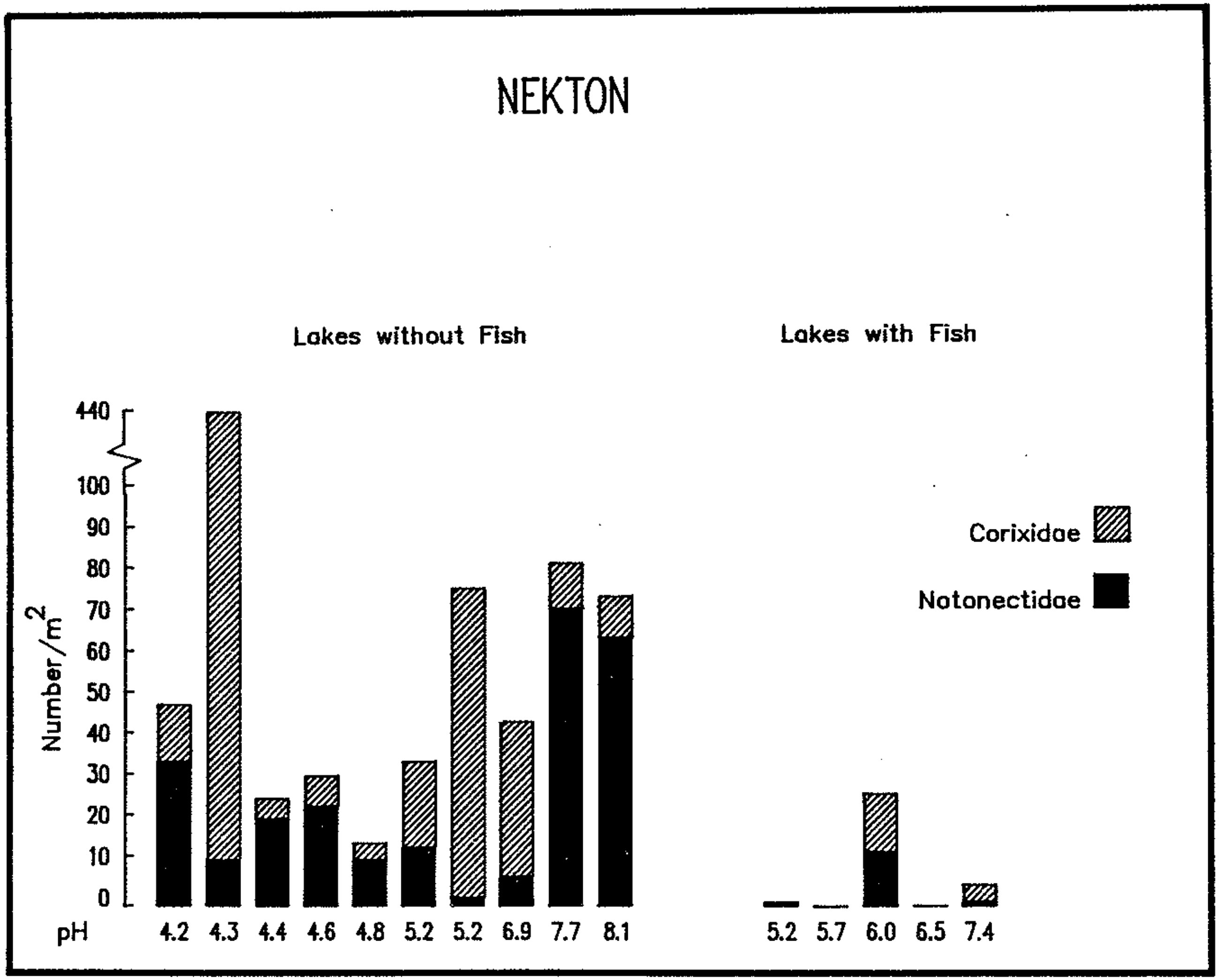


Figure 9. Abundance (number/m^2) of nektonic organisms (Corixidae and Notonectidae) sampled in lakes without fish (N = 10) and lakes with fish (N = 5) in the Wanapitei area in 1984.

the absence of fish, regardless of pH, and undoubtedly replace fish as top predators in the aquatic food chain as lakes acidify.

While low pH might benefit some nektonic organisms, as a result of altered predator-prey relatons, there was an overall depletion in benthic species richness on acid lakes sampled at Wanapitei (Table 1). Certain crustaceans (amphipoda) and gastropods (sphaeriid clams) occurred infrequently below pH 5, while other acid-sensitive organisms, in particular Ephemeropterans, were absent below pH 5.6 (Fig. 10b). Other benthic organisms, such as Odonata, showed a pronounced shift in species composition, with the number of immature Odonate taxa reduced on acid lakes (Fig. 10a) and dominated by only one Libellulid species, Leucorrhinia glacialis. While species composition varied greatly, the overall density of odonate nymphs did not differ markedly in relation to lake pH.

Under circum-neutral conditions (pH > 5.5), non-piscivorous species displayed specialized feeding habits. These habits were altered substantially under acid conditions. In non-acid conditions, both Common Goldeneye and Hooded Merganser took large numbers of nektonic prey, primarily notonectids, corixids and dytiscids, (Fig. 11 a,b). Both species increased this consumption under acid conditions, presumably in response to the increased availability of these organisms in the water column. This alteration in predator-prey relations might provide a short-term advantage for pursuit divers such as goldeneyes and Hooded Mergansers. While equally adept at diving, Common Goldeneyes take more benthic material, especially immature libellulids and Trichoptera. Hooded Mergansers exploit large numbers of the climbing Aeshnid dragonfly

Table 1. Presence/Absence of Benthic Organisms Taken in Drag-Net Samples from 20 Lakes in the Wanapitei Study Area in 1985.

Lake No.	408	401	248	013	259	404	530	922	410	197	527	199	016	333	905	409	005	920	298	247
pH	4.15	4.30	4.35	4.65	4.70	5.10	5.15	5.25	5.35	5.55	5.75	6.10	6.50	6.65	6.75	6.75	7.10	7.20	7.25	7.45
Ephemeroptera										+	+	+	+	+	+	+	+	+	+	+
Amphipoda							+	+				+	+		+	+	+	+	+	+
Sphaeriidae					+	+	+	+		+	+	+	+		+		+	+	+	+
Anisoptera	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

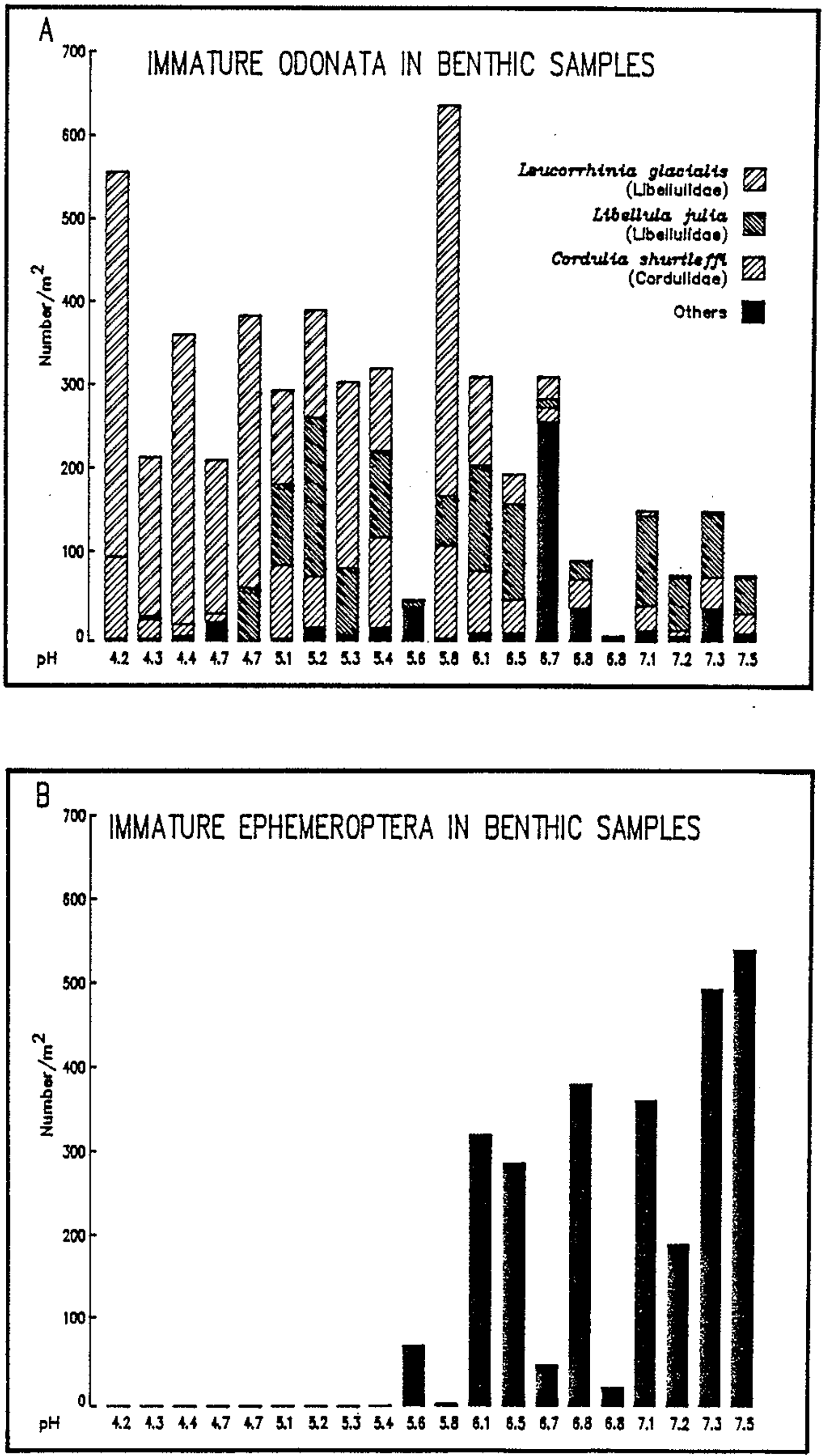


Figure 10. Abundance (number/m^2) of immature Odonata (A) and immature Ephemeroptera (B) collected in benthic-drag samples from 20 lakes in the Wanapitei area in 1985.

larvae, often found attached to submersed ericaceous shrubs or woody detritus (Merritt and Cummins 1978).

More generalized feeders, such as Ring-necked Duck and Black Duck, were seemingly unaffected either by acidity or by fish occurrence. Instead, broods of these species occupied shallow, nutrient-rich wetlands which contained a well-developed shorezone community (McNicol et al. in prep). In non-acid situations, Ring-neck ducklings took noticeably more surface insects (neuston)(Fig. 11c), especially waterstriders (Gerridae), which are often associated with emergent and floating-leaved vegetation. The Black Duck, a surface feeder, took large numbers of emerging insects (teneral forms), particularly Odonata on acid lakes, and Ephemeroptera on non-acid lakes, while also supplementing its diet with seed material (Fig. 11d).

The relationship between waterfowl and acidification is not a linear one, and is complicated by feeding specializations and other habitat selection parameters. However, all four non-piscivores modify their feeding habits between acid and non-acid conditions. On acid lakes, the consumption of Odonata, particularly the immature Libellulid dragonfly <u>Leucorrhinia glacialis</u>, by most species increases (Fig. 11). On acid lakes, consumption of Trichoptera, especially by goldeneyes, declines, while Ring-necked ducklings use fewer surface organisms. On acid lakes, both goldeneyes and Hooded Mergansers increase their consumption of nektonic prey, while Ephemeroptera, primarily used by Black Duck ducklings, are no longer consumed. As a result, there is less evidence of specialized feeding strategies on acid lakes, the diets of non-piscivorous species converging due to a reliance on the few common insect prey such as immature Libellulid dragonflies and nektonic insects.

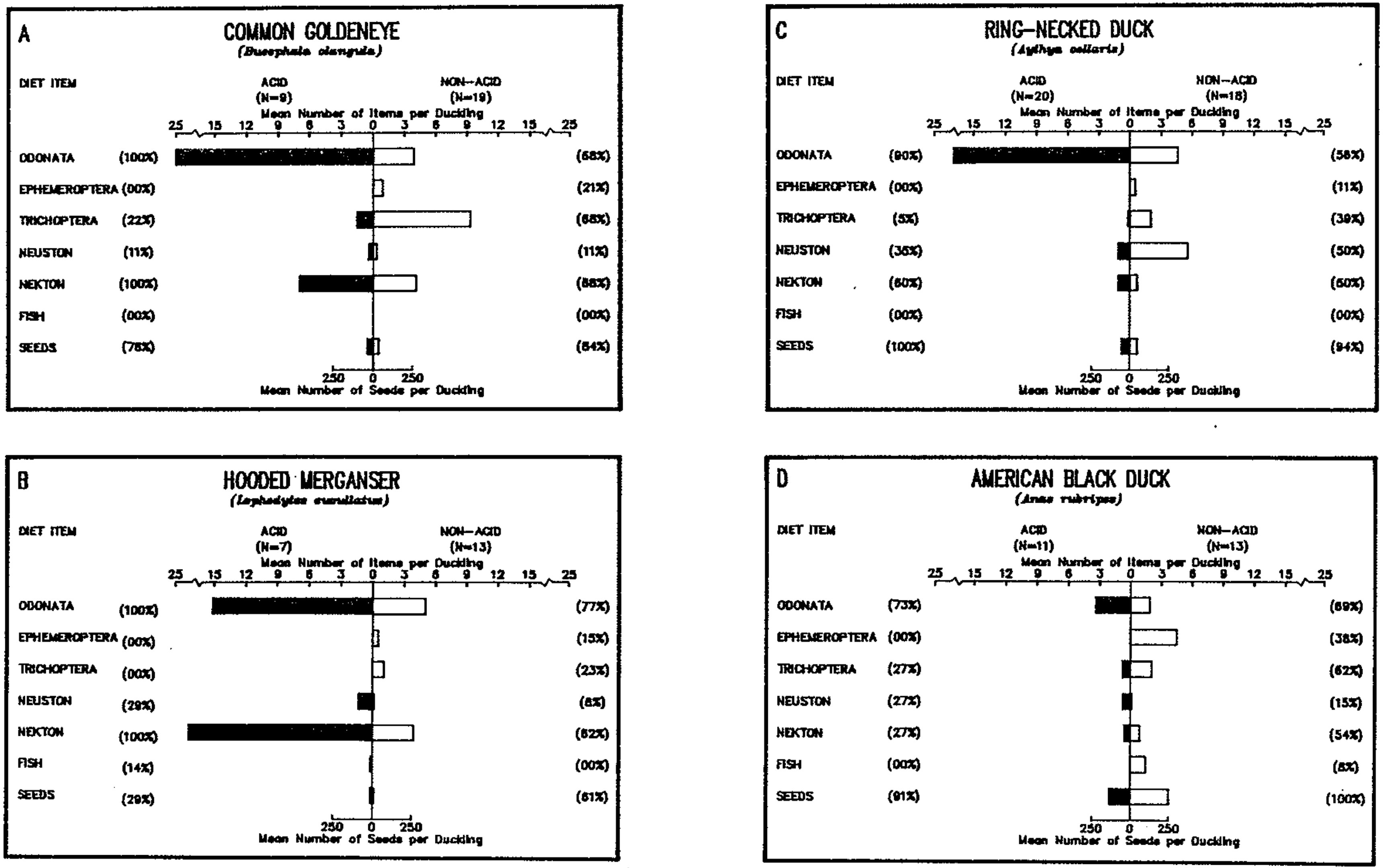


Figure 11. Comparative use of major aquatic insect prey, fish and seeds (expressed as mean number of items per duckling) by Common Goldeneye (A), Hooded Merganser (B), Ring-necked Duck (C) and Black Duck (D) collected in acid (pH < 5.5) and non-acid (pH > 5.5) lakes in 1984 and 1985.

CONCLUSIONS

Based on the results of this and other studies, it is possible to evaluate individual waterfowl species according to their inherent advantages and/or disadvantages as bio-indicators of lake acidification (Fig. 12). Not all species are equally at risk from the effects of lake acidification and therefore of equal value as bio-indicators. The following discussion focusses on the reliability of major ecological groups, namely piscivores and non-piscivores (insectivores and omnivores), as indicators of acid precipitation stress.

Early Response to Lake Acidification

Whether acidifying lakes represent sub-optimal brood-rearing habitat is difficult to establish, especially for non-piscivores. For example, the Common Loon is an ideal early indicator of aquatic ecosystem acidification because of its reliance on an abundant and healthy fish population for successful fledging of young (Barr 1973). The poor reproductive performance of Common Loons in the acid-stressed Wanapitei area, corroborated by similar findings in Ontario (Alvo 1985), Québec (DesGranges and Darveau 1985), New York (Trivelpiece et al. 1979) and Scandinavia (Almer et al. 1978), suggests that reproductive failure of this species provides a valuable early warning signal of deteriorating habitat quality at moderately high pH levels. Poor reproductive success of loons in northwestern Ontario (reductions in egg laying and in nest site and territorial fidelity) has been linked to elevated levels of mercury (Barr 1986). The availability of mercury to the aquatic food chain has been linked to acid precipitation effects. Both ecological and

Figure 12. Diagram illustrating advantages and disadvantages of using breeding waterfowl as bio-indicators of the effects acid precipitation on aquatic ecosystems.

BREEDING WATERFOWL AS BIO-INDICATORS OF ACID PRECIPITATION

ADVANTAGES

1) INDICATOR OF BIOLOGICAL RESPONSE TO ACIDIFICATION
   Ecological Effects
   Toxicological Effects
   Reproductive Impairment
2) GEOGRAPHIC DISTRIBUTION
3) POTENTIAL FOR LONG-TERM MONITORING
4) SOCIO-ECONOMIC IMPORTANCE
5) POTENTIAL USE OF VOLUNTEER MANPOWER AND NGO'S

DISADVANTAGES

ABILITY TO CONTROL OTHER REGULATING FACTORS

Nest Site Selection, Predation, Wintering and Migration Habits, Hunting Pressure toxicological effects of acid precipitation are likely to impair the reproductive success (hatching and fledging success, growth and condition of young) of Common Loons at pH levels (5-6) where buffering capacities become exhausted and fish reproduction is seriously affected.

Late Response to Lake Acidification

Hunter et al. (1985) have suggested that ducklings of several species of dabbling and diving ducks, most notably pursuit divers such as Common Goldeneyes, that feed largely on invertebrate prey (Swanson and Meyer 1973, Reinecke and Owen 1980), may derive some short-term benefits from breeding in acid and fishless conditions, as a result of reduced competition with fish for common insect prey. Eriksson (1979) and Eadie and Keast (1982) argued that competition between fish and Common Goldeneyes affected the selection of feeding localities and brood-rearing sites. However, experimental studies using imprinted Black Duck ducklings in Québec (DesGranges, in prep) and Maryland (Haramis and Chu, in prep) have shown impaired growth and reduced survival of ducklings on acidified wetlands. It therefore appears that both strong acidity and the presence of fish are required to disrupt duckling feeding to the extent of causing measurable declines in growth rates (Hunter in press). The lower reproductive success shown by non-piscivores in the acid-stressed Wanapitei area might result from the combined effects of acidity and fish predation limiting the abundance and availability of insect prey. While many extremely acidic ($pH < 4.5$) lakes are no longer capable of supporting fish populations in the Greater Sudbury area (Pitbaldo et al. 1980), most lakes undergoing acidification at Wanapitei and elsewhere in northeastern North America have become less productive and now have impoverished fish populations. At Wanapitei, half of the lakes containing fish support yellow perch, which is a particularly effective insectivore (Eriksson 1979, Post and Cucin 1984) and can tolerate a wide pH range (Ryan and Harvey 1980, Rask 1984). In these lakes aquatic insects are often less numerous (Bendell and McNicol in prep a). At Ranger Lake, cyprinids characterize the small, non-game fish populations of headwater lakes. Several common species, including Chrosomus spp. and fathead minnow (Pimephales promelas), are gape-limited predators, and can prey only on early instars of large aquatic insects. Less distinction in insect community structure and overall abundance was observed at Ranger Lake than in the extreme situations sampled at Wanapitei. Insect populations of moderately acid lakes (pH < 5-6) are probably too small to support both acid-tolerant yellow perch and ducks at the same time. As pH continues to decline, traditional brood-rearing sites may become less suitable for waterfowl forced to compete with remnant fish populations for insect prey. Such circumstances may arise regularly in sensitive headwater lakes throughout much of northeastern and central Ontario, when the complete elimination of fish populations does not often occur.

On those headwater lakes which lose acid-sensitive cyprinid populations, without replacement by more tolerant species, ducklings of several species must rely heavily on the few aquatic insect taxa which tolerate acid conditions and which proliferate in the absence of fish. Such a restricted resource spectrum seems likely to have reproductive effects. Increased diet overlap might result in greater intra- and interspecific competition for suitable brood-rearing sites. Continued degradation of aquatic habitat might deplete the remaining invertebrate prey, further limiting normal duckling growth and development. Metal burdens currently found in these few tolerant insect taxa (both benthic and nektonic) the reproductive capabilities of adults and offspring alike.

Each of these problems could impair reproduction for non-piscivores, including Common Goldeneye, Hooded Merganser, Ring-necked Duck and Black Duck, breeding in acid-stressed areas. Lowered reproductive success on sensitive headwater lake habitat throughout northeastern and central Ontario will presumably result in discernible population declines in the future. Long-term reproductive biology studies of representative species (insectivores and/or omnivores) will be useful to assess the biological status of systems undergoing acidification, because the reproductive performance of these species integrates both the direct effects of acidity on acid-sensitive prey (gastropods, ephemeropterans etc.) and the indirect effects of altered predator-prey relationships.

Summary

Not only do breeding waterfowl fulfill most of the essential requirements of a reliable bio-indicator species (Fig. 12), they also represent an important socio-economic resource in North America. As a natural resource, waterfowl produced in the boreal forest of eastern Canada provide substantial recreational and hunting opportunities for residents in southern Ontario and elsewhere. In view of its symbolic importance and its threatened status in many parts of the U.S., the

Common Loon is also an important species. In northeastern and central Ontario alone, more than 105,000 breeding pairs of ducks and loons nest in wetlands threatened by acid precipitation. Therefore, long-term population studies of selected species are warranted for a number of reasons.

Most species are common inhabitants of glacial lakes throughout much of the sensitive Precambrian Shield, in areas receiving varying inputs of acid deposition. The feasibility of long-term monitoring of reproductive success is good for most species. Due to the longevity of waterfowl and female fidelity to natal nesting areas (philopatry) (Bellrose 1976), long-term reproductive studies of marked individuals could provide the data on reproductive performance of individual females necessary to assess quantitative differences in recruitment to the population over time between areas of differing sensitivities to acid precipitation. Cavity-nesting species, including Common Goldeneye, Hooded Merganser and Common Merganser, are particularly suited to long-term population studies because of the potential for experimental manipulation using artificial nest boxes (Eriksson 1982, Savard 1982, Lumsden et al. 1980). Through the use of volunteer manpower (naturalists' clubs, cottage associations, etc.) and non-government organizations (such as Long Point Bird Observatory), a monitoring network could be implemented to generate the trend-through-time data required to assess the long-term effects of acidification on loon and selected duck species breeding success.

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