Role of river crayfish *Pontastacus leptodactylus* (Esch.) in maintaining the stability of freshwater bodies in Eurasia

E N Alexandrova¹ and K L Tarasov²,³

¹ The all-Russian Research Institute of integrated fish farming (VNIIR) – branch of the Federal State Budgetary Scientific Institution "Federal Research Center for Livestock – VIZh", Moscow Region, Noginsk District, Pos. Vorovskogo, Russia
² Moscow State University, Faculty of Biology, Department of Mycology and Phycology, Moscow, Russia
³ E-mail: coltar@yandex.ru

**Abstract.** The role of the long-toed crayfish (*Pontastacus leptodactylus leptodactylus*) in the hydrocenosis of a water body in the floodplain of the Rutka River, one of the tributaries of the Middle Volga, was studied in order to determine an ecologically grounded catch rate. During the study period, the population of *P. l. leptodactylus* had a high productivity and occupied the dominant status in the biocenosis among the components of animal origin. The amount of plant biomass consumption in summer by juveniles and sexually mature crayfish was calculated. Zoobenthos is consumed in relatively small quantities by all age groups of the crayfish population; zooplankton – by underyearlings. The consumption of aquatic vegetation by crayfish determines the importance of their role in restraining its growth and in limiting the eutrophication of the water body. The biomass of the *P. l. leptodactylus* population was calculated. It must always be present in the water body to maintain the stability of its biocenosis, which is possible if the annual catch of crayfish is limited to 10-15% of their commercial stock.

1. Introduction
River crayfish of the subfamily Astacinae Latreille, 1802 (hereinafter astacins) are large and long-lived invertebrates, native inhabitants of fresh water bodies of Eurasia, in which, under favorable conditions, they form populations with a high abundance. The fishing for broad-toed crayfish *Astacus astacus* (Linnaeus, 1758) and long-toed crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) supplies valuable trade items to the markets of European countries and Russia, and provides the population with gourmet and dietary foods. Due to the deterioration of the state of water bodies and the decline in crayfish stocks, which began in Western Europe in the 19th century, and in Russia – in the second half of the 20th century – along with the issues of fishing and breeding of crayfish, attention began to be paid to their ecological role in natural water bodies, in particular:

- the ability of astacin to occupy a key position in aquatic biocenosis and sustain the ecological stability of water bodies, limiting the development of macrophytes [1, 2];
- the composition of astacin food: their consumption of aquatic vegetation in the summer, and in the fall and in early spring – detritus [3, 4, 5];
- determination of the value of the permissible annual removal of sexually mature crayfish from populations, the level of which is determined at least 25% of the commercial stock (the so-called...
It is believed that this rate of annual removal of crayfish corresponds to the reproductive capacity of their populations. In the interests of fishing, proceeding only from the reproductive capacity of crayfish and without taking into account the role of their populations in the ecosystem, it is considered possible to catch: 46% of the population once every two years; 68% – when fishing once every three years; and up to 90% – when the population is harvested every four years [6].

Statement of the problem: catching crayfish without taking into account their ecological role in water bodies of the forest zone of Russia violates the stability of ecosystems of water bodies and leads to the degradation and death of crayfish populations. Removal from ecosystems of crayfish – ecological dominants – leads to the development of irreversible oligotrophic-eutrophic succession, which to a certain extent is constrained by the consumption of macrophyte biomass by crayfish [7]. Therefore, when determining the catch rate of crayfish, it is important to take into account not only the level of self-reproduction of their populations, but also the role of the latter in curbing the eutrophication of water bodies. In this study, the problem was solved by comparing the biomass of macrophytes in the water body at the end of the growing season (the so-called "standing harvest"), with the consumption of aquatic vegetation by crayfish, which occupies a significant share in their diets [3, 8].

Research questions:

- to determine the morphological and hydrographic characteristics of the water body inhabited by long-toed crayfish and the chemical composition of its aquatic environment;
- to study the structural composition of the aquatic biocenosis, to determine the trophic type of the reservoir inhabited by the highly productive population of *P. l. leptodactylus*, and the position of this population in the biocenosis;
- to determine the number, biomass and structure of the *P. l. leptodactylus* population in relation to the assessment of macrophyte consumption by crayfish;
- to assess the rate of allowable withdrawal by fishing of the population of *P. l. leptodactylus*, a part of which, as a deterrent to the development of oligotrophic-eutrophic succession, should always remain in the water body.

The aim of the study was to determine the permissible value of the commercial withdrawal from the biocenosis of the abundance and biomass of the *P. l. leptodactylus* population, which, intensively feeding on vegetation, inhibits the process of eutrophication of the water body. This circumstance stabilizes the initially favorable state of water bodies in the forest zone of the European part of Russia and has not only ecological, but also social significance.

2. Research methods

Monitoring observations of the water bodies of basins of the Seliger Lake, the Msta and Velikaya Rivers, tributaries of the Moskva River and the Middle Volga, which were carried out by the crayfish breeding laboratory of the Institute of Irrigation Fish Culture (VNIIR) from the end of the 20th century to the second decade of the 21st century, made it possible to collect the following information on the stages of the existence of populations of broad-toed and long-toed crayfish, including:

- about the conditions for the formation of new crayfish populations in water bodies;
- about the emergence in the biocenosis of a small water body of the dominant, highly productive population of *P. l. leptodactylus*, and its relationship with other components of the community;
- about changes in the crayfish population when exposed to intensive commercial exploitation.

The nature of the relationship of crayfish with components of aquatic ecosystems – with vegetation, with organisms of macrobenthos, plankton and microbenthos (pathogenic microorganisms) that infect crayfish with mycoses – was assessed in terms of trophic and parasitic relationships.

To solve this goal – to determine the value of the permissible commercial removal of crayfish from the population while maintaining the stability of the structure of the aquatic biocenosis of the water body – we used the data of ecological studies of a flowing water body with an area of 16 hectares, formed as a result of filling with clean river water of a lowered section of the floodplain of the Rutka River – a left-bank tributary of the Middle Volga. The ecosystem of this reservoir consisted of a limited number
of components: zooplankton; zoobenthos; macrozoobenthos – a highly productive population of *P. l. leptodactylus*; submerged (macrophytes) and surface vegetation. The existence of the crayfish population in the ecosystem of this water body consisted of the following stages: the initial formation of the population (1970s and 1980s); achievement by the population of *P. l. leptodactylus* maximum abundance (1985-1996); degradation of the population under the intense impact of unregulated fishing (1996-1999); the period of absence of the crayfish population in the water body, which began in the 2000s. Information about environmental events in the water body during the periods of the initial formation of the population, its degradation and absence in the reservoir was collected by the stuff of the VNIIR observation point by interviewing local residents; during the period when the population of *P. l. leptodactylus* was in high numbers – as a result of direct research on the water body. The characteristics of the water body inhabited by crayfish – hydrological, morphometric ones, chemical composition of its water – were obtained by carrying out a series of measurements using standard measuring instruments (hydrological spinner, Secchi disk, depth gauge, thermooximeter, etc.). Water samples taken from the water body were analyzed according to standard methods in chemical laboratories.

The size of the commercial stock of the population (its so-called "caught part") was determined according to the data on catches of 10 crayfish traps equipped with a meat attachment and placed in different parts of the water body, using the formula: \( N_c = Y_c S_m / E \), where \( N_c \) is the average number of crayfish of the commercial size more than 10 cm long, which was measured from the middle of the crayfish eye to the end of its caudal fin; \( Y_c \) – average catch of crayfish (in specimens) of 10 crayfish traps for 1 hour of their work; \( S_m \) – the so-called "crayfish useful area" – a predetermined area of a water body inhabited by crayfish; coefficient \( E \) is equal to 2 [6].

The biomass of crayfish from catches of crayfish traps – the so-called “captured part of the population” – was determined for males and females according to the data of individual weighing and measurements of their body length. The size of the “uncaught” part of the population (underyearlings; immature juveniles of 2–3 years of age less than 8.9 cm long) was calculated using coefficients characterizing the ratio of age groups in the structural model of the long-toed crayfish population from the Volgograd reservoir [6]. The biomass of the age groups of the crayfish population was calculated from the combined data on the number and average weight of males and females of the above listed age groups. The age of the crayfish was determined by the Harding method [9] using "probabilistic paper", which is currently used to determine the age structure of natural populations of shrimp and crayfish.

The width and length of the macrophyte zone in the reservoir were measured using a measuring twine, the density and biomass of macrophytes in the overgrown zone – by counting the root parts of plants collected from control plots with sizes from 0.25 to 1 m², and weighing after the water drained from them.

The abundance and biomass of zooplankton and benthos organisms were determined from hydrobiological samples taken in the water body using a small model of the Jedi net (plankton) and a Petersen bottom grab (benthos).

The species composition of zooplankton, benthos, and macrophytes was identified using keys drawn up for water bodies in central Russia [10, etc.].

The identification of microorganisms, among which there could be species pathogenic for crayfish, was carried out by the method of the so-called "traps" – flax or hemp seeds, placed in a sterile container with water from the surveyed reservoir, and the cultivation of pure cultures of oomycetes and microscopic fungi on microbiological media [11].

The relationship of crayfish with food resources in the water body – vegetation, zoobenthos, detritus – was determined by the results of the analysis of the stomach contents of juveniles and sexually mature crayfish, and their comparison with literature data [3, 8, 12, 13].

### 3. Research results

The long-toed crayfish (*P. l. leptodactylus*) population, which reached a high number in the 1990s, was formed after the inhabitants of a small village near the river moved to large villages in the 1970s and the
pollution of the water body with tree bark and other waste from their decorative craft stopped. The crustacean population was formed gradually, and at first it was poorly exploited by visiting fishermen.

The water body inhabited by the crayfish population was characterized by spring floods during melting of snows and autumn floods during the rainy season. The area of the water body ranged from 16 to 9.5 hectares, on average – 12.8 hectares; the temperature of its water in the summer period varied within 17-22 °C; temperature stratification was not observed. The bottom relief of the water body is gentle with a maximum depth of 6.5 m in its center. Gray clayey soil occupied about 70% of the entire area of the water body. Along the coast there was a clayey ground with an admixture of black silt, wood remains and large shells of dead bivalve molluscs.

A belt of aquatic vegetation with a width of 10-30 m and an area of 3.8 hectares was developed in the water body at a depth of ~ 2-2.5 m (zone of the photic layer) and stretched along the entire coastline, forming the most powerful accumulations of macrophytes in places of inflow and outflow of water. According to the chemical composition of water, the water body belonged to the hydrocarbonate class of medium mineralization (water hardness – 3.0 mg-eq/l); pH values ranged from 5.2 (livestock areas) to 8.15 (zone of macrophyte thickets). The content of dissolved organic matter (“permanganate oxidizability” – 14.4 mgO/l; “BOD5” – 3.36 mgO2/l) – was typical for mesotrophic water bodies. The concentration of sulfates (34.2 mg/l) and chlorides (30.5 mg/l) in water testified to the ecological purity of the catchment area of the water body.

Information on the age structure, number and biomass of the crustacean population inhabiting there during the period of its maximum productivity (1985-1995) is given in table 1.

Table 1. The number and biomass of the age groups of the highly productive population of *P. l. leptodactylus*, which lived in the riverbed water body of the Rutka River, a tributary of the Middle Volga.

| Age groups | % in the population | Number, individuals | Average weight of individuals, g | Biomass, in t (in g) |
|------------|---------------------|---------------------|----------------------------------|---------------------|
| Underyearlings (0+) | 49.4 | 75378 | 1.0 | 0.075 t (75378 g) |
| Juveniles, body length from 3.7 to 8.9 cm, 2-3 years old (1+, 2+) | 24.7 | 37689 | 18 | 0.68 t (678402 g) |
| "Caught" part of the population "(PDE) – sexually mature males and females – industrial stock of the population | 25.9 | 39520 | 55.6 | 2.20 t (2197312 g) |
| – size and biomass of the entire population: | | | | |
| – number of juveniles + UCHP | 50.6 | 77209 | – | 2.88 t (2875714 g) |

The table contains information about the 3 main age groups of the studied population of long-toed crayfish. The group of "underyearlings (0+)" consists of larvae of different ages – from III to VII (larval) age stages. The group of "immature juveniles" formed by crustaceans at the age of 2-3 years (1+, 2+) is the so-called "replenishment" of the population. A group of sexually mature males and females 3-5 years old and older, from which the reproductive herd of the population is formed, forms its so-called "commercial stock". Underyearlings differ from crayfish of other age groups – juveniles and sexually mature crayfish – by the nature of their diet, which largely consists of zooplankton organisms, small forms of zoobenthos, and includes very little vegetation.

To identify the dominant component of the ecosystem and the influence of the *P. l. leptodactylus* population for other components, the species composition and biomass of zooplankton, benthos, microbenthos, and macrophyte vegetation were determined (table 2). Information on microbenthos is given in the text.
Table 2. Abundance and biomass of taxonomic groups of zooplankton and macrobenthos, including some data on the population of P. l. leptodactylus, and about macrophytes.

| Biocenosis components | Number of taxonomic groups | Community group indicator, including: |
|-----------------------|---------------------------|----------------------------------------|
|                       |                           | Number ind./m² | Biomass, g/m² | Highest values (august) |
| Zooplankton           | 3                         | –             | 3.76 mg/m²    | (<7.6 mg/m²)            |
| Zoobenthos (without Anodonta) | 6 | 249.2 ind./m² | 2.4 mg/m²    | –                       |
| Pontastacus l. leptodactylus | 1 | 152587 ind. | 23.06 g/m²   | –                       |
| Macrophytes (only forage plants for crayfish) | 4 | – | in the water body – 103 g/m² | – |

Spring zooplankton in the water body for more than 90% of the biomass was represented by rotifers (3 species); at the beginning of summer, in June, cyclopoid-cladoceran complex (4 or more species) dominated; in July, the main biomass of zooplankton was formed by copepods – diaptomuses and cyclops; the end of August – the beginning of September were characterized by the dominance of cladocerans. In September, with a decrease in temperatures, the biomass of zooplankton sharply decreased, and rotifers disappeared. The macrobenthos community was divided into 2 ecological groups: peaceful and predatory aquatic organisms. The main biomass of peaceful aquatic organisms was made up of bivalve filter feeders, distributed up to two meters depths throughout the entire water body. Oligochaetes feeding on detritus were widespread to a depth of 5.5 m. Among the inhabitants of the thickets of plants, there were many larvae of caddisflies, mayflies, and dragonflies. Consumers of periphyton and detritus – small crustaceans (water donkeys) were few in number. The group of carnivorous forms of benthos was formed by chironomids (12 species). The basis of the biomass of zoobenthos was formed by the ubiquitous Chironomus plumosus and small forms of molluscs. An increase in the number of benthic organisms in the deep parts of the water body during the summer indicated a favorable oxygen regime at the bottom of the reservoir. When studying mycobiota, pure cultures of microscopic fungi were isolated – Varicosporium sp., Tetracladium sp., Heliscus sp. – saprotrophs on decaying plant debris. Species of oomycetes and microscopic fungi parasitizing on crayfish were not found in the water body. This fact is also confirmed by the low incidence of crayfish (2-3% in a sample of 200 specimens) with signs similar to those arising from rusty-spot disease [14]. The superiority of the biomass of long-toed crayfish (23.06 g/m²) over the biomass of other components of the biocenosis of animal origin (table 2) allows crayfish to be considered the dominant species in the ecosystem of a flowing water body formed in the floodplain of the Middle Volga tributary. The ichthyofauna of the water body consisted of representatives of the Ponto-Caspian freshwater complex – bream, rudd, etc., and was small in number. The most dangerous species of fish for crayfish – perch – is extremely rare.

The plant community of the water body consisted of submerged and emerging vegetation. In the composition of macrophytes of the thicket zone, the egg-capsule (Nuphar luteum Sm.) with a small admixture of the white water lily (Nymphaea alba L.) accounted for 44% (7.5t), the floating pondweed (Potamogeton natans L.) and brilliant pondweed (P. lucens L.) – 19% (3.2 tons), the hornwort (Ceratophyllum demersum L.) – 15% (2.5 tons). The species of surface plants – sedge, reed, water-plantain, arrowhead, rush, cattail and horsetail – in general, in terms of biomass, were 3.9 tons (22%). The biomass of forage macrophytes for crayfish was estimated at approximately 13.2 tons; the total biomass of macrophytes and other vegetation is 17.1 tons (0.171 g/m²). The area of macrophyte thickets (3.8 hectares) of the largest area of the water body (16 hectares) was 24%, of the average area (12.8 hectares) – 29.7%. The development of vegetation in the studied water body in terms of biomass was close to that in slightly overgrown water bodies of the forest zone [14].

The trophic relationship of crayfish with components of the biocenosis is as follows: zoobenthos organisms in a relatively small number were found in the stomachs of crayfish of all age groups; zooplankton constituted a significant part of the food of underyearlings; vegetation occupied a
significant part in the stomach contents of juveniles and sexually mature crayfish. The indicators characterizing the trophic relationship of long-toed crayfish with the macrophyte component of the biocenosis are shown in Table 3.

**Table 3.** Indicators of the trophic relationship of the population of *P. l. leptodactylus* with vegetation in the biocenosis of a small riverbed lake of the Rutka River, a tributary of the Middle Volga.

| Biomass of macrophytes edible for crayfish (so-called “standing harvest”) | Biomass of crayfish feeding on macrophytes, t | The entire diet of crayfish – consumers of macrophytes, t | Eaten during the summer crayfish-fed part of the crop macrophytes, % |
|---|---|---|---|
| 13.2 | 2.88 | 0.115 | 7.13 | 4.7 | 35.6 |

In the food of vegetation consumers – juveniles and sexually mature crayfish – it accounted for an average of 65.9%, which is 35.6% of the macrophyte harvest. Consuming a significant part of the biomass of the plant component of the biocenosis, the population of *P. l. leptodactylus* significantly prevented the growth of macrophytes and eutrophication of the reservoir. Table 4 shows the results of calculating the biomass of long-toed crayfish, the dominant species in the hydrobiocenosis under consideration, which must be present in the reservoir to stabilize its ecosystem.

**Table 4.** Determination of the value of the annual catch of crayfish, provided that the biomass of *P. l. leptodactylus* is preserved in water body, necessary to curb the growth of macrophytes, at the level of 2.88 t.

| Indicators | Catch of crayfish in % stock of population (39520 ind., 2.20 t). |
|---|---|
| Crayfish caught, individuals (t) | 9880 (0.6 t) 7904 (0.4 t) 5928 (0.3 t) 3952 (0.2 t) |
| Number (ind.) and biomass (t) of crayfish in the reservoir for the next after harvest at 80% survival of the “remnant” and average weight 55.6 g/ind. | 23712 25293 26874 28454 |
| The entire biomass of crayfish in the water body for the next year after the catch of the population with taking into account the value of the following indicators: biomass of the surviving part of the crayfish (t), its growth (t); replenishment (t). | 2.42 2.55 2.74 2.78 |

The biomass of the “remainder” of the population for the next year after its catch was calculated as the sum of the following indicators: biomass of 80% of crayfish that survived in the reservoir after catch, their growth during the current growing season by 20 g/individual, annual replenishment of the population with maturing juveniles by 0.63 t.

River crayfish, eating a large number of macrophytes, restrain their growth and eutrophication of water bodies, as well as the development of irreversible oligotrophic-eutrophic succession in them. This determines their important role in stabilizing the ecology of water bodies in the forest and forest taiga zones of Eurasia. Determination of the allowable catch rate of crayfish from a population that occupies a dominant status in the ecosystem of a water body favorable for their existence showed that stabilization of an aquatic biocenosis favorable for crayfish can be achieved with a catch not exceeding 10-15% of the commercial stocks of the population. At the same time, the crayfish remaining in the reservoir, feeding on macrophytes, can restrain overgrowth with vegetation and eutrophication of the water body.
4. Conclusions
Eurasian crayfish of the subfamily Astacinae, under favorable conditions, can form populations of high abundance, occupy a dominant position in freshwater bodies, and inhibit the development of irreversible oligotrophic-eutrophic succession in them.

Consumption by crayfish of aquatic vegetation counteracts its overgrowth and is a factor that stabilizes ecosystems, for example, at the mesotrophic level, and restrains the eutrophication of water bodies.

As a result of monitoring studies, it was found that the stable state of water bodies inhabited by crayfish is ensured by the preservation of their biomass at a level that prevents the growth of aquatic vegetation. This circumstance should be taken into account when determining the rate of allowable removal of the crayfish population by the fishery.

Analysis of the trophic relationship "crayfish – macrophytes" made it possible to consider that the annual catch rate of crayfish should be within 10-15% of the number of sexually mature crayfish from the so-called "caught" part of the population – its commercial stock.

From the economic point of view, crayfish, being the objects of the fishery producing valuable food products with gourmet and dietary properties, are in great demand in the European and Russian markets.

Populations of consumer valuable native crayfish of the Astacinae subfamily occupy a unique position in the biocenoses of Eurasian water bodies. They prevent their eutrophication, counteracting the development of stages of irreversible oligotrophic-eutrophic succession and deterioration of the quality of the aquatic environment. Becoming unsuitable for the life of crayfish, water bodies lose their value for mankind as reservoirs of clean water, sources of high-quality food products (crayfish, fish, etc.), and objects of recreation.

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