Journal of Experimental Marine Biology and Ecology
264 (2001) 15–28

Journal of
EXPERIMENTAL
MARINE BIOLOGY
AND ECOLOGY

www.elsevier.com/locate/jembe

Research into tolerance for the environment salinity in sea starfish *Asterias rubens* L. from populations of the White Sea and Barentz Sea

Olga L. Sarantchova*

O.A. Scarlato's White-Sea Biological Station, Zoological Institute, Russian Academy of Sciences, Universitetskaya nab. 1, St. Petersburg 199034, Russia

Received 1 June 2000; received in revised form 3 November 2000; accepted 12 May 2001

Abstract

Adaptive responses to salinity changes in three groups of sea starfish *Asterias rubens* L. at different ontogenetic stages were studied. These three groups are the starfish from the White-Sea population, the starfish from the Barentz-Sea population, and the starfish from the Barentz-Sea population experienced a year acclimatization period, the gametes and larvae produced by these three groups of starfish were studied as well. One hundred percent of eggs survived in the following conditions: the White-Sea starfish with the salinity ranged from 24‰ to 26‰; the Barentz-Sea ones survived at salinity of 34‰; the Barentz-Sea ones acclimatized in the White Sea survived within a range of 24–26‰. One hundred percent of gastrulae survived within the following salinity ranges: for the White-Sea starfish it is 18–26‰, for the Barentz-Sea ones—32–34‰; for the Barentz-Sea ones acclimatized in the White Sea—22–26‰. One hundred percent of bipinnaria larvae survived within the following salinity ranges: 12–28‰ for the White-Sea starfish, 20–38‰ for the Barentz-Sea ones; and 18–28‰ for the Barentz-Sea ones acclimatized in the White Sea. For the Barentz Sea starfish acclimatized in the White Sea, the preferred salinity range was shifted towards brackishwater too.

The most narrow limits of tolerance for salinity is typical for initial ontogenetic stages of the starfish, i.e. the stage of fertilizing the egg, and the stage of the gastrula. For bipinnariae of the White-Sea starfish, the critical value of salinity, at which 100% of them survived, appeared to be 12‰, in comparison with 16‰ for the adult starfish.

The population of the starfish from the White and Barentz Seas appeared to have some physiological differences revealing in different resistance of the animals, their gametes and larvae for the salinity influence. The White-Sea population might be considered as an example of the

---

* Tel.: +7-812-114-00-97, +7-812-311-42-38; fax: +7-812-114-04-44.
E-mail address: wsbs@online.ru (O.L. Sarantchova).

PII: S0022-0981(01)00298-2

initial stage of the physiological race isolation in the terms of salinity. However, according to the observed results, the revealed physiological differences are not hereditary. For the Barentz-Sea starfish, the shift of their salinity tolerance towards brackishwater was observed, and the range of their salinity tolerance became similar to the range for the White-Sea starfish.

Keywords: Asterias rubens; Larvae; Physiological races; Salinity; Starfish; Tolerance

1. Introduction

The sea starfish, *Asterias rubens* L., is a temperate species abundant in the Atlantic and Arctic coastal waters of Europe. It is extended northwards as far as Iceland, Northern Norway, Murman Coast (up to the Cape of Sviatoy Nos) and the White Sea, as well as up to the Eastern Greenland, southwards to Senegal but for the Mediterranean Sea (Diakonov, 1955). It is distributed through depths of 0–400 m. Evidently, the species is able to keep its vast range due to its eurybiotic and specifically euryhaline. But it is also well known that adaptive responses of *A. rubens* L. to changes of the most important abiotic factors (i.e. water salinity and temperature) change greatly through its range (Kowalski, 1955; Schlieper, 1957; Binyon, 1961, 1976, etc.). This is usually typical for the species with a vast range with different salinity and temperature conditions within it. Sometimes physiological differences may happen to be quite enough to distinguish different physiological races for such species including *A. rubens.*

The White and Barentz Seas, i.e. the waterbodies bordering the range of *A. rubens* from North–East, differ in their hydrological conditions. The Barentz Sea is a waterbody with almost oceanic salinity 32–34‰ and water temperature fluctuating within 0.5–9 °C. The White Sea has a unique hydrological regime and two-layered structure of its water. In the layer, deeper than 50-m water, temperature remains at about 0 °C and salinity—at 28–30‰ all over the year. In the upper layer, water temperature fluctuates from 0 and −1 to +20 °C throughout the year (Babkov and Golikov, 1984), and salinity ranges within 22–26‰, the major part of the year with abrupt falls, sometimes to 0–5‰ at the surface, during spring ice-breaks. *A. rubens*, like the other temperate fauna, is extended in the upper 20-m water layer and affected by all variety of seasonal changes in the water temperature and salinity.

In the previous experiments carried out on the adult *A. rubens* from the White Sea (Sarantchova, 1989; Sarantchova and Lukanin, 1989), the ranges of the salinity tolerance and temperature one, i.e. the ranges limited by the upper and lower lethal limits (Filippov, 1998), were determined. These ranges—“potential eco-niche” of *A. rubens* from the White Sea—reflect temperature and salinity fluctuations within the whole world species range. For example, the temperature tolerance range of the White Sea *A. rubens* lies between −1 and +25 °C, at the normal, for the White Sea salinity. It is corresponding with the temperature fluctuations in the starfish range, i.e. from 0 to 20 °C or even 23 °C for the Eastern coast of Denmark (Mileykovskiy, 1981). Salinity tolerance range for the White Sea *A. rubens* at the common temperature fluctuations is 16–34‰. The salinity of the Baltic and North Seas, where the starfish is spawning, is 15–35‰.

We compared salinity tolerance of starfish from two populations: from the White Sea, with the low level of salinity, and from the Barentz Sea, with the ordinary level of salinity. Acclimatization as a method of physiological specificity revealing was used. Major attention was paid to early ontogenetic stages. It should be noted that the term 'reproductive physiological race' is taken in the meaning by Mileykovskiy (1968, 1981), i.e. to identify intraspecific populations different in their ecology and spawning.

2. Material and methods

The study was carried out at O.A. Scarlato's White-Sea Biological Station of Zoological Institute (Chupa Bay, Kandalaksha Gulf, White Sea). Experimental works were conducted in isothermic rooms under constant temperature (12 °C), and light conditions during the summer and autumn in 1994–1996.

Three groups were investigated: starfish from the White Sea, starfish from the Barentz-Sea and starfish from the Barentz Sea that had been acclimatized to the salinity and temperature regime of the White Sea. The Barentz-Sea starfish were taken from the Dalnezelenetskaya Bay (69°N, 36°E) with water salinity as high as 32–33‰. Being brought to the Chupa Bay, Kandalaksha Gulf, White Sea (66°20′N, 34°E) with the summer water salinity of 24–26‰, they were put into a holding net fixed to a raft. They were regularly fed by fresh mussels. After a year, only about 10% of the starfish in the holding net died. The low value of elimination evidences that it was not because of acclimatization, but because of some other reasons.

Each of the three groups of *A. rubens* are different in their origin; the experiments were carried out according to the same scheme. Starfish, which had been previously held under their natural salinity, spawned in laboratory. It was the way, how, the gametes, then embryos and larvae were bred. The White-Sea starfish and the Barentz-Sea starfish acclimatized in the White Sea were cultivated under their natural salinity of 24‰, and the Barentz-Sea ones were cultivated under their natural salinity of 34‰. All of them have served as materials for the experiments on identifying the limits of their salinity resistance. During these experiments, the survival rate of the eggs being fertilized was tested at different salinity. For gastrulae, bipinnariae and adult starfish the limits of salinity tolerance zone was determined. For adult starfish, the share of preference for any certain salinity under the condition of their choice from the available salinity was counted.

Data on the size and age of embryos, larvae and adult starfish used in experiments are presented in Table 1.

Table 1
Age and size of specimens at different ontogenetic stages of *A. rubens* in experiment

Stage	Age	Size
Egg being fertilized	–	180–220 mkm
Gastrula	2–3 days	160–180 mkm
Bipinnaria	10 days	320–370 mkm
Starfish	more than 2 years	10–80 mm (radius)

2.1. Eggs being fertilized

This stage was investigated most thoroughly as it is a rather weak point in the life cycle. The survival rate of the eggs being fertilized was tested under salinity varying in a range from 10‰ to 42‰ with 2‰ intervals.

Artificial fertilization was performed in the following way. During the tests, the unfertilized egg cells were put into seawater with either lowered or increased salinity, and during the control tests—into the water with natural salinity. Sperm suspension was added to them so that one to two drops of thick suspension were added to 250 ml of water. During the experiments, sexual material from several animals was used. To get larva material for control tests, the fertilized eggs were put into 5-l tanks permanently aerated. Afterwards, the larvae at demanded stages were taken from these tanks for experiments. At later stages, larvae were fed with mixture of plankton algae *Monochrysis* sp. and *Dunalliella* sp. Embryos and larvae tested under different salinity were kept in micro-tanks ($V = 10–15$ ml). The water was changed regularly with aerated water of the same salinity.

To determine the survival rate of the eggs being fertilized, the number of alive and dead eggs and embryos in the field of the microscope view were counted. As the survival criteria, the number of the gastrulae properly developing 2 days after the fertilization was used. Then the gastrulae were observed for 3 days, so the total exposition made up 5 days.

Survival rate and share of alive embryos with normal development are presented in percents of the total amount of egg cells. The shares were compared using the ANOVA procedure with the program Statistica 4.3 with arcsin-transformated variants (Lakin, 1990).

2.2. Embryos and larvae

When studying these stages, the limits of the tolerance zone were defined, i.e. the salinity range where embryos' survival rate was as high as 95–100% of the one recorded in the control under natural salinity (24‰ and 34‰—see above). When identifying the range, the larvae were put into the seawater of either higher or lower salinity than the natural one. Values of the tested salinities, within the investigated range, differed in 2‰ steps. The values of salinity, under which elimination of the larvae was recorded, were considered to be out of the tolerance range. Besides, the limits of 100% lethal zone were revealed.

Embryos and larvae in samples were counted by one. Experiments were carried out according to the same plan. Three replicates with 10 specimen in each were used for all the tested salinities.

2.3. Starfish

When defining salinity tolerance range for adult starfish, it was not survival rate that was revealed, but an adequate faster response to an external influence, i.e. depressing of feeding activity for more than 3 days.

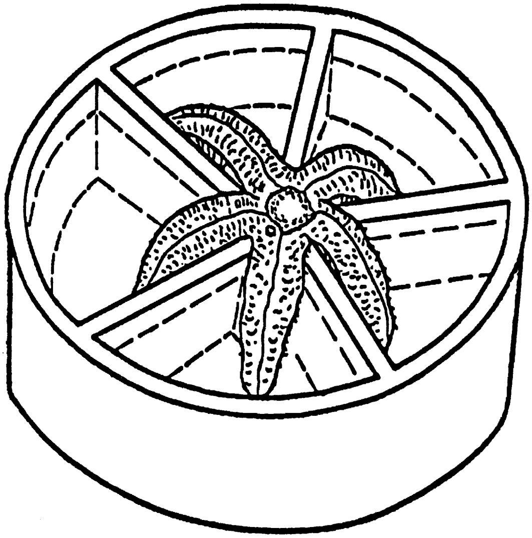

Fig. 1. Experimental installation for studying the behaviour of starfishes when choice of salinities are available.

When studying behaviour of starfish, when choice of water-salinity was available, an original modification of the device generally used in such experiments (Polunina, 1965, etc.) was taken. The device has a shape of a round uncovered vessel made of plastic foam (Fig. 1). Radial walls divide the vessel into five equal parts. The walls run from the central area, where the tested starfish is placed. The end of each of the starfish's arms is placed into a compartment with the water of different salinity. The starfish crawls into the compartment with the water of the salinity of its choice. The water of the salinity from 15‰ to 42.5‰ was used during the experiment with the step interval of 2.5‰. We counted the proportion of each salinity value from the total amount of the available salinity values, and estimated the standard error for each mean value of the share (Lakin, 1990).

3. Results

The results of the experiments for each subsequent stage are presented below. All the three groups of starfish of different origin follow one after the other.

3.1. Egg being fertilized

3.1.1. Of starfish from the White Sea

The greatest amount of the fertilized eggs, having developed properly into gastrulae for 2 days, is recorded under natural salinity 24‰ and makes up 51% of total egg amount (Fig. 2a). The same amount of fertilized eggs later developed into regular embryos is recorded under salinity 26‰–50% (Fig. 2a).

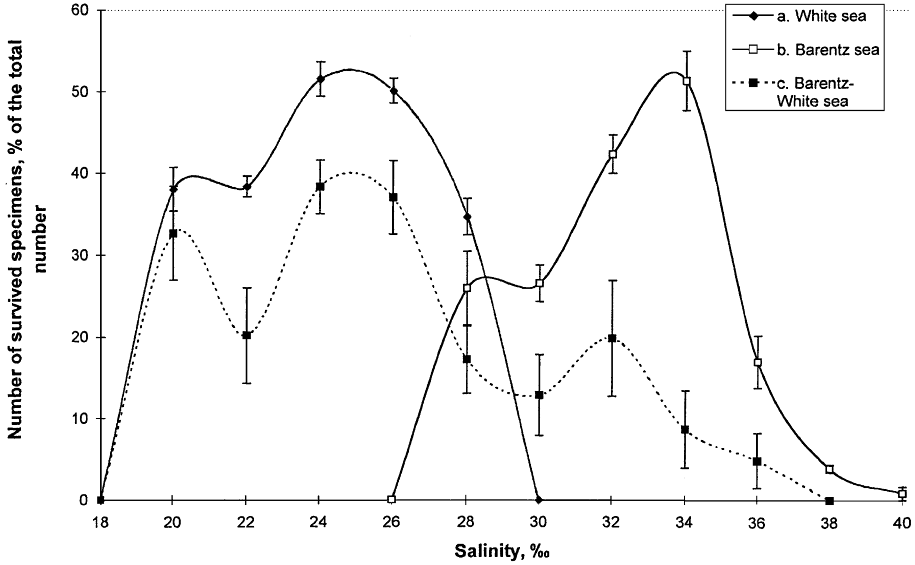

Fig. 2. Survival rate of eggs being fertilized by *A. rubens* from three populations under different salinities: (a) White-Sea animals; (b) Barentz-Sea animals; (c) Barentz-Sea animals after 1 year acclimatization in the White Sea. Error bar correspond to ± S.E.M., $n = 6$.

Under salinity of 20–22‰ and 28‰, the amount of fertilized eggs developed into embryos is less—only 38% and 34%, correspondingly (Fig. 2a). Under salinity of 20–22‰ and 28‰, embryo development is somehow retarded in comparison with the control level of 24–26‰. For instance, under the control level, all the fertilized eggs develop into gastrulae within 2 days, while under 20–22‰ and 28‰, the same time later, the gastrulae make up only 60% of all the embryos, all the rest are blastulae.

Under salinity of 16‰, and lower as well as under 34‰ and higher, the fertilization is unsuccessful, and one can clearly see the defects of cell coats and nucleus.

Under salinity of 18‰ and 30‰, only single cells are fertilized and manage to develop to the stage of 16–32 blastomeres and then they die before they turn into blastula.

3.1.2. Of starfish from the Barentz Sea

The greatest amount of fertilized eggs, having developed properly into embryos within 2-day period, is recorded under natural salinity of 34‰ and makes up 51% of total amount of eggs (Fig. 2b).

Under salinity of 26‰ and lower, the fertilization is unsuccessful and eggs die.

Under salinity of 36‰ and 38‰, correspondingly, 17% and 4% of normal embryos are recorded (Fig. 2b). Their development, we followed up to the stage of dipleurula larvae, was more retarded than in the control.

Under 40‰ only a few cells are fertilized (Fig. 2b), then they develop into dipleurula larvae but with retardation as well.

Table 2
The effect of salinity upon the survival rate of the eggs being fertilized in *A. rubens* of different origin estimated by ANOVA

Origin	*F*	df	p
White Sea	49,98	5	< 0.001
Barentz Sea	37,97	6	< 0.001
Barentz Sea–White Sea	6,33	10	< 0.001

3.1.3. Of starfish from the Barentz Sea after acclimatization in the White Sea

The greatest amount of fertilized eggs, having developed properly into embryos within 2 days, is recorded under natural salinity of 24‰ and 26‰–38% and 37%, respectively (Fig. 2c).

Under 20‰ and 22‰, the amount of normal embryos is less and makes up 32% and 20%, respectively (Fig. 2c).

Under the salinity of 18‰, the fertilization is depressed and is recorded only for a few specimens that die afterwards.

Under 28‰, 30‰ and 32‰, the number of eggs normally fertilized is low as well—17%, 13%, and 20% of embryos, respectively, were found (Fig. 2c).

Under 34‰, 36‰ and 38‰, they are even fewer—9.5% and 0% (Fig. 2c).

The effect of salinity upon the survival rate of the eggs, being fertilized in *A. rubens* of different origin, is represented in Table 2. One may see that the effect is significant for all the three groups of the starfish of different origin.

3.2. Gastrula larvae

3.2.1. Of starfish from the White Sea

The highest survival rates (95–100% of that in control) of the gastrulae and their development with no deviations is recorded under salinity of 18–26‰ (Table 3).

Under 12‰ and 30‰, the death of the larvae is observed.

Under 16‰ and 28‰, during the first day of the experiment, the larvae activity is considerably depressed in comparison with the control salinity (24‰).

3.2.2. Of starfish from the Barentz Sea

The high survival rate of gastrulae up to 95–100% of the control and their further normal development are recorded under salinity 32–34‰ (Table 3).

Table 3
Limits of tolerant salinity zone in eggs, larvae and adult starfish in groups of different origin (exposure period 5 days)

Stage	From the White Sea	From the Barentz Sea	From the Barentz Sea and then from the White Sea
Egg being fertilized	24–26	34	24–26
Gastrula	18–26	32–34	22–26
Bipinnaria	12–28	20–38	18–28
Starfish	16–34	20–40	20–34

The salinity of 20‰ and 45‰ causes 100% elimination of the larvae.

3.2.3. *Of starfish from the Barentz Sea after acclimatization in the White Sea*

The survival and normal development of 95–100% of the larvae are recorded under the salinity of 22–26‰ (Table 3).

Under 16‰ and 30‰, the death of the larvae is observed.

3.3. *Bipinnaria larvae*

3.3.1. *Of starfish from the White Sea*

In the environment, with the salinity of 14–28‰, all the larvae live for 10 days at least (Table 3).

Under the salinity of 12‰, some of the larvae die within 6–10 days, under the salinity of 10‰, all of them die during the first day of the experiment.

3.3.2. *Of starfish from the Barentz Sea*

One hundred percent survival of the larvae, in comparison with the control, is recorded under salinity of from 20‰ to 38‰ (Table 3).

Under salinity of 10‰ and 50‰, all the larvae die during the first day of the experiment.

3.3.3. *Of starfish from the Barentz Sea after acclimatization in the White Sea*

One hundred percent survival of the larvae in comparison with the control is recorded under salinity varied from 18‰ to 28‰ (Table 3).

3.4. *Starfish*

3.4.1. *From the White Sea*

Tolerance salinity range according to the starfish feeding observation is from 16‰ to 34‰ (Table 3).

3.4.2. *From the Barentz Sea*

The feeding depressing of the starfish has not been observed, under the salinity varying from 20‰ to 40‰ (Table 3).

3.4.3. *From the Barentz Sea after acclimatization in the White Sea*

Vital activity of this group of starfish is not depressed, under the salinity varying from 20‰ to 34‰ (Table 3).

3.5. *A. rubens behaviour when the water of different salinity is chosen*

The results of the research of preference behaviour of *A. rubens* show its ability of quick adaptive reorganization proceeding at the organism level.

The starfish from the White-Sea and Barentz-Sea populations choose different water salinity corresponding to their natural environment salinity. So, the White-Sea starfish prefer the salinity of 22–25‰, and the Barentz-Sea ones—32.5–35‰ (Fig. 3a). Even after 2 weeks of acclimation to the White Sea salinity, the Barentz-Sea starfish choose the salinity of 25‰ and 27.5‰ as often as that of 32.5‰ (Fig. 3b). After a year of acclimatization, they prefer quite clearly the salinity of 25‰ and 27.5‰—49.0 ± 0.6% and 58.5 ± 0.6%, correspondingly (Fig. 3b).

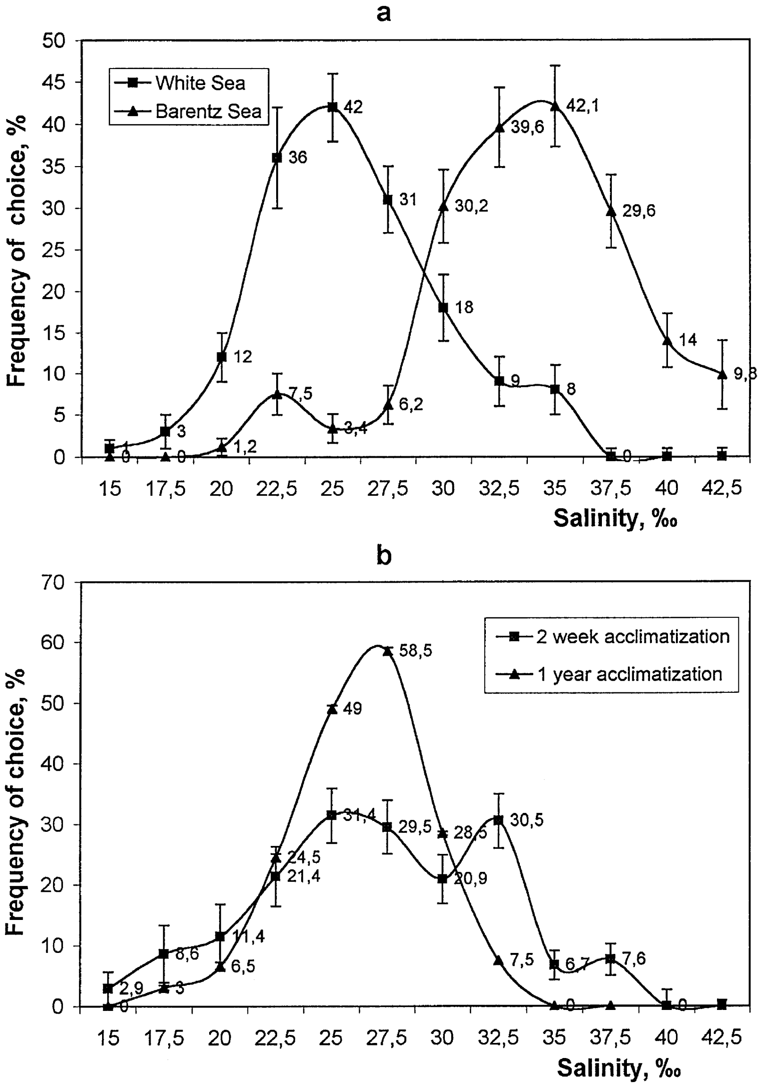

Fig. 3. Choice of definite water salinity by *A. rubens* from different populations: (a) White-Sea and Barentz-Sea animals; (b) Barentz-Sea animals after 2 weeks and 1 year acclimatization in the White Sea. Error bars correspond to ± interval of confidence ($^{*}p < 0.05$).

4. Discussion

The role of salinity as well as the temperature, may be significant in spatial distribution and reproduction of sea invertebrates (Thorson, 1946; Kinne, 1971). Firstly, this is true for the water-bodies with salinity significantly different from the oceanic one. Secondly, it is characterized for estuaries with either regular or irregular short-term and seasonal changes in salinity (Mileykovskiy, 1981; Mees et al., 1993; Montague and Ley, 1993; Richmond and Woodin, 1996; Stolyarov and Burkovskii, 1996, Kashenko, 1997; Burkovskii et al., 1998; etc.).

The White Sea is characterized by both types of salinity fluctuations.

Possibly, it is the lower salinity that is responsible for the starfish spawning being somehow lagged in the White Sea—it takes place at the end of June or July as a rule under higher temperature than in the Barentz Sea, where it may start in May–June (Mileykovskiy, 1981). The strongest of seasonal fluctuations of salinity appears to be the spring salinity-fall occurring due to ice melting. The heavy salinity fall, with the absence of wind mixing, caused the mass throw-out of starfish onto sandy beaches of Dvina Bay, White Sea, in spring 1990. Probably, they had lost their capability for holding themselves on hard substrate—this capability is significantly depressed when the salinity falls down to 16‰ (Berger and Naumov, 1995).

The comparison of adaptive responses to water-salinity changes of invertebrates from the White and Barentz Seas, with the help of the method of cross-acclimatization (Korringa, 1957; Loosanoff, 1958; etc.), was carried out for two mollusc species—*Littorina obtusata* and *Mytilus edulis*. The study revealed that as a result of long-term acclimatization, physiological differences disappeared (Berger, 1986; Lukanin, 1971).

Adaptive responses to salinity changes of *A. rubens* from the White Sea have not yet been compared with the adaptive responses of specimens from other water-bodies of Northern Europe, for those reproductive physiological temperature or salinity races are well known. For instance, Mileykovskiy (1968, 1981) describes two temperature races starting to spawn under 3.5–4.5(6.5) and 6.5–9.0 °C, and a salinity race from the Kiel Bay (Germany) that spawns under 13–15 °C (Binyon, 1961). The reason of isolation of starfish, from the Kiel-Bay population of the Baltic Sea (15‰) into a specific race, was the significant differences between them and the starfish from the North Sea population (30‰) (Kowalski, 1955; Schlieper, 1957; Binyon, 1961). So the North-Sea starfish spawn in March–September, the Baltic-Sea ones in May–June; the former has gotten larger eggs. The differences in the motor activity of the animals and chemical composition of the skeleton were found.

The lowest limit of salinity zone, that can be tolerated by *A. rubens* from the North and Baltic Seas makes up 23‰ and 8‰, correspondingly (Binyon, 1961). It is not quite clear if the salinity of 23‰, i.e. the lowest limit of the starfish tolerance zone in the North Sea, is enough for their reproduction. The lowest salinity limit, which provides reproduction cycle of the starfish in the Baltic Sea, appears to be 15‰ (the Kiel Bay). The Baltic Sea starfish population of Rugen Island, under salinity 8‰, consists of the adult specimens, and exists due to the larvae introduction, as the starfish of the water-body is sterile (Brattström, 1941; Kinne, 1971). The starfish from the North Sea die within a week under the salinity of 18‰ (Binyon, 1961), except the population in the bay of Scotland existing under 16‰ (Binyon, 1976). Thus, the starfish from the Baltic and North Seas have different salinity resistance, and these differences are inherited—cross-acclimatization leads to the death of animals from the both populations (Schlieper, 1957).

Let us present the adaptive reactions of *A. rubens* from the White and Barentz Seas stage after stage subsequently.

The narrowest salinity-range in which 100% of specimens survive is typical of the early ontogenetic stages, from the stage of egg cell being fertilized to gastrula-larva one (Table 3). During ontogenesis, this range is getting wider. Like some other marine invertebrates, with external fertilization spermatozoons of the White-Sea starfish, are rather euryhaline, and have the survival range of 100% in the water with the salinity of 10–36‰ (Sarantchova, 1989).

The later planktonic stages of the White-Sea starfish appeared to be more resistant to the salinity decreasing than the adult starfish. So, 100% of bipinnariae and brachiolariae (personal data) survive under the salinity of 12‰, but 100% of the starfish do it under the salinity of 16‰ (Table 3). The similar data were observed for the starfish *A. amurensis*: bipinnariae survive under the salinity of 13‰ (Sagara and Ino, 1954), while the adults survive under the salinity no less than 18‰ (Mikulich and Birulina, 1970).

The resistance to salinity decreasing is typical for planktonic larvae of some of marine invertebrates, e.g. crustacean *Gammarus capillata* (Kinne, 1971), scyphomedusae *Aurelia aurita* and *Cyanea capillata* (Lukanin, 1976), chitons *Acanthochitona rubrolineata* and *Ishnochiton hakodadensis* (Kashenko, 1985), trepang *Stichopus japonicus* (Kashenko, 1992), mussel *M. edulis* (Yaroslavtseva et al., 1989), oyster *Crassostrea gigas* (Yaroslavtseva et al., 1990), etc. Such revelation of adaptive plasticity seems to be possible for the marine invertebrates with free plankton larvae, which has the function of the species spreading.

According to the obtained results, the response to salinity fluctuations is different for the White- and Barentz-Seas starfish. Thus, 100% fertilization of eggs and embryo development is observed for the White-Sea starfishes under the salinity of 24–26‰, for the Barentz-Sea ones—under 34‰ (Table 3). Under the salinity of 32–34‰, no fertilization of the White-Sea starfish takes place and all egg cells die (Fig. 2a). Vice versa, the salinity fall to 24–26‰ causes the death of all egg cells of the Barentz-Sea starfish (Fig. 2b). However, acclimatization of the Barentz-Sea starfish in the White Sea shifts the survival range of the fertilized egg cells towards lower salinity values. After a year of acclimatization of the starfish, 100% fertilization and development of the eggs occurs within salinity range of 24–26‰ (Fig. 2c).

One hundred percent survival range of gastrulae lies within 18–26‰ for the White-Sea starfish, and within 32–34‰ for the Barentz-Sea ones. For the Barentz-Sea specimens acclimatized to the White-Sea environment the range shifts towards lower salinity and makes up 22–26‰ (Table 3).

The range of salinity resistance for bipinnariae of the Barentz-Sea starfish acclimatized in the White Sea shifts in the similar way (Table 3). For the White-Sea starfish bipinnariae, the 100%—survival range makes up 12–28‰, for the Barentz-Sea ones—20–38‰. After the acclimatization in the White Sea, the survival rate for the latter appears to be 18–28‰.

It seems possible to suppose that had we carried the experiments on acclimatization of *A. rubens* from the Barentz Sea to the White Sea (or vice versa) at the stages of fertilized eggs or early larvae, the gametes and larvae would have died. However, a year preliminary acclimatization of the Barentz-Sea starfish in the White Sea affected upon the salinity resistance of both the starfish themselves and gametes, embryos and larvae produced by them. As a result, the 100%-survival range shifted towards lower salinity. The adaptive plasticity physiological reactions of the acclimatizing starfish is approved with the results of the researches of the behaviour of *A. rubens* with the choice of water salinity (Fig. 3).

Thus, population of *A. rubens* from the White and Barentz Seas have certain physiological differences, and it might be supposed that the White-Sea population of the starfish species presents an initial stage of a new salinity physiological race isolation. We think that the term "reproductive physiological race", in its common meaning, is not quite relevant in this case: physiological differences of the *A. rubens* population from the White and Barentz Seas are not inherited, and they disappeared after a long-term acclimatization of the specimens from the Barentz Sea in the White Sea.

Acknowledgements

I am grateful to V.E. Luleev for his technical help, to Dr. A.A. Sukhotin for his help in statistic data processing and T.E. Dobrova for her help with the translation. *[SS]*

References

Babkov, A.I., Golikov, A.N., 1984. Hydrobiocomplexy Belogo morya. [Hydrobiocomplexes of the White Sea] Zoologicheskiy Institut, Academya Nauk SSSR, Leningrad, p. 104 (In Russian).

Berger, V.Ja., 1986. Adaptatsii morskikh molluskov k izmeneniyam solenosti sredy. [Adaptations of Marine Molluscs to Environmental Salinity Changes] Nauka, Leningrad, p. 214 (In Russian).

Berger, V.Ja., Naumov, A.D., 1995. Vliyanie solenosti na sposobnost morskikh zvezd *Asterias rubens* prikreplyatsya k substratu. [Influence of salinity on the ability of starfishes *Asterias rubens* L. to attach to substrate] Biol. Morya (Vladivostok) 22 (2), 99–101 (In Russian with English abstract).

Binyon, J., 1961. Salinity tolerance and permeability to water of the starfish *Asterias rubens* L. J. Mar. Biol. Assoc. U. K. 41 (1), 161–174.

Binyon, J., 1976. The effect of reduced salinity upon the starfish *Asterias rubens* L. together with a special consideration of the integument and its permeability to water. Thalassia Jugosl. 12 (11), 11–20.

Brattström, H., 1941. Studien über die Echinodermen des Gebietes zwischen Skagerak und Ostsee, besonders des Øresundes, mit einer Übersicht die physische Geographie. Diss. Gleerup, Lund, Untersuch. aus dem Øresund 27, 329.

Burkovskii, I.B., Stolyarov, A.P., Udalov, A.A., 1998. Lichinki kak faktor formirovanya soobtshestva ilisto-peschanoy litorali Belogo morya. [Larvae as a factor of development of macrobenthos community in mud–sand littoral of the White Sea] Zool. J. 77 (11), 1229–1241 (In Russian with English abstract).

Diakonov, A.M., 1955. O sposobnosti iglokojikh vydergivat' ponijenie normalnoi okeanicheskoi solenosti. [About abilities of Echinodermata to sustain reduction of normal oceanic salinity] DAN SSSR 102 (2), 373–374 (In Russian).

Filippov, A.A., 1998. K metodam opredelenya solenostnoi tolerantnosti vodnykh bespozvonochnykx. [About methods of salinity tolerance determination in water invertebrates] Ecologiya 4, 291–296 (In Russian).

Kashenko, S.D., 1985. Vliyanie opresnenya na rannyi ontogenez nekotorykh vidov khitonov zaliva Petra

Velikogo (Yaponskoe more). [Influence of freshening of water on early onthogenetic stages of some species of the chitons from the Gulf of Great Piter] Biol. Morya (Vladivostok) 4, 27–33 (In Russian with English abstract).

Kashenko, S.D., 1992. Vliyanie opresnenya na razvitie dal'nevostochnogo trepanga. [Influence of freshening of water on early development stages of the Sea of Japan cucumber *Stichopus japonicus*] Biol. Morya (Vladivostok) 3–4, 43–52 (In Russian with English abstract).

Kashenko, S.D., 1997. Vliyanie solenostnoi acclimatsii trepanga *Stichopus japonicus* na adaptivnye sposobnosti raznykh stadyi ego razvitiya. [Effects of salinity acclimation of the sea cucumber *Stichopus japonicus*] Biol. Morya (Vladivostok) 23 (2), 93–100 (In Russian with English abstract).

Kinne, O., 1971. Salinity–animals–invertebrates. Mar. Ecol. (London) 1 (2), 820–995, etc.

Korringa, P., 1957. Water temperature and breeding throughout the geographical range of *Ostrea edulis*. Annee Biol. 33 (1/2), 1–17.

Kowalski, R., 1955. Untersuchungen zur Biologie des Seesternes *Asterias rubens* L. in Brackwasser. Kiel. Meeresforsch. 11 (2), 201–213.

Lakin, G.F., 1990. Biometriya. Vys. Shkola, Moskva 352 (In Russian).

Loosanoff, V.L., 1958. Challenging problems in shellfish biology. Perspectives in Marine Biology. Univ. California Press, Berkeley, Los Angeles, pp. 483–496.

Lukanin, V.V., 1971. Izmenenie obmena i diapazona aktivnosti u belomorskikh midyi pri akklimatsii k razlichnym solenostyam (ne vykhodyatshim za pamki normalnogo diapazona). [Changes in metabolism and range of activity in White Sea *Mytilus edulis* during its acclimation to different salinities (in normal range)] Molluski 4, 39–40 (In Russian).

Lukanin, V.V., 1976. Adaptivnye reaktsii belomorskoi scyfomeduzy *Aurelia aurita* (L.) na izmeneniya solenosti. [Adaptive reactions of the White Sea Scyphomedusae *Aurelia aurita* (L.) to salinity changes]Solenostnye adaptatsii vodnykh organizmov. Zoologicheskyi Institut, Academiya Nauk SSSR, Leningrad, pp. 26–58 (In Russian).

Mees, J., Dewicke, A., Hamerlynck, O., 1993. Seasonal composition and spatial distribution of hyperbenthic communities along estuarine gradients in the Western Shelde. Neth. J. Aquat. Ecol. 27 (2–4), 359–376.

Mikulich, L.V., Birulina, M.G., 1970. Regeneratsiya amurskikh morskikh zvezd i vliyanie na nikh nekotorykh abioticheskikh faktorov v usloviyakh dlitel'nogo soderjaniya v akvariumakh. [Regeneration in Amur starfishes and influence of abiotic factors on them during prolonged keeping in aquariums] Ecologiya 4, 106–107 (In Russian).

Mileykovskiy, S.A., 1968. Razmnojenie morskoi zvezdy *Asterias rubens* v Belom, Barentzevom, Norvejskom i drugikh evropeiskikh moryakh. [Reproduction of the starfish *Asterias rubens* L. in White Sea, Barenz Sea, Norwegian Sea and other European Seas] Oceanologiya 8 (4), 693–704 (In Russian).

Mileykovskiy, S.A., 1981. Ekologiya razmnojeniya morskogo bentosa. [Ecology of Reproduction in Marine Benthos] Nauka, Moskva, p. 92 (In Russian).

Montague, C.L., Ley, J.A., 1993. A possible effect of salinity fluctuation on abundance of benthic vegetation and associated faune in notheastern Florida Bay. Estuaries 16 (4), 703–717.

Polunina, O.A., 1965. O sposobnosti morskoi zvezdy *Asterias rubens* razlichat' solenost' morskoi vody. [A possibility of starfish *Asterias rubens* L. to distinguish a salinity of seawater] DAN SSSR. 165 (2), 451–453 (In Russian).

Richmond, C.E., Woodin, S.A., 1996. Short-term fluctuations in salinity: effects on planctonic invertebrate larvae. Mar. Ecol.: Prog. Ser. 133, 167–177.

Sagara, J., Ino, T., 1954. The optimum temperature and specific gravity for bipinnaria and young of Japaneses starfish, *Asterias amurensis* Lutken. Bull. Jpn. Soc. Sci. Fish. 20 (8), 689–693.

Sarantchova, O.L., 1989. Otnoshenie *Asterias rubens* Belogo morya k temperature i solenosti vody. [The attitude of *Astrerias rubens* from the White Sea to water temperature and salinity] Tr. Zool. Inst. , V. 192. ZIN AN SSSR, Leningrad, 86–104 (In Russian).

Saranchova, O.L., Lukanin, V.V., 1989. Adaptivnye reaktsii morskoi zvezdy *Asterias rubens* i midii *Mytilus edulis* iz Belogo Morya k izmenenyu solenosti sredy. [Adaptive responses in the starfish *Asterias rubens* L. and the blue mussel *Mytilus edulis* L. from the White Sea to salinity changes] Biol. Morya (Vladivostok) 5, 29–35 (In Russian with English abstract).

Schlieper, C., 1957. Comparative study of *Asterias rubens* and *Mytilus edulis* from the North Sea (30 par 1.000 S) and the Western Baltic Sea (15 par 1.000 S). Annee Biol. 33 (3/4), 117–127.

Stolyarov, A.P., Burkovskii, I.B., 1996. Sezonnye izmeneniya struktury makrobentosa estuaria Belogo morya (s vyrajennym gradientom solenosti). [Seasonal changes in the macrobenthos structure of the White Sea estuary (in well-difined gradient of salinity)] J. Obtshei Biol. 57 (2), 95–111 (In Russian with English abstract).

Thorson, G., 1946. Reproduction and larval development of Danish marine bottom invertebrates with special reference to the planktonic larvae in the Saund (Øresund). Medd. Komm. Dan. Fisk.-Havunders, Ser. Plankton 4 (1), 523.

Yaroslavtseva, L.M., Naydenko, T.Kh., Sergeeva, E.P., 1989. Vliyanie opresneniya na rannie stadii razvitiya s'edobnoi midii iz Belogo morya. [Effect of reduced salinity on early development stages of the edible mussel from the White Sea] Biol. Morya (Vladivostok) 6, 30–37 (In Russian with English abstract).

Yaroslavtseva, L.M., Sergeeva, E.P., Kashenko, S.D., 1990. Izmenenie chuvstvitelnosti k opresneniyu v ontogenese gigantskoi ustritsy. [Euryhalinity changes in ontogenesis of the oyster *Crassostrea gigas* L] Biol. Morya (Vladivostok) 6, 36–42 (In Russian with English abstract).