Breeding waterfowl in eutrophicated lakes in south Sweden

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Introduction

In recent years an increasing number of studies have been devoted to restoration plans for 'destroyed' Swedish lakes, inspired by the successful lake restoration experiments in Lake Hornborgasjön and Lake Trummen (Björck 1972). In most cases the lakes involved in these studies were previously oligotrophic lakes that had been severely polluted by sewage. However, some studies examined possibilities to restore formerly good bird lakes, often as a result of lowering of the water level combined with increased leakage of nutrients from surrounding agricultural land. Many of the polluted lakes also had become good waterfowl localities as a result of eutrophication. A study of possible waterfowl management in lake restoration projects that were not primarily ornithological was therefore initiated by the National Swedish Environmental Protection Board. This study was undertaken during 1974–1975 (Nilsson 1976) and included censuses of breeding and roosting waterfowl in all lake restoration projects of possible importance for waterfowl plus some bird lakes. Details of the census work is available in files at the National Swedish Environmental Protection Board. Further data from bird lake projects were obtained from unpublished reports and from Nilsson *et al.* (1976).

This paper examines breeding waterfowl communities in different kinds of polluted lakes and in relation to different environmental parameters. Previously Utschick (1976) has discussed roosting waterfowl in south Germany in relation to the degree of eutrophication (cf. also Bezzel 1975; Bezzel & Reicholf 1974).

Study areas

Twenty-nine lakes were included in the study (Figure 1), of these No. 20 and No. 25 were censused in 1974. The others were censused in 1975. No. 14 was only partially covered and Nos. 9 and 10 are special cases not included in the general analysis. Lake No. 9 is situated in a bog area and has a special water chemistry. The lake is not polluted but restoration was initiated because of increasing growth of vegetation after cessation of grazing.

The different lakes are briefly characterized below. They have been fully documented in files at the National Swedish Environmental Protection Board.

Seven main types of lake were separated:

A. One large oligotrophic lake with polluted bays. Lake No. 26 had characteristic oligotrophic conditions for most of its area, but was heavily polluted by industrial phosphorus in one bay, resulting in heavy growth of submerged vegetation and reed.

B. Four moderately polluted oligotrophic lakes. They were all polluted by sewage and although now free of discharges, have not recovered. There are rich growths of reed and other macrophytes along the shores and algal blooms in summer. Submerged vegetation occurs to some extent.

C. Three small eutrophic lakes with lowered water levels. No. 10 could have been included in this category but has been omitted as it is no longer a lake but a marsh with some ponds. The lakes in this category had their water levels lowered during the first decades of this century. An increase in emergent vegetation initially made them into good waterfowl localities but later, in some cases, they deteriorated. Recently, with increased leakage of nutrients from agricultural land, the emergent vegetation has increased markedly. These lakes generally have rather good water quality and submerged vegetation but their shallowness makes them liable to oxygen deficiency in winter.

D. Five polluted eutrophic lakes, including three well known bird lakes that have been polluted by sewage, which is now treated. The lakes have experienced a heavy growth of reed and various macrophytes, especially floating vegetation such as waterlilies. The water has heavy algal blooms that had resulted in a severe deterioration of submerged vegetation. Besides the three typical lakes in this category, Lake Ågestasjön (20) is included together with Lake Hjälstaviken (25), a bay of Lake Mälaren. No. 20 was only indirectly polluted and No. 25 not at all, but both show the same characteristics in the vegetation as a typical polluted lake.

E. Kyrkbytjärn. This lake has special hydrological conditions, the water level showing marked variation related to changes

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in the river Dalälven. The lake was originally slightly eutrophic but has been polluted by sewage.

F. Six heavily polluted previously oligotrophic lakes. Five were of the typical clear-water oligotrophic type with sparse emergent vegetation. Heavy pollution by sewage led to a very dense shoreline growth

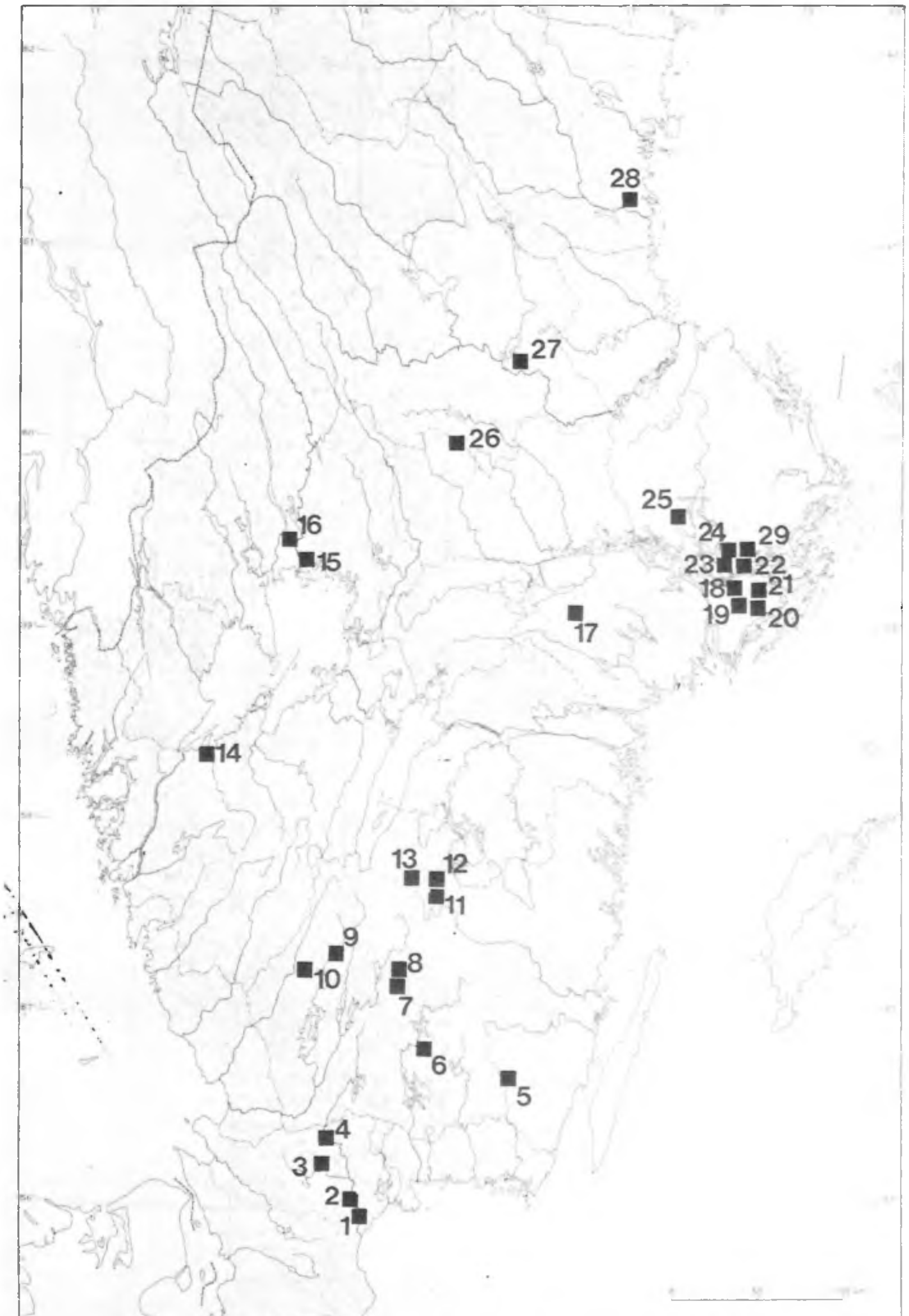

Figure 1. The geographical location of the lake restoration projects included in the present study.

of reed and other macrophytes with carpets of water-lilies in deeper water. In the open water they have very heavy blooms of algae, and are therefore devoid of submerged vegetation. In addition Lake Trummen (6) was of this category but it has partially recovered as an effect of restoration work and no longer fits the category.

G. Six small polluted urban waters. These previously more or less oligotrophic waters had experienced heavy pollution by sewage. Except for their size and situation in an urban environment they are similar to category F.

Note. Some of the lakes appear on the List of the (Ramsar) Convention of Wetlands of International Importance Especially as Waterfowl Habitat. ((W) viz. No. 9 (Kävsjön) = CW No. 7; No. 1 & 2 = CW No. 3.)

Methods

All breeding waterfowl (i.e. divers, grebes, ducks, coots and moorhens) were included in the surveys. The breeding ducks and moorhen were censused by repeated counts of territorial pairs or assumed pairs according to a standard procedure (Andersson & Nilsson 1976). Other species were counted by finding nests, though in some lakes with dense vegetation this was combined with counts of territorial pairs.

Data on water chemistry were obtained from the lake restoration plans and normal limnological measurements were undertaken. Shore lengths were measured from detailed vegetation maps; the border of dense floating vegetation being taken as outer border of the shore.

Lake 20 and Lake 25 were not counted in the present study but the methods used were essentially the same, the lakes however being surveyed in 1974. These two lakes in many respects showed deviating values and are therefore shown in brackets in the graphs.

Results

Composition of waterfowl communities

The naturally eutrophic lakes had the richest waterfowl communities, as measured by the number of different species (Table 1). In both the polluted eutrophic lakes and eutrophic lakes with lowered water level the Coot *Fulica atra* had a high dominance, whereas the Great Crested Grebe *Podiceps cristatus* constituted a lower percentage than in the other lakes studied.

The polluted formerly oligotrophic lakes had a different waterfowl community. Lake Hörken (26), that was only partially polluted, had a high share of breeding Goldeneye *Bucephala clangula*, typical of oligotrophic lakes, and Black-throated Divers *Gavia arctica* also bred. The heavily polluted bays on the other hand were characterized by Great Crested Grebes and Coot.

The heavily polluted formerly oligotrophic lakes had a waterfowl community, dominated by Great Crested Grebe *Podiceps cristatus*, Coot *Fulica atra* and Mallard *Anas platyrhynchos*. Moreover they had smaller numbers of waterfowl species typical of naturally eutrophic lakes. This picture was also found in the moderately polluted lakes but the Great Crested Grebes were not so prominent here.

Waterfowl abundance in relation to water conditions

The highest densities of waterfowl (pairs/km^2) were found in the smallest waters. This could be expected, as waterfowl pairs per km of shore line are a better measure of waterfowl abundance except for the Great Crested Grebe.

Taking all waterfowl together, the eutrophic lakes and heavily polluted lakes had similar overall densities of waterfowl, the moderately polluted lakes and the partially clear Lake Hörken having much lower values. The polluted eutrophic lakes and the eutrophic lakes with lowered water level had similar values in pairs/km shore, except for the grebe, where pairs/km^2 gave similar values. The heavily polluted lakes had a high abundance of Great Crested Grebe. On polluted lakes dabbling ducks were more sparse on the former oligotrophic than on the eutrophic lakes; diving duck abundance was higher on the oligotrophic lakes than on the eutrophic lakes.

Waterfowl abundance (pairs/km^2 of water area and pairs/km of shore) was compared with total phosphorus content (measured as log Total-P), with total phosphorus in combination with total nitrogen (measured as (log Total-P) × (log Total-N)), and with conductivity of the water (ionic content). The influence of Ca^{2+}, alkalinity etc was also examined. The content of total phosphorus was chosen as a suitable measure of eutrophication as phosphorus in combination with nitrogen is a limiting factor for the production in most lake eco-systems. Moreover the concentration of these elements is markedly increased by direct or diffuse pollution.

Table 1. Composition of waterfowl communities and density of waterfowl in various types of eutrophicated lakes in south Sweden.

Type of Lake (see text)	A	B	C	D	E	F	G
Ref. No. of Lakes	26	4, 7, 8, 15	5, 16, 28	1, 2, 17, 20, 25	27	11, 12, 13, 19, 21	3, 18, 22 23, 24, 2
Number of lakes	1	4	3	5	1	5	6
Total area km²	9·60	6·74	1·10	20·45	0·34	6·67	0·86
Total shore-length km	60·50	30·25	10·55	51·80	3·25	42·70	11·90
Percentage composition of water fowl fauna							
Gavia arctica	1·60	—	—	—	—	—	—
Podiceps cristatus	12·80	20·80	4·10	13·70	5·00	34·70	12·40
Podiceps auritus	0·80	—	8·80	—	—	—	—
Anas platyrhynchos	12·80	30·80	17·70	21·40	18·80	20·80	41·40
Anas crecca	5·80	9·00	10·90	3·90	10·00	3·10	0·80
Anas querquedula	—	0·60	0·70	2·20	1·30	—	—
Anas strepera	—	—	—	1·20	—	—	—
Anas penelope	—	—	1·40	—	2·60	—	—
Anas clypeata	—	—	1·40	5·10	—	0·20	—
Aythya fuligula	13·60	—	2·80	5·40	3·80	6·80	1·60
Aythya ferina	—	1·20	4·80	2·50	—	3·50	1·60
Bucephala clangula	30·40	7·30	7·50	1·60	11·30	6·80	—
Mergus merganser	3·20	1·20	—	—	—	0·70	—
Tadorna tadorna	—	—	—	0·50	—	—	—
Branta canadensis	—	5·10	0·70	0·10	—	0·20	—
Anser anser	—	—	—	0·70	—	—	—
Cygnus cygnus	—	—	0·70	0·10	—	—	—
Cygnus olor	0·80	2·40	0·70	4·40	1·30	0·50	1·60
Fulica atra	20·00	16·20	34·70	34·30	37·50	18·20	32·20
Gallinula chloropus	—	5·60	3·40	2·80	8·80	4·60	6·60
Total No. of waterfowl pairs	125·00	178·00	147·00	867·00	80·00	548·00	121·00
No. of pairs/km²							
Podiceps cristatus	1·50	5·40	5·50	5·80	11·70	28·50	17·40
Anas platyrhynchos	1·70	8·00	23·60	9·10	44·10	17·10	58·10
Anas total	2·40	10·50	42·70	14·30	76·50	19·80	59·30
Diving ducks	6·20	2·50	20·00	4·10	35·30	14·50	4·60
Fulica atra	2·60	4·20	46·40	14·50	88·20	15·00	45·30
Total waterfowl	13·00	26·00	133·60	42·40	235·30	82·20	140·70
No. of pairs/km shore							
Podiceps cristatus	0·26	1·22	0·57	2·30	1·23	4·44	1·26
Anas platyrhynchos	0·26	1·82	2·46	3·59	4·62	2·67	4·20
Anas total	0·38	2·38	4·45	5·66	8·00	3·09	4·28
Diving ducks	0·98	0·56	2·09	1·60	3·69	2·27	0·34
Fulica atra	0·42	0·96	4·83	5·73	9·23	2·34	3·28
Total waterfowl	2·06	5·88	13·93	16·73	24·62	12·83	10·17

A significant correlation was found between the abundance of Great Crested Grebe (whether measured as pairs/km² or pairs/km) compared with total phosphorus or total phosphorus in combination with total nitrogen (Figure 2). The various duck species and coot did not show any correlations with chemical content of the water.

Waterfowl abundance in relation to the heterogenity of habitat

The abundance of waterfowl (pairs/km²) was also compared with the heterogenity of the habitat, measured as shore-index, i.e. the length of shore in km per km² of water area.

A significant correlation was found both for dabbling ducks and diving ducks (Figures 3 and 4). The correlation coefficient for

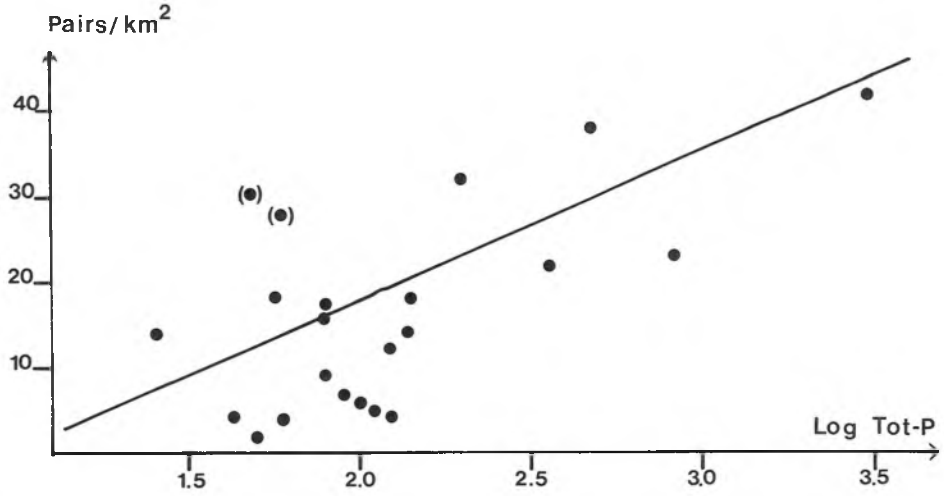

Figure 2. Relation between the density of Great Crested Grebe *Podiceps cristatus* and pollution measured as log total phosphorus ($\mu g/l$ water). Correlation coefficient $r = 0{\cdot}64$ ($P < 0{\cdot}01$), regression coefficient $b = 17{\cdot}4$. Hjälstaviken (25) and Ågestasjön (20) in brackets, see text!

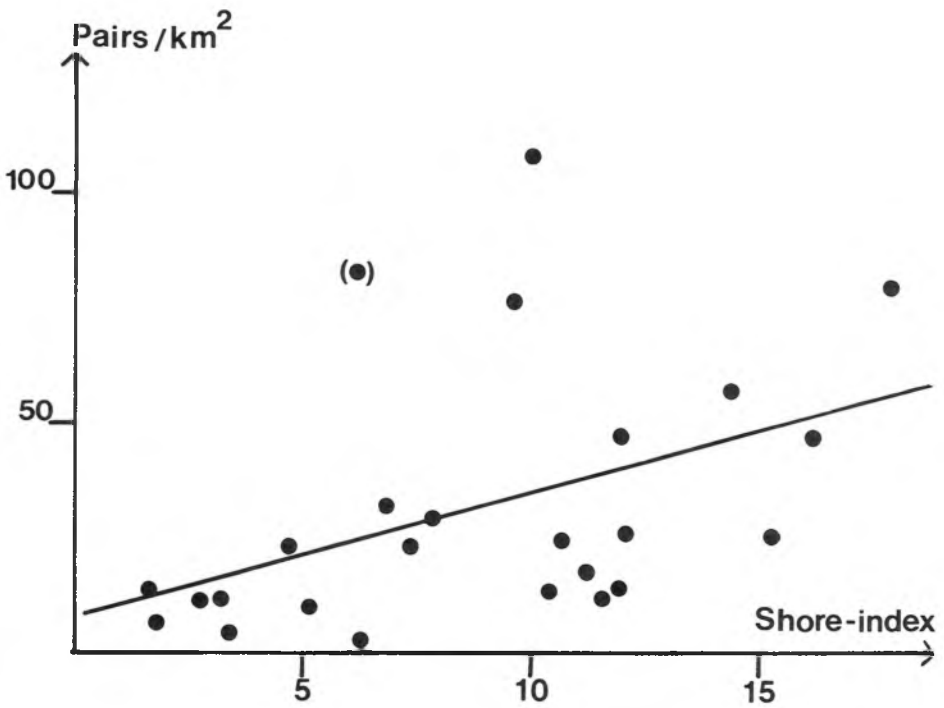

Figure 3. Relation between density of dabbling ducks *Anas spp.* and shore-index (km of shore per km² of water area). Correlation coefficient $r = 0{\cdot}45$ ($P < 0{\cdot}05$), regression coefficient $b = 2{\cdot}8$.

Mallard versus shore-index was similar to the correlation obtained for total dabbling ducks. Lakes with colonies of Black-headed Gull *Larus ridibundus* showed higher abundance of diving ducks than lakes without gull colonies, mainly being due to higher numbers of Tufted Ducks *Aythya fuligula*. The correlation between shore-index and duck abundance was even stronger when all ducks were combined and compared with shore-index on a long-basis (Figure 5).

The abundance of Coot was also significantly correlated with shore-index ($r = 0{\cdot}67$, $P < 0{\cdot}001$).

For neither ducks nor coot was there correlation between shore-index and pairs/km of shore.

The Great Crested Grebe did not show any significant correlation with shore-index when all lakes were treated together. However, for the larger heavily polluted lakes there seemed to be a linear increase in grebe pairs per km^2 with increasing shore-index. In the more moderately polluted lakes an increase was noted up to a limit at about 16–18 pairs per km^2. Three lakes fall out of this picture, the two atypical lakes 20 and 25, and lake 12. In the case of the last some reed had been eliminated, this probably affecting breeding grebes.

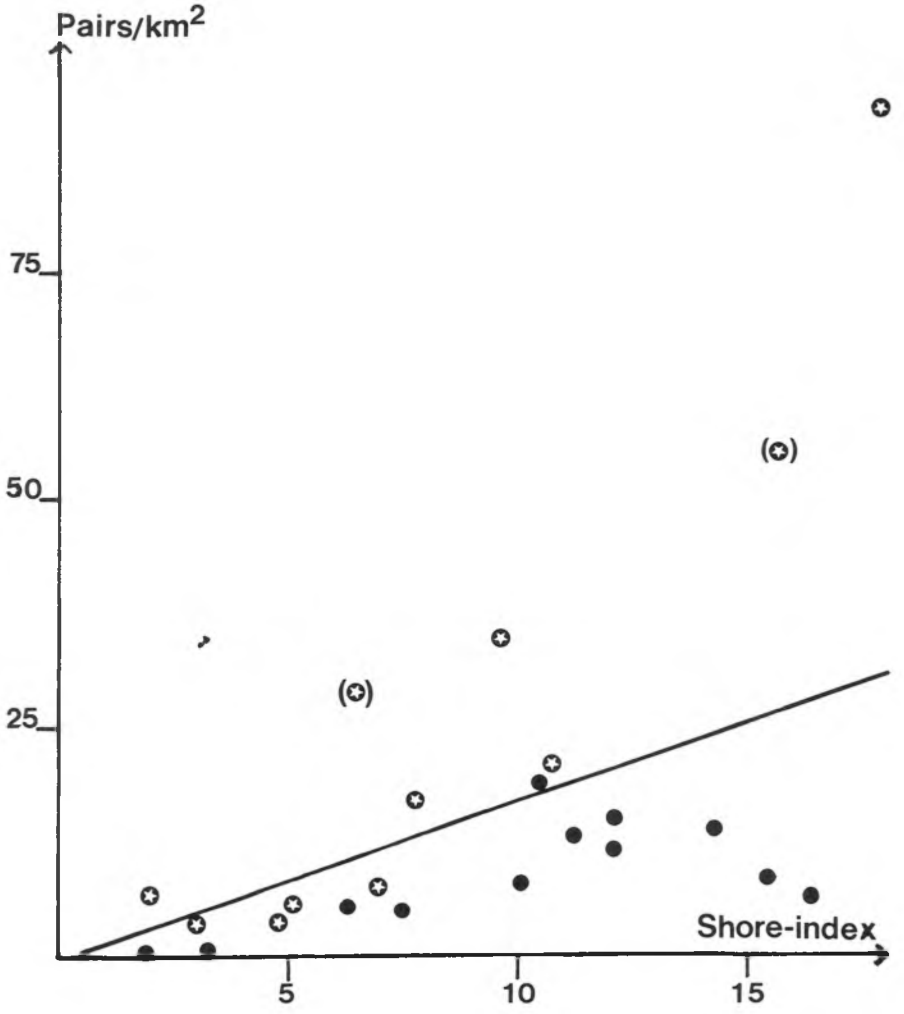

Figure 4. Relation between the density of diving ducks and shore-index. Dots = lakes without gull colonies, dates with stars = lakes with colonies of Black-headed Gull *Larsus ridibundus*. Correlation coefficient $r = 0{\cdot}45$ ($P < 0{\cdot}05$), regression coefficient $b = 1{\cdot}8$.

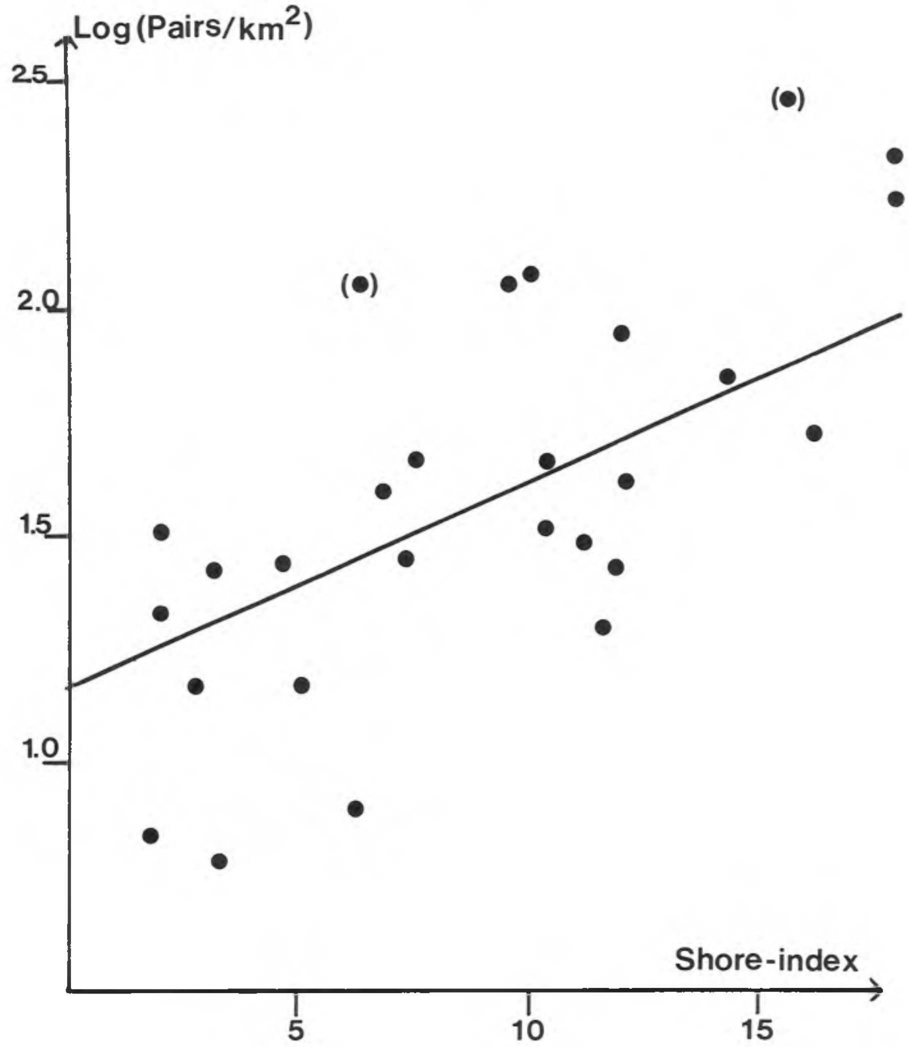

Figure 5. Relation between the overall density of ducks (on log scale) and shore-index. Correlation coefficient $r = 0{\cdot}74$ ($P < 0{\cdot}001$), regression coefficient $b = 0{\cdot}045$.

Waterfowl diversity in relation to pollution

The diversity of the waterfowl communities of the lakes studied was calculated according to the Shannon-Weaver formula, i.e.

$$D = -\Sigma p_1 \ln p_1$$

A comparison of the diversity indices for the waterfowl communities with the degree of pollution measured as log Tot-P yielded a significant negative correlation (Figure 6). In the other extreme, oligotrophic lakes probably have lower diversities than naturally eutrophic lakes or moderately polluted oligotrophic lakes. The unpolluted lake Kävsjön (not included in the graph) had a lower diversity than the other lakes. Probably some sort of bell-shaped curve would result if a whole spectrum of lakes were studied.

Discussion

Breeding duck populations are often thought to be regulated by the availability of food resources and behavioural spacing mechanisms (Dzubin 1969; Dzubin & Gollop 1972; McKinney 1965; Patterson 1976).

Females, in the period prior to egglaying and their ducklings are dependent on invertebrates during their early life (Bengtsson 1971; Bartonek & Murdy 1970; Bartonek & Hickey 1969; Krapu 1974; Swanson & Meyer 1973). A correlation between chemical factors regulating invertebrate production in the water and duck abundance could therefore be expected.

In the present study it was however not possible to find any correlation between the density of duck pairs and water chemistry (cf. also Pattersson 1976). However, the lakes were all more or less polluted with a high nutritive status (Johansson & Karlgren 1974). The heavily polluted oligotrophic lakes had higher densities of several species than clear or moderately polluted lakes. Density values reported from oligotrophic lakes in south Finland by Haapanen (1973) were also markedly lower than those found in the moderately polluted lakes in Sweden.

On the other hand, for eutrophic lakes polluted waters had lower densities of diving ducks than unpolluted ones. Ekstam (1975) reported about 10 pairs/km^2 of Pochard *Aytha ferina* from unpolluted, eutrophic Lake Tåkern compared to about 4 pairs/km^2 of all diving ducks in the polluted lakes in the present study. Similarly Onno (1970) reported much higher densities of diving ducks from Estonian eutrophic waters. On the other hand the densities of Mallard on the clean Estonian lakes were the same as those on the polluted lakes of the present study. Overall, densities for all waterfowl of the polluted lakes in south Sweden were similar to waterfowl densities reported for the eutrophic lakes of South Finland (Haapanen & Paasivirta, 1973).

In clean eutrophic lakes the free water areas are characterized by extensive meadows of submerged vegetation such as Stonewort *Chara* (Ekstam 1975), an important substrate for invertebrates of importance as duck food (Szijj 1965). *Chara* is sensitive to pollution by phosphorus (Forsberg 1964). Moreover the algal blooms of polluted lakes will reduce the available light at the bottom and will thus adversely affect the submerged vegetation. Polluted lakes will therefore lack the important submerged vegetation and will thus offer poor feeding conditions for diving ducks.

The heterogenity of the lakes was found to be a more important factor for the number of breeding duck pairs than water chemistry. This might be due to the fact that all lakes studied were more or less polluted. On the other hand Pattersson (1976) in a study of ponds in Canada found that duck populations in spring were mainly correlated with environmental heterogenity such as basin morphometry. In summer significant correlations were found between duck numbers and chemical factors of importance for food productivity. A correlation between the nutritive status of the water and the

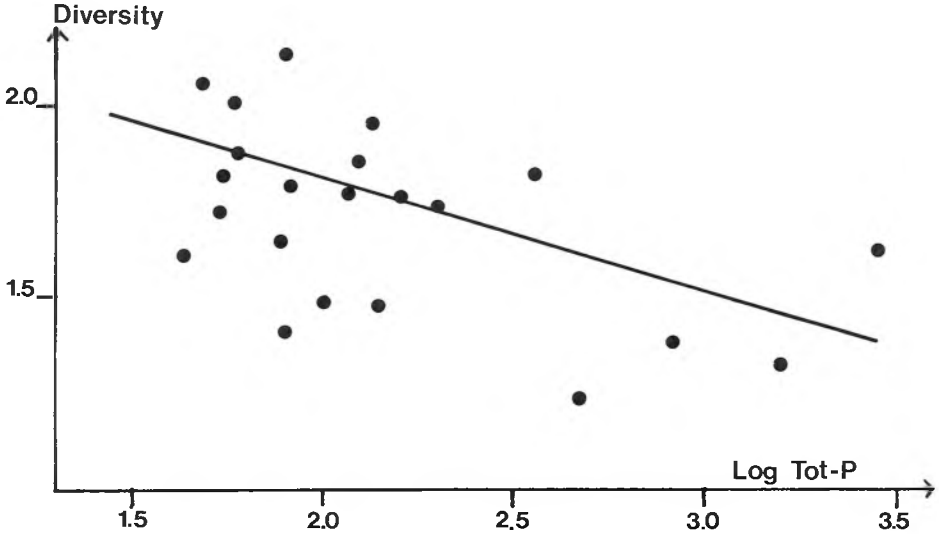

Figure 6. Relation between diversity (Shannon-Weaver index) and pollution (measured as log Total-P). Correlation coefficient $r = -0{\cdot}49$ ($P < 0{\cdot}05$), regression coefficient $b = -0{\cdot}29$.

number of roosting ducks was found in southern Germany by Utschick (1976).

In the Great Crested Grebe there was a marked increase in abundance with increasing pollution, but they were only partially influenced by environmental heterogenity. With moderate pollution they seemed to reach a maximum density, the pairs remaining territorial. In heavily polluted lakes no such limit was experienced. In these lakes the production of plankton and thus of fishes was high, allowing crowded populations of grebes which formed colonies instead of being territorial. Utschick (1976) in his study in southern Germany found a close correlation between increasing numbers of roosting grebes and the productivity of the lakes.

In the Coot no correlation was found between abundance and the nutritive status of the lakes, this species using submerged vegetation for food. Coot abundance was however positively correlated with the shore index.

The eutrophication of a formerly oligotrophic lake will thus first have positive effects on the density of breeding waterfowl although clear water species such as divers disappear. With moderate pollution most of the original species will remain, often in higher densities, and new species will appear. With increasing eutrophication the waterfowl communities will be dominated by a few species, particularly Great Crested Grebes. The pollution of a naturally eutrophic lake on the other hand will lead to a poorer waterfowl community as the important submerged vegetation is destroyed and diving ducks decrease. The decreasing diversity with increasing pollution was also found for roosting waterfowl in southern Germany (Bezzel & Reicholf 1974, Bezzel 1975, Utschick 1976).

Summary

In 1975 censuses of breeding waterfowl were undertaken in 29 Swedish lake restoration objects. These data were used to compare waterfowl abundance with chemical and physical features of the lakes. The abundance of ducks (*Anas* and *Aythya*) and Coot *Fulica atra* did not show any significant correlations with chemical factors, all lakes however were polluted to some extent. In a more general way duck and Coot abundance was higher in the richer lakes. A positive correlation was on the other hand found between shore complexity and duck abundance.

The Great Crested Grebe *Podiceps cristatus* was positively correlated with increasing amounts of total phosphorus in the water, a measure of pollution. The species diversity decreased with increasing phosphorus content.

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