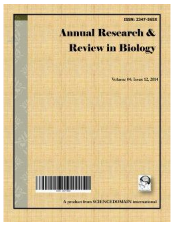

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Comparative Assessment of Biological and Fisheries Productivity of Caspian Sturgeons Species

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Authors' contributions

This work was carried out in collaboration between all authors. Authors LAZ and BMN designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors TFK and NNP managed the analyses of the study. Author MAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Based on the model describing the dynamics of the number of generations of fish during the life cycle, the influence of growth and maturity on the biological and commercial productivity of conditional populations of Caspian sturgeon, formed from 1.0 million specimens of yearlings, was studied. On the biomass of conditional sturgeon populations, their gross output and catch are influenced by the length of yearlings, the size and age of maturity, the periodicity of spawning, the rate of linear and weight growth of individuals, and the degree of stocks catching. The highest yield of biomass and catch, obtained from 1 million yearlings, is observed in Beluga (*Huso huso*), then Ship Sturgeon (*Acipenser nudiventris*), Russian sturgeon (*Acipenser gueldenstaedtii*), Stellate Sturgeon (*Acipenser stellatus*) and sterlet (*Acipenser ruthenus*).

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1. INTRODUCTION

The fisheries management is a complex process comprising fisheries biology information, stock status, and predator/prey relationships, habitat needs, and many others socioeconomic needs, in addition the law enforcement issues. Understanding how all of these factors interact is a difficult task, even for experts in fisheries science and management [1].

Full knowledge of the fish population is impossible to obtain, so biologists are trying to obtain as much information about the fish population as resources permit. Frequent assessments may be necessary because the size, structure and distribution of the population fluctuate in response to environmental change. Estimates of parameters for the growth of species of fish are important not only to understand the history of life and behavior, but also to manage fish resources, because they allow us to estimate the potential productivity [2,3,4].

When developing activities, aimed at the restoration and conservation of fish stocks, there arises the task of determining the abundance, biomass and commercial productivity of populations originating from farmed juveniles. This problem concerns not only artificial, but also natural reproduction [5]. Despite the urgency, address the issue in research proper attention is not given, and in this subject there are only a few publications [6,7].

About 80% of the spawning grounds for Caspian sturgeons became unavailable to the these valuable fishes after the Volgograd Dam was built and that almost all sturgeons could not use the natural reproduction area, mainly due to the reduction of adult fish entering upstream where spawning grounds are located [8,9,10]. And as a result the scientists warned about the drastic decline of the spawning stock biomass in the Volga River system and the Caspian Sea because Volga River was provided the biggest portion of the overall sturgeons' recruitment [11].

The aim of our research is to determine the comparative assessment of the biological and commercial productivity of the Caspian sturgeons at the group level, since their reserves are currently at a critically low historical minimum and need urgent restoration [12,13,14].

2. MATERIALS AND METHODS

Material for the present research were published data on the linear and weight growth, characteristics of maturity, the age composition of spawning schools, the periodicity of spawning, the maximum size and age of five species of Caspian sturgeons [15,16,17,13].

All calculations were carried out for conditional populations, formed from the annual recruitment $R_{0,1}$ = 1.0 million Yearlings. The abundance and biomass of conditional populations with an annual replenishment of 1.0 million specimens was calculated using a discrete model describing the change in the number of generations of fish throughout life:

$$N_t = R_{0,1}(1 - v_{m_1} - v_{f_1})(1 - v_{m_2} - v_{f_2})(1 - v_{m_t} - v_{f_t}), \quad (1)$$

Where N_t is the number of sturgeon generation at the age of t; $R_{0,1}$ the initial number of the generation (replenishment of the conditional population) at the age of yearling, $t = 0{,}1$ year, $v_{m_1}, v_{m_2} \ldots v_{m_t}$, $v_{f_1}, v_{f_2} \ldots v_{f_t}$ respectively, the coefficients of the annual natural and fishing mortality of the generation in the age *t*.

During the calculations it was assumed that the sturgeon fishery is not conducted in the sea and is carried out only in the river during the spawning period of the producers.

Calculations of abundance and biomass of conditional sturgeon populations were conducted in a prospective order, starting from the first age group = 1.0 million specimens, to older ages. The calculations used a specially designed program, implemented in the environment of electronic spreadsheets «Microsoft Excel 2014".

The concepts included in the equation (1) real coefficients annual natural v_{m_t}, fishing v_{f_t} and total mortality v_{z_t} were determined by the formulas of Rickera [18], Borisov [19,20], Borisov and Zalesskikh [21], Zikov [15] and Zikov et al. [16,17]:

$$v_{m_t} = \frac{n_{m_t}}{N_t} \quad (2)$$

$$v_{f_t} = \frac{n_{f_t}}{N_t} \quad (3)$$

$$v_{z_t} = \frac{n_{m_t} + n_{f_t}}{N_t} = \frac{n_{z_t}}{N_t} \quad (4)$$

Where n_{m_t} the number of individuals of generations of age *t*, dying within a year from the action of natural causes; n_{f_t} - the number of individuals of the generation at the age of *t*, seized by the fishery (including official, unaccounted and poaching catch); n_{z_t} the total number of individuals of the generation at the age of *t*, dying during the year as a result of catch and the action of natural causes:

$$n_{z_t} = n_{m_t} + n_{f_t}\,.$$

Since the fishery is based on the catch of spawners migrated to spawn, in calculation we used the notion of the spawning stock mortality factor, the value of which was calculated as:

$$v_{fn_t} = \frac{n_{f_t}}{n_t}, \quad (5)$$

Where n_t is the number of producers (spawners) of age *t* entering the river v_{fn_t} is the coefficient of fishing mortality of spawners at this age.

The number of spawners entering the river of the spawning stock n_t at the age of *t* was counted on the basis of the number of generational stocks N_t, the rate of their maturity and the periodicity of spawning:

$$n_t = \frac{\gamma}{\tau} N_t, \quad (6)$$

Where γ is the proportion of individuals of the generation who have reached maturity and are included in the spawning population (the coefficient of the sexual maturation of the generations), τ – is the indicator of the periodicity of spawning of producers.

The indicator of periodicity of spawning τ means that if fish spawns annually (τ = 1), then all sexually mature individuals of the population participate in reproduction. If it occurs once in 2 years (τ = 2), 50% of mature fish participate in spawning, and the remaining individuals with gonads at intermediate stages of development are on the foraging, skipping spawning. At spawning periodicity, once in 3 years (τ = 3) spawning stock forms 33% of the total number of mature fishes, and the remaining 2/3, or 67%, continue to feed. Skipping spawning mature individuals are the reserve of the spawning stock and must not be withdrawn by fishing.

The number of producers that make up the spawning stock of the conditional population was calculated as the sum of the numbers of the generations that make up it:

$$N_n = \sum_{t_f}^{T} n_t\,. \quad (7)$$

Where, t_f is the age of population that entry into the spawning (commercial). From the expressions (3), (5), (6) it follows that the ratios of fishing mortality of generations v_{f_t} and spawning population v_{fn_t} are related to each other by the relationship:

$$v_{f_t} = \frac{\gamma}{\tau} v_{fn_t}\,. \quad (8)$$

The amount of catch N_f received from a conditional population was calculated, the sum of catches of separate age groups:

$$N_f = \sum_{t_f}^{T_f} n_{f_t}\,, \quad (9)$$

Where t_f and T_f is the age of the beginning and the end of the period of commercial exploitation of generations.

The catch of sturgeons n_{f_t}, obtained from the spawning generations included in the spawning stock n_t was calculated according to the formula (5), based on their abundance and the given value of the mortality factor of the spawning stock v_{fn_t} :

$$n_{f_t} = v_{fn_t} n_t \quad , \tag{10}$$

Sturgeons catch, obtained from the whole generation N_t, was calculated from the ratio (6) as:

$$n_{f_t} = v_{fn_t} \frac{\gamma}{\tau} N_t \, . \tag{11}$$

The number of individuals of the populations that died during the year from the action of natural causes was calculated from equation (2) by the formulas:

$$n_{m_t} = N_t v_{m_t} \tag{12}$$

$$N_m = \sum_{t_o}^{T_f} n_{m_t} \tag{13}$$

Where: t_o is the age of the first age group of the population.

N_m - The number of individuals of the population that die within a year from the action of natural causes.

A similar method was used to determine the annual total loss of the number of individuals in conditional populations, which, according to (3), represent the sum of annual commercial and natural losses:

$$N_z = \sum_{t_o}^{T_f} (n_{m_t} + n_{f_t}) = N_m + N_f \tag{14}$$

The indicators of the biomass of the conditional population were obtained by multiplying the values of the population by the corresponding weights of the age groups:

$$B_t = N_t W_t \tag{15}$$

$$B_{n_t} = n_t W_t \tag{16}$$

$$B_{f_t} = n_{f_t} W_t \tag{17}$$

$$B_{m_t} = n_{m_t} W_t \tag{18}$$

$$B_{z_t} = n_{m_t} W_t + n_{f_t} W_t = B_{m_t} + B_{f_t} \tag{19}$$

$$Q = \sum_{t_o}^{T} B_t \qquad (20),$$

$$Q_n = \sum_{t_f}^{T} B_{n_t} \qquad (21),$$

$$Q_f = \sum_{t_f}^{T} B_{f_t} \qquad (22),$$

$$Q_m = \sum_{t_0}^{T} B_{m_t} \tag{23}$$

$$Q_z = Q_m + Q_f \tag{24}$$

where B_t is the biomass of the sturgeon generation at the age of *t*; B_{n_t} biomass of the generation of producers entering the river at the age of *t*;; B_{f_t} - catch of the age group, expressed in weight units; B_{m_t} - biomass of the generation of fish at the age of *t*, dying from natural causes; B_{z_t} - the biomass of the generation of fish at the age of *t*, dying from total mortality - the combined effects of fishing and natural causes; Q - total biomass of the conditioned population; Q_n - biomass of the spawning stock of the conditional population; Q_f - the annual catch (fishery return) received from a conditional population in weight units; Q_m - biomass of individuals of a population that die within a year of natural causes; Q_z - biomass of individuals of the population, dying from the overall mortality.

The production P_t, or the annual increment of the biomass of generations was calculated by conventional methods [22,23,24] using the formula:

$$P_t = \frac{(N_t + N_{t+1})}{2} (W_{t+1} - W_t) \quad ; \tag{25}$$

Where N_t, N_{t+1} are number of generations of sturgeons in related age groups; W_t, W_{t+1} is the average body weight of individuals in contiguous ages.

The gross output Q_p of the conditional sturgeons' populations was calculated by summing up the output of the individual generations entering the population:

$$Q_p = \sum_{t_o}^{T} P_t \quad ; \tag{26}$$

The values of *P/B* - the coefficients of generations were calculated as the ratio of the gross annual increment of P_t to their biomass B_t:

$$\frac{P_t}{B_t} = \frac{P_t}{N_t W_t}; \tag{27}$$

The value of the *P/B* - coefficients was determined as the ratio of the production of the biomass of the conditional population Q_p to its biomass Q:

$$\frac{Q_p}{Q} = \frac{\sum P_t}{\sum B_t} \tag{28}$$

The natural mortality factors included in the population number of model (1) were calculated using an equation that takes into account the variability of their values during life from age t (Table 2) [25,26,13]:

$$v_{m_t} = 1 - At^k (T^k - t^k) \tag{29}$$

Where *A, k,* T^k are constants

The constants *A, k,* T^k of the natural mortality equation (29) were calculated from the values of the constants of the linear and weight growth equations of Shmalhausen [27] and the allometric ratio of length to body weight of fish:

$$l = qt^k \tag{30}$$

$$W = pt^C \tag{31}$$

$$W = \alpha l^\beta \tag{32}$$

where *l, W* - length and body weight of sturgeon at the age of *t; q, p,* α - constants, numerically characterizing the length and body weight of yearlings - fish at the age of *t* = 1 year, as well as the body weight of fish with length *l* = 1; *k, C, β* are constants that numerically characterize the relative rate of linear and weight growth of fish at the age of *t* or at a length *l* [28,26].

The values of the constants of the growth equations (30) - (32) were calculated using statistical applications of the Excel-2010 spreadsheet package based on the literature data on the actual length and body weight of fish in different ages [15,16,13,17].

It should be noted that the constants of the equations of linear and weight growth (32) - (34) are related to each other by the relations:

$$p = \alpha q^\beta \tag{33}$$

$$C = \beta k \tag{34}$$

Therefore, in the case of limitation of ichthyological data on growth, the constants *p* and *C* of the weight growth equation (31) can be calculated based on the values of the constants of the linear growth equation (30) and the allometric length – weight ratio of fish (32).

The values of constants *A,* T^k the equations of natural mortality (29) were calculated from the values of the constants *q, k, C, β* of linear and weight growth equations, as well as the size and age characteristics of sexual maturation of sturgeon generations by formulas:

$$A = \frac{1 - v_{mp}}{t_p^{\,2k}} \tag{35}$$

$$v_{mp} = 1 - e^{-M_p} \tag{36}$$

$$M_p = \frac{\beta k}{t_p} = \frac{C}{t_p} \tag{37}$$

$$t_p = \left(\frac{l_p}{q}\right)^{\frac{1}{k}} \tag{38}$$

$$T^k = \frac{L}{q} = \frac{2l_p}{q} \tag{39}$$

$$T = \left(\frac{L}{q}\right)^{\frac{1}{k}} \tag{40}$$

where: v_{mp} the lowest value of the natural death rate of the generation at the age of maturity; l_p

and *tp* - the length and age of maturity, at which 50% of individuals of the generations become sexually mature; *Mp* is the instantaneous coefficient of natural mortality at maturity; *L* - maximum biological length of individuals in the population $L = 2l_p$; *T* is the maximum theoretical age of fish.

With the help of the equation of the allometric growth (23), auxiliary parameters were also calculated-the mass of the sturgeon's body w_p at which 50% of the generations are maturing and the maximum theoretical mass of the fish body W_m, corresponding to the maximum biological length *L*:

$$w_p = \alpha l_p^{\ \beta} \qquad (41),$$

$$W_m = \alpha L^{\beta} \qquad (42).$$

Moreover, in our studies it was assumed that between the length of 50% maturity, l_p and the largest biological length *L* of sturgeons, the Fulton- Dryagin ratio [29] is maintained, according to which the sexual maturation of fish on average, occurs when individuals of about ½ characterize the species or population of the greatest biological size, i.e. at $l_p = 0{,}5L$.

In our calculations we used the values of the coefficients of sexual maturation of sturgeons generations γ , published in literary sources [15,16,17,13].

3. RESULTS AND DISCUSSION

Primarily, we have demonstrated that the biological indicators of exploitation can be calculated from readily available data.

The values of the constants and parameters of the growth equations, natural mortality, and the characteristics of maturity and the calculated indices of the life span of Caspian sturgeons are given in Table 1. The calculated values of these parameters and the constants were closely corresponding to their actually observed values [15,16,17,13].

Analysis of the values of the constants and parameters characterizing the growth, sexual maturity, life expectancy and natural mortality of Caspian sturgeon shows that among these species the highest rate of linear and weight growth in the first year of life is distinguished by the Beluga (Table 1).

Beluga yearlings have a length q = 57.5 cm, mass p = 677.9 g. the lowest values of these constants - q = 15.6 cm and p = 25.8 g have been noted in sterlets (*Acipenser ruthenus*). The average size of the yearlings of these species varies by a factor of 4, the mass by a factor of 30. The Shipp Sturgeon *(Acipenser nudiventris*), Russian sturgeon (*Acipenser gueldenstaedtii*) and sterlet (*A. ruthenus*) occupy an intermediate position in this respect, the length of their yearlings' ranges from 33.6 to 45.6 cm, the mass from 143.6 to 437.3 g (Table 1).

It should be noted that at other equal conditions, the body length of the stellate sturgeon remains higher than the size of other sturgeons because of an elongated rostrum. The constants *k* and *C* of the growth equations characterize the rate of relative linear and weight growth of fish. Numerically, they are equal to the rate of relative growth of fish in their ages $t = 1$ .In this respect, the fastest relative linear and weight growth is noted in sterlet (*k* = 0.687, *C* = 2.112), the slowest in the spike (*k* = 0.438, C = 1.381). In Beluga, Russian sturgeon and stellate sturgeon, the relative growth rate remains at a close level (Table 1).

The curves of linear and weighted Caspian sturgeons' growth, constructed according to the corresponding growth equations (Table 1) are shown in Fig. 1.

Analysis of the obtained growth curves shows that among the Caspian sturgeons the fastest growing is the Beluga. The growth of a Shipp, Russian sturgeon and stellate sturgeon, is more delayed. The Sterlet has a slower growth among Caspian sturgeons (Fig. 1).

The allometric relationship (42) describes the relationship between the length and mass of the fish body. With an increase in the value of the constant *β*, the degree of curvature of the curves of the allometric growth increases and the increase in body weight of the fish along the length occurs at a faster rate.

Age t_p , length *lp* and body weight w_p at maturity in sturgeons vary widely (Table 1). In the fastest growing species - the Beluga, the values of these indicators are t_p = 15.7 years, l_p = 200 cm, w_p = 40.9 kg, in slow-growing sterlet, respectively

t_p = 5.47 years; l_p = 50 cm; w_p = 0.887 kg. The magnitude of these indicators in different species of Caspian sturgeon, however, varies in 3 - 46 times. The characteristics of sexual maturity of the Shipp Sturgeon, Russian sturgeon and stellate sturgeon have close to average values. The length, age and mass of sexual maturity of sturgeons are related to each other through the corresponding growth equations (30-32), (38).

The maximum length, age and body weight of fish of different species of sturgeons also differ significantly. The highest values of these indices are recorded in the Beluga L = 400 cm, T = 72.8 years, W_m = 400 kg, the lowest values for sterlet L = 100 cm, T = 15.0 years, W_m = 7.6 kg. In the Ship Sturgeon, Russian sturgeon and stellate sturgeon their values are close to average (Table 1).

In accordance with the theoretical approach used in our studies, the smallest value of instantaneous M_p and annual v_{mp} coefficients of

Table 1. The values of the constants and parameters of the growth equations and natural mortality of Caspian sturgeons (cm, years).

Constants, parameters	Species of Caspian sturgeons				
	Beluga ***Huso huso***	**Ship Sturgeon** ***Acipenser nudiventris***	**Russian Sturgeon** ***Acipenser gueldenstaedtii***	**Stellate Sturgeon** ***Acipenser stellatus***	**Sterlet** ***Acipenser ruthenus***
q	57,52 (Yearlings 25-65 cm)*	45,55 (Fingerlings 23-29 cm)	33,64 (Yearlings 30 cm)	37,02 (Fingerlings 28-40 cm)	15,56 (--)
k	0,4523	0,4381	0,4793	0,4935	0,6870
α	0,0011	0,0026	0,0074	0,0016	0,0048
β	3,290	3,151	3,000	3,167	3,100
p	677,9 (Yearlings 570-720 gr.)*	437,3 (--)	281,8 (Yearlings 250 gr.)*	143,6 (--)	23,813 (--)
C	1,4881	1,381	1,4379	1,5628	2,1291
l_p	200,0 (In a spawning herd from 135 cm)	135,0 (In a spawning herd from 97 cm)	105,0 (In a spawning herd from 80-90 cm)	115,0 (In a spawning herd from 87 cm)	50,0 (--)
L	400,0 (Rarely up to 425 cm)	270,0 (In catches up to 2010 cm)	210,0 (In catches up to 200-210 cm)	230.0 (In catches up to 195 cm)	100,0 (In catches up to 79 cm)
w_p	40905,5 (39100 gr)	13417,0 (--)	8566,4 (--)	5201,8 (--)	887,3 (--)
W_m	400101,4 (Rarely up to 520 Kg.)	119179,2 (In catches up to 78 Kg.)	68531,4 (In catches up to 60-65 Kg.)	46714,5 (In catches up to 24.7 Kg.)	7607,5 (In catches up to 2.9 Kg.)
t_p	15,724 (11,0-18,0 year)	11,942 (8-16 year)	10,750 (8-12 year)	9,942 (8-13 year)	5,471 (--)
T	72,80 (In catches up to 60 year)	58,10 (In catches up to 31 year)	45,64 (In catches up to 40-50 year)	40,50 (In catches up to 28-30 year)	15,01 (In catches up to 9 year)
M_p	0,0946	0,1156	0,1338	0,1572	0,389
v_{mp}	0,0903	0,1092	0,1252	0,1455	0,322
T^k	6,954	5,928	6,242	6,213	6,425
A	0,0752	0,1014	0,0898	0,0886	0,0657

** All values in parentheses are actually observed values of biological characteristics of sturgeon according to literature data [46; 47; 48; 49].*

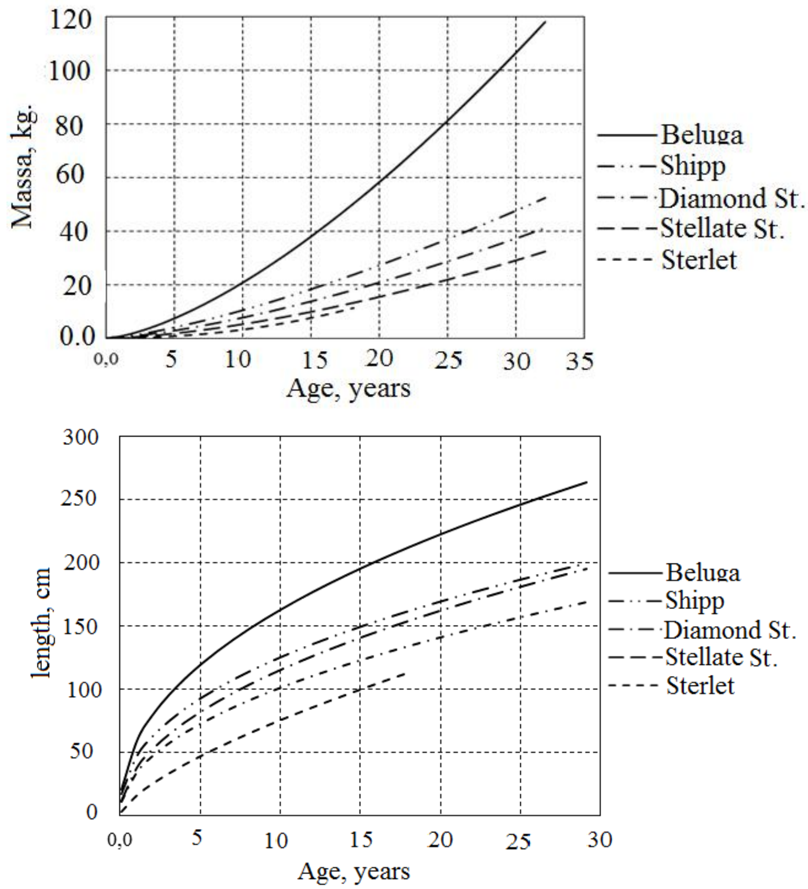

Fig. 1. Curves of linear and weight growth of Caspian sturgeons

natural mortality at maturity age t_p depend on the rate of relative weight gain of fish C and the age of maturity. Therefore, their values are lowest in species with late maturity (Beluga), and the highest - in species with early maturity (sterlet). The values of these coefficients in the Ship Sturgeon, Russian sturgeon and stellate sturgeon are close to their average for sturgeons' size.

An example of calculating the probabilistic population of stellate sturgeon from annual replenishment $R_{0,1}$ = 1.0 million specimens, fishing mortality coefficient of spawning stock v_{fn_t} = 0.3 and spawning period τ = 3.0 years, is shown in Table 2.

An analysis of the data obtained showed that the annual replenishment $R_{0,1}$ = 1.0 million individual of conditional population of stellate sturgeon with a population of 2187.1 thousand specimens is formed, biomass is 2.007 thousand tons.

The number of generations of stellate is decreases according to decreasing curves. Unlike the abundance curves, the biomass of generations in time changes according to a single-vertex dome-shaped curve with a maximum at the age of maturity (Table 2).

The coefficients of natural mortality of individuals of the population during their lifetime vary according to the U - shaped curve, the minimum of which v_{mp} = 0.146, is the age of maturity t_p = 9.9 years (Table).

With the given values of the coefficient of maturity for generations γ, the coefficient of fishing mortality v_{fn_t} = 0.3 and the periodicity of spawning of producers is τ = 3.0 years, a spawning stock numbering 38.3 thousand individuals is formed in the population and biomass of 0.276 thou. tons (Table 2).

The absolute annual natural loss of individuals of stellate sturgeon is N_m = 988.5 thousand individuals, the natural loss of biomass is Q_m = 0.532 thousand tones. The annual catch of spawning stellate sturgeon producers is N_f =11.48 or Q_f = 0.083 thousand tons, the total annual loss of population - N_z = 1000.0 thousand individuals, the total loss of ichthyomass - Q_z = 0.615 thousand tons.

The analysis shows that 1.15% of the annual recruitment ($R_{0,1}$= 1000.0 thousand individuals), 4.15% of the total biomass of the population $Q =$ 2.0 thousand tons and 13.5% of the annual total biomass loss Q_z = 0.615 thousand tons. Total annual loss of stellate sturgeon from catch and natural causes N_z = 1000.0 thous. Individuals, corresponds to the value of the annual recruitment $R_{0,1}$ = 1000.0 thousand individuals and it is be with it in the balance ratio.

The gross production of the stellate sturgeon population under the given operating conditions is Q_p = 0.615 thousand tons and also corresponds and is in the balance ratio with the annual total loss $Q_m + Q_f$ = 0.615 thousand tons of biomass (Table 2), which indicates the correctness of the calculations.The highest values of the *P/B* coefficient are at the beginning of the life of generations. As the age increases, *P/B* - the coefficients of stellate generations decrease (Table 2) [30]. Tables 3 to 8 show the effect of the degree of catch of the spawning stock v_{fn_t} and the periodicity of spawning of the producer's *τ* on the numbers, biomass and other quantitative characteristics of the conditional populations of Caspian sturgeons.

Among the species studied, the highest abundance of the conditional population is noted for the Shipp Sturgeon, then for the Russian sturgeon, stellate sturgeon, and Beluga. The population of sterlet has the lowest number. The highest biomass was observed in the conditioned population of Beluga, then the Shipp Sturgeon, Russian sturgeon, stellate sturgeon. It is the lowest in sterlet (Table 3).

From the data of Table 3 it follows that the number and biomass of sturgeon populations remain maximal in the absence of fishing (v_{fn_t} = 0), when the loss of generations of individuals occurs only under the influence of natural causes (Table 2). With an increase in the fishery mortality ratio from 0 to v_{fn_t} = 0.9, the number of populations of different species of sturgeons is reduced by 3 - 5%, biomass by 45.4 - 52.3%. Such differences in the decline in numbers and biomass are due to the fact that the sexually mature part of the population used by the fishery has a significantly smaller population and a higher individual mass of individuals than the non-immature part on which the fishery is based (Table 2).

As the period between the two spawning times (*τ*) increases, the number and biomass of populations increase, as the stocks of the spawning part are reduced because of the increase of the number of adults missing the spawning (Table 4). The abundance and biomass of spawning stocks of the studied sturgeon species varies considerably (Table 4).

The highest number of spawning stock has a Shipp Sturgeon, the spawning stock of Russian sturgeon, stellate sturgeon and sterlet are less numerous. The lowest number of spawning stock is recorded in Beluga (Table 4). The low number of spawning stock of beluga is explained by the increased natural loss of individuals in the early stages of development, preceding the beginning of the reproduction season. The duration of the immature period of development with high values of natural death rates in Beluga is the highest (Table 1).

The highest biomass of the spawning shoal is recorded in Beluga (Table 4). Lower it remains in the Shipp sturgeon, Russian sturgeon, stellate sturgeon and sterlet (Table 4). The high biomass of the spawning stock of Beluga is explained by the significant individual body weight of sexually mature fish (50 – 250 kg.) (Fig.1).

As the values of fishing mortality ratios increase from 0 to v_{fn_t} = 0.9, the number and biomass of spawning stocks of sturgeons is reduced by 47.6 - 67.9%, biomass by 70.0 - 79.3%. If the period between two spawning periods increases from 1.0 to 5.0 years, the number of spawning stock decreases by 55.4-62.8%, and biomass by 38.9-52.4% (Table 4). The catch resulting from sturgeon populations depends on the abundance and biomass of spawning stocks, the fishing mortality rate v_{fn_t} and the spawning period τ of sexually mature individuals. The effect of these factors on sturgeon catches is shown in Table 5.

The lowest catches in the Beluga are observed, the maximum - in the Shipp sturgeon, then the Russian sturgeon, Stellate sturgeon and Sterlet. Despite the lowest number of spawning stocks, the Beluga catches in biomass remain the highest among sturgeons (Table 5). This is explained by the highest among the sturgeons weight of spawning producers of Beluga (Fig. 1).

Less significant biomass catches are noted in the Shipp sturgeon, Russian sturgeon, stellate sturgeon and Sterlet (Table 5). With an extension in the periodicity of spawning from 1 to 5 years, catches of sturgeons are reduced due to a decrease in the number and biomass of spawning stocks respectively (Table - 5).

Annual absolute natural losses in abundance and biomass in different species of sturgeons are different (Table 6).

The annual natural loss in the number of individuals is highest in Beluga and sterlet. In the Shipp Sturgeon, Russian sturgeon and stellate sturgeon, natural losses are relatively lower and their values are close to each others (Table 6).

Annual natural losses of biomass are highest in Beluga, less significant in Shipp, then in sturgeons, stellate sturgeon and sterlet (Table 6). With an increase in the period between two spawning periods from 1 to 5 years, the annual natural loss of sturgeons due to a reduction in the number and biomass of spawning stocks is increasing.

The absolute annual total loss of the population in a stable state at any given values of the fishing mortality coefficients should be equal to the value of the annual recruitment that compensates for the total annual loss of the abundance [31]. In our study, the annual total fish loss corresponds to the annual recruitment $R_{0,1}$ = 1.0 million individuals (Table 5). If the annual total loss remains above the annual recruitment - the population size decreases with time, if higher - it grows [32].

The annual total loss of biomass of populations consists of fishes that died during the year from the impact of fishing and natural causes [33]. Calculations showed that the annual total loss of sturgeon's biomass is the highest in Beluga and decreases in the Shipp, Russian sturgeon, stellate sturgeon and sterlet (Table 7).

With an increase in the rates of fisheries removal from 0 to v_{fn_t} = 0.9, the total loss of sturgeons biomass of populations Q_z is reduced by 15.5-21.6%, as their total biomass falls (Table3). With a increase in the periodicity of spawning from 1 to 5 years, the annual total loss of biomass rises, as the annual catch decreases (Table 5), and annual natural losses far exceeding the catch (Table 5.6) increase.

The dynamics of the biomass of populations over time determines the ratio between the annual total loss Q_z and the gross output of the population Q_p (Table 7).

The biomass of the population increases if the production Q_p exceeds the biomass of the total annual losses Q_z (Table 7) and decreases if the total losses exceed the biomass increment.

Despite the fact that fishing mortality hypotheses were frequently evaluated for many short and moderate longevity species [34, 35], they rarely studied for longer-lived fishes such as sturgeons. In our calculations (Table 7), the annual total losses of biomass Q_z correspond to the production of the population Q_p.

Among the sturgeons the most highly productive is the Beluga, then the Shipp, the Russian sturgeon, the stellate sturgeon and the sterlet. It is well documented that ecosystems are under strong fishing pressure show a strong decrease in the abundance and biomass of target species [36,37]. And with an increase in the values of fishing mortality rates, the production of species decreases, as increase in fishing leads to a decrease in biomass.In our results the case of an increase in the period between two spawning, sturgeons' production increases as catches fall, and the biomass of the population increases.

In accordance with the data of Tables 3, 7 and equation (28), the values of *P/B* coefficients, which characterize the relative growth rate of the biomass of sturgeon populations, were calculated (Table 8).

The highest values of *P/B* - coefficients are noted in sterlet, then stellate sturgeon and Russian sturgeon. The value of *P/B* - coefficients in Beluga and Shipp is lower than in other sturgeon species (Table 8). As the fishing loads increase, the production rate of the biomass of populations increases, which is associated with a reduction in the population of the number of older age groups, *P/B* - whose coefficients are lower than in young ages. Thus, fishing, seizing individuals of older ages, contributes to the growth of biological productivity of populations [38,39].

Our researches have shown that the biological and fisheries productivity of Caspian sturgeons is influenced by the size of yearlings' *q*, the length l_p , the age of maturity t_p and the other biological indicators associated with them (Fig. 2).

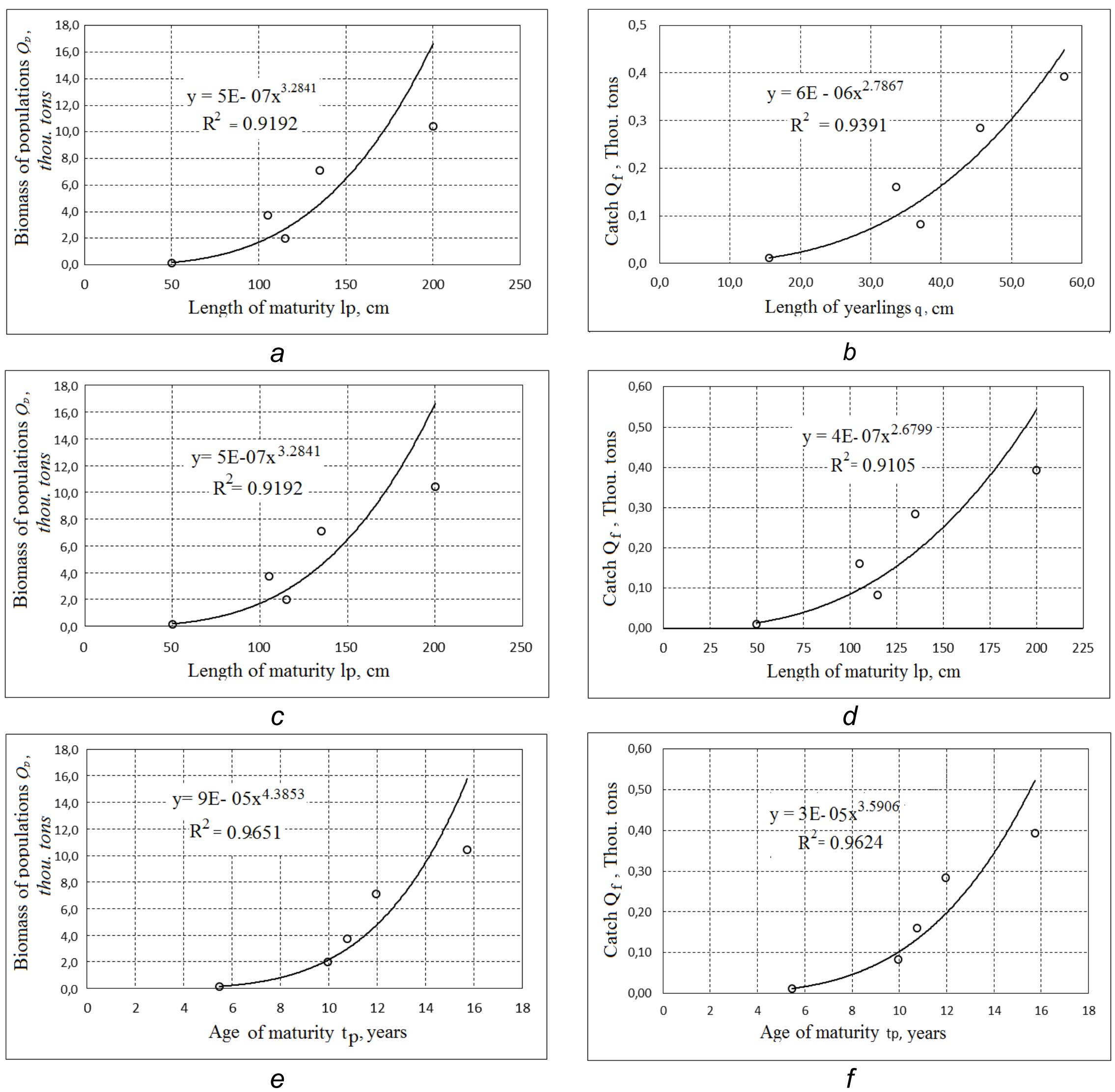

Fig. 2. Influence of the size of yearlings *q*, length l_p and age of puberty *tp* on biological *Q* and commercial Q_f productivity of Caspian sturgeons

Table 2. Quantitative characteristics of growth, abundance, biomass, natural mortality rates, gross production, spawning herd, annual commercial, natural and total loss of the conditioned population of stellate sturgeon, formed from recruitment $R_{0,1}$ = 1.0 million. (v_{fn_t} = 0.3, τ = 3.0)

Age, t (Year)	Length, l (cm)	Mass, W (Kg)	Coefficient of natural mortality, v_m,	Conditional population		The proportion of mature fish, γ (unit.)	Spawning stock	
				N_t, (thou individ)	B_t, (thou. ton)		abundance n_t, (thou individ)	Biomass, B_{n_t} (thou. ton)
0,1	11,9	0,004	0,626	1000,0	0,004	0,000	0,000	0,000
1,1	38,8	0,167	0,447	374,1	0,062	0,000	0,000	0,000
2,1	53,4	0,458	0,346	206,9	0,095	0,000	0,000	0,000
3,1	64,7	0,842	0,278	135,3	0,114	0,000	0,000	0,000
4,1	74,3	1,303	0,231	97,68	0,127	0,000	0,000	0,000
5,1	82,7	1,833	0,197	75,11	0,138	0,000	0,000	0,000
6,1	90,4	2,424	0,174	60,28	0,146	0,000	0,000	0,000
7,1	97,4	3,073	0,159	49,79	0,153	0,100	1,660	0,005
8,1	103,9	3,776	0,150	41,39	0,156	0,200	2,759	0,010
9,1	110,1	4,530	0,146	34,37	0,156	0,350	4,010	0,018
10,1	115,9	5,331	0,146	28,16	0,150	0,500	4,694	0,025
11,1	121,4	6,179	0,151	22,63	0,140	0,700	5,281	0,033
12,1	126,7	7,071	0,159	17,64	0,125	0,900	5,291	0,037
13,1	131,8	8,005	0,169	13,25	0,106	1,000	4,417	0,035
14,1	136,6	8,980	0,183	9,682	0,087	1,000	3,227	0,029
15,1	141,3	9,995	0,198	6,945	0,069	1,000	2,315	0,023
16,1	145,9	11,05	0,216	4,872	0,054	1,000	1,624	0,018
17,1	150,3	12,14	0,236	3,332	0,040	1,000	1,111	0,013
18,1	154,6	13,27	0,258	2,212	0,029	1,000	0,737	0,010
19,1	158,7	14,43	0,281	1,421	0,021	1,000	0,474	0,007
20,1	162,8	15,63	0,305	0,880	0,014	1,000	0,293	0,005
21,1	166,7	16,86	0,331	0,523	0,009	1,000	0,174	0,003
22,1	170,6	18,13	0,359	0,298	0,005	1,000	0,099	0,002
23,1	174,3	19,42	0,387	0,161	0,003	1,000	0,054	0,001
24,1	178,0	20,75	0,417	0,083	0,002	1,000	0,028	0,001
25,1	181,6	22,12	0,448	0,040	0,001	1,000	0,013	0,000
26,1	185,2	23,51	0,480	0,018	0,000	1,000	0,006	0,000
27,1	188,6	24,93	0,512	0,008	0,000	1,000	0,003	0,000
28,1	192,0	26,38	0,546	0,003	0,000	1,000	0,001	0,000
29,1	195,4	27,86	0,580	0,001	0,000	1,000	0,000	0,000
30,1	198,7	29,38	0,615	0,000	0,000	1,000	0,000	0,000
Total	-	-	-	2187,1	2,007	-	38,27	0,276

Continuation of Table 2

Age, *t* (years)	Caches		Natural mortality		Total mortality		Gross production,	*P/B*
	n_{f_t}, (thou individ)	$B_{f\,t}$, (thou. ton)	n_{m_t}, (thou individ.)	B_{m_t}, (thou. ton)	n_{z_t}, (thou individ.)	n_{z_t}, (thou. ton)	P_t (thou. ton)	
0,1	0,000	0,000	625,9	0,053	625,9	0,053	0,112	1,908
1,1	0,000	0,000	167,2	0,052	167,2	0,052	0,085	0,933
2,1	0,000	0,000	71,53	0,046	71,53	0,046	0,066	0,591
3,1	0,000	0,000	37,67	0,040	37,67	0,040	0,054	0,430
4,1	0,000	0,000	22,56	0,035	22,56	0,035	0,046	0,338
5,1	0,000	0,000	14,83	0,032	14,83	0,032	0,040	0,278
6,1	0,000	0,000	10,49	0,029	10,49	0,029	0,036	0,236
7,1	0,498	0,002	7,898	0,027	8,396	0,029	0,032	0,205
8,1	0,828	0,003	6,189	0,026	7,017	0,029	0,029	0,181
9,1	1,203	0,005	5,008	0,025	6,212	0,030	0,025	0,163
10,1	1,408	0,008	4,121	0,024	5,529	0,031	0,022	0,147
11,1	1,584	0,010	3,413	0,023	4,997	0,032	0,018	0,135
12,1	1,587	0,011	2,797	0,021	4,384	0,032	0,014	0,124
13,1	1,325	0,011	2,244	0,019	3,569	0,030	0,011	0,115
14,1	0,968	0,009	1,769	0,017	2,737	0,025	0,008	0,107
15,1	0,695	0,007	1,378	0,014	2,073	0,021	0,006	0,100
16,1	0,487	0,005	1,054	0,012	1,541	0,018	0,004	0,094
17,1	0,333	0,004	0,786	0,010	1,119	0,014	0,003	0,089
18,1	0,221	0,003	0,570	0,008	0,791	0,011	0,002	0,084
19,1	0,142	0,002	0,399	0,006	0,541	0,008	0,001	0,080
20,1	0,088	0,001	0,269	0,004	0,357	0,006	0,001	0,076
21,1	0,052	0,001	0,173	0,003	0,226	0,004	0,001	0,072
22,1	0,030	0,001	0,107	0,002	0,136	0,003	0,000	0,069
23,1	0,016	0,000	0,062	0,001	0,078	0,002	0,000	0,066
24,1	0,008	0,000	0,034	0,001	0,043	0,001	0,000	0,064
25,1	0,004	0,000	0,018	0,000	0,022	0,000	0,000	0,061
26,1	0,002	0,000	0,009	0,000	0,010	0,000	0,000	0,059
27,1	0,001	0,000	0,004	0,000	0,005	0,000	0,000	0,057
28,1	0,000	0,000	0,002	0,000	0,002	0,000	0,000	0,055
29,1	0,000	0,000	0,001	0,000	0,001	0,000	0,000	0,053
30,1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,051
Total	11,481	0,083	988,5	0,532	1000,0	0,615	0,615	0,297

Table 3. The effect of fishing mortality v_{fn_t} and spawning periodicity of τ on the number and biomass of conditional populations of Caspian sturgeons

fishing mortality v_{fn_t}	Fish species, abundance, *N* (thousand individuals)					Fish species, biomass, Q (thousand tons)				
	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet
0,0	2215,3	2623,9	2353,9	2239,5	1577,4	14,80	9,60	4,88	2,57	0,17
0,1	2188,7	2582,5	2324,5	2218,5	1569,1	12,78	8,51	4,39	2,33	0,16
0,2	2169,0	2550,2	2300,9	2201,3	1561,9	11,39	7,72	4,01	2,15	0,14
0,3	2154,0	2524,4	2281,5	2187,1	1555,7	10,41	7,11	3,72	2,01	0,13
0,4	2142,1	2503,3	2265,3	2175,1	1550,3	9,69	6,65	3,49	1,89	0,12
0,5	2132,5	2485,7	2251,6	2164,9	1545,4	9,14	6,28	3,30	1,80	0,11
0,6	2124,6	2470,8	2239,8	2156,1	1541,1	8,71	5,98	3,15	1,72	0,11
0,7	2118,0	2458,0	2229,6	2148,4	1537,2	8,36	5,74	3,02	1,66	0,10
0,8	2112,2	2446,8	2220,6	2141,7	1533,6	8,08	5,53	2,91	1,60	0,10
0,9	2107,3	2437,0	2212,5	2135,7	1530,4	7,84	5,36	2,82	1,56	0,09
τ	Abundance, *N* (thousand individuals)					Biomass, *Q* (thousand tons)				
1,0	2107,3	2437,0	2212,5	2135,7	1541,1	7,84	5,36	2,82	1,56	0,11
2,0	2137,1	2494,1	2258,2	2169,8	1555,7	9,40	6,46	3,39	1,84	0,13
3,0	2154,0	2524,4	2281,5	2187,1	1561,9	10,41	7,11	3,72	2,01	0,14
4,0	2164,9	2543,2	2295,7	2197,5	-	11,12	7,55	3,93	2,11	-
5,0	2172,5	2556,1	2305,3	2204,5	-	11,63	7,86	4,08	2,18	-

Table 4. Influence of the fishing mortality rate (v_{fn_t}) and spawning period (τ) on the abundance and biomass of spawning stocks of sturgeon populations

v_{fn_t}	Fish species, abundance, N_n (thousand individuals)					Fish species, biomass, Q_n (thousand tons)				
	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet
0,0	46,40	85,00	67,59	54,49	38,91	2,71	1,73	0,87	0,46	0,050
0,1	38,12	72,42	58,75	47,91	35,37	2,06	1,38	0,71	0,38	0,042
0,2	32,13	62,80	51,76	42,60	32,39	1,62	1,13	0,60	0,32	0,035
0,3	27,65	55,29	46,16	38,27	29,86	1,31	0,95	0,51	0,28	0,031
0,4	24,22	49,29	41,59	34,68	27,69	1,09	0,81	0,44	0,24	0,027
0,5	21,52	44,44	37,81	31,68	25,81	0,92	0,70	0,38	0,21	0,023
0,6	19,36	40,43	34,64	29,14	24,18	0,80	0,61	0,34	0,19	0,021

v_{fn_t}	Fish species, abundance, N_n (thousand individuals)					Fish species, biomass, Q_n (thousand tons)				
	Beluga	**Ship Sturgeon**	**Diamond sturgeon**	**Stellate sturgeon**	**Sterlet**	**Beluga**	**Ship Sturgeon**	**Diamond sturgeon**	**Stellate sturgeon**	**Sterlet**
0,7	17,59	37,08	31,96	26,96	22,75	0,70	0,54	0,30	0,17	0,019
0,8	16,12	34,25	29,67	25,09	21,49	0,62	0,49	0,27	0,15	0,017
0,9	14,88	31,82	27,68	23,45	20,37	0,56	0,44	0,25	0,14	0,015
τ	Abundance, N_n (thousand individuals)					Biomass, Q_n (thousand tons)				
1,0	44,64	95,46	83,04	70,35	48,37	1,67	1,33	0,74	0,42	0,041
2,0	34,19	70,11	59,42	49,68	29,86	1,50	1,13	0,61	0,34	0,031
3,0	27,65	55,29	46,16	38,27	21,59	1,31	0,95	0,51	0,28	0,024
4,0	23,17	45,56	37,69	31,08	-	1,15	0,81	0,43	0,23	-
5,0	19,91	38,72	31,82	26,15	-	1,02	0,71	0,37	0,20	-

Table 5. Influence of the degree of catch of the commercial stock and the periodicity of spawning τ on catches obtained from conditional populations of Caspian sturgeons

Fishing mortality v_{fn_t}	Species of fish, the catch piece N_f (thous. specimens)					Species of fish, the catch weight Q_f (thous. tones)				
	Beluga	**Ship Sturgeon**	**Diamond sturgeon**	**Stellate sturgeon**	**Sterlet**	**Beluga**	**Ship Sturgeon**	**Diamond sturgeon**	**Stellate sturgeon**	**Sterlet**
0,0	0,0	0,0	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,000
0,1	3,8	7,2	5,9	4,8	3,5	0,21	0,14	0,08	0,04	0,005
0,2	6,4	12,6	10,4	8,5	6,5	0,32	0,23	0,13	0,06	0,008
0,3	8,3	16,6	13,8	11,5	9,0	0,39	0,28	0,16	0,08	0,011
0,4	9,7	19,7	16,6	13,9	11,1	0,44	0,32	0,18	0,10	0,013
0,5	10,8	22,2	18,9	15,8	12,9	0,46	0,35	0,20	0,11	0,014
0,6	11,6	24,3	20,8	17,5	14,5	0,48	0,37	0,21	0,11	0,015
0,7	12,3	26,0	22,4	18,9	15,9	0,49	0,38	0,22	0,12	0,016
0,8	12,9	27,4	23,7	20,1	17,2	0,50	0,39	0,23	0,12	0,016
0,9	13,4	28,6	24,9	21,1	18,3	0,50	0,40	0,24	0,12	0,017
τ	caught specimens N_f (thous. specimens)					caught weight Q_f (thous. tones)				
1,0	13,4	28,6	24,9	21,1	14,5	0,50	0,40	0,22	0,12	0,015
2,0	10,3	21,0	17,8	14,9	9,0	0,45	0,34	0,18	0,10	0,011
3,0	8,3	16,6	13,8	11,5	6,5	0,39	0,28	0,15	0,08	0,008
4,0	7,0	13,7	11,3	9,3	-	0,34	0,24	0,13	0,07	-
5,0	6,0	11,6	9,5	7,8	-	0,30	0,21	0,11	0,06	-

Table 6. Influence of the degree of catch v_{fn_t} and periodicity of spawning of producers' τ on the annual natural loss of conditional sturgeon populations

Degree of catch v_{fn_t}	Species, natural decline in numbers N_m (Thous. Individl)					Species, natural decline in biomass Q_m (Thous. ton)				
	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet
0,0	1000,0	1000,0	1000,0	1000,0	1000,0	2,88	1,96	1,16	0,67	0,102
0,1	996,2	992,8	994,1	995,2	996,5	2,55	1,74	1,05	0,61	0,092
0,2	993,6	987,4	989,6	991,5	993,5	2,33	1,59	0,97	0,57	0,085
0,3	991,7	983,4	986,2	988,5	991,0	2,19	1,48	0,90	0,53	0,080
0,4	990,3	980,3	983,4	986,1	988,9	2,10	1,41	0,86	0,51	0,075
0,5	989,2	977,8	981,1	984,2	987,1	2,03	1,35	0,82	0,49	0,072
0,6	988,4	975,7	979,2	982,5	985,5	1,98	1,30	0,80	0,47	0,069
0,7	987,7	974,0	977,6	981,1	984,1	1,94	1,27	0,77	0,46	0,067
0,8	987,1	972,6	976,3	979,9	982,8	1,90	1,24	0,75	0,44	0,065
0,9	986,6	971,4	975,1	978,9	981,7	1,88	1,21	0,74	0,44	0,063
τ	The annual natural loss in the abundance N_m (Thous. Individl)					The annual natural decrease in the biomass Q_m (Thous. ton)				
1,0	986,6	971,4	975,1	978,9	985,5	1,88	1,21	0,74	0,44	0,069
2,0	989,7	979,0	982,2	985,1	991,0	2,06	1,38	0,84	0,49	0,080
3,0	991,7	983,4	986,2	988,5	993,5	2,19	1,48	0,90	0,53	0,085
4,0	993,0	986,3	988,7	990,7	-	2,29	1,56	0,95	0,56	-
5,0	994,0	988,4	990,5	992,2	-	2,37	1,62	0,98	0,57	-

Table 7. Influence of fishing mortality v_{fn_t} and spawning period τ on annual total losses and production of biomass of conditional populations of Caspian sturgeons

Fishing mortality v_{fn_t}	Species, total losses in biomass Q_z (Thous. ton)					Species, production biomass Q_p (Thous. ton)				
	Beluga	Ship Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet	Beluga	Shipp Sturgeon	Diamond sturgeon	Stellate sturgeon	Sterlet
0,0	2,88	1,96	1,16	0,67	0,102	2,86	1,95	1,15	0,67	0,101
0,1	2,75	1,88	1,12	0,65	0,097	2,74	1,87	1,11	0,65	0,097
0,2	2,66	1,82	1,09	0,63	0,094	2,65	1,81	1,08	0,63	0,094
0,3	2,59	1,77	1,06	0,61	0,091	2,58	1,76	1,05	0,62	0,091
0,4	2,53	1,73	1,04	0,60	0,088	2,53	1,73	1,03	0,60	0,088
0,5	2,49	1,70	1,03	0,59	0,086	2,49	1,70	1,02	0,59	0,086

0,6	2,45	1,67	1,01	0,58	0,084	2,45	1,67	1,00	0,59	0,084
0,7	2,42	1,65	1,00	0,57	0,082	2,43	1,65	0,99	0,58	0,082
0,8	2,40	1,63	0,99	0,57	0,081	2,40	1,63	0,98	0,57	0,081
0,9	2,38	1,61	0,98	0,56	0,080	2,38	1,61	0,97	0,57	0,080
τ	Total losses in biomass Q_z (Thous. ton)					Production biomass Q_p (Thous. ton)				
1,0	2,38	1,61	0,96	0,56	0,084	2,38	1,61	0,97	0,57	0,084
2,0	2,51	1,71	1,02	0,60	0,091	2,51	1,71	1,02	0,60	0,091
3,0	2,59	1,77	1,06	0,61	0,094	2,58	1,76	1,05	0,62	0,094
4,0	2,64	1,81	1,08	0,63	-	2,63	1,80	1,07	0,63	-
5,0	2,67	1,83	1,09	0,63	-	2,66	1,82	1,09	0,63	-

Table 8. Influence of the degree of catch of spawning stocks v_{fn_t} and the periodicity of spawning *τ* on *P/B* - coefficients of conditional sturgeon populations

Degree of catch v_{fn_t}	***P/B* – coefficients, (Q_p/Q), (uni.)**				
	Beluga	**Ship Sturgeon**	**Diamond sturgeon**	**Stellate sturgeon**	**Sterlet**
0,0	0,193	0,203	0,236	0,261	0,590
0,1	0,214	0,220	0,254	0,278	0,626
0,2	0,232	0,235	0,269	0,293	0,661
0,3	0,248	0,248	0,283	0,307	0,693
0,4	0,261	0,260	0,296	0,319	0,723
0,5	0,272	0,270	0,308	0,330	0,751
0,6	0,282	0,279	0,318	0,340	0,776
0,7	0,290	0,287	0,327	0,348	0,800
0,8	0,297	0,295	0,335	0,356	0,822
0,9	0,304	0,301	0,343	0,363	0,843
τ	*P/B* – coefficients, (Q_p/Q), (uni.)				
1,0	0,304	0,301	0,343	0,363	0,776
2,0	0,267	0,265	0,302	0,325	0,693
3,0	0,248	0,248	0,283	0,307	0,661
4,0	0,236	0,238	0,273	0,297	-
5,0	0,229	0,232	0,266	0,290	-

The resulting graphs (Fig. 2) show that as the length of yearlings *q* increases, the size and age of maturity, the biological and commercial productivity of sturgeons increases. The highest biomass, were at species that are characterized by the fastest linear growth in the first year of life.

The length of yearlings, the size and age of maturity are among themselves in a functional relationship mediated through the equations of linear and weight growth (30 - 32). But the most important factor determining the biological productivity of different species is the rate of growth of individuals in the first year of life and the biologically related with the size and age characteristics of maturity [40,41] (Fig. 2).

It should be noted that in the wild fish yearling growth is not constant and depends on the conditions of existence in the first year of life – the amount of heat entering the water basin, the state of the hydrochemical regime, security of food for fish and others. Therefore the Generation that formed in different ecological conditions of the environment can be different growth rate; depends on the natural mortality and population abundance [42,43]. It should also be noted that between the lengths *q*, the body weight *p* of yearlings, the relative velocity of linear growth *k*, and the weight growth C in fish, there is an inverse relationship that allows the growth, regardless of the starting yearlings' size, to keep the growth on optimum level typical for the species or population. Therefore, studies of the biological and fisheries productivity of fish should be carried out taking into account the variability of growth and sexual maturity at the intrapopulation generation level [44,45].

Furthermore, in this context, one should not forget about the effect of negative ecological changes on the morpho-physiological status and biological traits of population groups of sturgeons [43].

4. CONCLUSION

1. We have demonstrated that the biological limits of exploitation can be calculated from data that is readily available.
2. The growth of Caspian sturgeons is characterized by a wide variability. The size of the fast-growing and slow-growing species varies considerably. The fastest linear and weight growth is Beluga, more slowed growth observed in the Shipp, Russian sturgeon, stellate sturgeon and sterlet.
3. The most delayed maturation observed in Beluga; further earlier - the Shipp Sturgeon, Russian sturgeon stellate sturgeon and sterlet respectively.
4. The highest biological production indicators are characterized the Beluga, then Shipp Sturgeon, Russian sturgeon, stellate sturgeon and sterlet. These species yield catches corresponding to their biomass.
5. The biomass of populations formed from the recruitment unit ($R_{0,1}$ = 1.0 million specimens), and the size of catches is highest in species characterized by the fastest growth in the first year of life (Beluga).
6. The abundance, biomass of populations and the value of catch are influenced by the fishery and the periodicity of spawning of spawners. Increasing the degree of fishing withdrawal of spawners leads to an increase in catch and reduce the number and biomass of exploited populations by fishing. Reduction of the periodicity of sturgeons spawning contributes to the growth of stocks.
7. The highest yield of biomass and the magnitude of the resulting catches are observed in species with a higher size of yearlings, length and age of maturation. The values of these indicators are linked analytically through the equations of linear and weight growth.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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