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Establishment of the Baikalian endemic amphipod *Gmelinoides fasciatus* Stebb. in Lake Ladoga

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Abstract

Gmelinoides fasciatus Stebb., a small amphipod from the Lake Baikal basin, was discovered in July 1988 in Lake Ladoga, the largest European lake. *G. fasciatus* likely invaded Lake Ladoga as a consequence of its intentional introduction, aimed at enhancing fish production, in some Karelian Isthmus lakes close to Lake Ladoga's western shore in the early 1970's. Benthos studies conducted in 1989 and 1990 revealed that *G. fasciatus* was well established in littoral communities along the western and northern shores of Lake Ladoga. *G. fasciatus* was the dominant species in these littoral communities and contributed over 70% of the macroinvertebrate biomass. The species was abundant in different macrophyte beds and stony littoral areas, both in heavily polluted and undisturbed sites. The maximum abundance and biomass of *G. fasciatus* was about 54,000 ind m^{-2} and 160 g (wet wt.) m^{-2}. Negative impacts of *G. fasciatus* on native species have been observed. Studies are needed to identify the effects of *G. fasciatus* on the functioning of littoral communities and to predict and control the spread of this amphipod.

Introduction

The invasion of freshwater ecosystems by exotic invertebrates has recently captured the attention of the scientific community. Well-documented examples of such events include the establishment of dense non-indigenous populations of the bivalve mollusc *Dreissena polymorpha* (Pallas), and the cladoceran crustacean *Bythotrephes cederstroemi* (Schoedler) in the North American Great Lakes. These species were introduced into the Great Lakes in the mid-1980's from their native habitats in Europe probably as a result of ballast water discharge from trans-oceanic ships. They spread rapidly throughout the five Laurentian Great Lakes and have been transported to other lakes and rivers in North America (Garton & Berg, 1990; Griffiths *et al.*, 1991; Yan *et al.*, 1992). Lake Ladoga has been considered a possible source of *Bythotrephes* (Sprules *et al.*, 1990). The negative impacts of *Dreissena* and *Bythotrephes* on the ecosystems of the Great Lakes have been extensively discussed (Lehman, 1987; Griffiths *et al.*, 1991; Hebert *et al.*, 1991; Haag *et al.*, 1993; Lehman, 1993; Vanderploeg *et al.*, 1993).

Unlike the unintentional introductions of exotic invertebrate species in North America, the exotic species invasions in Russia have in many cases been deliberate. Large-scale introductions of exotic invertebrates into lakes and reservoirs were planned to enhance fish production. The small Baikalian amphipod *Gmelinoides fasciatus* Stebb. (maximum size about 15 mm) was considered one of the most suitable animals for such introduction because of its ability to adapt to varying environmental conditions in the shallow zone of lotic and lentic ecosystems, and its high productivity (Greze, 1951; Bekman & Bazikalova, 1951; Bekman, 1962). Originally endemic to the Baikal basin, *G. fasciatus* was introduced during the 1960's and 1970's into several lakes and reservoirs in the European part of Russia and in Siberia (Ioffe & Nilova, 1975; Mitskevich, 1984; Zadoenko *et al.*, 1985; Fig. 1). Its ability to actively migrate and its predatory habits were not considered (Bekman, 1962). As a result, *G. fasciatus* has spread quickly from the introductions and has had strong negative impacts on native species in many lakes (Borodich, 1979; Safronov, 1993).

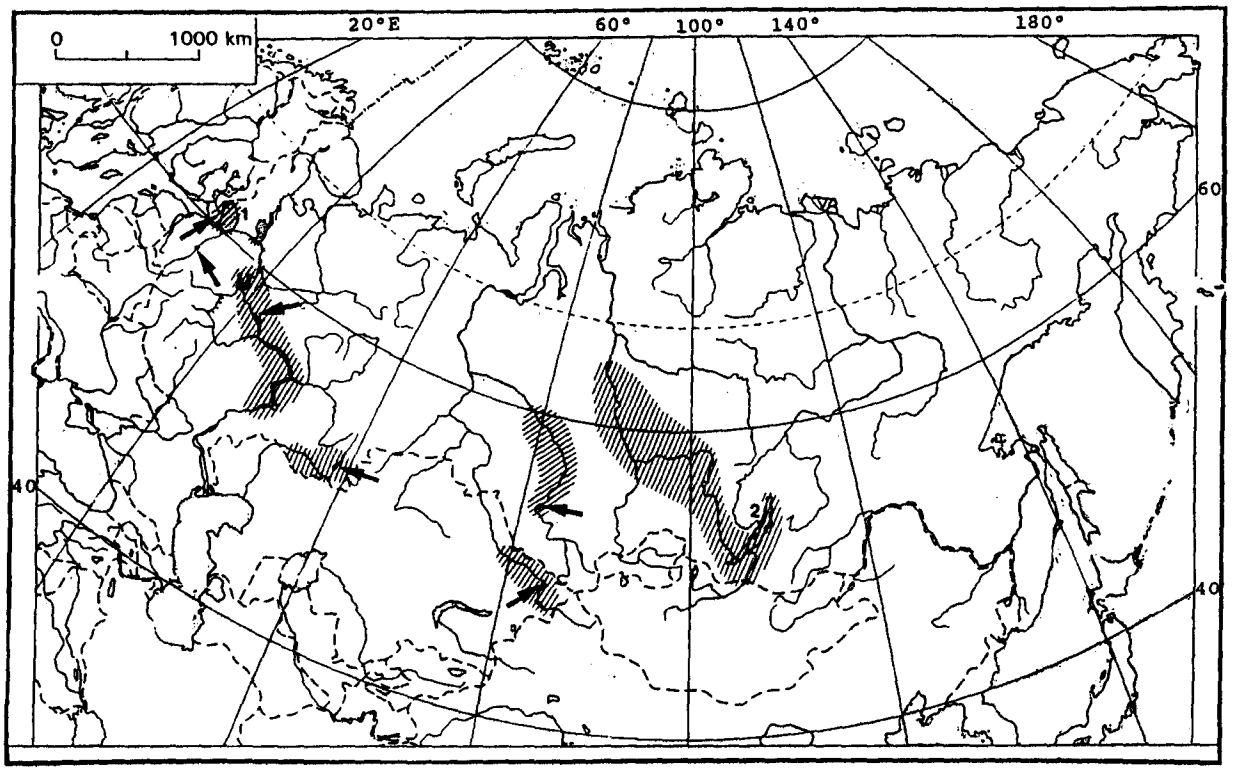

Fig. 1. Worldwide distribution map for *Gmelinoides fasciatus*. Arrows indicate sites of its intentional introductions. 1 – Lake Ladoga; 2 – Lake Baikal

G. fasciatus was first described in Lake Baikal in 1874 by B. Dybowsky, who named this amphipod *Gammarus zebra*, for its specific striped colour pattern (Bazikalova, 1945). *G. fasciatus* seems to resemble the zebra mussel *Dreissena polymorpha* not only in body coloration, but in its potential to be a successful invader. This study describes the establishment of *G. fasciatus* in Lake Ladoga, the largest European lake, following its deliberate introduction into some Karelian Isthmus lakes during the early 1970's (Arkhiptseva *et al.*, 1977).

Material and methods

Quantitative samples from altogether 70 sampling points at 41 locations, representing the major macrophyte associations in the littoral zone of Lake Ladoga, were collected during three cruises in the July months of the years 1988–1990. These cruises comprise the first extensive set of macrophyte habitat sampling of Lake Ladoga, and most locations and sites were sampled for the first time. Sampling was performed in littoral vegetation with a large tube sampler (diam. 0.4 m, height 1.4 m; for the device and sampling technique, see Panov & Pavlov, 1986). Each sample contained macrophytes, debris, detritus, and animals collected from 0.125 m^2 of bottom. Because of the arduous processing of such large samples, only one sample was collected at each sampling site. The sampling device was previously used in the Neva Bay, Gulf of Finland, where the littoral communities are very similar to those of Lake Ladoga in terms of the main macrophyte associations, structure of benthic communities, and density of macroinvertebrates. In the Neva Bay study the differences between replicate samples were generally less than 20% and 30% for total abundance and biomass estimates, respectively (Panov & Pavlov, 1986). Based on these data, one sample per site was considered sufficient for a preliminary quantitative survey of Lake Ladoga littoral communities.

Qualitative sampling by hand net was conducted in stony littoral areas. Both quantitative and qualitative samples were preserved in the field with a 4–5% formalin solution. In the laboratory, macroinvertebrates were separated from the substratum, sorted, weighted on a

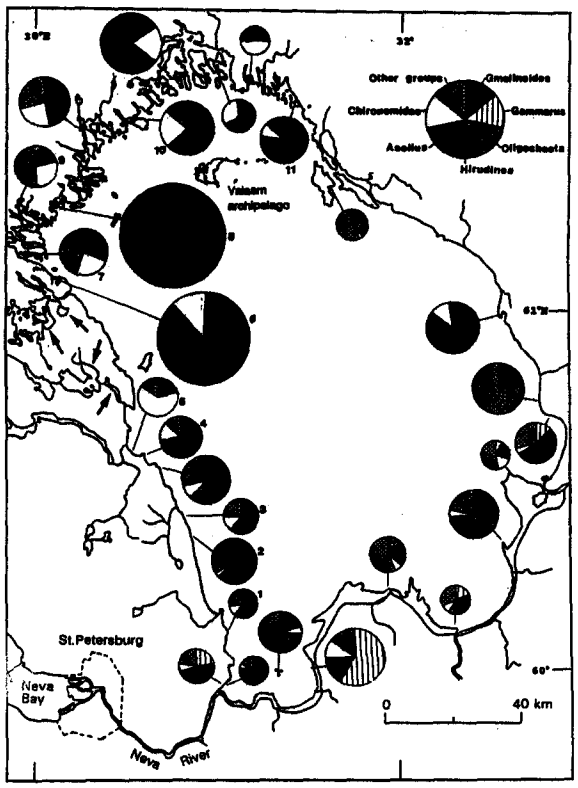

Fig. 2. Structure of littoral communities of macroinvertebrates in Lake Ladoga in 1988–1990. Areas of the circles are proportional to biomasses. Arrows indicate sites of the initial *Gmelinoides fasciatus* introductions in lakes of the Karelian Isthmus in the early 1970's. *G. fasciatus* was encountered in Lake Ladoga at the sites indicated with numbers.

torsion balance with 0.1 mg precision and preserved in 60% alcohol.

Results

The first individuals of *Gmelinoides fasciatus* were found in 1988 in quantitative samples of macroinvertebrates in beds of *Phragmites* and *Potamogeton* in the Petrokrepost Bay, south-western Lake Ladoga (Fig. 2). In the 1989–90 collections, *G. fasciatus* was recorded in almost one third of the 50 quantitative samples in macrophyte beds in western and northern Lake Ladoga.

G. fasciatus was the dominant species in many macrophyte beds as well as in stony littoral areas along the western and northern shores where it comprised over 70% of the total macroinvertebrate biomass. *G. fasciatus* was abundant both in heavily polluted and

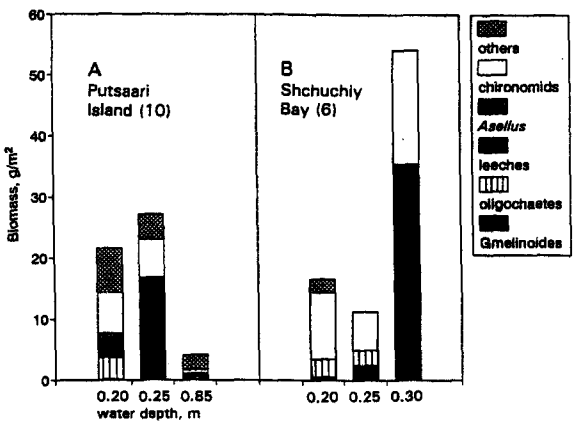

Fig. 3. Horizontal distribution of *Gmelinoides fasciatus* along littoral transects near the Putsaari Island (Site 10 in Fig. 3; A) and in the Schuchiy Bay (Site 6; B). Water depths at the sampling sites indicated below the bars.

Table 1. Selected data on the littoral sampling sites of Lake Ladoga where *Gmelinoides fasciatus* was found in late July samples in 1988–1990 (cf Fig. 2). Site coordinates, water depth, dominant vegetation, and *G. fasciatus* abundance and biomass are provided.

Site	Coordinates	Depth (m)	Macrophyte association	Abundance (ind m^{-2})	Biomass (g m^{-2})
1	60°06.2′N, 31°05.0′E	0.9	*Phragmites**	24	0.07
2	60°22.9′N, 30°53.0′E	0.2	Mixed	8	0.02
3	60°34.2′N, 30°40.8′E	0.8	*Phragmites*	32	0.06
4	60°36.2′N, 30°36.3′E	0.8	*Phragmites*	168	0.17
5	60°37.1′N, 30°32.1′E	0.7	*Phragmites*	264	0.88
6	61°04.8′N, 30°05.4′E	0.5	*Typha**	37,400	121.00
7	61°08.8′N, 29°56.0′E	0.7	*Phragmites*	16	0.13
8	61°16.8′N, 30°06.8′E	0.4	*Eleocharis**	53,800	158.60
9	61°17.6′N, 29°53.6′E	0.7	*Phragmites*	32	0.32
10	61°31.2′N, 30°33.4′E	0.25	*Carex**	17,000	16.20
11	61°34.8′N, 31°27.2′E	0.4	*Carex*	2,770	11.80

* At these sites, *G. fasciatus* was also encountered in other macrophyte beds.

in undisturbed sites. The maximum abundance (about 54,000 ind m^{-2}) and biomass (about 160 g (wet wt.) m^{-2}) of *G. fasciatus* was found in *Eleocharis* beds in a small oligotrophic bay of Kojonsaari Island (Site 8 in Fig. 2). A dense population of *G. fasciatus* was also found in *Typha* beds of the eutrophic Shchuchiy Bay (Site 6) where its abundance and biomass averaged about 37,000 ind m^{-2} and 120 g m^{-2}, respectively. In stony littoral areas of Shchuchiy Bay the densities were probably even higher. *G. fasciatus* appears to have been one of the first macroinvertebrates to colonize this bay after elimination of pulp mill discharges in 1986. *G.*

fasciatus was also dominant in *Carex* beds in Pitkäranta Bay which were heavily polluted by oil products, and in other northern locations. The biomasses of *G. fasciatus* encountered in Kojonsaari and Shchuchiy Bay were five to ten times greater than the mean total macroinvertebrate biomasses of the macrophyte associations of Lake Ladoga (Fig. 2). In all habitats studied, the most dense populations of *G. fasciatus* were recorded at depths of 0.25–0.5 m (Fig. 3, Table 1).

In sites with dense populations of *G. fasciatus*, the abundance of other macroinvertebrates was usually much lower than in communities without this species. The native amphipod, *Gammarus lacustris* Sars, was the dominant species in stony littoral areas of western Lake Ladoga in the 1960's (Kuzmenko, 1964), but it was completely replaced by *G. fasciatus* by the late 1980's. In stony littoral areas, the native communities of *Gammarus* and abundant fauna of stoneflies, caddisflies and mayflies were found only along the shore of Valaam Island in the centre of northern Lake Ladoga where *G. fasciatus* was absent. In macrophyte beds *G. fasciatus* and *Gammarus* were very seldom found together. The isopod *Asellus aquaticus* (L.) was also scarce in sites with abundant *G. fasciatus*. *Gammarus* was abundant in sites at the southern shore, where *G. fasciatus* was not encountered (Fig. 2).

Discussion

After its intentional introduction in the early 1970's into some lakes on the Karelian Isthmus close to Lake Ladoga's western shore (Fig. 1), *Gmelinoides fasciatus* was able to spread by active swimming upstream and downstream. The spreading of *G. fasciatus* into Lake Ladoga might have taken place already in the late 1970's, since when it has successfully established itself as the dominant macroinvertebrate in some littoral communities along the western and northern shores.

The densest populations of *G. fasciatus* in Lake Ladoga exceed the typical maximum figures reported in other water bodies. Usually its abundance and biomass do not exceed 15,000 ind m^{-2} and 20–30 g(wet wt.) m^{-2}, respectively (Borodich, 1979; Mitskevich, 1984; Savateeva, 1985; Vizer, 1986). The maximum biomasses registered in its native habitats in Lake Baikal basin are 60–100 g(wet wt.) m^{-2} (Bekman, 1962).

This study revealed negative effects of established populations of *G. fasciatus* on other members of the littoral macroinvertebrate communities in Lake Ladoga, especially on the native amphipod *Gammarus lacustris*. *G. fasciatus* is known to negatively influence *Gammarus* in Eastern Siberia, and is considered as the main biotic factor limiting *Gammarus* distribution and abundance in that region (Vizer, 1986; Safronov, 1993). Marked decline of native Caspian amphipod populations was observed in Gorkovskoye Reservoir of the Volga River after intentional introduction of *G. fasciatus* (Borodich, 1979).

The adverse effects of *G. fasciatus* on native species are probably due to both effective competition and direct predation. *G. fasciatus* is one of the smallest freshwater amphipods in Europe, and it has a rather short generation time (approximately 1.5 months for females in the shallow bays in Lake Ladoga). *Gmelinoides* individuals hatched in late May and early June are able to breed in July, having attained a body length of about 4 mm. In contrast, *Gammarus* in Lake Ladoga are not able to reach sexual maturity during their first summer. *Gammarus* females must reach a body length of at least 8 mm before they mature. While the young of *Gammarus* are produced primarily only in June of each year, recruitment of newly hatched *G. fasciatus* occurs throughout much of the summer (Panov, unpublished data).

Both *Gmelinoides fasciatus* and *Gammarus lacustris* are omnivorous animals that are able to feed on detritus, plant debris and periphyton, but they prefer to prey on small invertebrates. *Gammarus*, in littoral macrophytes in the Neva Bay, have been shown to actively migrate to areas with high abundances of small invertebrates, and to concentrate in habitats with low structural complexity where they can forage more effectively (Panov, 1988). Active migrations of *G. fasciatus* were recorded after the sudden appearance of large numbers of cladoceran crustaceans in Shchuchiy Bay of Lake Ladoga (A.I. Nikolaev, Aquarium Service Company "Genus", St. Petersburg, pers. comm.). Diel migrations of *G. fasciatus*, possibly related to the foraging behaviour of this species, have also been registered in Shchuchiy Bay. The amphipods concentrate in macrophyte beds and upper stony littoral during the day, presumably to escape fish predation. *G. fasciatus* is able to effectively prey on cladoceran crustaceans. Individuals in our aquaria fed aggressively on small and medium sized *Daphnia magna*. In aquaria initially without *Daphnia*, the pattern of distribution of *Gmelinoides* changed just minutes after *Daphnia* were introduced, as the *Gmelinoides* began to actively swim after and catch these planktonic crustaceans. These obser-

vations seem to suggest that *G. fasciatus* is a more effective littoral predator than *Gammarus*, but there are no quantitative comparative studies. In the absence of animal food in aquaria, *G. fasciatus* can consume detritus and periphyton, and it can survive at least one month without any food (A.I. Nikolaev, pers. comm.). Its active preying on cladoceran crustaceans suggests that *G. fasciatus* might even have a detrimental impact on some life stages of littoral fishes through competition for food.

G. fasciatus seems to be better able to escape fish predation than *Gammarus lacustris*, and it is also much more resistant to various kinds of pollution and low dissolved oxygen levels than *Gammarus*. Because *G. fasciatus* is known to spread rapidly across water basins through active upstream and downstream migrations (Borodich, 1979; Safronov, 1993; Panov, unpublished data), its future establishment along the eastern and southern shores of Lake Ladoga, as well as its further spreading into other streams and lakes of the Lake Ladoga drainage basin, including such large water bodies as Lake Onega and Lake Saimaa also appears probable. Even though *Bythotrephes cederstroemi* was recently introduced into the North American Great Lakes, presumably from Lake Ladoga in ballast water of ships (Sprules *et al.*, 1990), a similar introduction of *G. fasciatus* into other European and North American water basins is not so likely, because it is restricted to littoral areas. Unfortunately another possibility for *G. fasciatus* to invade water basins in Europe and North America now exists, because this species is being exported to developed countries as live food for aquarium fish.

Further research is needed to identify the impacts of *G. fasciatus* on the littoral communities of Lake Ladoga, as well as to predict and control the spread of this amphipod. Such research efforts should include studies of distribution, abundance and life history of *G. fasciatus* in lakes of Karelian Isthmus and in Lake Ladoga, patterns of migrations, prey preferences, predation rates, and interactions with other invertebrates and fish in littoral communities.

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