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Modeling for Scenarios for Stock Recovery of Russian Sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov in the Absence of Natural Reproduction

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Abstract—A new model describing the dynamics of sturgeon (Acipenseridae) population unable to recover or ranked as depleted is proposed as a depleted artificially-stocking population (DAP) model. The model composed of two submodels is implemented in the R language. One of the submodels provides the opportunity to adjust the appropriate parameters used in a global model (the rate of natural mortality of a mature fish stock in a population and the artificial reproduction efficiency) with the optimization-based methods, while the second submodel deals with various scenarios for fish stock recovery over the forecast period. Scenarios are characterized by two parameters: the quantity of juvenils released by sturgeon hatcheries and the commercial fish catch decline caused by the illegal fishing practices and the fish catch for science-based targets. The estimates for the pattern of the Russian sturgeon Acipenser gueldenstaedtii in the Sea of Azov indicate that its stock may be recovered to the target level of 10 thousand tons with the baseline and optimistic scenarios by 2037—2048 relative to the artificial reproduction efficiency and the extent of illegal, unreported, and unregulated fishing. With respect to pessimistic scenarios, the stocks are not expected to recover.

Keywords: Russian sturgeon *Acipenser gueldenstaedtii*, population, modeling, fish stock recovery, Sea of Azov

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INTRODUCTION

At present, a catastrophic decline in the Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov (Chepurnaya and Rekov, 2017; Rekov and Chepurnaya, 2018) can be observed. The authors focused on the task of estimating the possible ways to recover this fish stock under various factors affecting it. In order to consider the possible variants for recovering the Russian sturgeon population in the Sea of Azov, the long-term dynamics of the population size need to be analyzed, which may be done in general with the cohort, surplus production models, and the methods used in case of a lack of information (Babayan et al., 2018).

The cohort methods can provide the opportunity to consider the biological characteristics in modeling the fish population. However, they have the higher standards for volume and quality of the input data (including the data on the age structure in fish catches). However, they are unusable in case of insufficient statistics on commercial fishing.

Surplus production models are less demanding for input data. Within this approach, the population is considered as an aggregation of similar specimens without regard to their age structure. Parametrization of a production model requires the time series of fisheries statistics, including the annual catches and the fishing effort over many years. These time series should cover a rather long interval period, longer then the specimen life cycle for a certain population. In addition, the data on the fishing effort should be standardized.

The data limited methods (DLM) (Carruthers et al., 2014) were developed for cases described by the insufficient quality-dimension input data. They particularly involve the model based on the depletion-based stock reduction analysis (DB-SRA) (Dick and MacCall, 2011). It is based on the production model describing the mature stock recruitment functionally related to its biomass. This model can provide the opportunity to estimate the guide setting and the dynamics of retrospective study of stock biomass, which is followed by prognosis based on supposition that the production capacity of a population is not changed over time. The DB-SRA model was efficiently used to estimate the status of a population of the stellatus *A. stellatus* in the Caspian Sea (Ye and Valbo-Jørgensen, 2012; Sapharaliev et al., 2019).

However, its application relative to the Russian sturgeon in the Sea of Azov is impossible, since the natural reproduction in this species is absent for many years because of inaccessible spawning grounds after overregulation of streamflows of the Don and Kuban rivers.

According to the data obtained by Gorbacheva et al. (2020), the generations of the Russian sturgeon in the Sea of Azov, those born since 1972, comprise 100% of sturgeon hatchery-reared fish, except the generations as those born between 1978 and 1981, which comprise approximately 30% of specimens of natural reproduction. However, the last statement is of doubtful authenticity, since the error in age estimation of fish caught in the subsequent years cannot be avoided. Therefore, it can be considered that reproduction of the Russian sturgeon in the Sea of Azov in the last 30 years does not depend on the mature stock quantity or biomass. The data on the Russian sturgeon catches in the last 20 years are not available, because its commercial fishing in the Sea of Azov has been banned since 2000. In addition, the expert estimates for illegal, unreported, and unregulated fishing (IUU fishing) are available only for the 1994—1999 period (Chepurnaya et al., 2008). Therefore, it is not possible to use the production models including DB-SRA model because of the absence of natural reproduction of a sturgeon population and the missing data on fishing catches and efforts.

In this context, the actual task is to develop a model for population dynamics, based on the datasets of artificial fish stock recovery, retrospective patterns in commercial catches, IUU fishing intensity estimates, and biological characteristics of the Russian sturgeon *Acipenser gueldenstaedtii*.

EXPERIMENTAL

In order to assess the stock of the Russian sturgeon in the Sea of Azov in model dynamics, the depleted artificially-stocking population (DAP) model was developed. This model is implemented in the R language (R Core Team, 2016). It is composed of two submodels. One of the submodels refers to adjusting the model parameters with the method of least squares. An iterative procedure of comparing the model range values for the mature fish stock in a population (B_y) and the values for the same stock, received with the accounting surveys data 1981—1999 ($B_{prior(y)}$) is used.

Smoothing data of accounting surveys with the three-point moving average method is predominantly performed to separate out the interannual fluctuations and inaccuracy assessment with the direct method. This submodel records the time series for catch datasets over a long-term period, including both the catches in official fisheries (C_f) and the illegal, unreported, and unregulated catches (C_{iuu}). In addition, it includes the data on the annual juvenile fish release from the fish hatcheries ($N_{juv(y)}$) and the mature specimen medium weight (W_M) estimated with the data on the age-related dynamics of body weight ($W(x)$) based on the gender. The values for the catches of IUU fishing over 1989—1999 were produced with the piecewise-linear approximation of expert reviews for 1994—1999 (Fig. 1). With respect to the 1981—1988 period, it was assumed that the IUU-fishing catches comprised 10% of the official fishery catches. Any values for this parameter in the Azov-and-Don water basin for the given period are unfortunatelly unavailable.

Setting up the model involves optimization of the parameters as the annual rate of mature fish natural mortality (φ_M), the post-release survival rate of juvenile fish up to the age at maturity (rr) (equivalent to the commercial stock recovery rate), and the mature-fish stock biomass for the first year of the selected period in the model settings (B_0).

Estimation of the mature-fish stock biomass per year is performed with the formula:

$$B_{rec(y)} = Njuv_{y-i} W_M rr, \quad (1)$$

where i denotes the age at maturity and $Njuv_{y-i}$ denotes the number of juvenile Russian sturgeon released per year (y–i).

The agreed value $rr = 0.01$ (1%) is used as the initial value in the model, which is reconciled with the published data: 1.1–1.3% (Boiko and Kalinkina, 1961; Makarov, 1964; Rekov and Korneev, 1987) and 0.6% (Zaidiner et al., 2000).

The biomass of the mature stock at the start of the following year is estimated with the formula:

$$B_{y+1} = B_y\left(1 - \varphi_M\right) + B_y\left(\frac{W_y}{W_M}\right) + B_{rec(y)} - C_{total(y)}, \quad (2)$$

where B_y denotes the mature stock biomass at the start of a year (y), $C_{total(y)} = C_y + C_{iuu-y}$, where C_y and C_{iuu-y} denote the time series for the official fishery catches and the IUU-fishing catches, respectively, per year (y), φ_M denotes the annual rate of natural mortality, W_M denotes the average body mass of the mature stock specimens, and W_y denotes the average annual body-mass gain in mature specimens.

The values for the relationship between the mature-specimen body mass and its age were estimated (for the males at 6—21 years old ($W1(x)$) and the females aged 10 to 25 ($W2(x)$). It was performed with the average long-term data (Kozlitina et al., 2005) and the linear functions ($R^2 = 0.97$ in both cases) as $W1(x) = 0.8482x + 1.47$ and $W2(x) = 1.764x - 5.013$, respectively. The agreed average values for the annual body mass gain in males and females (0.848 kg and 1.764 kg, respectively) $W_y = 1.306$ kg were subsequently used in the estimates.

The average age at sexual maturity is determined based on the curve of the sexual maturity in the Rus-

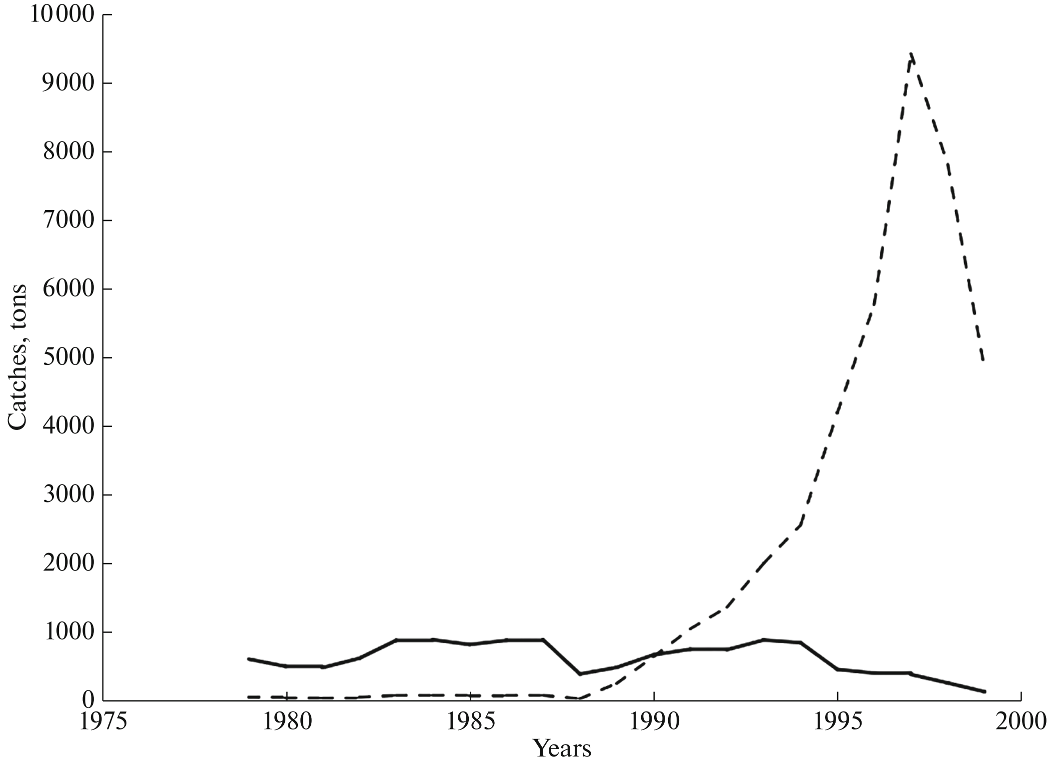

Fig. 1. Time series of official (—) and IUU catches (---) used to model the stock of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov.

sian sturgeon with the Logit-model method (Mikhailyuk and Piatinskii, 2020). The agreed value for it is 14 years (17 years for females and 12 years for males), which is consistent with the results of the Chepurnaya and Rekov (2017). The average body mass of a specimen at the age at maturity (W_M) is considered as 17 kg.

It should be noted that the DAP model involves estimation for two periods, where the first period is selected for setting up the model (1981—1999), while the second period is prognostic (2021—2050). As a rule, there are some gap years between these periods under the fishing moratorium, when the model does not evaluate the stock.

The stock assessment is performed with the method of accounting surveys of sturgeon fish in some month (m) except at the beginning of a year. Therefore, re-estimation of the B_y model range was performed prior to the moment of of accounting surveys. The biomass stock for month *m* in year *y* is calculated with the formula:

$$B_{my} = B_y + \left(B_{y+1} - B_y\right)\frac{m}{12}. \quad (3)$$

The second submodel deals with various scenarios to manage the fish stock in the forecast period. The estimates for the mature-stock biomass in the forecast period are performed with the same equation (2) and the same set of optimal values for rates (φ_M and rr). However, it requires setting up the biomass stock for the previous year, 2020, since accounting survey showed the value close to zero. Therefore, it is agreed as $B_{0(2020)} = 0$.

The prognostic model analyzed 24 stock recovery scenarios for different combinations of two managing parameters: the number of hatchery-reared juvenile fish released relative to the time lag of 14 years equal to the age at maturity ($Njuv_{y-14}$) and the IUU catch share in the biomass stock at the beginning of each year (*biuu-coef*). Prior to 2020 included, the quantity of juvenile fish released to the wild (*Njuv*) is well known (the data of hatchery official statistics). Since 2021, the *Njuv* constant value is set up for each scenario. Since 2035, it intends to determine the amount of fish recruitment biomass (B_{rec}) according to formula (1). Different scenarios deal with the four *Njuv* levels in the forecast period. They include the observed long-term average release level with 3 million units, the optimistic release scenario version with 5 million units, the pessimistic scenario version with 1 million units, and the maximum value observed in the retrospective cycle with 7 million units.

The *biuu-coef* coefficient values of 1, 5, 7, 10, 15, and 20% are set up in the range of 1 to 20% of biomass stock at the start of the year, which do not exceed the limits for this parameter in the retrospective period (20%).

In order to test the validity of a constructed model, the model sensibility test as a diagnostic procedure was performed. The sensibility test provides the opportunity to assess the model deviations of the local optima from the global optima of the model parameter estimates (stock biomass, recruitment biomass, and fishing mortality), which can cause the modeling errors, when setting up the optimal option scheme (φ_M, *rr*, and B_0). The uncertainty test can provide the opportunity to measure the deviations in assessing the stock biomass, occurring because of the uncertainty in the estimates of the fishing mortality in the retrospective period.

The sensibility test was performed with 75% of all the three-parameter options (φ_M, *rr*, and B_0) selected at random. Thereafter, re-estimation of all the characteristics for stocks (the biomass stock, its recruitment biomass, and the fishing mortality) is performed for each of the selected option sets. It is followed by sorting the estimates produced for each accounting year (y) in ascending order and determining the median estimates and 95-% confidence intervals for each year. The intervals calculated for each case represent the estimates for the potential degree of the actual stock size because of the model incorrect parameterization seemed quite possible. The sensibility test procedure is performed as an iterative procedure of the Monte-Carlo method. The produced median estimates and confidence intervals are compared with the model estimates produced via general optimization (φ_M, *rr*, and B_0) in order to determine the degree of reliability and validity of the stock assessment.

The test for uncertainty of the dynamic system of "stock-fishery" to the factor associated with variability in the fishing mortality was performed according to the procedure of testing the models in ICES/FAO (*Precautionary*..., 1996; *A Fishery*..., 2002) (this test is especially important because of the uncertainty in the estimates for catches by IUU fishing). The idea of the procedure is in the potential degree of variability in the stock size relative to the fishing mortality variations observed in the retrospective time period. This test is used to perform long-term forecasting of the potential variation in the stock biomass relative to the previous observations for the dynamic system "stock-fishery". The standard deviation value for a range of values for the fishing mortality in the retrospective period is used as variability estimation. Thereafter, this value is converted to the scale of the stock biomass estimates. Based on the performed variability estimation and the known values for the averages of biomass stock in the retrospective period, the pseudo-random sequences for the biomass stock estimates are generated. The produced pseudo-random sequences are sorted in ascending order. Thereafter, the 95-% confidence intervals are estimated.

Despite the commercial fisheries of the Russian sturgeon in the forecast period is not expected, the acceptable catch validated by the science-based targets for research work and artificial reproduction (hereinafter, total allowable catch for research work (TAC RW)) is, nevertheless, modeled by the forecast submodel. Assessment of TAC RW is performed in order to measure the exact amount of catch, which cannot significantly affect the mature stock in the prognostic model period. Therefore, a certain proportion of a confidence interval size is estimated to assess the biomass stock, based on the uncertainty test results and the baseline prognosis scenario (*biuu-coef* = 0.1, *Njuv* = 3 million units). This range can describe the potential degree of variability in the stock size each year. It is considered that a small catch share of this range should not significantly affect the stock biomass in the forecast period.

In order to determine an insignificant share of TAC RW, the share of the uncertainty range at several levels (1, 5, 10, 50, and 100%) was tested. In addition, the conclusion for the insignificant impact of TAC RW was taken based on analyzing its effect on the time period of achieving the guideline for management (B_{tr}). The impact level was considered insignificant, when the time period of reaching the target baseline shifted no longer than a year.

RESULTS

The optimal decision-making procedure for the input data over the 1981—1999 period resulted in producing the estimates for three major parameters of the model (Table 1). The recruit biomass and stock biomass estimates (Fig. 2) for retrospective period were performed based on the optimal decisions for the model parameters with equations (1)—(3). An increase in the rate of fishing mortality (Fig 2c) at the end of setting up the model is associated with both the high-level estimates for illegal catch (Fig 1) and the sharp decline in stock biomass. The sensibility and uncertainty tests (Fig. 3 and Fig. 4, respectively) were performed to diagnose the results of modeling.

The analysis of the Russian-sturgeon stock dynamics produced for the retrospective study period in setting up the model (Fig. 2a) showed that the environmental conditions during the period favorable for the stock recovery (1988—1998) could provide the opportunity to maintain the population mature-stock biomass at the level of 10 thousand tons. Thus, the problem of fish stock recovery up to this level (B_{tr} = 10000 tons) as a baseline for management of the Russian sturgeon stock and fishing activities was considered to overcome with the projection-based scenarios. Therefore, the stock is considered recovered, if its biomass reached 10000 tons in modeling the possible projection-based scenarios.

With respect to the forecast period, the 24 scenarios with different combinations of the key parameters including the number of hatchery-reared juveniles

Table 1. Estimates for three parameters of DAP model for the stock of the Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov

Parameter	Initial value	Target changing ranges	Optimal value
φ_M	0.05	0.04–0.10	0.0412
rr	0.01	0.005–0.020	0.0182
B_0, tons	6000	4000–8000	4400

released 14 years ago (*Njuv*) and the *biuu-coef* coefficient constant throughout the entire forecast period were observed. A scenario with strategies of annual releasing 3 million hatchery-reared specimens (at the level of an average long-term release in the retro period) was sampled as a baseline (and most real) scenario at *biuu-coef* = 0.1 (10% stock biomass at the beginning of a year). Fig. 5 shows the estimates for the mature population stock and the recruitment biomass for the baseline scenario. The recovery of the Russian sturgeon for commercial fishing is not considered. However, insignificant catch validated by the TAC RW at the level of 1% of the confidence interval size measured by the uncertainty test for science-based target works and generation of the hatchery replacement broodstock is set up (Fig. 6).

The baseline scenario provides a guideline for the stock biomass of 10 thousand tons in 2048, which can continue to increase, if the fisheries regime remains the same (Fig. 5). The recruitment biomass tends to stabilize at 931 tons since 2035 in case of the annual hatchery-reared yearling release fixed at 3 million units.

Fig. 6 shows the stock dynamics with the confidence intervals estimated for the conditions similar to

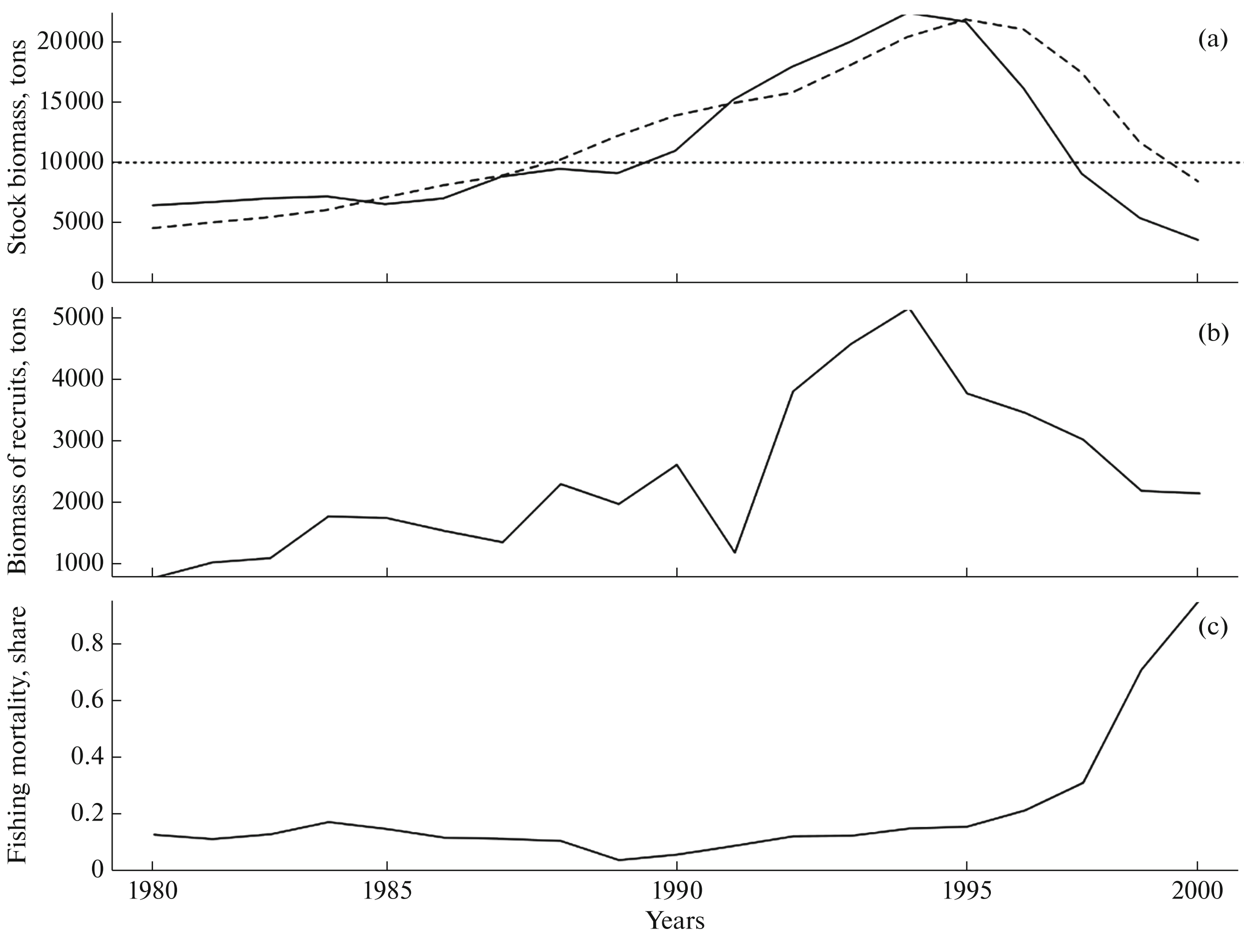

Fig. 2. Results of modeling the parameters for the stock of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov in the period of setting up the model in 1981—1999: (a) stock biomass, (b) biomass of recruits, (c) fishing mortality rate, (---) denotes DAP model, (—) denotes data on fish-counting captures, and (···) denotes the target baseline for 10 thousand tons.

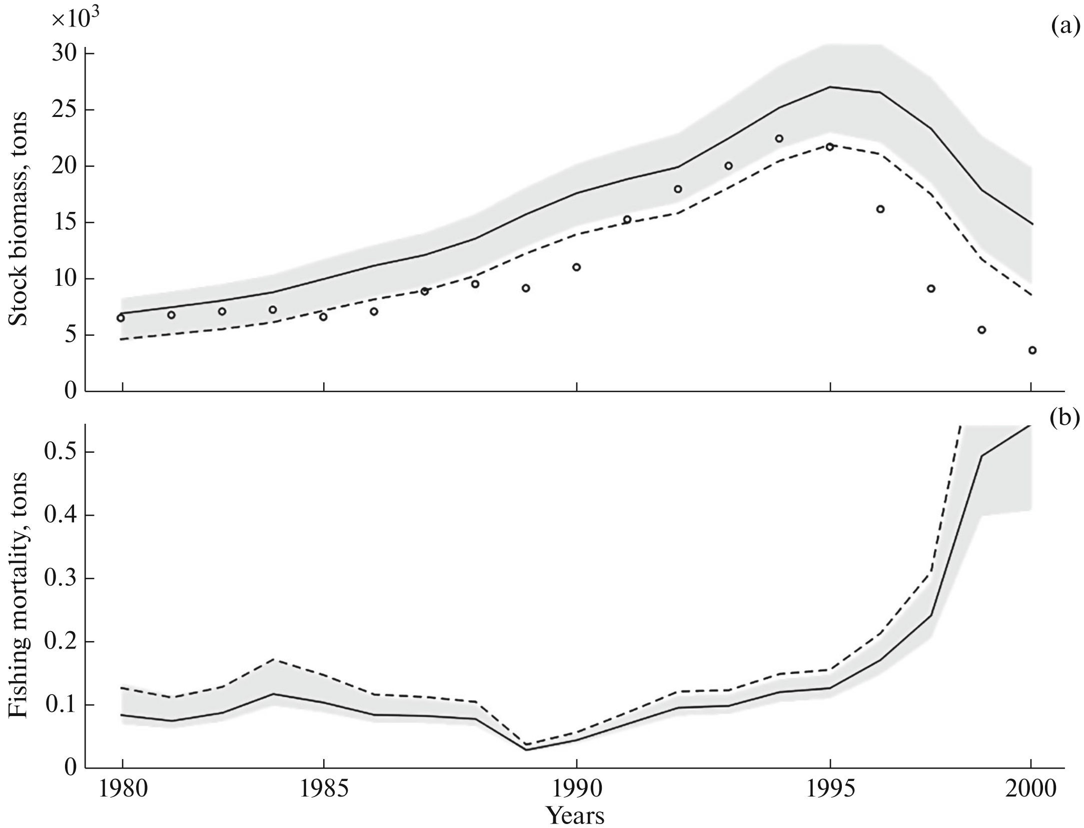

Fig. 3. Sensibility test to estimate the stock biomass (a) and the fishing mortality (b) in Russian sturgeion *Acipenser gueldenstaedtii* in the Sea of Azov; the Monte-Carlo method,when setting up the optimal option scheme. (---) denotes model estimates relative to global optimization, (—) denotes median estimates after the Monte-Carlo procedure, (■) denotes confidence intervals (p = 0.95) of median estimates, (○) denotes direct estimates of the mature stock with the accounting survey method.

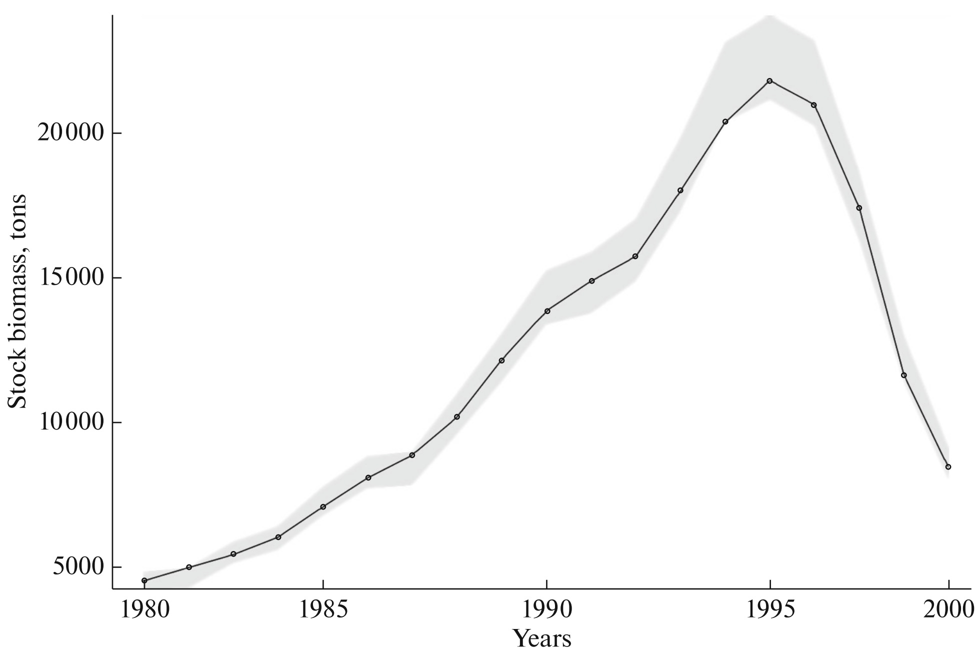

Fig. 4. Uncertainty test to estimate the stock biomass of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov relative to variation in its fishing mortality at setting up the model. See Fig. 3 for designation.

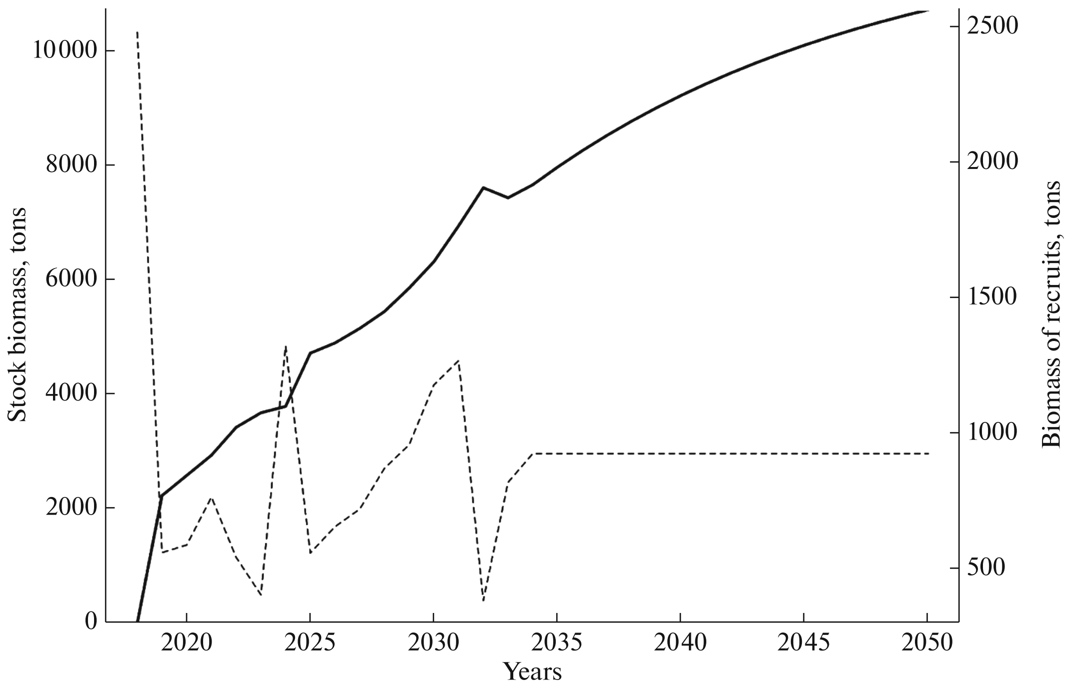

Fig. 5. Outcomes of prognostic dynamic model for stock biomass (—) and recruitment biomass (---) of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov according to the baseline scenario, 2018—2050.

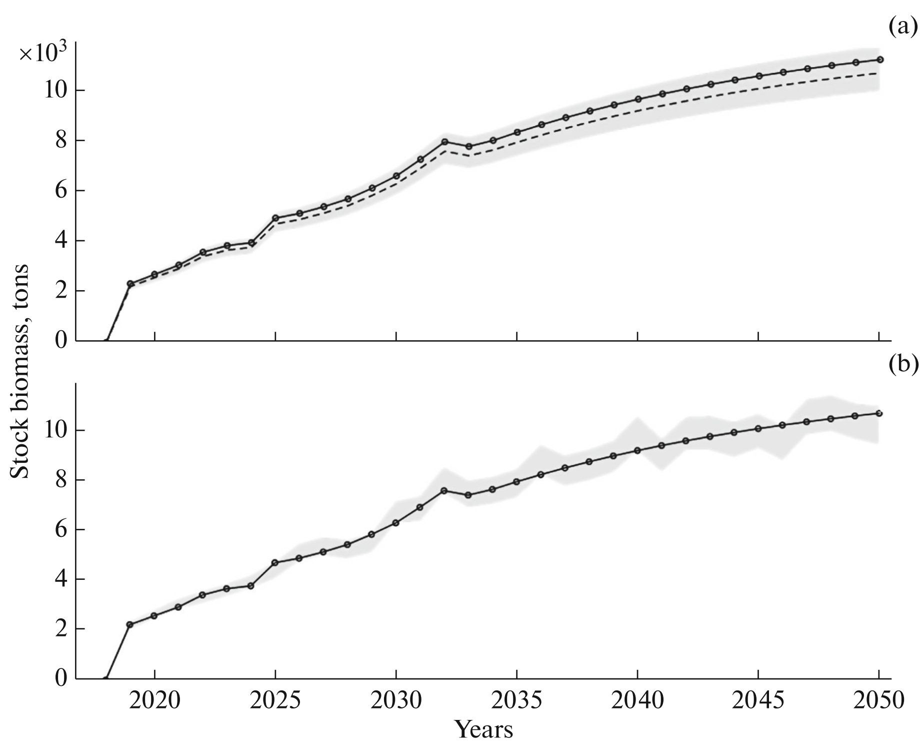

Fig. 6. Baseline scenario for prognosis for the stock biomass of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov in 2018—2050: (a) sensibility test, (b) uncertainty test, (---) denotes model estimates for stock biomass, and (—) denotes the test median estimate; See Fig. 3 for the other designation.

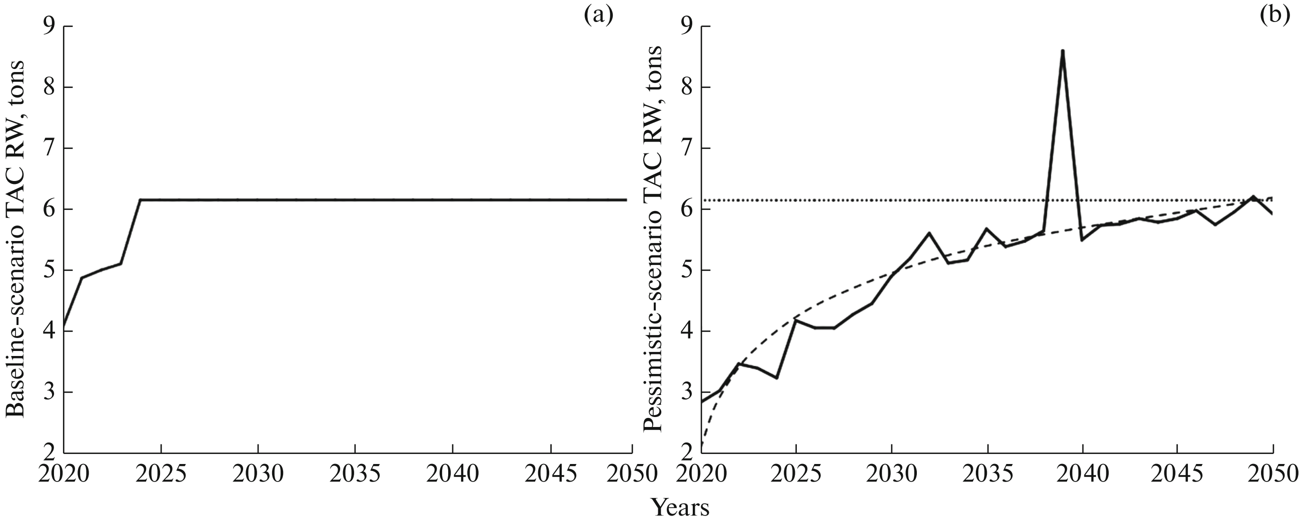

Fig. 7. Total allowable catch for Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov for the research work and reproduction (TAC RW) targets by model outcomes for shares of uncertainty in 2020—2050. (a) a baseline scenario (*Njuv* = 3 million units., *biuu-coef* = 0.1), (b) pessimistic scenario (*Njuv* = 3 million units, *biuu-coef* = 0.2), (—) denotes the theoretically allowable level of TAC RW, (···) denotes the upper asymptote of a maximum potential for TAC RW (6.13 tons) by the logarithmic curve ($y = 1.2664\ln(x) + 1.7869$, $R^2 = 0.7559$), and (- -) denotes logarithmic approximation for stock biomass estimates.

those in the retrospective model. It is based on the coefficient of fishing mortality according to the uncertainty test (Fig. 6b) and the test of sensibility to the start-up parameters based on the Monte-Carlo procedure (Fig. 6a) at $p = 0.95$ significance value.

The equation for the total allowable catch in the forecast period after 2034 is expressed as the formula: $C_{total(y)} = C_y + C_{iuu-y} = C_y + biuu\text{-}coef \times B_y$. Symbol C_y denotes the allowable catch for the TAC RW, insignificant for the mature-stock biomass, (Fig. 7) and C_{iuu-y} denotes the IUU-catch extent proportion of the mature stock biomass in the beginning of the year ($C_{iuu-y} = biuu\text{-}coef \times B_y$).

The test results for different levels of TAC RW throughout the forecast period showed that an insignificant shift for a year of achieving the model-based guideline is generated at 1% catch of a confidence interval size relative to the stock estimates in the uncertainty test. In order to prevent any disorder in the process of stock recovery because of uncertainty in IUU fishing, the limited (maximum permitted) quantity for TAC RW for different scenarios was decided to estimate taking into account the probability of occurring the most pessimistic scenario. The maximum value for TAC RW in all the scenarios was fixed at the maximum level estimated for the pessimistic scenario, which comprised 6.13 tons (*biuu-coef* = 0.2 and *Njuv* = 3 million units). This value corresponds to the maximum value for the non-line function describing the correlation between a given year and its annual catch limit in the forecast period (Fig. 7b). The probable TAC RW values produced for the baseline scenario are set up into all the modeling scenarios as the values for the legal fish catch (C_y).

The other three scenarios for the fish stock recovery with the other values for *Njuv*, but the same value for *biuu-coef* = 0.1, estimated for the baseline scenario, are present in Fig. 8 along with the baseline scenario. The stock biomass for these four scenarios varies similarly up to 2034 as long as the real quantity of juvenile fish released determines the Njuv.

The outcomes of the prognostic submodel for all of the 24 scenarios of stock dynamics given in four variants of numbers of juvenile fish released annually (1, 3, 5, and 7 million units) at the six reference variants of values for *biuu-coef* (0.01, 0.05, 0.07, 0.10, 0.15, and 0.20) are present in Table 2.

DISCUSSION

The outcomes of modeling for a retrospective period (Fig. 2a) can indicate the steady increase in the mature stock biomass in 1985—1995, which is ensured by the large numbers of hatcherey-reared fish released in the previous period (1971—1995). Since 1995, a sharp decline in the stock biomass at the reference rapid depletion of the commercial fish stock, which was mostly caused by the IUU fishing-based catch in this period.

The sensibility test outcomes (Fig. 3) indicate the satisfactory level of model estimate validity. However, their uncertainty tends to increase since 1990. Thus, the estimates for two parameters assessed by the model (the stock biomass and the fishing mortality) are dis-

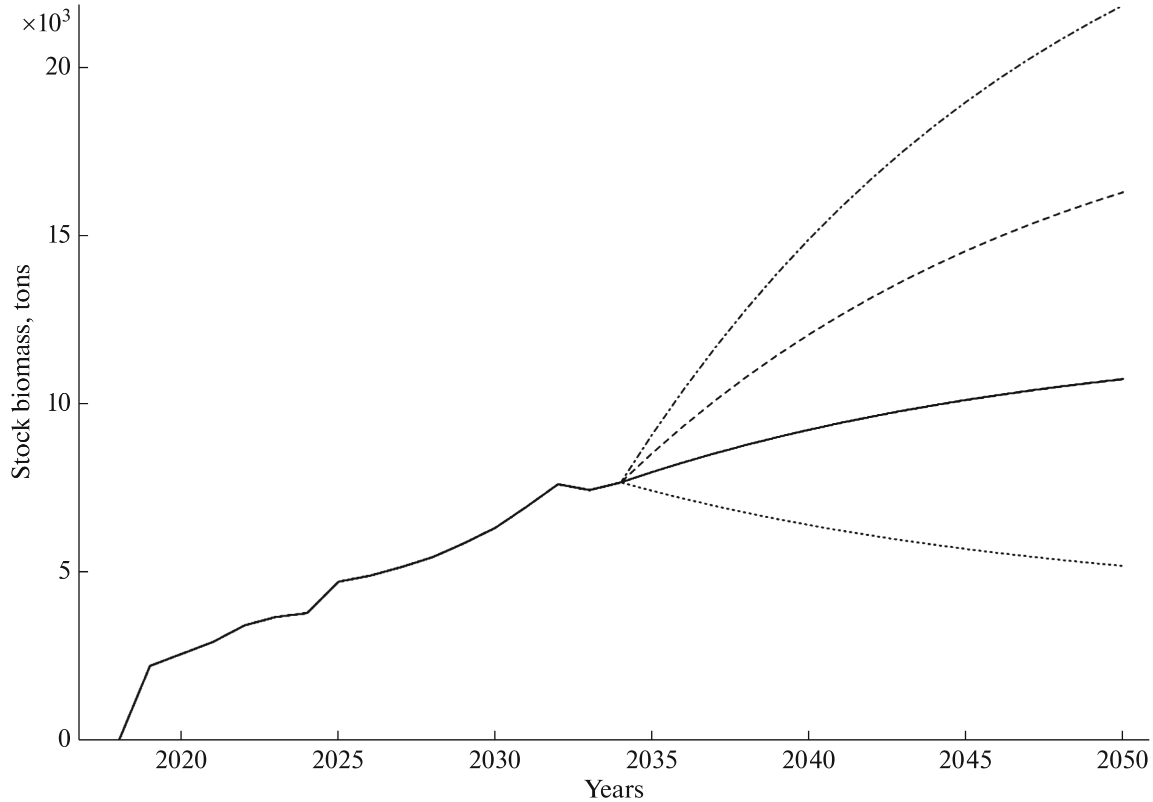

Fig. 8. Four scenarios for biomass stock recovery of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov (taking into consideration the catch for the TAC RW for a baseline scenario relative to *biuu-coef* = 0.1) relative to the different quantity of hatchery-reared juvenils for releases after 2034. (···), (—), (– –), and (– · –) denote 1 million units/year, 3 million units/year, 5 million units/year, and 7 million units/year, respectively.

played outside the confidence intervals and shifted aside the median to the same side. A meaningful conclusion based on this test may be drawn on the shift in the model estimates for three parameters relative to the absolute optimum setup, which can cause the upward and downward bias when measuring the stock biomass and the fishing mortality, respectively.

The uncertainty test outcomes (Fig. 4) also indicate the longer ranges of the probability estimates after 1990. Thus, a decrease in the predictive validity of a retrospective model setup is probably caused by the insufficient information on IUU fishing activities and the multifold intensity increase in its effects on the Russian sturgeon population from year to year. In additon, a decrease in the predictive validity of the produced estimates for stock biomass, recruits, and fishing mortality after the 1990s is probably caused by uncertainty and (or) time variability in parameters *rr* and φ_M in different model periods. Parameters *rr* and φ_M in the model are considered constant. This model assumption may be incorrect, however, this is considered appropriate with the limited data.

All the prognostic model scenarios excluding the most pessimistic scenarios generally indicate the opportunity to recover the Russian sturgeon stock in a long-term perspective. Thus, the most probable scenario, where the IUU-fishing catch is no more than 10% of stock biomass as of the beginning of a year and the number of hatchery-reared juvenils released into the wild remains at the level of the long-term average of 3 million units, assumes recovery the mature-fish stock biomass up to 10 thousand tons by 2048. With respect to the high numbers of the hatchery-reared juvenils released into the wild (5 million units), it may occur by 2037.

The more optimistic scenarios (under the stricter management of IUU fishing and with the increased capacity of hatcheries) provide the opportunity to recover the stock up to the model-based guideline level by 2028. In addition, the scenarios, where the number of the hatchery-reared juvenile fish released into the wild comprises 7 million units per year, seem quite optimistic. Thus, the B_{tr} guideline level may be reached, despite 15% IUU-fishing catches of the stock biomass.

Table 2. Analysis outcomes for 24 scenarios for stock recovery of Russian sturgeon *Acipenser gueldenstaedtii* in the Sea of Azov

Number of juvenile fish for release, million units/year	Item	*biuu-coef*					
		0.01	0.05	0.07	**0.10**	0.15	0.20
3	Stock biomass in 2050, tons	43150	21495	15915	**10749**	6386	4281
	Year of achieving B_{tr} = 10 thousand tons	2029	2032	2035	**2048**	*	*
	Stock trends	+	+	+	+	+	+
5	Stock biomass in 2050, tons	55061	29854	22977	**16296**	10216	7032
	Year of achieving B_{tr} = 10 thousand tons	2029	2032	2035	**2037**	2048	*
	Stock trends	+	+	+	+	+	+
1	Stock biomass in 2050, tons	31238	13136	8853	**5202**	2557	1532
	Year of achieving B_{tr} = 10 thousand tons	2028	2032	*	*	*	*
	Stock trends	+	+	–	**–**	–	–
7	Stock biomass in 2050, tons	66973	38213	30039	**21843**	14045	9781
	Year of achieving B_{tr} = 10 thousand tons	2028	2032	2035	**2036**	2039	*
	Stock trends	+	+	+	+	+	+

*The target level is not reached; biomass stock trend after 2034: "+" and "–" denote increase and decrease, respectively; the outcomes of scenarios present in Fig. 8 are given with the demi-bold font

Moreover, the more pessimistic scenarios are also observed. Thus, it seems impossible to reach the baseline level of stock recovery until 2050 regardless of the numbers of the hatchery-reared juvenils released in case of weakening the regulation on the IUU fishing activities (variant *biuu-coef* = 0.20). With respect to the low numbers of the hatchery-reared fish released (1 million units per year), the prognosis is also unfavorable, since the baseline level cannot be achieved, exhibiting a declining trend in the fish stock biomass.

The survey outcomes coincide well with the withdrawl decisions of the other authors (Chepurnaya et al., 2008; Chepurnaya and Rekov, 2017; Rekov and Chepurnaya, 2018), who report the critical state of the Russian sturgeon stock in the Sea of Azov in the period of fishing bans and the predominant negative effects of IUU fishing. In addition, they inform that releases of juvenils of 2.8 million units per year and no less are required for the stock recovery. This number of fish for release is used in the baseline scenario considered in this research paper. In addition, Shlyakhov et al. (2005) also indicate the IUU fishing practice as a predominant negative factor affecting the Russian sturgeon stock biomass.

Modeling the possible TAC RW for the scientific and reproduction targets indicates the available resources for catch with increasing the stock from 4.86 to 6.13 tons in 2022 and 2050, respectively, according to the baseline scenario (Fig. 7a). In the pessimistic scenario, the catch for the TAC RW and reproduction targets may comprise 3.46 tons and 5.90 tons, respectively (Fig. 7b). The outcomes of modeling have showed that the catch of such quantity cannot have any significant effect on the mature-fish stock biomass over the forecast period under consideration. This recommendation coincides well with the protocol on the "XXXII session of the Russian and Ukranian Fisheries Commision for the Sea of Azov", where the Russian sturgeon fishing activities are banned. With respect to the catch for the scientific and reproduction targets, the TAC quotas for the Russian Federation and Ukraine were set at 3.81 and 0.20 tons, respectively. It should be noted that the present recommendations for the TAC RW are not expected to have any significant impact on the fish stock dynamics within the modeling scenarios.

CONCLUSIONS

The proposed DAP model may be used in a case, when the stock reproduction is maintained only by releasing the hatchery-reared juvenile-fish. The other essential condition to use the model is relevant to the available estimates for the fish stock and the fisheries resources in the favorable period of the stock development until the closure for fishing activities. The DAP model may by applied to both the sturgeon species and the other fish species with artificial reproduction.

It should be noted that it is rather difficult to estimate the real fishing mortality because of the uncertain level of IUU fishing and, especially, its variability. The factor of IUU fishing, which substantially exceeds the values for legal fish catch, tends to introduce the high percentage of uncertainty in the model output. The high uncertainty facing the authors' development may be avoided in modeling, if the catch data represent the reliable time series data.

The outcomes can indicate the depleted status of the Russian sturgeon stock in the Sea of Azov at present. The long-term scenarios considered within the modeling involve both the optimistic turn of events followed by increasing the stock biomass and the pessimistic situation, which may cause the long-term population collapse. The published papers of the other authors (Shlyakhov et al., 2005; Chepurnaya et al., 2008; Chepurnaya and Rekov, 2017; Rekov and Chepurnaya, 2018) can prove a high probability of a pessimistic scenario.

The model outcomes have shown that implementation of the optimistic scenario requires the relevant administrative actions to prevent the IUU fishing practices and to intensify the hatchery-reared juvenile release activities.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict of interests.

Statement of the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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