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Dynamics of Fish Colonization of an Experimental Artificial Reef in Peter the Great Bay, Sea of Japan

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Abstract—An experimental artificial reef (AR) was built in Peter the Great Bay (Sea of Japan) to compensate for the biotope of *Zostera* destroyed by sea urchins. After eight years, the number of fish species on the AR increased from 5 to 18 and the fish biomass increased from 3.07 up to 37.1 g/m^2. Nonmigrating species (*Opisthocentrus*, young-of-the-year rockfishes, elegant sculpin) formed the bulk of the population; and migrant species (flounders, frog and great sculpins, sea raven) made up the greater portion of the biomass (up to 34 g/m^2). Cage reefs are recommended to compensate for destroyed habitats, particularly *Zostera* beds.

Key words: Artificial reef, fish colonization of artificial reefs, *Zostera* bed.

In recent years, the construction of artificial reefs (ARs) has been started to mitigate the loss of destroyed natural habitats—coral reefs [17] and seagrass beds [15]. Before reef deployment, it is desirable to estimate the effectiveness of artificial reefs [3], i.e., to elucidate the rate of reef colonization by fishes and the possible number of fish species. In such research, knowledge of the temporal dynamics of AR colonization by fish is very important, and analogous studies have been performed in seas at various latitudes [11, 12, 14, 16].

In some areas of Peter the Great Bay, *Zostera marina* beds were grazed by sea urchins. As a result, the species composition of fishes has been impoverished and their abundance has declined [6, 7]. A study of the ichthyofauna of various AR types [5] revealed a high similarity of fish populations in natural seagrass beds and cage mariculture grounds.

Reports on the fish abundance dynamics on AR in Peter the Great Bay are scarce and are not supported by reliable data [2, 9]. As a rule, surveys of the AR biota were made at various time intervals; however, the temporal dynamics of populations have not been studied [1, 8, 10].

The aim of this work was to make a cage AR to partly rehabilitate the ichthyofauna of a *Zostera* bed grazed by sea urchins and to elucidate the dynamics of reef colonization by fishes.

MATERIALS AND METHODS

This study was conducted on one AR from 1995 to 2003. The experimental AR was deployed in early September 1995 in the southwestern part of Peter the Great Bay at the entrance to a small nameless bay in the north of Bolshoi Pelis Island (Far Eastern State Marine Reserve). Here, in 1992–1993, the sea urchins *Strongylocentrotus nudus* and *S. intermedius* destroyed a *Zostera marina* bed, which occupied the middle of the bay at a depth of 2–10 m. At the entrance of the bay, an underwater ridge of boulders extends 3 to 12 m, partly separating the bay from the sea. Not to interfere with the traffic of small-size vessels, the AR was placed 25–30 m from the outer side of the underwater ridge on a silty sand bottom at a depth of 20 m. The AR was made up of two garlands of cages generally used for artificial cultivation of the Japanese scallop (one garland was covered by a fine-meshed net) and one garland consisting of halves of plastic balls 300 mm in diameter (Fig. 1). Each garland was 5–6 m long; cages and floats in the garlands were set 0.5 m apart, and there were 10–11 such elements altogether. The floats were polyurethane-foam balls, and the anchors were 25–30 kg boulders. The garlands were arranged into a triangle, at 5–7 m apart. The AR structure was quite stable against storms and currents, and, in spite of some modifications (deviation of 20°–30° from the vertical due to the action of currents, detachment of floats), it remained in the same location. If part of the floats was torn off, 2 to 3 m of the garland sank to the bottom and provided a voluminous refuge.

Visual observations were made using scuba every year in August–September by the author of the paper. A series of 10 dives was made to study the species composition and abundance of fish on the AR. In all, 78 counts were made. The absolute length of fishes was assessed visually, and the weight was calculated by the length–weight relationships [5, 7]. The mean values for the numbers of fishes were obtained by adding up the

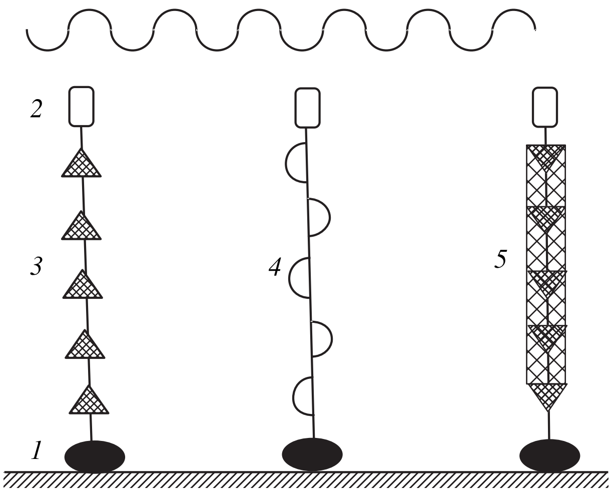

Fig. 1. A schematic figure of the experimental artificial reef. (*1*) boulders; (*2*) floats; (*3*) garland of cages; (*4*) garland of halves of plastic balls; (*5*) garland of cages covered by a net.

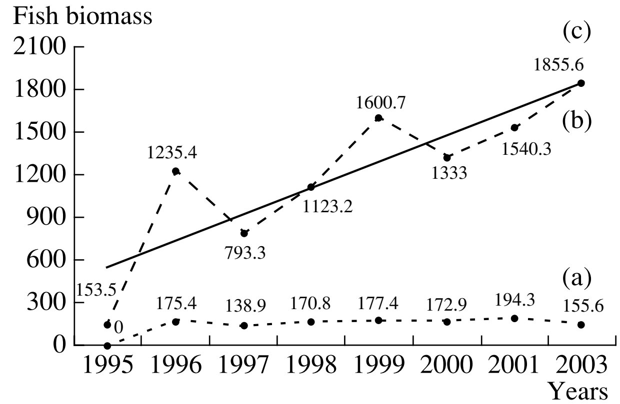

Fig. 2. Change in fish biomass at the experimental artificial reef (in the area of 50 m^2) at Bolshoi Pelis Island in August–September 1995–2003. (a) Biomass of resident fishes; (b) total fish biomass; (c) tendency of change in total fish biomass.

data of annuals counts. The total biomass of fishes was calculated as the sum of the weight of all fishes in the bottom area occupied by the AR (on the circumference with a radius of 4.0 m ≈ 50 m^2), and the surface area of all garlands of the AR was taken to be 18.8 m^2 (radius of cage 0.2 m, length 5.0 m).

Species composition and the number of fishes recorded on the experimental artificial reef (in the area of 50 m^2) at Bolshoi Pelis Island in August–September 1995–2003

Species	Number of fishes in one count (mean ± error of mean), ind.
Bathymaster derjugini	0.19 ± 0.06
Chirolophis japonicus	0.46 ± 0.19
Opisthocentrus ocellatus	4.7 ± 1.8
O. zonope	45.2 ± 16.3
Ernogrammus hexagrammus	0.047 ± 0.011
Sebastes taczanowskii	0.33 ± 0.12
S. trivittatus juv.	4.1 ± 2.6
S. minor	1.0 ± 0.3
S. minor juv.	11.6 ± 5.6
Hexagrammos octogrammus	0.06 ± 0.01
Radulinopsis spp.	1.46 ± 0.63
Myoxocephalus stelleri	0.27 ± 0.09
M. brandti	0.2 ± 0.08
M. polyacanthocephalus	0.009 ± 0.003
Bero elegans	14.8 ± 5.9
Hemitripterus villosus	0.42 ± 0.17
Acanthopsetta nadeshnyi	0.25 ± 0.06
Pleuronectes yokohamae	0.47 ± 0.21
P. schrenki	03 ± 0.07

RESULTS AND DISCUSSION

Control observations made in 1995 showed that in the area where the AR was deployed 1 to 5 fish species dwelled permanently: 1–2 ind. of sculpins *Radulinopsis derjugini* and *R. derjavini*; flounders (*Acanthopsetta dadeshnyi, Pleuronectes yokohame*, and *P. schrenki*) were encountered episodically in the same numbers. The total biomass of these species of fish was rather low, 153.5 g/50 m^2 (Fig. 2).

Until early October 1995, fish were not encountered on the AR, nor were other organisms. In 1996, *Laminaria*, hydroids, and ascidians appeared on the garlands and sea stars and sea urchins were encountered as well. The species composition (see table) and the total biomass of fishes (Fig. 2) increased sharply. The number of species increased to 17; however, *R. derjugini* and *R. derjavini* were not found. The pricklebacks *Opisthocentrus zonope* and *O. ocellatus* occurred singly or in groups of 12–15 ind. in thick growths of *Laminaria* and hydroids throughout the length of the garlands. Juveniles of *Bero elegans* were also found singly or in groups of 7 ind. throughout the length of the garland, without any depth preference. Young-of-the year rockfish *Sebastes trivittatus*, as well as juvenile and adult *S. minor*, always occurred near the boulders that served as anchors, up to 1.5 m from the bottom. In some groups, there were up to 40 ind. of juvenile *S. minor.*

In 1997–1999, the garland epibiosis increased, the species composition of fishes stabilized, and total biomass of fishes showed a clear tendency towards increasing (Fig. 2). There were no marked differences between garlands. The warbonnet *Chirolophis japonicus* occurred almost constantly at the boulders. The ronquil *Bathymaster derjugini* was found more rarely. The rockfish *S. taczanowskii* and the sea raven *Hemitripterus villosus* were encountered episodically. The sculpins *Myoxocephalus stelleri, M. brandti*, and

M. polyacanthocephalus and flounders were also recorded. The total fish biomass was made up of the biomass of small resident fish permanently dwelling near the garlands (both species of *Opisthocentrus*, sculpins *B. elegans*, juvenile rockfish *Sebastes*) and the biomass of large migratory fish (visitors)—flounders, adults of *Sebastes*, and sculpins. Following reef colonization in 1996, the abundance and biomass of resident fishes remained nearly the same (Fig. 2). However, the numbers of visitors on different days of observations varied drastically; nevertheless, they formed the greater portion of the fish biomass, up to 1700 g/50 m^2 (Fig. 2) or 34 g/m^2.

The number of large sculpins, sea ravens, adult rockfishes, and *Chirolophis japonicus* increased, while the number of pricklebacks *Opisthocentrus*, sculpins *B. elegans*, and juvenile rockfishes decreased when the garlands lost flotation because of heavy fouling, thus forming voluminous refuges better suited to the former group than vertically erect garlands. After the reefs became afloat, the number of species of both groups remained the same.

In 1999–2003, species composition of fishes on the AR was unchanged and the total biomass continued to grow slowly because of the more frequent occurrence of visiting fishes. The lower portion of garlands (about 1 m) became silted and part of the epiphytic organisms perished; but resident fishes living among the garlands moved upward, and their total numbers and biomass were almost unchanged (Fig. 2).

Our experiment showed that artificial structures of this type can effectively compensate for the loss of natural habitats, particularly *Zostera* beds. Despite the much greater depth of AR deployment (20 m), compared to natural seagrass beds (2–10 m), the biomass values for resident fishes in these habitats were similar: 7.4–10.3 g/m^2 at the AR and 14.2 g/m^2 in the *Zostera* bed [4]. The total fish biomass in the AR area (37.1 g/m^2) was many times higher than the biomass of fishes during control examination before the AR deployment (3.07 g/m^2) and markedly exceeded the biomass of fishes in the *Zostera* bed.

Juvenile rockfish *S. taczanowskii* are abundant among *Zostera*, but they were most often not found on the AR because of the unusual depth of the habitat and the bottom type. Adults of the rockfishes *S. taczanowskii, S. trivittatus*, and *S. schlegeli*, previously common inhabitants of the AR [5], occurred rarely on the AR near Bolshoi Peles Island. Evidently, the nearby stone ridges are a more appropriate substrate for these fishes. The navaga *Eleginus gracilis* and sand lance *Hypoptychus dybowskii* were not recorded at the AR. The Alaska greenfish *Hexagrammos octogrammus*, which was previously encountered at the outer edges of *Zostera* bed, was very rare. If the artificial reef is set at shallower depths where *Zostera* beds are common, the species composition of fishes on the AR would possibly be closer to that of the natural seagrass bed.

Generally, the artificial reef is colonized by fishes within 2–6 months [18, 19]; final stabilization continues for 1–5 years [11, 13]. The species composition and number of fishes on the AR at Bolshoi Pelis had stabilized in the first two years with slight changes in succeeding years. Similar data were reported for other ARs in Peter the Great Bay [1]. This can be explained by the presence of refuges and food resources, which are the main conditions for resident fishes. In the year of its setting, the AR provides merely a refuge; and its further colonization by sedentary and attendant organisms provides food for the AR fishes. Visiting fishes use the AR as a temporary refuge; they do not feed constantly here so their abundance variations are not great. The 12-fold increase in the total fish biomass on the Bolshoi Pelis AR (Fig. 2), compared to the surrounding areas, is higher than the value reported for other ARs, by 1.4-fold [2]. This difference is due to the place and time of deployment of the AR, as well as the design of a particular artificial reef.

In the fall, the natural activity of fishes is decreased, which is characteristic even for fishes of the tropical latitudes [14]; therefore, their demands for vacant refuges and food are also reduced. This is the reason why fishes were absent from the AR in the year of its deployment. If the AR is set in spring or in early summer, it is rapidly colonized by fishes [2] and invertebrates [8] because the settlement of planktonic larvae begins at that time. Interestingly, even squid was repeatedly encountered on the top of the AR.

Thus, deployment of a cage AR in the spring can be recommended for mitigating the loss of natural *Zostera marina* beds.

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