RESPONSES OF RUFFE (GYMNOCEPHALUS CERNUUS (L.)) ABUNDANCE TO EUTROPHICATION

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ABSTRACT

The responses of ruffe (Gymnocephalus cernuus (L.)) abundance to eutrophication were studied in the brackish water of the Baltic Sea off Helsinki. The productivity gradients in the area permitted an analysis of the dependence of ruffe catches taken with gill nets in 1969 to 1972 on spatial differences in eutrophication level. There appeared to be a relationship between the level of primary productivity and the catch per unit effort of ruffe. The gill net catches showed that ruffe were more abundant in eutrophic than oligotrophic areas but less abundant in the most eutrophic areas. Due to the better purification of municipal sewage and the relocation of effluent discharge sites, primary production has declined in the most eutrophicated inner bays during recent decades. The responses of ruffe reproduction to these changes were studied on the basis of catches taken with small beach seines in 1982 to 1996. The number of zero-catches of 0+ ruffe increased significantly after oligotrophication, but decreased again in 1996 after the accidental reintroduction of waste waters.

INDEX WORDS: Ruffe, reproduction, abundance, eutrophication, oligotrophication, Baltic Sea, Finland

INTRODUCTION

Freshwater fish in the Baltic Sea almost exclusively inhabit nearshore areas (Ojaveer et al. 1981). There are, however, differences between species. The ruffe (Gymnocephalus cernuus (L.)) is found further offshore than any other freshwater species, regularly occurring at least 30 km offshore at a depth of 50 m, although in very low density (Lehtonen 1976). A similar decreasing trend in occurrence toward higher salinity (31 A‰) was observed in the Elbe estuary (Thiel et al. 1995). Ruffe can reproduce at salinities of up to 7 to 9‰ (Klinkhardt and Winkler 1989, Vetemaa and Saat 1996); salinity does not therefore limit the occurrence of ruffe in the sea area off Helsinki, where it is less than 5.5‰ in the surface water. The higher water temperatures in the inshore than offshore areas (Rinne 1988) seem to provide better growth conditions for fish larvae (Urho and Hilden 1990). Since there does not seem to be much difference in temperature between the inner bays with different trophic conditions (Lappalainen and Lehtonen 1995), it is possible that better growth is achieved through eutrophication (Holker and Hammer 1994).

The effects of eutrophication on fish populations were studied in the sea area off Helsinki in 1969 to 1972, at a time when municipal waste waters heavily loaded the inner archipelago areas, in particular the three inlets which are the main reproduction areas for the freshwater fish species, ruffe included. During these same years the waters in the outer archipelago and open part of the Gulf of Finland were oligotrophic. Such a situation provides a good opportunity to compare differences in fish abundance in areas with different trophic levels. Sand-strom (1986) recorded lower ruffe catches in the

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vicinity of effluent sites than in moderately polluted areas, but in some other studies the highest catches were obtained closest to a pollution site (Hansson 1987). Ruffe catches have been observed to increase along a productivity gradient (Bergman 1991), but decreasing abundances due to eutrophication of lakes have also been reported (Biro 1977, Leach et al. 1977). The responses of adult ruffe to eutrophication thus seem to be rather inconsistent. Furthermore, information about ruffe reproduction at different eutrophication levels is almost totally lacking.

Since the late 1970s better purification of sewage has led to a considerable reduction in nutrient levels, especially in the semi-enclosed inlets and bays off Helsinki. Before then the fish populations had experienced many changes, among them an increase in the biomass of cyprinids and the almost total disappearance of northern pike (Esox lucius L.), burbot (Lota lota (L.)), whitefish (Coregonus lavaretus (L.)), and ide (Leuciscus idus (L.)) (Anttila 1972). Since the 1980s the waste water has been discharged to the edge of the open sea which has improved the quality of water in the inshore inlets. These changes have resulted in a rapid decrease in primary production and some reorganization of the fish community structure.

We here examine how catches of ruffe varied among areas with different trophic status in the early 1970s and how the lower amounts of nutrients influenced the abundance of 0+ ruffe during the oligotrophication process in the 1980s and 1990s.

STUDY AREA

The study area, in the Baltic Sea off Helsinki, is characterized by an archipelago belt and three large semi-enclosed inlets with a water depth of less than 5 m. Most of the littoral areas are edged with dense reed (Phragmites australis) belts. The central inlet, Vanhankaupunginlahti, receives waters from the River Vantaanjoki, with a mean discharge of 15 to 20 m$^3$/s (Viljamaa 1988). The amount of treated sewage entering the inlets increased until 1986, after which waste water was directed 10 km offshore via a pipeline. Ten years later, in October 1995, the pipe broke and waste water was temporarily redischarged into the inlet Vanhankaupunginlahti for 6 months.

The average water depth in the archipelago belt, which extends for 7 to 12 km offshore, ranges from 10 to 20 m, the maximum being over 40 m. Outside this belt, in the open Gulf of Finland, the water is usually more than 30 m deep, reaching depths as great as 100 m. Surface salinity varies from 0 to 5.5‰, being lowest in estuaries and inlets and highest in the open sea. Variations in primary production ability are high between different areas, production being highest in the inner areas (Peso-nen et al. 1995). The chlorophyll $a$ content has diminished in all study sites since the early 1980s, most conspicuously so in the inlets. For instance, in Vanhankaupunginlahti the summer (July to September) chlorophyll $a$ content (about 30 mg/m$^3$) in the 1990s was one-fifth of that in 1970 to 1986 (Peso-nen et al. 1995). A similar decreasing trend has been observed in many other water quality variables (total P, total N, fecal coliform bacteria, blue-green algae, and primary production rate). The pipe breakage increased the phosphorus, nitrogen and bacteria contents in Vanhankaupunginlahti in 1996 (Norha et al. 1996).

MATERIALS AND METHODS

Catches from gill net fishing during the ice free period, May to November in 1969 to 1972, were used to study the dependence of ruffe catches on primary production. Water quality data were collected by Helsinki City Water Conservation Laboratory. The primary production ability (Pesonen et al. 1995) was compared with changes in 0+ ruffe catches taken with a larval seine in a rather heavily eutrophicated inlet, Vanhankaupunginlahti, in 1982 to 1996 (Fig. 1). During this period the phosphorus content decreased, resulting in a decrease in the mean value of the primary production rate, from 1,500 to 4,800 to 800 to 1,800 mg C/m$^2$Vd after 1986.

Gill net fishing was performed with a set of nets having mesh sizes of 12, 17, 20, 25, 27, 35, 40, 45, 60, and 75 mm (bar lengths). The nets were 30 m long and 1.5 m high, with 0.15 mm (mesh size 12 mm), 0.17 mm (17-45 mm), and 0.20 mm (60 mm) twine thickness. The gill nets were set out in random order after midday and lifted up the following morning, giving a 16 to 20 hour fishing period. Results are expressed as mean catch per set of nets (i.e., catch per unit effort, CPUE). The total number of fishings was 228, and the number of fishings per site ranged from 4 to 21.

The catches in 1969 to 1972 were analyzed using ANOVA, with four eutrophication zones as category variables. The zones were based on primary productivity measurements made at 1 to 6 different depths at 54 stations in 1966 to 1972 (Pesonen 1988) (Fig. 1). The year was used as a covariate to allow for inter annual
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FIG. 1. The study area and the primary production zones in the sea area off Helsinki in 1969 to 1972 drawn according to measurements made at the sampling stations (black circles) (Pesonen 1988). Primary production rate contours in units of mgC_{tot}/m^3/d.

variations. The initial analysis showed that ruffe seemed to be less abundant in the most eutrophicated areas than in moderately eu-trophicicated areas. A non-linear relationship between ruffe CPUE and eutrophication, as annual average primary production at each netting station, was tested using a quadratic regression model (SY-STAT 1992).

0+ ruffe were sampled with a beach seine measuring 10.5 m x 2.5 m, having 20-m ropes and a mesh size of 5 mm overall and 1 mm in the cod end. The samples were taken during the day. Ten sampling stations in Vanhankaupunginlahti were hauled on three occasions between 22 June and 16 August, at intervals of 2 to 4 weeks, in 1982 to 1995. Each haul covered an area of 30 to 100 m^2.

The median catch of ruffe in the seinings was below one in all years. Therefore, the seine catch of ruffe was treated as a nominal variable. The occurrence of 0+ ruffe during the discharge of waste water into Vanhankaupunginlahti (up to 1986) was compared with the situation after the waste water was led out to the outer archipelago (1987 to 95). Due to an accident in late 1995, waste water was led into the study area once again in 1996. The prevalence of 0+ ruffe in 1982 to 1995 was tested using a $\chi^2$-test in a two-way table (SYSTAT 1992) and compared with the prevalence in 1996.

RESULTS

Ruffe catches were smallest in the outer archipelago, which is part of the most oligotrophic zone (1). The slightly eutrophicated zone (2) was the only one to consist of both outer and inner archipelago areas. There the tendency of catches to decrease toward more exposed areas was significant (t-test, p < 0.05). Net catches were highest in the inner archipelago, where primary production was 200 to
TABLE 1. Effect of eutrophication on ruffe net catches (CPUE) off Helsinki. The study area was divided into four zones according to primary production: 1) <100 mg C$_{tot}$/m$^3$/d; 2) 100 to 200 mg C$_{tot}$/m$^3$/d; 3) 201 to 1,000 mg C$_{tot}$/m$^3$/d; and 4) >1,000 mg C$_{tot}$/m$^3$/d.

<table>
<thead>
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<th>Groups</th>
<th>Sum-of-squares</th>
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<th>p</th>
<th>df</th>
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<td>Covariant Year</td>
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<tr>
<td>Within groups</td>
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<tr>
<td>Bartlett test</td>
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<td>&gt; 0.10</td>
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<td>15</td>
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<td>ns</td>
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<td></td>
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1,000 mg C$_{tot}$/m$^3$/d, but decreased toward the less eutrophicated outer archipelago and the most eutrophicated bays (Table 1, Figs. 1 and 2). In the most eutrophic bay, Laajalhti, the catches were significantly smaller than in the other two inlets. Even though the catches in Vanhankaupunginlahti and Vartiokylanlahti did not differ significantly from each other, they were still considerably larger in Vartiokylanlahti, the cleaner of the two bays (Fig. 3, ANOVA, Tukey).

Year was a significant covariate for ruffe catches. Catches followed a logical development for fish population dynamics. The average CPUE was 10 ruffe in 1969, increasing to 16 in 1970, and peaking at 34 ruffe in 1971. The CPUE decreased to an average of 29 ruffe in 1972.

**FIG. 2.** Net catches (CPUE) of ruffe in 1969 to 1972 in four eutrophication zones (1= <100 mg C$_{tot}$/m$^3$/d; 2= 100 to 400 mg C$_{tot}$/m$^3$/d; 3= 401 to 1,000 mg C$_{tot}$/m$^3$/d and, 4= >1,000 mg C$_{tot}$/m$^3$/d).

**FIG. 3.** Net catches (CPUE) of ruffe in three bays with different levels of primary production. Pp = Primary production (mg C$_{tot}$/mm$^3$/d).
FIG. 4. The relationship between net catches (CPUE) of ruffe and primary production in the archipelago off Helsinki, Gulf of Finland. The line is estimated using a quadratic regression model. $\square = 1969$, $O = 7970$, $\Delta = 7977$ and $\nabla = 7972$.

The relationship between primary production (mg C$^{tot}$/m$^3$/d$^1$) and ruffe CPUE could be described with a non-linear quadratic model (Fig. 4), even if the rate of explanation was low:

$$\ln(\text{CPUE}) = a + b\ln(\text{production}) + c(\ln(\text{production}))^2 \ (n = 72, p < 0.05, R^2 = 0.31),$$

where: $a = -11.45$, $b = 5.09$ and $c = -0.43$.

The model assumed a strong asymptotic correlation between the parameters estimated ($a - b = -0.99$, $a - c = 0.98$, $b - c = -1.00$). Within 95% confidence limits, CPUE could be anything from virtually non-decreasing to zero at high primary production levels. The model overestimated the catches from 1969 and 1970, but underestimated those from 1971 and 1972. The residuals did not, however, differ significantly between the years.

As long as the sewage plant conducted waste water into Vanhankaupunginlahti Bay, 0+ ruffe frequently occurred in seine catches. During this period, 1982 to 1986, the inter-annual variation in zero-catches was 58 to 80%. Once the pipeline to the outer archipelago had been constructed, the frequency of zero-catches increased significantly (Table 2) and in 1987 to 1995 the inter-annual variation of zero-catches was 80 to 100%. Within 1 year after the accident the frequency of zero-catches had fallen to 55% (Fig. 5).

**DISCUSSION**

In an investigation of fish assemblages in 179 Finnish lakes, Jarnefelt (1949) found ruffe in all eutrophic lakes studied as well as in most oligotrophic, dystrophic, and mesotrophic lakes. He concluded that ruffe favors eutrophic and dystrophic lakes, being a dominant species in them. Falk (1969) observed that ruffe made up over 50% of gill net catches in eutrophic areas of Lake Saimaa, but only 4% in oligotrophic areas. Several authors (e.g., Fedorova and Wetkasow 1974, Diehl 1988, Bergman 1991, Orpana 1991, Bergman and Greenberg 1994, Rosch et al. 1996) have suggested that, as a generalist feeder, ruffe is a better competitor for food than, say, perch and many cyprinids. This is due to the ruffe’s well developed sensory organs, especially in eutrophic or turbid waters, where light intensity is low (Disler and Smirnov 1977, Gray and Best 1989, Popova et al. 1997).

Changes in fish population size are often associated with eutrophication (Anttila 1972, Leach et al. 1977, Bergman 1990). Ruffe is generally considered to be a species able to benefit from eutrophication (Jarnefelt 1949, Anttila 1972, Lind 1977), a viewpoint supported by our findings. There may, however, be a level of eutrophication above which the abundance of ruffe begins to decline. In the early 1970s ruffe catches were
TABLE 2. Effect of wastewater on seine catches of 0+ ruffe in Vanhankaupunginlahti Bay. Ruffe abundance is expressed as number of zero-catches per haul with ruffe catches, analyzed as pre (1982 to 1986) vs. post (1987 to 1995) removal of wastewater.

<table>
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<tr>
<td>Presence of ruffe</td>
<td>0</td>
<td>68</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>n</td>
<td>170</td>
<td>280</td>
<td></td>
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</table>

lower in the most eutrophic western inlet (Laajalahti) than in the other two inlets studied. The slightly eutrophic, eastern inlet (Vartiokylanlahti) had the highest ruffe CPUE of all fishing sites. The most probable reason for the low ruffe catches in the western inlet was the lower oxygen content in late winter, when oxygen saturation was, on average, only 20 to 30% (Peso-nen 1971). In the very eutrophic, central inlet oxygen conditions were better, primarily due to water entering it from the River Vantaanjoki. We cannot, however, exclude the possibility that catchability, too, may be lower in the most eutrophicated areas than in less eutrophicated areas. Bergman (1991) found that ruffe catches increased with the increasing productivity gradient, the maximum of which, however, remained at the level at which the catches in our area began to decline.

A partial reason for the higher ruffe CPUE in nearshore areas may be spawning site preference. Fairchild and McCormick (1996) found that normal production of ruffe larvae was not possible at temperatures below 6°C. In the Baltic Sea, the shallow inshore inlets are warmer and less exposed to up-wellings of cold water than the outer areas and so are much more suitable for larval production.

Our results imply that the reproduction of ruffe is sensitive to changes in water quality, a tendency that may induce high fluctuations in the year-class strength. Rather early in their development, ruffe larvae favor a secretive mode of life, inhabiting the near-bottom strata. By the time they have reached a size of 20 mm, ruffe larvae have well-developed sensory systems, body form, and pigmentation and are well-adapted to demersal life (Disler and Smirnov 1977, Urho 1996). The beach seine is not therefore the best gear for catching young ruffe, as was also shown by our small catches. Kjellman et al. (1996) took the largest catches of ruffe in non-vegetated sites of a vegetation belt, where catches of other 0+ fishes were lowest. There are two explanations for this: either 0+ ruffe escape under the seine in vegetated areas or they are able to utilize the open water areas that other species avoid. The latter explanation is supported by our findings that in 1996 the frequency of zero-catches of 0+ ruffe was lower than before. At the same time, other abundant fish species reacted in the opposite manner (Table 3). It seems that, already as larvae, ruffe might be able to fill the open niches. There are also indications that a low dissolved oxygen content may affect the predation pressure on estuarine fish larvae (Breitburg et al. 1994). We found that ruffe are able to reproduce at a rather high level of eutrophication, although the larvae may suffer fin damage (Urho 1989), and hence later survival is not guaranteed.

<table>
<thead>
<tr>
<th>Species</th>
<th>1982–86</th>
<th>1987–95</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring (Clupea harengus)</td>
<td>10</td>
<td>53</td>
<td>3</td>
</tr>
<tr>
<td>Smelt (Osmerus eperlanus)</td>
<td>252</td>
<td>1,158</td>
<td>76</td>
</tr>
<tr>
<td>Perch (Perca fluviatilis)</td>
<td>22</td>
<td>142</td>
<td>4</td>
</tr>
<tr>
<td>Pike-perch (Sizostedion lucioperca)</td>
<td>9</td>
<td>33</td>
<td>1</td>
</tr>
<tr>
<td>Roach (Rutilus rutilus)</td>
<td>122</td>
<td>33</td>
<td>2</td>
</tr>
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</table>

To conclude, it is evident that ruffe could be one of the most successful benthic feeders in hypereutrophic waters. However, it requires a high oxygen content (Kovac 1997), and this is not common in eutrophic waters in winter. Although the evidence is indirect, we suggest that a low oxygen content may become a restricting factor for the abundance of ruffe in hypereutrophic areas even if reproduction were to succeed.

REFERENCES


