Rational use of freshwater ecosystem resources in crayfish farming

E N Alexandrova\(^1\) and K L Tarasov\(^2\)

\(^1\)The all-Russian Research Institute of irrigation fish farming of the Ministry of science and higher education of the Russian Federation (FGBNU VNIIR), Noginsk district, village Vorovskogo 142460, Moscow region, Russia
\(^2\)Moscow State University, faculty of Biology, Department of Mycology and Algology, 1, Leninsky Gory, 119992 Moscow, Russia

E-mail: coltar@yandex.ru

Abstract. Using freshwater resources of the mixed forest zone in Russia when growing larvae of crayfish belonging to the subfamily Astacinae in order to obtain a planting material (PMC) is considered in the framework of the functioning of the ecosystem that is formed in cages placed in surface layers of bodies of water. Aquatic vegetation, with which, according to the technical regulations, net cages are filled, creating shelters for larvae, is an autotrophic producer, whose consumers are organisms of benthic fauna chopping and detritizing it. Crayfish larvae in this ecosystem are heterotrophic macroconsumers that consume benthic invertebrates, vegetation, and detritus. The saprobic component of the ecosystem - microorganisms-destructors of dead organic matter are bacteria and fungi, some species of which cause mycoses of crayfish larvae. The studies conducted are devoted to determine the parameters of the functioning of the ecosystem formed in cages, providing the formation of fodder and other resources necessary for the cultivation of PMC.

1. Introduction

Even before the middle of the 19th century, many ponds of the middle band of the Eurasian Continent were inhabited by numerous populations of river crayfish of the subfamily Astacinae Latreille, 1802 (hereinafter referred to as “astacins”), objects of trade and market trade in several countries of Europe and the Russian Empire [1]. Since the middle of the 19th century, due to the deterioration of the state of water bodies and the spread of mycotic diseases, the number of astacins everywhere has decreased. The restoration of stocks of valuable species of astacins began in the 20th century since the demand for dietary and gourmet foods from them remained. Since the 1970s In Europe and the republics of the USSR, various methods have been developed for the production of planting material for crayfish (PMC), which is necessary for restoring astacin populations both in natural water bodies and for growing them to commercial conditions in farms. Traditional technologies for growing PMC are based on the use of industrial devices - pools or aquariums into which water is supplied, and feeds of plant and animal origin, including live food organisms, are introduced [2,3]. Technologies in this area are based on the use of electric power, measures to maintain the quality of the aquatic environment, and feed of artificial origin. Due to the exactness of PMC to the growing conditions, in particular, to the concentration of oxygen and calcium in the water, the significant loss of larvae during the growing process, as well as...
the low consumer demand for them, such technologies are costly and not cost-effective. These circumstances make it necessary to develop low-cost methods for obtaining PMC, in particular, based on the use of natural resources of aquatic ecosystems.

Problem statement: The use of the resources of natural reservoirs in the production of PMC is caused by the need to reduce the expenditures for restoring the natural reserves of crayfish and cultivating them on farms. The problem was solved within the framework of the original technology, in which cages placed in natural reservoirs are used [4, 5]. Resources for growing PMR, such as the necessary habitat, food supply, etc., are formed in cages as a result of the functioning of the ecosystem formed in them.

2. Research questions
Study the structural composition of the ecosystem formed in cages filled with water vegetation and immersed in the surface layer of the reservoir (“original technology for growing PMC”). A comparison was made with the ecosystem formed in aquariums or in reservoirs equipped with automatic exchange equipment in the water environment, which are fed with artificial feed for PMC (“traditional technology for growing PMC”).

Carrying out experiments on the selection of materials for the manufacture of cages for breeding crayfish; set the optimal dimensions for them.

The defining readings for the choice of reservoirs which fit to work on astaciculture in the mixed forest zone of the European part of Russia.

Comparison of astacin larvae grown under different conditions according to the size-mass (or weight) characteristics and the occurrence of lesions on their body that favor the development of mycoses.

The purpose of the study is to determine the conditions for growing PMC using ecosystem resources formed in cages located in open water bodies (“original technology”).

3. Research methods
When studying the feed resource for astacin larvae formed in cages and the possibility of satisfying their food needs, we were based on data from selected hydrobiological samples to determine the species composition and biomass of benthic organisms in the heterotrophic layer of the ecosystem. The average daily need of fodder organisms for the grown larvae was calculated according to the data on the weight growth, survival rate and consumption of animal food per 1 g of body weight of larvae from the III to VI age stages during the initial planting for the cultivation of 250 larvae per 0.5 m² of cage bottom (500 specimens / 1 m²) [4, 6]. The quality of the PMC grown by the original methods in cages on the ADS (algal detritus substrate), and according to the traditional technology - in aquariums with an automatic water supply and artificial feeding, was evaluated for stage VI larvae obtained from eggs of Pontastacus leptodactylus Esch. from the same population inhabiting the reservoir of the Middle Volga (figure 1-1). When determining the dimensions of cages used for growing PMC according to the original technology, the behavior features of crayfish – inhabitants of the bottom surface of water bodies and the possibility to simplify the work of their cultivation were taken into account. In contrast to the devices intended for keeping the inhabitants of the pelagic — shrimps and planktonophagous fish, immersed in the depth of the photic layer of the reservoir and differing in significant volumes of the internal cavity, the optimization of the dimensions of cages for keeping young crayfish was carried out in the direction of increasing the area of their bottom surface and lowering the height of the walls. In experiments on optimizing the dimensions of astaciculture conducted in lakes, ponds, and canals, 32 cages of various types were used (figure 1), in which 66471 Astacin larvae of the genus Pontastacus Bott were grown and 13555 copies of larvae of Astacus astacus.
Figure 1. Cages for breeding crayfish.
1 - large cages stretched on stakes stuck in the bottom of a reservoir (a lake in the Middle Volga region). 2 - platform with hatches for installing cages, located in the coastal part of the reservoir, and a standard type of cage (lake in the Velikaya River basin, Pskov Region). 3 - cages placed on a support structure constructed in the pelagic part of the pond (fish farming in the Msta River basin, Vyshnevolotsky District of the Tver Region). 4 - cages installed along with the canal Bank (ibid.).

The success of larval cultivation in cages is determined by the ability to select for it reservoirs corresponding to requirements of oxyphilic and oligosaprobiont astacins and convenient for carrying out works on astaciculture [7,8]. Selection of such reservoirs is carried out taking into account such characteristics as the aqueous medium chroma and transparency, pH value, the concentration of dissolved oxygen, the water temperature on the surface, and at the bottom of the reservoir, the distribution area of higher aquatic vegetation. Information on these indicators was collected at the site of the survey of the reservoir, using appropriate instruments. The requirements for reservoirs suitable for growing PMC astacins are summarized in the “Research Results” section. Determination of the total mineralization of water, the content of principal ions in it, organic matter, permanganate, and dichromate oxidizability, as well as species composition and biomass of zooplankton and benthos organisms, was carried out in hydrochemical and hydrobiological laboratories using appropriate methods [9, 10]. The degree of water pollution was estimated by the data on the total number of microorganisms by direct counting methods [11]. The number of saprotophic microbes was determined by inoculating titers of test water on MPA medium (meat-peptone agar) by the doctor-microbiologist of the Pustoshka Veterinary Laboratory (Pskov Region) Е. А. Komarova.

4. Results of studies
The cultivation of PMC according to the original technology in cages filled with higher aquatic vegetation and placed in a pond is based on the formation in the cages of a food base for astacin larvae consisting of vegetation, benthic organisms, and detritus. Cages are the main technical devices used in the original technology. Compared to cages for maintenance of shrimp, which differ in significant volumes of the internal cavity, high sidewalls, and relatively small bottom surface, in cages for growing PMR, the proportion of the bottom surface to the total volume is increased 3 times [5]. Standard crayfish
cages with a bottom area of 0.5 m² are made of nylon sieve with mesh ~ 2x2 mm, equipped with a frame supporting their rectangular shape, and covered with a lid (figure 1:2). The configuration of supporting structures for placing crayfish cages in the surface layer of water bodies depends on the nature of the increase in depths in their coastal zones (figure 1-4).

Table 1. Chemical composition and sanitary-hygienic indicators of the aquatic environment of water bodies in the forest zone of the European part of the Russian Federation, suitable for cage cultivation of planting material for crayfish.

| Feature Names                          | Units measuring | Indicators                                                                 |
|----------------------------------------|-----------------|---------------------------------------------------------------------------|
| Water color                            | visual assessment| Bluish green, light yellow - let’s say                                    |
| Transparency of water, gradation       | by Secchi disk, m| medium / 2-4, high / 4-8 small / 1-2                                      |
| Content of O₂                           | mg / l          | 6-8 is optimal; 4-7 is acceptable                                         |
| Active reaction of the aquatic environment | pH              | 7.0-8.8                                                                  |
| Salt composition of water              | Cations, anions | Hydrocarbonate-calcium                                                     |
| Total mineralization                   | total ions, mg / l| 200-500                                                                  |
| Total water hardness, gradation        | mg equiv / l    | medium 4-8, low < 4                                                       |
| Total iron, mg / l                     |                 | <0.5-0.7                                                                 |
| Hydrogen sulfide                       | mell            | lack                                                                      |
| Ammonium ion, mg / l                   |                 | <0.1                                                                     |
| Permanganate oxidability, including:   | mgO / l         | Allowed 7, 5-10.0                                                         |
| The total number of microorganisms     | mln cells / ml  | <1                                                                        |
| The number of saprotophic bacteria     | thousand cells / ml| <0.5                                                                      |
| developing on MPA                      |                 |                                                                           |
| The presence in the pond of oomycete   | bioassay        | result negative                                                          |
| Aphanomyces astacin *                  |                 |                                                                           |
| Occurrence of crayfish with rust-spotted disease in a local crayfish population* | permissible % of cancers with RPG per 100-200 specimens. in sample | <10                                                                        |

*Crayfish lakes are characterized by an area of 50 ha or more, a gradual increase in depths in coastal areas at various maximum depths; rivers are distinguished by the presence of bays and backwaters; their length is more than 10 km. Water exchange in deep lakes is from 0.25 to 1, in medium-deep ones from 1 to 4, in shallow lakes and rivers, from 4 to 16 volumes per year. Soils in reservoirs are dense pebble-sand, clay, peat, calcareous. Regarding thermals (thousand gr. days> 100°C), crayfish water bodies are typified as moderately warm (1000-2000⁰) and warm (2000-4000⁰). Water temperatures in the surface layer in the open period are 15–24 °C. According to trophicity, the ponds are oligo-mesotrophic, mesotrophic, mesotrophic-eutrophic; according to the trophophytic structure, benthosporophytic ones, in which the energy flow and biological transformations of substances pass through a range of hornwort and Chara phytocenoses; by saprobity - oligosaprobic with the transition to oligobetomesosaprobic and betamesosaprobic types [13]. The compliance of the reservoir with astacin requirements depends on the condition of its catchment area. The growth of industrial centers, the intensification of agriculture and recreation on the catchment area destroy the ecological stability of water bodies.

The technological and environmental characteristics of the original and traditional methods for growing PMC are systematized in table 2. Elements of the ecosystem formed in cages are considered as interconnected environmental components [14].
Table 2. Ecological and technological characteristics of two methods of growing planting material for crayfish (PMR) of the astacins.

| Ways of growing PM | The original method | The traditional way |
|--------------------|---------------------|---------------------|
| Environmental elements in cages filled with aquatic vegetation, located in the surface layer of an open reservoir | a) Water plants | a) Vegetation and food - are not |
| - Potamogeton lucens L., and other Potamogeton spp., Chara sp., Ceratophyllum demersum L., Elodea canadensis Michx. | b) Compound feed food for PMC | b) ecosystem components |
| growth devices | c) Remains of feed and dead organics | c) Food resource for microconsumers - decomposers - mold fungi and bacteria |

- The value of the element of the environment: - in the ecosystem
  - a) Autotrophic producers
  - b) Consumers - shredders of plants – feed organisms for macroconsumers – astacin larvae settling to the bottom of cages
  - c) Sapropel (dead protoplasm), organisms of macroconsumers
- - in technology
  - a) Plant part of feed and shelter for PMC; do not change, but are added
  - b) Habitat of benthic organisms - feed organisms of cultivated larvae
  - c) Dead plants
  - a) Asylum and vegetative part of the feed for the PMC;
  - b) are replaced in 7-9 days.
  - c) Nutrient source for PMC
  - d) Polluting elements of the aquatic environment

Aquatic vegetation - Chara sp., Potamogeton lucens L., and others, with which, according to the technological procedure for growing PMC, mesh cages are filled, is in the cage ecosystem an autotrophic producer that captures light energy and assimilates chemicals dissolved in water. Small organisms caught in cages on vegetation from a mesotrophic reservoir - crustacean Asellus aquaticus (L.), species of the chironomid family, and other benthic invertebrates participate in the formation of detritus, chopping the vegetation on which they feed (figure 2).

Figure 2. Fodder organisms of larvae of astacins in a sample of characean algae planted in a cage: Asellus aquaticus L., Tendipes gr. plumosus, Pisidium sp. and others.

In the ecosystem of cages installed in a mesotrophic-eutrophic reservoir, autotrophic producers were aquatic plants - Ceratophyllum demersum L., Potamogeton lucens L., and others; heterotrophic consumers were dominated by larvae of small dragonflies (Odonata), dipterans (Diptera) - Polypedilum nobesculosum, Tendipes gr. plumosus, species of Oligochaeta.

The degree of microconsumers - mold and putrefaction fungi - decomposers of dead protoplasm, was judged according to the number of saprotrophic bacteria grown on a meat-peptone agar (MPA) after seeding titers of water taken away in the setting zone of cages. In the water taken directly under the cages, colony-forming saprotrophic bacteria was 270 cells, in a sample of water taken at a certain distance from the cages, it was 180 cells. In both cases, the number of saprotrophic bacteria in 1 ml of water was within the normal range (100-1000 bacteria), which is typical for the category of “pure water” according to the Mikel scheme [1]. The insignificance of the pollution of the reservoir from the cages can be explained by the constant movement of water masses in the zone of their installation under the influence of wind or current.

Aquatic vegetation, which according to the technical regulations is filled with both net cages and industrial devices as plant food and shelters for larvae, in both cases, functions as an autotrophic producer. However, if in devices the vegetation is regularly replaced as it withers, in cages, it is not
changed, but only added fresh to maintain the height of the plant layer. As a result, in the cage ecosystem the so-called “heterotrophic layer” of withering vegetation and benthic organisms is formed that feed and grind it, what does not happen in industrial devices.

In turn, the herbivorous inhabitants of the heterotrophic layer and other heterotrophic organisms that have crept into the cages from the pond - shredders of vegetation form the feed resource for PMC. It is known that the nutritional needs of astacin larvae of III-VI age stages in living organisms according to E.A. Tamkevičienė [6] make up 65.5% of all food eaten, including vegetation. An assessment of the nutritional needs of farmed astacin larvae and the possibility of satisfying it due to the feed resource formed in the heterotrophic layer of the cage ecosystem is given in table 3. The data for calculating the table indicators are named in the “Research Methods” section and were obtained during the experimental cultivation of PMR in cages.

**Table 3.** Biomass of benthic organisms – inhabitants of the heterotrophic layer of the ecosystem of cages located in a mesotrophic water body, and an assessment of its ability to meet the need of PMR for forage organisms during their cultivation.

| Indicators | Predominant species of the live feed for astacin larvae | The biomass of the predominant feed organisms per 100 g of chara, and their share of the biomass of the entire sample |
|------------|--------------------------------------------------------|------------------------------------------------------------------|
| The predominant types of food organisms (kb), their biomass in 100 g of characean algae taken away from heterotrophic layer of a cage | *Asellus aquaticus*<br>*Physa fontinalis* | 0.511 g (40.6%) |
| Average daily demand for 76 days in a live feed (250 individuals of larva, planted in the cage for growing), g | | 7.2 |
| The biomass of feed organisms with the presence daily in cages of 2 kg of algae, g | | 13.0 |

Accounting for feed organisms for PMR grown from III to VI age stages with a planned yield of 125 ind./0.5 m² (initial planting 250 ind./0.5 m²), and calculation of the average daily need for the live food of larvae (7.2 g / day), suggest that 2.5 kg of *Chara* in the heterotrophic layer of the cage contains 13.0 g of feed organisms, which is 1.8 times higher than the average daily requirement of larvae grown for 76 days. This value of the feed resource is sufficient to meet the average daily need for live feed of 250 cultivated astacin larvae. (The permissible daily plant load per 1 cage of 2.5 kg was established experimentally.)

Regarding the development of the saprobic layer, the following information was obtained. In industrial devices, the remains of feed and dead protoplasm accumulate and become noticeable due to the development of mold and putrefactive fungi on them, as well as bacteria. In mesh cages, this layer is hardly noticeable because it is washed out. If bacteria play a positive role in a balanced ecosystem of aquaculture, then a massive growth of bacteria can occur in a simplified ecosystem of intensive production, what leads to increased mortality and deterioration of the quality of cultivated objects. Under aquaculture, the bacterium *Pseudomonas* sp. can cause serious septicaemia in crayfish, and bacteria can also be found in hemolymph [15, 16]. Bacteria grow rapidly in the presence of organic particles in water, at pH close to neutral, the concentration of dissolved oxygen is 6-8 mg / l, water temperatures in the summer in the range of 15-20 °C. Under such conditions, not only bacteria but also mold and putrefactive fungi - destructors of dead protoplasm, which also develop on damaged parts of the body of crayfish, develop on dead protoplasm and feed residues not removed from industrial tanks. Table 4 shows the results of comparing P. leptodactylus larvae of the same age obtained from eggs from a lake in the Middle Volga region (figure 1-1), and grown under different conditions: in cages installed in the same lake and aquarium with water exchange and filtration, installed in the laboratory for crayfish breeding in VNIIR (Moscow Region).
Table 4. The number of lesions on the body of the larvae of Pontastacus leptodactylus (P.L.), grown in an aquarium with water exchange and filtration, and grown on an algal substrate in a cage located in the surface layer of the reservoir.

| Number of larvae in the sample, ind. | Age of larvae, day | Body length mm | Body weight mg | P resulting damage I larvae, % |
|-------------------------------------|-------------------|----------------|----------------|-------------------------------|
| P. l. larvae grown in cages on a plant substrate (flowing lake in the Middle Volga region) | 575               | 51             | 25.2           | 401.5                         | 6.2                           |
| P. l. larvae grown in an aquarium with filtration and regular water exchange | 115               | 51             | 20.8           | 178                           | 33                            |

5. Conclusion
Studies have shown that the ecosystem which forms in cages used for growing PMR consists of three main components:

- the upper layer of aquatic vegetation embedded in cages is an autotrophic component of an ecosystem that absorbs light energy and assimilates simple chemical compounds dissolved in water;
- the layer beneath it is a heterotrophic component of an ecosystem in which, under the influence of consumers - benthic organisms eating and grinding vegetation - a feed resource is formed for cultivated astacin larvae, which act as macroconsumers in this ecosystem, and devastate other heterotrophic organisms - food objects for cultivated larvae. It was established that the constant presence in the cage of 2.5 kg of algal mass, which may contain about 13.0 g of feed organisms, will satisfy the average daily need for a live food of 250 ind. larvae planted in a cage for growing for 76 days;
- no water pollution was detected at the installation site of the cages since the lowest saprobic layer of the ecosystem in which microconsumers-destructors (bacteria, mold, and putrefactive fungi) develop is washed out of the net cages with a constant fluctuation of water masses. Nevertheless, for the installation of cages in a water body, one should choose the places where the conversion of water masses takes place and organize monitoring of the level of water pollution in the places of their installation.

The technology of growing PMC in cages installed in open water bodies allows using natural resources for production, not consuming electricity, and purchased food. This makes it promising for the large-scale production of planting stock for valuable species of crayfish during carrying measures to restore their population.

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