RUSSIAN AQUACULTURE OF STURGEON FISHES IN MODERN CONDITIONS

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ABSTRACT
Under the current conditions of valuable fish species depletion, sturgeon aquaculture is intended to solve two major problems, such as restoring natural stocks and saturating the consumer market with delicacy products. Artificial reproduction is the only feasible way of preserving the sturgeon gene pool in Russia's water bodies, since natural reproduction has been reduced to zero. Commercial sturgeon farming addresses the needs of the consumer market in the context of the ban on commercial fishing. The article deals with the issues of the state and prospects of sturgeon aquaculture development.

Keywords: *aquaculture, sturgeon, artificial reproduction, commercial sturgeon farming.*

INTRODUCTION

Around the world, interest in the unique relict fish species of sturgeon continues unabated, even while their natural populations are becoming extinct. This is explained by the fact that sturgeon fish have extraordinary adaptability, a large habitat, species biodiversity and, most importantly, food value. Sturgeon fish are used to make delicacies that are in great demand among the population. The Caspian basin used to be the world's leading producer of these species, with catches of 25,000-27,000 tonnes, or over 90% of the world's total catch, but since 2005 Russia has imposed a ban on commercial catches, as natural resources have reached critical levels. It was decided to allow sturgeon producers to catch sturgeon only for scientific research and artificial reproduction, but even for these purposes single species are caught, and only occasionally. The depletion of natural resources necessitates the active development of sturgeon aquaculture in two directions. Firstly, this is farming and release of juveniles into natural water bodies to replenish natural resources. Secondly, it is production of commercial products in the form of black caviar and flesh of sturgeon for the consumer market.

In the Caspian Sea basin, sturgeon aquaculture has been developing since the middle of the previous century. At the same time, while artificial reproduction was put on an industrial basis earlier than in other countries, namely in the late 1950s, commercial sturgeon farming began to develop much later than in other countries, only at the beginning of this century. Under the current conditions, only aquaculture sturgeon delicacies are available on the global consumer market, as their commercial fishing is banned in almost all regions of the world.

Our aim was to analyse the current state of the two areas of sturgeon aquaculture in Russia and to identify ways of further development.

MAIN POINTS

Sturgeon farming, as an independent branch of aquaculture, has a long history. It is generally accepted that the beginning was made by Professor Ovsyannikov, who in 1869 found sterlet spawning grounds on the Volga near the city of Simbirsk. Then, together with Scientist Peltsam, they carried out work on fertilization of this sturgeon species eggs under artificial conditions for the first time. This marked the beginning of the development of biotechnology for the artificial reproduction of sturgeon species. Later Soviet scientists A. Borodin, V. Meyer, M. Voskoboinikov, N. Arnold, F. Schmidt, N. Gerbilski, N. Derzhavin, V. Milstein, and others laid the foundation for the biotechnology of artificial reproduction of these valuable fish species [13]. Experimental work on the artificial reproduction of sturgeons was carried out in 1916, and in 1919 the first instruction on sturgeon farming was issued.

1.1. Artificial reproduction of sturgeon

Artificial reproduction of sturgeon on an industrial scale first began in the Caspian Sea basin and was caused by the regulation of the Volga River runoff by hydraulic structures, which had an extremely negative impact on the spawning migration routes of spawners. The developed bio-technique for sturgeon farming was put into industrial production in the middle of the previous century, when 13 sturgeon farms were put into operation in the Caspian Sea region, with a total capacity of 90 million young beluga, Russian sturgeon and starry sturgeon species. The standard weight of young fish was 4 to 5g for beluga, 3 to 4g for Russian sturgeon and 2 to 3g for starry sturgeon [18].

Over the entire period of sturgeon farms in the Caspian states, from the 1950s to the present, over 3 billion standard juvenile sturgeon were farmed and released into the sea, with the Russian share accounting for 80%. Over 90 million juvenile sturgeons were released into the Caspian Sea annually until almost the end of the 1980s. The maximum volume of juvenile fish release in Russia was reached in 1992 and amounted to 67.0 million fish. At the same time, it should be taken into account that the Caspian Sea's feed makes it possible to increase the release of juvenile sturgeons to 150 million, including 59.5% for sturgeon, 25% for starry sturgeon, and 15% for beluga.

Analysis of the dynamics of juvenile sturgeon release by fish farms in the Lower Volga Region is presented in Figure 1.

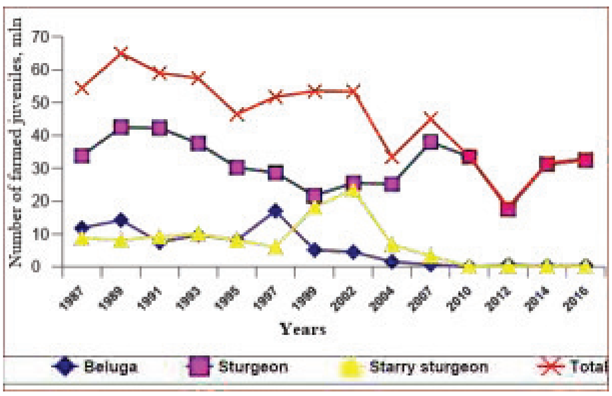

Figure 1. Dynamics of artificial reproduction of sturgeons by Volga farms [2].

The data presented shows that since the mid-1990s there has been a gradual decline in the release of juvenile fish, with the largest reductions observed in two species - beluga and starry sturgeon; the numbers of juvenile Russian sturgeon have also been subject to negative changes, but to a lesser extent. Nevertheless, thanks to farm-based artificial reproduction the Caspian Sea's sturgeon stock was restored, and in the 1980s the Soviet Union produced over 24,000 tonnes of these fish, with around 2,500 tonnes of black caviar being exported alone. At the beginning of this century, the share of farmed fish reached 95% for beluga, 45% for starry sturgeon and 70% for sturgeon [22]. This was due to the fact that after the commissioning of the Stalingrad Hydroelectric Station in 1958, the spawning migration route for spawners of migratory fish species was reduced to 450 km. Female and male beluga have almost completely lost their traditional spawning grounds. The spawning grounds of Russian sturgeon have been reduced by 80% and only starry sturgeon retained the possibility of natural breeding on the Volga to a certain extent.

Since 1995, the scale of artificial reproduction of sturgeon has begun to sharply decrease, amounting to no more than 37 to 50 million fish. [2], its efficiency gradually began to decline, and the commercial return (species that have reached sexual maturity) does not exceed 1%. This is caused by the fact that many juveniles die in the release areas before reaching the sea [26]. A sharp reduction in the release of juvenile sturgeon occurred at the end of the 1990s, as shown by the curve in Figure 2.

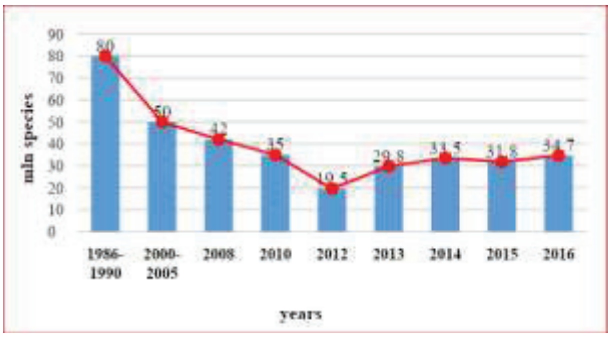

Figure 2. Release of juvenile sturgeon by farms in Astrakhan Oblast.

In 2010, for example, production had already halved to 35 million species, whereas all farms had a total production capacity of 65 million species. The worst situation was in 2012, when the farm capacities were only utilized for a third and the output was only 19.5 million young sturgeons, with Russian sturgeon accounting for 80-85%. Subsequently, the number of juveniles began to increase and reached a level of 33 to 35 million species. It should be noted that young beluga and starry sturgeon were in the worst situation; their share was only 15-20% of the total population. This crisis situation was caused by a shortage of male and especially female sturgeons of natural origin. It was not possible to procure the necessary number of spawners. Only a few species of the spring spawning population in the lower Volga River were caught for fish farming purposes, with the winter forms showing poor fish-biological indicators of mature spawners and response to hormonal influences.

The biotechnology originally developed and introduced into industry for the production and farming of juvenile sturgeons to replenish natural resources, the reduction of which was caused by the regulation of the Volga, involved the single use of wild spawners for fish farming purposes, as the Caspian Sea had the richest stocks of sturgeons. But when the increasing shortage of females for fish eggs became an urgent issue, methods of intra-vital obtaining of reproductive products were introduced. While intra-vital semen was obtained from males without much difficulty, the surgical extraction of mature eggs from female sturgeon fish was rather difficult. Soviet scientists developed two ways of intra-vital obtaining of eggs by surgical means, such as Burtsev's method, which involved an incision in the abdominal cavity, through which the ripened eggs flowed out arbitrarily [4], and Podushka's method of undercutting the oviducts; the latter was widely used in sturgeon farming practice, as it was less painful and almost bloodless [20]. The ability to keep female and male sturgeons alive allowed them to be used repeatedly in fish farming processes, as it is known that these fish are long-lived and repeatedly mature up to 10-12 times during their lifetime. Hence, it is possible to rapidly form breeding flocks by domestication or adaptation of wild animals to artificial conditions. The creation of breeding flocks has so far not been given the importance it deserves, as there have been sufficient numbers of spawners in the Volga. However, with a growing shortage of spawners, this problem has become of paramount importance, and since the end of the 1990s the farms have launched activities to create breeding flocks for the purposes of artificial reproduction of sturgeon fish.

Methods of forming breeding flocks were developed by Soviet scientists and are widely used in sturgeon farming, both for artificial reproduction and for commercial farming. The method of domestication of sturgeon spawners captured from natural habitats became common in the Caspian Sea basin during the catching period of such specimens. This method is based on the fact that operated females adapt to pond conditions after the removal of reproductive products. The difficulties of this method consisted in transferring wild specimens to the consumption of unusual fodder. It was very difficult to accustom sturgeon fish to artificial fodder, but Astrakhan fish farmers learned to do this, and currently up to 96% of beluga and 85% of Russian sturgeon are fed with compound feed, but 55-60% of starry sturgeon do not consume artificial feed in ponds [6]. A big advantage of this method of domestication is the reduction of the time required for the formation of breeding flock by two to three times before the re-maturation of this flock. It should also be noted that this method eliminates inbreeding - the closely related crossing of females and males - which is of great importance in fish farming. The spawn-to-spawn method is based on the offspring being reared from the fertilization of the eggs and subsequent rearing under artificial conditions until sexual maturity. This method is common where there are no fish of natural origin. Its major disadvantages are that the process of forming breeding flocks until maturity take up a lot of time, because sturgeon fish are late maturing (beluga matures at 18-20, Russian sturgeon at 16-17 and starry sturgeon at 10-12 years), and the second disadvantage is the possibility of inbreeding, which leads to non-viable offspring [7]. However, this method has the significant advantage of knowing the history of each specimen, which is well adapted to the artificial environment from the very first day. This advantage is of great importance as it enables breeding activities, which are very important, especially in commercial sturgeon farming.

Sturgeon farms for artificial reproduction in Astrakhan Oblast began forming breeding flocks in the late 1990s (1998-1999), using the two methods listed above, first raising juveniles for the flock and then applying domestication [27]. It can be considered that they started to do it in time, because in fact six farms did not stop working on releasing juveniles into water bodies of the Volga-Caspian basin for one day due to lack of spawners. Contemporary analysis of the use of sturgeon spawners for artificial reproduction shows that since 2002 there has been an increasing trend in the role of fish from breeding flocks (Figure 3).

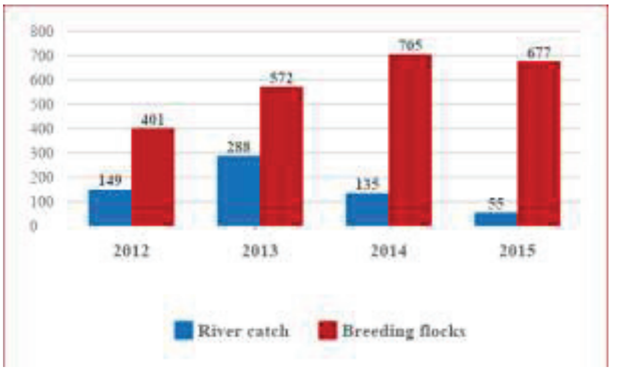

Figure 3. Sturgeon spawners of different origins participating in artificial reproduction.

Compared to only 50% of farmed spawners in 2013, they already accounted for 85% in 2015 [1]. Starting in 2017 and all subsequent years, the artificial reproduction farms switched completely to working with spawners from breeding flocks. It should also be noted that until 2016, predominantly domesticated fish were used in sturgeon farms, but then the fish breeding process began to involve spawners from rearing and breeding flocks, i.e. formed by the spawn-to-spawn method, it can be argued that these fish are artificially bred. The number of juvenile sturgeon fish produced and reared from such females and males will increase every year, and in the next few years (7-10 years) it is predicted that the release of juvenile fish will be 55-60 million fish instead of the 37 million fish released in 2020 [24].

Thus, in the current conditions of artificial reproduction of sturgeon, given the absence of spawners caught from the natural habitat, fish farming processes will be provided for females and males from formed breeding flocks, which are undoubtedly the so-called *golden pool* in sturgeon breeding. At present and in the near future they will play the main role in the restoration of natural populations of these valuable relict fish species.

1.2. Commercial sturgeon farming

Farming sturgeon for the purpose of obtaining valuable delicacies does not solve the issues of reproduction of natural stocks but allows to supply sturgeon deficit to the market in the absence of commercial fishing.

The history of commercial sturgeon farming dates back to the end of the 19th century, when sterlets were released into ponds for their natural food base - zooplankton and benthos - under sparse stocking conditions. The experiment had positive results, with sterlets gaining weight well and the survival rate at the fingerling stage being 40%. Subsequently, live feed and then minced fish were added to intensify the processes in an experimental regime.

There was great interest in the commercial farming of sturgeon in countries that did not have natural stocks of these valuable fish species. In the 1970s and 1980s, fish farmers in the USA and European countries (Germany, France, Italy, Israel, etc.) mastered Soviet biotechnology and began large-scale production from farmed sturgeon [6, 11, 29, 31]. Later, Chinese fish farmers started to raise sturgeon and received state support in the form of four preferences: long-term interest-free loans, tax exemptions for 5 years, subsidies for feed and electricity, and financial support for scientific research on sturgeon farming. All of this contributed to the fact that China now occupies a leading position in the global consumer market, with over 30,000 tonnes of sturgeon being farmed each year in the country.

To date, manuals on both extensive and intensive sturgeon farming methods are developed and published. Extensive methods are applied in large water bodies under polyculture conditions, low stocking densities, without special feeding, using only the natural food base (zooplankton and benthic communities), which allows to obtain low fish productivity up to one ton per hectare. This method has not found support among fish farmers and is practically not used in sturgeon farming. The semi-intensive method involves the use of small ponds of 1 to 3 hectares. Young sturgeon fish are farmed in a polyculture with herbivorous fish with combined feeding, such as natural forage and paste feed. Here the fish productivity increases to 4-5 tonnes per hectare. The best results are achieved when sturgeon fish are raised in small-area ponds (less than 0.05 ha) under monoculture conditions, high stocking densities and abundant feeding with mixed fodder or feed mixture. Under these conditions, fish productivity of up to 100 tons per hectare can be obtained. In fact, fish farming is carried out in an intensive way [16].

However, intensive farming is the most widespread method of commercial sturgeon farming. It includes the use of monoculture, high stocking densities and feeding with mixed fodder. This method is good to use in fish nurseries and pools. When sturgeons are farmed in nurseries, the nurseries are set up in deep water bodies or watercourses, and the fish grow under the natural variation of the temperatures. Sturgeons are thermophilic fish, therefore nursery farming is mainly used in the Southern Russia, where the required temperature is maintained for 180 to 200 days a year, or in reservoirs on the discharge waters of thermal power plants and nuclear power stations. The pool method uses either a direct water supply or a recirculating aquaculture system (RAS). In the first case, this method is not much different from the nursery method, as the fish grow in conditions of natural temperature variation, thus fish grow and gain weight well in such pools, when the groundwater is fed at a constant optimum (19-22°C) temperature. This method of sturgeon farming is being developed in China, in South America and in some regions of Russia [9].

Practice shows that the most effective way of rearing sturgeon fish is to use RAS. This method has a number of significant advantages, namely that fish grow well, gain weight quickly and reach sexual maturity in a short time due to the year-round optimum water temperature, intensive feeding with balanced feedstuffs, ease of operation and the possibility of computer-controlled production processes. However, a major disadvantage is the high-energy intensity of such systems, which increases the cost of the product, with energy costs accounting for 30% of total costs [28].

The development of biotechnology for the commercial farming of sturgeon was actively pursued in the Soviet Union in the 1970s. It is generally accepted that the development of commercial sturgeon farming started in 1958 with Prof. Nikolyukin's hybrid of beluga and sterlet - bester - which showed good fish-breeding qualities, such as high resistance, survival rate, growth rate. This hybrid is widely used around the world [12, 19].

Unfortunately, in Russia commercial sturgeon farming started rather late, for the first time the energy sector representatives expressed interest in this area of aquaculture, in particular at the end of the 1980s the *Akvatron Joint-Stock Company* was established, which used the nursery method of farming. In 28 sturgeon fish farms, fish were raised in nurseries set up in water reservoirs at thermal power plants and nuclear power plants; here sturgeons, with plenty of feeding, quickly reached commodity weight (3-4 kg) and breeding stocks were formed [25]. But then, in the mid-1990s, the *Rosenergetika* management decided to liquidate its non-core enterprises and breeding stocks were destroyed [10].

Thus, Russia, which had all the possibilities, among which are the developed biotechnology of sturgeon breeding, technology of obtaining breeding material from spawners of natural origin, the formulation of specialized mixed fodder, specialists who were trained only in Russia, unfortunately did not use such advantages in time.

Over the past 12 years alone, commercial sturgeon farming has been actively developing in Russia. In 2 years, the number of sturgeon fish farms in the country has increased by 30%, from 78 farms in 2018 to 102 in 2020. Experts estimate that the commercial sturgeon industry worldwide produced 102,500 tonnes of fish in 2015, a 20% increase compared to the previous year and a 160% increase compared to 2010 [15]. Russia's share reached 3.75% with 3,845 tonnes [23]. In Russia, commercial sturgeon farming has only been developing since the 2000s, when the natural stocks of these valuable fish species reached a critical level of aquaculture. In 2017, Russian sturgeon aquaculture reached a record 3,871 fish, an increase of 6.3% over the previous year and more than 54% over 2006 (Fig. 4) [17, 23].

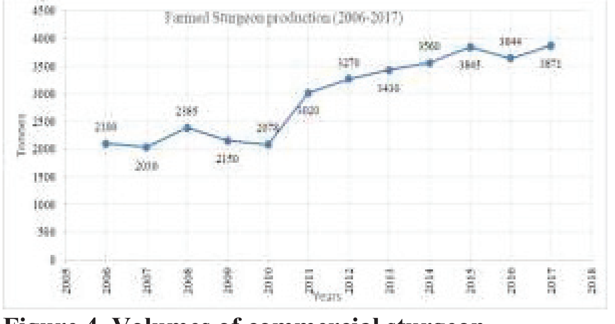

Figure 4. Volumes of commercial sturgeon production in Russia [17, 23].

Caviar production from farmed sturgeon fish in Russia to date is over 50 tonnes per year (Fig. 5). The data on sturgeon caviar production presented in Figure 6 show a significant increase in this product over the last 10 years, with 54.4 tonnes produced in 2018, an increase of 315% compared to 2007 [30].

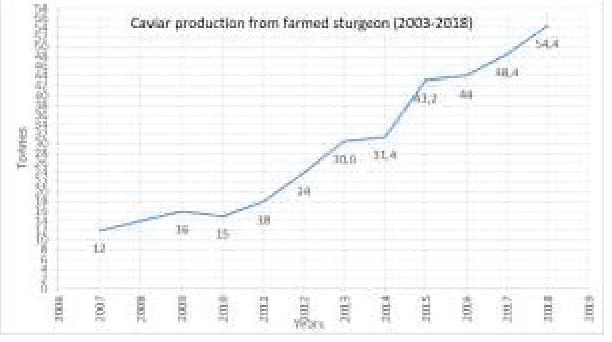

Figure 5. Caviar production from sturgeon fish farms in Russia (2003-2017).

It should be taken into account that since 2007 sturgeon caviar in Russia has only been produced from farmed fish, since a ban on commercial sturgeon fishing came into force in 2005 [23, 30].

CONCLUSION

This analytical review confirms that aquaculture of these valuable hydrobionts is actively developing in the context of dwindling natural stocks of sturgeons. The known two areas of sturgeon aquaculture represented by artificial reproduction and commercial sturgeon farming are being actively developed in Russia. Sturgeon aquaculture in Russia is designed to solve important problems, namely the preservation and restoration of natural stocks in the Caspian Sea and meeting consumer demand for valuable delicacies. At the same time, it should be taken into account that the modern conditions have undergone significant changes in the biotechnology of artificial reproduction of sturgeon fish, with farmed fish being used in fish breeding processes instead of spawners caught from their natural habitat. Farmed breeding flocks formed for the purposes of artificial reproduction allow the juveniles of these valuable fish species to be released into natural water bodies in the absence of natural spawners. It contributes to solving one of the main problems of preserving and restoring natural sturgeon populations by the only possible means, through artificial reproduction, as the natural reproduction of these bio-resources has been reduced to zero. In this regard, more attention needs to be paid to the formed breeding flocks in addressing the conservation of the natural gene pool of sturgeon fish. The biological characteristics of sturgeon spawners kept and matured under artificial conditions should be studied in detail and systematically in order to make better use of their potential fish breeding capacity. The active development of commercial sturgeon farming enables valuable sturgeon products to be supplied to the world market, although their volumes have not yet fully met demand. In the past, when the Soviet Union was a monopolist in black sturgeon caviar, the world market consumed up to 2,500 tonnes of this product. The *Russian caviar* brand is still known around the world. Currently, demand for this product is met by only 45%.

Thus, the successful development of sturgeon aquaculture today is a guarantee that unique relict fish will not be lost to our descendants, as natural populations will be preserved, and valuable delicacies will be available on the consumer market.

AUTHORS' CONTRIBUTIONS

The article was written by a team of authors, with all authors contributing equally to the theoretical analysis of the problem. Lidiya Vasilyeva analysed and summarized the collected materials and prepared the first version of the article; Adelya Anokhina prepared and designed the illustrative material, i.e., charts, diagrams, and drawings. Damelya Magzanova prepared the final version of the article in accordance with the requirements of the editorial board, Svetlana Gutsulyak did the work of collecting primary material from sturgeon fish farms in the country and searching for missing data on the Internet.

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