Influence of fish pond culture on the fish fauna of Ladoga Lake

N P Milyanchuk, N V Ilmast, O P Sterligova
Institute of Biology KRC RAS, Petrozavodsk, 185910 Russia
e-mail: ilmast@mail.ru

Abstract. The species composition and biological indices of Ladoga Lake fish near trout farms were studied. Water bodies with commercial rainbow trout production were found to be polluted mainly by nutrients and fish metabolic products that activate eutrophication processes. The functioning of a trout farm was shown to affect the fish population structure of the lake. Fish with spring spawning are preferred. Roach, perch and ruff now predominate in the fish farm area. Fish aggregates in the lake differ considerably in biomass from those in open lake zones. Fish density indices near the fish pond lines were observed to increase almost twofold. Local fish species aggregate near the fish ponds because they eat trout food. The linear and weight growth rates of roach, perch and ruff near the fish ponds were shown to be much higher than those in the remote zones of the lake, because the above fish also eat the leftovers of trout food washed out of the fish ponds. Commercial trout production requires integrated monitoring for assessment of the current condition of the water bodies affected by fish farming.

1. Introduction
Aquatic ecosystems are known to be influenced by both climatic (variations in water regime and temperature) and anthropogenic (commercial fishing, pollution, introduction of alien species, etc.) factors. The influence of economic activities on natural ecosystems is steadily increasing [1, 2, 3, 4, 5, 6]. One type of anthropogenic influence on water bodies is artificial breeding of aquatic organisms.

The need to develop aquaculture, primarily fish farming, is due to a decline in the production of fish and other aquatic organisms in sea water and the unstable condition of the fish stock in freshwater bodies. In the Republic of Karelia, the commercial production of the rainbow trout *Parasalmo mykiss* (Walb.) was launched in the 1980s. By now, its annual production rate has increased to over 20 000 t. Karelia is a national leader in commercial rainbow trout farming (about 70%); annual trout production is expected to increase to 30 000-35 000 t.

Success in fish culture is provided by abundant water resources, a favourable climate, a well-developed transportation network and skilled staff. As fish prices are moderate, high-quality profitable commercial products from fish ponds are made available over a short time (1.5 years). Over 60 trout farms, located mainly in freshwater zones, now function in Karelia.

It is known that the construction of a fish farm is equal in the pollution rate of natural water bodies to the putting in operation of a small factory or plant. Large amounts of food, metabolic products and medicinal preparations from trout farms are discharged into Karelia’s lakes. Therefore, a considerable increase in commercial trout production in the northern region may result in their rapid eutrophication. The increasing use of natural water bodies for fish culture disturbs the hydrological, hydrochemical and...
hydrobiological regimes of aquatic ecosystems [7]. The ongoing functioning of fish farms also affects the aboriginal fish fauna of water bodies. Yet, the scope of scientific research in this field is very small.

The Ladoga is Europe’s largest freshwater lake. Natural conditions were conducive for the formation of a lake ecosystem with high-quality water, but in the early 1960s signs of man-induced lake eutrophication were observed.

The Ladoga Lake watershed area is known as a highly developed economic zone with more industrial plants than in other parts of Russia. In the past decade, human economic activities in the watershed area have become more extensive. Therefore, nitrogen and phosphorus concentrations in the water bodies of northern Priladozhye have increased. Eutrophication is most obvious in the most heavily polluted lake bays. There are now several trout farms in the skerries. Active fish farms are local, but they contribute markedly to eutrophication.

The goal of our project is to study the structure and dynamics of Ladoga Lake’s fish population affected by large-scale commercial fish farming.

2. Materials and methods
Fish samples were taken from Jakimvaara Bay of Ladoga Lake in 2016–2018. Samples were collected in and away (about 5 km) from fish ponds. Experimental fishing was done using 30 m long and 1.8 m high nets (15-40 mm mesh). The nets were placed at various depths and were exposed for 12 hours. The fish samples were processed by standard methods [8, 9]. The length, body mass, sex and gonad maturity of the samples were estimated. To determine the age of the fish, the scales, gill covers (operculum) and otoliths were sampled and analyzed. Abundance indices, understood as the size of catch per unit of fishing effort, were used for comparing fish abundances in various fishing zones.

Ladoga Lake (61°09ʹ N, 31°20ʹ E), located in the Neva River watershed, is part of the Baltic Sea basin. Its water area makes up 40% of Karelia. Depths in excess of 100 m are typical of the northern Ladoga. An important fish farming lake in NW Russia, the Ladoga is fed from the watershed basin covering an area of 258 km² [10]. The Ladoga can be described as a mesotrophic type of lake, as indicated by the quantitative characteristics of plankton and benthos. The main morphometric characteristics of Ladoga Lake are shown in Table 1.

| Characteristic                  | Value    |
|--------------------------------|----------|
| Surface area of the lake, km²  | 17700    |
| Islands area, km²              | 457      |
| The volume of the lake, km³    | 910      |
| Average depth, m               | 51       |
| Greatest depth, m              | 230      |
| Catchment area, km²            | 258300   |

3. Results and discussion
The fish fauna of Ladoga Lake consists of 43 species. Whitefish, vendace, smelt, perch, roach, pike-perch, bream, pike, ruff and burbot are of special commercial value.

The current condition of commercial fishing is controlled by both natural and anthropogenic factors. The former are related to a stage at which Ladoga Lake’s production potential has decreased. Natural factors are accompanied by the influence of human activities (increased amounts of nutrients and toxic substances discharged into the lake, the poor condition of spawning grounds, the construction of hydropower plants, illegal fishing, etc.). Catches of practically all commercial species are now observed to decline. Some of the species become rare and endangered, while others become less abundant, although they remain commercially valuable.

The condition of the fish fauna in of northern Ladoga Lake (Jakimvaara Bay) in the fish farm area was assessed. Analysis of experimental catches has shown that the fish population of the bay consists
of 5 species of 4 families: vendace, smelt, roach, perch and ruff. Roach, perch and ruff were most abundant in the fish pond area.

Roach (*Rutilus rutilus*) is an aggregative, abundant, ubiquitous fish. Its abundance is controlled mainly by natural mortality and to a lesser extent by catching. Ladoga roach becomes sexually mature in the fourth year of life, when it has an average length of 13 cm and a mass of 40 g. The age composition of control catches was represented by individuals of 2+ to 10+; 5+ to 10+ fish predominated (over 50%). The fish varied in length from 10.5 to 21.5 cm and in mass from 15 to 180 g (Fig. 1). Comparative analysis of roach growth has shown that its linear-weight indices in the trout pond area are much higher than those of roach from the remote parts of the lake (control).

![Figure 1. Weight growth of the roach of Lake Ladoga](image)

Perch (*Perca fluviatilis*) is widespread in Ladoga Lake. It becomes sexually mature in the third year of life, when it has a length of 11-12 cm and a mass of 20-30 g. The age composition of perch catches in the fish pond area consisted of 2+ to 9+ individuals; fish in the third and fifth year of life prevailed (about 70%). The samples had a length of 10.5 to 24 cm and a mass of 22 to 230 g (Fig. 2). Comparative analysis of perch growth shows that age 2+ to 6+ fish in the fish pond area display elevated linear-weight indices; fish older than 7 years do not show valid differences in growth.

Ruff (*Gymnocephalus cernuus*) is an aggregative bottom fish which occurs near the shore and in the central zone of the lake. It becomes sexually mature at the age of 2-3 years, when it has a length of 5-8 cm and a mass of 6-7 g. The age composition of control catches consisted of four age groups (1+ - 4+); four-year-old ruff predominated (около 50%). The fish varied from 5 to 11.9 cm in length and from 3 to 26 g in mass (Fig. 3). Analysis of ruff growth has indicated that the samples from the trout pond area display elevated linear-weight indices. For example, age 1+ samples from the fish pond area had a length of 6.6 cm and those from the control group 5.1 cm; age 2+ samples had a length of 8.8 cm and 7.2 cm; aged 3+ samples 9.9 cm and 8.9 cm; and aged 4+ samples 11.3 cm and 11 cm, respectively.
To describe the space-time fish distribution pattern, density indices, understood as catches per unit of fishing effort, were used. A unit of fishing effort is understood as catch (individuals) per unit of time (one hour) per unit area (1000 m$^2$) of net cloth. Analysis of the fish density index in the trout pond area was 0.867 inds./m$^2 \times h \times 10^3$ and that in the control zone 0.493, respectively.

4. Conclusions

Thus, the analytical results of our studies have shown that the fish population of the trout pond line area in Ladoga Lake is dominated by spring spawning carp and perch species (over 90%). The functioning of the trout farm in the lake is indicated by increased nutrient concentrations; this, in turn, results in more active eutrophication caused mainly by the food and metabolic products of fish. The studies have revealed substantial differences in the biomass of fish aggregates that vary with distance from the farm. Accessible food discharged continuously from the fish farm is the main factor responsible for the formation of fish aggregates near the nursery ponds. The linear and weight growth rate of fish near the
nursery ponds was found to be much higher than that of fish from the remote zones of the lake. This is due to extra food, trout food leftovers, washed out from the nursery ponds and made available to the fish. The functioning of the trout farms was shown to affect the hydrochemical and hydrobiological regimes, as well as the fish population of Ladoga Lake. Fish that spawn in spring and eat mainly benthic organisms (roach, perch and ruff) are preferred. Analysis of our results shows that commercial trout farming requires integrated monitoring for assessing the current condition of the water bodies used.

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