Population Viability Analysis of the Danube sturgeon populations in a VORTEX simulation model
APPENDIX TO THE ARTICLE

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1. Model parameterization

In order to define population parameter values for each of the six Danube sturgeon species, a literature survey was conducted. All publications that were found to contain important life history parameters, or information about the management of sturgeon populations in the Danube River and Black Sea basins, were included in the final determination of the parameter values that will be included in the model. On the basis of the data that was present in the available literature, data sheets were made for each Danube sturgeon species with the values for each of the basic parameters that are necessary for scenario building in Vortex (see chapter 3). Available publications that describe PVA studies performed on other sturgeon species were also assessed, in order to get experience on the estimation of different life history parameters. Furthermore, a number of experts on sturgeons from the Danube River basin were contacted and meetings with them were arranged, in order to improve estimation of specific life history parameters.

In general, for parameters that were provided by different authors as ranges or that were inconsistent in provided values, a most probable mean value was determined, and ranges were included in the model as environmental variation through establishing a standard deviation for the mean value. If ranges provided by different authors were inconsistent, values that were given in the majority of the publications were applied, and the other values were included in the sensitivity analysis (for details see chapter 2).

There is a significant uncertainty regarding the maximum age of reproduction. In most of the publications that are dealing with the ecology and life history of sturgeons, this issue has not even been raised or touched upon. Nearly all contacted sturgeon experts have claimed that sturgeons can reproduce throughout their whole life. On the other hand, according to some sources they stop reproducing significantly before reaching their maximum age (Williot et al. 2005; Lagutov and Lagutov 2008; Williot pers. comm.). In the end, the opinion of the majority of sources was applied and the maximum age of reproduction was set to be the same as the maximum longevity of the species. The effect of the existence of senescence on the results of simulation was assessed through the sensitivity analysis.

Although there are no real data on the type of mating system (how many males and females participate in a single spawning event), most interviewed experts claimed that it is polygynous (there are also some unpublished studies confirming this, for example Kynard in press citt. in Suciu pers. comm.), so this system was applied in simulations as well. As it most often has been defined in sturgeon PVAs (Pine et al. 2001), sex ratio was set to be equal, and effects of an unequal sex ratio were tested in the sensitivity analysis.

Sturgeons do not spawn every year (Reinartz 2002), because the egg development process (vitellogenesis) typically requires more than one year, so only a small fraction of the total population takes part in the annual spawning (Beamesderfer et al. 2007). The percentage of individuals of each sex that participate annually in spawning was established as $S=100/I$, where I represents the time between two spawning migrations.

When a studied species has too large mean and maximum number of offspring for an individual-based model like Vortex, it is recommended to redefine reproduction by condensing a series of mortality events at early life stages, and thus to include in the offspring only those that survive to a certain age (Kjos et al. 1998 citt. in Miller and Lacy 2005). Miller and Lacy (2005) have suggested that this approach could be useful for modelling fish populations, so it was applied in this study as well. For estimating the mean and the maximum number of offspring, mean and maximum fecundity for each of the studied sturgeon

species was multiplied by the survival rate from age 0 to 1, and the resulting value was applied. Since the natural mortality for age 0 to 1 was thus already included in the model through the number of offspring, natural mortality for this age group was set to be 0.

It is a common opinion that the natural mortality is one of the most difficult vital rates to be determined (Boyce 1992; Beissinger and Westphal 1998; Beissinger 2002). This is unfortunately also true for the sturgeon species, and there are no data on the natural mortality for populations in the Danube River. As proposed by Boyce (1992), in such situations it is feasible to either use data from similar species or areas, or to explore behaviour of the model across the range of possible values. We have tried to apply both approaches here. For determination of the age 0 to 1 mortality, values from other sturgeon species and PVA studies were used. The mortality for egg to age 1 class was similar among all models and studied sturgeon species, it ranged from 0.9996 to 1.0 (Pine et al. 2001; Jager 2005, 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007). These values were applied in this study as well; the middle value of the given range (0.9998) was used as the mean and 0.9996 as the minimum age 0 to 1 mortality rate. As was already described above, these values were incorporated in the model through the number of offspring.

It is believed that sturgeon longevity is characterized by a low mortality rate after the first few years of age, but there is no empirical data that would confirm this (Beamesderfer et al. 1995). Most of the authors of other sturgeon PVAs have used simple natural mortality distribution across age classes, i.e. the same values were used for both juveniles after the first year and for adults (Jager 2001, 2005, 2006; Jager et al. 2001; Heppell 2007; Beamesderfer et al. 2007; Kennedy and Sutton 2007). Such an approach was shown to be ecologically unrealistic when we tried to apply it in Vortex, since a uniform distribution of age specific mortality allowed the existence of only a small number of adults in a population, and prevented them from reaching the old ages that have been reported for these species. When we have tried to test behaviour of the model across different sets of mortality rates, as proposed by Boyce (1992), it became apparent that it would be necessary to place a larger mortality on the younger age classes and significantly lower mortality on adults, so that a certain number of older individuals can still be present in the population with the normal age distribution.

In order to define a starting point for the determination of age specific natural mortality, we have used Rikhter and Efanov's method for the estimation of natural mortality for fish species in temperate regions. This equation requires only the age at maturity of females as the input variable, and provides the total natural mortality rate, not the age-specific one. Calculations with Rikhter and Efanov's equation were made in the FISAT II (2000) computer program for fish stock assessments. Values obtained by this approach are presented in Table 1.

Table 1 Values of annual natural mortality obtained by the Rikhter and Efanov's method for each of the six studied species

	Beluga	Russian sturgeon	Stellate sturgeon	Sterlet	Ship sturgeon	Atlantic sturgeon
Average age at maturity of females[a]	15	14	10	5	13	14
Natural mortality	0.056	0.067	0.130	0.317	0.080	0.067

[a] See the chapter 3 for references regarding the age at maturity estimation

Upon obtaining these values, we have made a fitting of the natural mortality for each species, in order to get the most realistic distribution of mortality rates for different age classes. The fitting was performed with the aim to meet two basic criteria at the same time: 1) At the stable age distribution, populations had to contain enough adult specimens, of which a certain number had to be of higher age, close to the maximum longevity reported for these species. In other words, mortality had to be set in such a way to allow individuals to reach their maximum reported ages. 2) The deterministic population growth rate (r) should reach pre-determined levels.

Deterministic growth rate is one of the key demographic parameters, but the available data on the r value for sturgeon populations is poor, especially for the populations in the Danube River. According to some sources, the most common population growth rates for sturgeon populations are low, being close to 0.05 (Bruch 2008), 0.10 (Secor and Niklitschek 2002), or varying between 0.05 and 0.15 (Balnath et al. 2008). Based on this information, we have applied three different population growth rates for each species: 0.05, 0.10 and 0.15. In order to acquire such growth rates, age specific natural mortality was fitted so that

each of these *r* values was met in different scenarios (see chapter 3 for the natural mortality rates). All scenarios and simulations were tested against each of the three defined population growth rates.

According to Jager (2001), sturgeons are known to experience fluctuations in year class strength, and are unlikely to ever reach a true stable age distribution (Heppell 2007). Pine et al. (2001) stated that sturgeons probably demonstrate variable recruitment, where a few large year-classes make up a high percentage of the adult standing stock. In this study, age distribution at the beginning of each simulation was set to be stable, since the stochastic fluctuations in the age distribution and year-class strength already represent an integral part of simulations in the Vortex. This approach also makes the least number of assumptions since the stable age distribution is a direct function of the demographic rates chosen, whereas any other distribution must be supported by additional information. Furthermore, an unstable age distribution in itself creates population fluctuations that may mask the effects of other factors that were assessed. We have included the option of environmental concordance between reproduction and survival, in order to represent the actual situation in the environment, where bad years for reproduction (e.g. unsuitable hydrological regime in the river) are usually also bad years regarding survival. This approach was chosen since it as well meant the least number of assumptions, and makes the results more conservative, in the sense that it does not lead to underestimation of actual threats.

In order to simulate the environmental variation in natural mortality, we have assumed that younger age groups have much higher annual variability in natural mortality, and that it drops towards the adult age groups. We have applied the general rule that the standard deviation of the natural mortality of each of the age 1 to 3 age groups was equal to 40 percent of the natural mortality of those age groups. For the age groups from the age 4 to adulthood it was equal to 25 percent and for the adults it was 10 percent of the age specific natural mortality. However, if the mean mortality of a certain age plus two standard deviations resulted in a higher value than 100 (Mean + 2 x S.D. > 100), the standard deviation was reduced to the level where the expression was equal to 100. Variation in natural mortality of the age 0 to 1 was incorporated through the standard deviation of the mean number of offspring.

According to Allendorf and Ryman (2002), a population persisting over a certain number of years does not have to imply that it is viable, since it might have already experienced such significant changes that it is not likely to persist for additional period of time. Therefore, it is often prudent to employ a pseudo-extinction criterion, which represents a certain threshold population size below which the population is likely to experience dire demographic and genetic changes, leading to a significant extinction probability (Beissinger and Westphal 1998; Akçakaya 2000). According to Akçakaya (2000), the introduction of a pseudo-extinction threshold is also considered to be conservative, and can diminish the problem of having to incorporate factors that are dominant at low population sizes, such as inbreeding depression and Allee effects, for which there is usually insufficient knowledge. Based on the above described reasons, we have decided to use a pseudo-extinction criterion in this study, instead of scoring the risk of reaching absolute extinction. After running a number of test scenarios with varying population size for each species, in order to determine the relationship between the population size and the extinction probability, we have set the pseudo-extinction threshold to be at the population size of ten individuals, which was applied for all scenarios and all six species.

For the sake of greater simplicity and in order to reduce the number of assumptions already made in the model parameterization, some parameters like density dependence in reproduction and the existence of catastrophic events were not included in the model. While the demographic stochasticity is incorporated in the Vortex model, the problem of other Allee effects was partly resolved by introducing pseudo-extinction (Akçakaya 2000).

The number of iterations was set at 1 000 for all simulations, in order to increase the precision of the results. Since sturgeons are long lived species (some reaching even 100 years of age), a longer duration of simulations was necessary, so most scenarios were set to last for 500 years. Although the long-term projections can lead to serious statistical difficulties and the uncertainties are accumulating proportionally to the length of the simulation, they will do so much more slowly for species with a long generation time (Lande 2002). Exceptions were the stocking scenarios, where population recovery was monitored, which required much shorter time spans, usually less than 100 years.

The age 0 to 1 natural mortality was incorporated in the model through the proportional reduction of number of offspring produced, so young-of-the-year that have not survived up to the age 1 were not considered in the simulation. Therefore, it is important to note that in the future text, population size (*N*) does not include embryos and young-of-the-year that will not survive up to the age 1. For example, the population size of 2 000 individuals applied in some scenarios represents a much larger actual population,

since the number of offspring that will succumb to natural mortality during the first year of life can be up to few thousand times larger.

Except in the sensitivity analysis and the stocking scenarios, the carrying capacity was usually set to be equal to the initial population size, as was done by Reed et al. (2003).

2. Scenario development

The starting point of the Danube sturgeon PVA in the Vortex simulation model was the construction of basic scenarios. They were made for each of the six studied species, by applying the most probable values that describe their life history that are currently available (chapter 3). Each basic scenario was simulated with the three different fittings of age specific natural mortality, which were producing three different deterministic population growth rates (r), i.e. 0.05, 0.10 and 0.15 (for an explanation on the natural mortality fitting process see chapter 1). Each of them was simulated at six different population sizes (50, 100, 200, 500, 1 000 and 2 000). Therefore, in order to cover different potential population growth rates and the behaviour of the model at different population sizes, there were 108 basic scenarios developed, 18 for each species. Carrying capacity was set to be equal to the initial population size, and the duration of the simulation was 500 years, so the model could be sensitive to the effects of those processes that are likely to emerge slowly. Main output values that were tracked in basic scenarios were the probability of pseudo-extinction, mean population size of extant populations, expected heterozygosity, the number of extant alleles and the mean time to extinction.
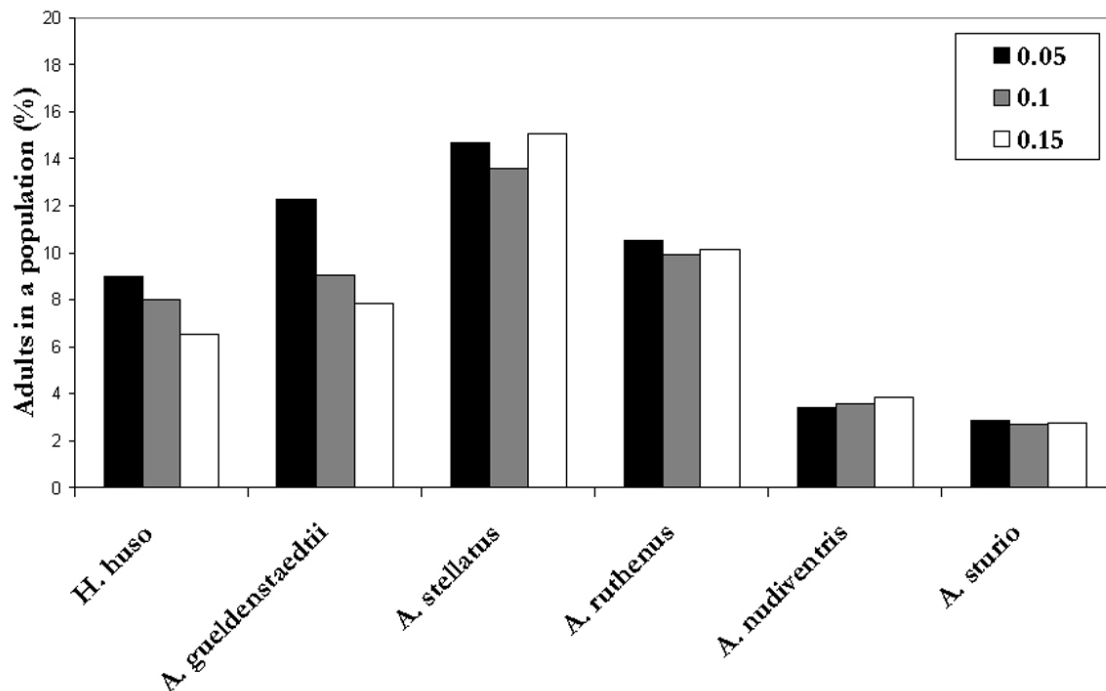
Fig. 1 Proportion of adults in the six studied sturgeon species, according to calculated stable age distributions based on demographic input data for simulation scenarios. Results for three rates of population increase (r) are shown

There are two general approaches that can provide comparability among different sturgeon species. One is to set the carrying capacity equal for all studied species, with all age classes included in the population total. The other one would be to vary the carrying capacity based on the calculated stable age structure, with the aim to apply the ceiling to the number of female adults only disregarding the number of males, juveniles and subadults, and to achieve the same value for all species. Both approaches cannot be applied at the same time, since different life histories would produce different stable age distributions of the

six Danube sturgeon species (Fig. 1). Therefore, another set of basic scenarios was developed that followed the latter approach. Since the ratio between adult males and females differs among species (due to the differing mortality between sexes, caused by different age at maturity), comparability can not be achieved for both genders in the same scenario, so females were chosen as the more critical gender in this case. As the initial step of the scenario development, a species was randomly chosen, and the initial population size was set to a level which gave large variation in output variables among scenarios. The stable age distribution was next calculated, to produce the corresponding number of adult females. For the remaining species, the initial population size was then increased or decreased to the level where the same number of adult females was reached. Simulations were run for 500 years, and the carrying capacity was set to be the same as the initial population size.

As stated by Miller and Lacy (2005), an important part of any PVA is the sensitivity analysis. It can reveal effects of uncertainty in applied parameters, as well as the relative influence of different parameters to the population dynamics and model projections (Miller and Lacy 2005). Therefore, in order to test the dependence of the model behaviour on changes in each of the life history parameters, as well as to span the ranges of life history parameter values provided by different authors, a sensitivity analysis was conducted. All simulations that were part of the sensitivity analysis were run at the population size $N=50$ and carrying capacity set at 2 000. Basic scenarios with this setup were also run for each of the studied species, in order to enable the comparison of the results. Since the initial testing had shown that most of the simulations have resulted in population recovery during the first 100 years of simulation, the duration of all sensitivity analysis scenarios was set to 100 years. In order to test the effect of change in any single parameter, only one parameter was being changed at a time. The age distribution of the initial population was kept constant in all scenarios that were compared, to avoid the effect of change in age distribution when life history parameters are being modified. The tested change in each parameter was either reflecting the ranges provided for that parameter by different authors, or some general amount of change was applied (e.g. ± 50 percent). As was done in the basic scenarios, sensitivity analysis of each parameter was also tested against three different population growth rates. Ranges of values applied for each life history parameter are presented in chapter 4. Output variables that were tracked during the sensitivity analysis simulations were the pseudo-extinction probability, deterministic and stochastic population growth rates, expected heterozygosity, and the mean time needed for population to reach half of the carrying capacity.

Relationships between the deterministic population growth rate and the probability of pseudo-extinction, as well as between the deterministic population growth rate and the expected heterozygosity, were assessed separately for each studied species, in order to determine the potential of the deterministic growth rate as a general predictor of the overall population viability. Since the variables lacked normality of distribution, they were compared with Spearman's non-parametric correlation test.

Results of the sensitivity analysis were assessed through the use of two distinct approaches, a ranking technique and regression analysis. For each studied species, absolute changes in output variables (pseudo-extinction probability, deterministic and stochastic population growth rates, expected heterozygosity, and the mean time to recovery), that were caused by changes in each of the life history parameters, were ranked from the highest to the lowest. This ranking was performed separately for each of the three population growth rates applied, and the ranks were then summed for each life history parameter (i.e. six rank values were summed for each life history parameter – results of the increase and decrease in parameter value, respectively, for each of the three growth rates). Life history parameters were then ranked separately for each output variable, thus revealing the relative influence of each parameter on the output variables. Ranks were also summed across output variables for each species, as well as across species for each output variable, in order to determine which life history parameters have the overall highest influence on sturgeons and their viability.

Regression was performed separately for each studied species and for each of the three population growth rates. Output variables (pseudo-extinction probability, deterministic and stochastic population growth rates, expected heterozygosity, and the mean time to recovery) acquired from the each sensitivity analysis scenario were used as the dependant variables and values of life history parameters applied in those scenarios were used as the independent variables. Regression analysis was performed in the SPSS software (version 15.0).

As the unsustainable fishery is considered to represent the most detrimental impact on the viability of Danube sturgeon populations (Reinartz 2002; Lenhardt et al. 2006), harvest scenarios made a significant portion of the simulations made within this study. The basic questions that were addressed in harvest scenarios were the determination of the threshold level of the harvest pressure below which population

viability would still be preserved, as well as to compare the vulnerability of different sturgeon species to harvest. General model setup was similar as in the basic scenarios – both the initial population size and the carrying capacity were set at 2 000, and simulations were run for 500 years. The harvest was introduced in the model as the percentage of adults taken every year. The same pressures were always applied to both sexes, since it is believed that they are exposed to similar fishing efforts, due to lack of sexual dimorphism (Vassilev pers. comm.). The harvest was applied first at a 5 percent level (meaning that 5 percent of the adult part of the population was taken), and then increasing it in each new scenario by 5 percentage units, until population extinction was the most likely outcome. The harvest was performed each year, during the whole duration of the simulation. Since the fishery in the Black Sea, performed by Ukraine in the past, was also directed at subadults (Vassilev pers. comm.), as is the illegal Sterlet fishery in Serbia, special scenarios were developed where the two oldest age groups of subadults were also harvested, with the same harvest pressure applied as for the adults. Subadult harvest was introduced in the model through the increase of natural mortality of those age groups, because there was no way to introduce it as the percentage of subadults that were taken through the regular harvest platform. The age distribution of the initial population was kept constant. Main output variables that were tracked for the harvest scenarios were the pseudo-extinction probability, mean population size of extant populations, expected heterozygosity, the mean time to extinction, and the number of individuals that were harvested.

Supportive stocking is one of the main conservation measures applied to sturgeons worldwide, and this approach has also been widely applied in the Danube River basin (Reinartz 2002; Williot et al. 2002; Vassilev 2006). In order to test the effectiveness of this measure, a series of stocking scenarios was developed. The main goal was to test different approaches in supportive stocking, and their influence on the population viability. Since it was important to track the time that population needed to recover after the release of stocked individuals, the general setup of the model was similar to the one used in the sensitivity analysis – initial population size was 50, carrying capacity was set at 2 000, and the duration of simulations was 100 years. In general, stocking dynamics (e.g. time of the release, number of releases) varied between different scenarios along three main dimensions: total number of individuals that was released, age of released individuals (whether they were juveniles or adults), and the temporal scale of stocking (whether the same number of individuals was released in a single year, or during several years). The sex ratio of released individuals was always set to be equal. Initially scenarios were run with a smaller number of individuals released in the first year of simulation, and then the total number was increased in each new scenario until recovery was the most likely outcome. Each step was afterwards tested with two additional dynamics of release, but with the same total number of released individuals kept to be the same - release was conducted every second year or every year during the initial 10 year period of the simulation. Since the juveniles below age 1 are most often used in stocking activities, separate tests were run with juvenile and adult fish being released. Main output variables that were tracked for the stocking scenarios were the pseudo-extinction probability, mean population size of extant populations, expected heterozygosity, number of extant alleles, the mean time needed for population to reach half and 75 percent of the carrying capacity, and the stochastic population growth rate, both during and after the stocking period.

As proposed by a number of different authors (Ebenhard 2000; Beissinger 2002; Hanski 2002; Reed et al. 2002), results of all scenarios were used more to compare their relative effects, for instance to compare different management scenarios, then to use them as the absolute predictions. An extinction risk of $p<0.05$ is commonly applied as the threshold to evaluate viability (Beissinger and Westphal 1998), so it was used in this study as well.

3. Input data sheets for basic scenarios in Vortex simulations

General input data that was used in basic scenarios for all species:
Number of iterations: 1 000
Number of years: 500
Extinction definition: N < 10
Number of populations: 1
Inbreeding depression: no
Concordance of environmental variation in reproduction and survival: yes
No of types of catastrophes: 0
No of population state variables: 0

Dispersal: off
Age distribution: stable age distribution
Initial population size and Carrying capacity (K) tested for 6 different values in 6 scenarios: N and K = 50, 100, 200, 500, 1 000 and 2 000
SD in K due to environmental variation: 0
Future change in K: no
Harvest: no
Population supplemented: no

3.1. Huso huso – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 15
> (13-15 *Bloesch et al. 2006*; *Reinartz 2002*; 14-26 *Bacalbaşa-Dobrovici 1991*; 16-18 (17) *Ciolac and Patriche 2005*; *Ristić 1963*; 16-22 *Lenhardt et al. 2005*; 16-23 *Vassilev 2006*)

Age of first offspring for males: 11
> (10-13 *Bloesch et al. 2006*; *Reinartz 2002*; 11 years *Ristić 1963*; 11–14 *Ciolac and Patriche 2005*; 12-14 years *Bacalbaşa-Dobrovici 1991*; 12-16 *Lenhardt et al. 2005*; 14-18 years *Vassilev 2006*)

Maximum age of reproduction: 100
> (>50 years *Ristić 1963*; 100 historic *Pikitch et al. 2005*; >100 years *Vassilev 2006*; *Reinartz 2002*; *Bloesch et al. 2006*; 118 years *Lenhardt et al. 2005*)

Maximum number of progeny per year: 360 (900 000 * 0.0004)
> (964 800 *Reinartz 2002*; 3 200 000 (frequently 900 000) *Ciolac and Patriche 2005*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Sex ratio at birth – in % males: 50

Density dependent reproduction: no
Percent adult females breeding: 17%
Environmental variation in % adult females breeding: 1.5 percentage units
> (each 5-7 years *Lenhardt et al. 2005*)

Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 108 (540 000 * 0.0002)
Standard deviation in number of offspring per year: 30
> (506 000 *Ciolac and Patriche 2005*; 574 400 *Reinartz 2002*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Percent males in breeding pool: 20%
> (Each 4-7 years *Lenhardt et al. 2005*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	80.0 ± 10.0	70.0 ± 15.0	50.0 ± 20.0
age 2 to 3	70.0 ± 15.0	50.0 ± 20.0	30.0 ± 12.0
age 3 to 4	50.0 ± 12.5	30.0 ± 7.5	15.0 ± 3.75
age 4 to 5	20.0 ± 5.0	14.0 ± 3.5	9.0 ± 2.25
age 5 to 15	5.6 ± 1.4	5.6 ± 1.4	5.6 ± 1.4
age 15+	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]

age 1 to 2	80.0 ± 10.0	70.0 ± 15.0	50.0 ± 20.0
age 2 to 3	70.0 ± 15.0	50.0 ± 20.0	30.0 ± 12.0
age 3 to 4	50.0 ± 12.5	30.0 ± 7.5	15.0 ± 3.75
age 4 to 5	20.0 ± 5.0	14.0 ± 3.5	9.0 ± 2.25
age 5 to 11	5.6 ± 1.4	5.6 ± 1.4	5.6 ± 1.4
age 11+	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

3.2. Acipenser gueldenstaedtii – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 14
      (12-13 *Vassilev 2006*; 13-15 *Bacalbaşa-Dobrovici 1991*; *Ciolac and Patriche 2005*; 12-16 *Reinartz 2002*; *Bloesch et al. 2006*; *Lenhardt et al. 2005*)
Age of first offspring for males: 12
      (7-8 *Vassilev 2006*; 8-12 *Bacalbaşa-Dobrovici 1991*; *Ciolac and Patriche 2005;* 11-13 *Reinartz 2002*; *Bloesch et al. 2006*; *Lenhardt et al. 2005*)
Maximum age of reproduction: 50
      (46 *Lenhardt et al. 2005*; 48 *Birstein 1993*; 50 *Vassilev 2006*; >50 *Reinartz 2002*; *Pikitch et al. 2005*; *Manea 1966 citt. in Rochard et al. 1991*)
Maximum number of progeny per year: 160 (400 000 * 0.0004)
      (400 000 eggs *Ciolac and Patriche 2005*; 406 800 *Reinartz 2002*; *Bloesch et al. 2006*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001*; *Jager 2005*; *Jager 2006*; *Bajer and Wildhaber 2007*; *Kennedy and Sutton 2007*)
Sex ratio at birth – in % males: 50

Density dependent reproduction: no
Percent adult females breeding: 21%
Environmental variation in % adult females breeding: 2 percentage units
      (about 20% *Reinartz 2002*; each 3-5 years (sex?) *Vassilev 2006*; 4 *Pikitch et al. 2005*; 5-6 *Lenhardt et al. 2005*; *Reinartz 2002*; >6 years *Vlasenko et al. 1989 citt. in Rochard et al. 1991*)
Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 34 (170 000 * 0.0002)
Standard deviation in number of offspring per year: 9
      (125 000-135 000 *Ristić 1963*; 29 500-406 800 (range) *Reinartz 2002*; 140 000 *Ciolac and Patriche 2005*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001*; *Jager 2005*; *Jager 2006*; *Bajer and Wildhaber 2007*; *Kennedy and Sutton 2007*)
Percent males in breeding pool: 25%
      (about 20 % *Reinartz 2002*; each 3-5 years (sex?) *Vassilev 2006*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	70.0 ± 15.0	50.0 ± 20.0	20.0 ± 8.0
age 2 to 3	45.0 ± 18.0	20.0 ± 8.0	9.0 ± 3.6
age 3 to 4	20.0 ± 5.0	11.0 ± 2.75	6.7 ± 1.68
age 4 to 5	10.0 ± 2.5	6.7 ± 1.68	6.7 ± 1.68
age 5 to 14	6.7 ± 1.68	6.7 ± 1.68	6.7 ± 1.68
age 14+	6.7 ± 0.67	6.7 ± 0.67	1.0 ± 0.1

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15

age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	70.0 ± 15.0	50.0 ± 20.0	20.0 ± 8.0
age 2 to 3	45.0 ± 18.0	20.0 ± 8.0	9.0 ± 3.6
age 3 to 4	20.0 ± 5.0	11.0 ± 2.75	6.7 ± 1.68
age 4 to 5	10.0 ± 2.5	6.7 ± 1.68	6.7 ± 1.68
age 5 to 12	6.7 ± 1.68	6.7 ± 1.68	6.7 ± 1.68
age 12+	6.7 ± 0.67	6.7 ± 0.67	1.0 ± 0.1

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

3.3. Acipenser stellatus – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 10
> (7 *Bacalbaşa-Dobrovici 1991*; 7-10 *Reinartz 2002*; *Bloesch et al. 2006*; 8–10 *Ciolac and Patriche 2005*; 8-12 years *Vassilev 2006*; average 10 *Lenhardt et al. 2005*; *Pikitch et al. 2005*; *Ristić 1963*)

Age of first offspring for males: 6
> (5 *Bacalbaşa-Dobrovici 1991*; 4-7 *Lenhardt et al. 2005*; *Ciolac and Patriche 2005*; 5-6 *Reinartz 2002*; *Bloesch et al. 2006*; 5-8 *Vassilev 2006*; 6 *Ristić 1963*)

Maximum age of reproduction: 35
> (27 *Lenhardt et al. 2005*; *Birstein 1993*; 35 *Reinartz 2002*; *Bloesch et al.* 2006; historic 41 *Pikitch et al. 2005*)

Maximum number of progeny per year: 160 (400 000 * 0.0004)
> (180 000 *Ciolac and Patriche 2005*; 430 000 *Reinartz 2002*; *Bloesch et al. 2006*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Sex ratio at birth – in % males: 50
> (*Ciolac and Patriche 2005*)

Density dependent reproduction: no
Percent adult females breeding: 25%
Environmental variation in % adult females breeding: 2.5 percentage units
> (not less than 3-4 year *Lenhardt et al. 2005*; Sea of Azov *Reinartz 2002*; 3 times in life Ural River *Lagutov and Lagutov 2008*; Sea of Azov *Reinartz 2002*)

Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 30 (150 000 * 0.0002)
Standard deviation in number of offspring per year: 9
> (80 000-180 000, 150 000 *Reinartz 2002*; 145 000-160 000 *Ristić 1963*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Percent males in breeding pool: 29%
> (not less than 3-4 year *Lenhardt et al. 2005*; Sea of Azov *Reinartz 2002*; 3 times in life Ural River *Lagutov and Lagutov 2008*; Sea of Azov *Reinartz 2002*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	60.0 ± 20.0	45.0 ± 18.0	27.0 ± 10.8
age 2 to 3	40.0 ± 16.0	25.0 ± 10.0	20.0 ± 8.0
age 3 to 4	25.0 ± 6.25	14.0 ± 3.5	13.0 ± 3.25
age 4 to 5	15.0 ± 3.75	13.0 ± 3.25	13.0 ± 3.25
age 5 to 10	13.0 ± 3.25	13.0 ± 3.25	13.0 ± 3.25
age 10+	13.0 ± 1.3	13.0 ± 1.3	5.0 ± 0.5

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	60.0 ± 20.0	45.0 ± 18.0	27.0 ± 10.8
age 2 to 3	40.0 ± 16.0	25.0 ± 10.0	20.0 ± 8.0
age 3 to 4	25.0 ± 6.25	14.0 ± 3.5	13.0 ± 3.25
age 4 to 5	15.0 ± 3.75	13.0 ± 3.25	13.0 ± 3.25
age 5 to 6	13.0 ± 3.25	13.0 ± 3.25	13.0 ± 3.25
age 6+	13.0 ± 1.3	13.0 ± 1.3	5.0 ± 0.5

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

3.4. Acipenser ruthenus – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 5
> (*Bacalbaşa-Dobrovici 1991*; 4-7 *Reinartz 2002*; *Bloesch et al. 2006*; *Lenhardt et al. 2005*; 7 *Vassilev 2006*)
Age of first offspring for males: 4
> (3-4 *Bacalbaşa-Dobrovici 1991*; 3-5 *Reinartz 2002*; *Bloesch et al. 2006*; *Lenhardt et al. 2005*; 3-7 *Manea 1966 citt. in Rochard et al. 1991*; 4 *Vassilev 2006*)
Maximum age of reproduction: 26
> (24 *Reinartz 2002*; *Bloesch et al. 2006*; 25 *Vassilev 2006*; *Simonović 2001*; *Kolarević 2004*; 26 *Lenhardt et al. 2005*; 26 (archaeological remains) *Reinartz 2002*)
Maximum number of progeny per year: 43 (108 000 * 0.0004)
> (108 000 *Reinartz 2002*; *Kolarević 2004*; *Bloesch et al. 2006*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)
Sex ratio at birth – in % males: 50
> (*Reinartz 2002*)

Density dependent reproduction: no
Percent adult females breeding: 70% (33.33-100%)
Environmental variation in % adult females breeding: 15 percentage units
> (every year *Manea 1966 citt. in Rochard et al. 1991*; 1-2 *Jankovic 1958 citt. in Rochard et al. 1991*; *Bacalbaşa-Dobrovici 1991*; *Reinartz 2002*; 1-3 *Vassilev 2006*)
Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 12 (58 000 * 0.0002)
Standard deviation in number of offspring per year: 5
> (7 000–108 000 *Reinartz 2002*; *Kolarević 2004*; *Bloesch et al. 2006*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)
Percent males in breeding pool: 75%
> (every year in Danube *Reinartz 2002*; *Manea 1966 citt. in Rochard et al. 1991*; 1-2 (sex?) *Bacalbaşa-Dobrovici 1991*; 1-3 (sex?) *Vassilev 2006*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	62.0 ± 19.0	50.0 ± 20.0	40.0 ± 16.0
age 2 to 3	39.0 ± 15.6	35.6 ± 14.24	31.7 ± 12.68
age 3 to 4	32.5 ± 8.13	31.7 ± 7.93	31.7 ± 7.93

age 4 to 5	31.7 ± 7.93	31.7 ± 7.93	31.7 ± 7.93
age 5+	31.7 ± 3.17	31.7 ± 3.17	28.0 ± 2.8

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	62.0 ± 19.0	50.0 ± 20.0	40.0 ± 16.0
age 2 to 3	39.0 ± 15.6	35.6 ± 14.24	31.7 ± 12.68
age 3 to 4	32.5 ± 8.13	31.7 ± 7.93	31.7 ± 7.93
age 4+	31.7 ± 3.17	31.7 ± 3.17	28.0 ± 2.8

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

3.5. Acipenser nudiventris – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 13
> (12-14 *Rochard et al. 1991*; in Kura River *Reinartz 2002*; in Kura River *Bloesch et al. 2006*; *Lenhardt et al. 2005*; Average 17 *Pikitch et al. 2005*)

Age of first offspring for males: 8
> (6-9 *Rochard et al. 1991*; in Kura River *Reinartz 2002*; in Kura River *Bloesch et al. 2006*; *Lenhardt et al. 2005*)

Maximum age of reproduction: 36
> (36 years *Vassilev 2006*; in Ural River and Aral Sea *Reinartz 2002*; in Ural River *Bloesch et al. 2006*; *Lenhardt et al. 2005*)

Maximum number of progeny per year: 520 (1 300 000 * 0.0004)
> (1 300 000 *Reinartz 2002*; *Bloesch et al. 2006*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Sex ratio at birth – in % males: 50

Density dependent reproduction: no
Percent adult females breeding: 42%
Environmental variation in % adult females breeding: 4 percentage units
> (2-3 *Lenhardt et al. 2005*; *Reinartz 2002*; averagely every 3 years (global data) *Pikitch et al. 2005*)

Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 150 (40-260) (750 000 * 0.0002)
Standard deviation in number of offspring per year: 50
> (200 000–1 300 000 *Reinartz 2002*; *Bloesch et al. 2006*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Percent males in breeding pool: 50%
> ((2) *Reinartz 2002*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	86.0 ± 7.0	80.0 ± 10.0	70.0 ± 15.0
age 2 to 3	70.0 ± 15.0	60.0 ± 20.0	50.0 ± 20.0
age 3 to 4	50.0 ± 12.5	40.0 ± 10.0	35.0 ± 8.75
age 4 to 5	26.0 ± 6.5	20.0 ± 5.0	18.0 ± 4.5
age 5 to 13	8.0 ± 2.0	8.0 ± 2.0	8.0 ± 2.0
age 13+	8.0 ± 0.8	8.0 ± 0.8	5.0 ± 0.5

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	86.0 ± 7.0	80.0 ± 10.0	70.0 ± 15.0
age 2 to 3	70.0 ± 15.0	60.0 ± 20.0	50.0 ± 20.0
age 3 to 4	50.0 ± 12.5	40.0 ± 10.0	35.0 ± 8.75
age 4 to 5	26.0 ± 6.5	20.0 ± 5.0	18.0 ± 4.5
age 5 to 8	8.0 ± 2.0	8.0 ± 2.0	8.0 ± 2.0
age 8+	8.0 ± 0.8	8.0 ± 0.8	5.0 ± 0.5

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

3.6. Acipenser sturio – basic scenario input parameters

Reproductive system: polygynous
Age of first offspring for females: 14
> (8-12 in Po River *Holcik et al. 1989 citt. in Gessner et al. 2007*; 8-14 in Rioni River *Elanidze et al. 1970 citt. in Rochard et al. 1991*; in Rioni River *Ninua 1976 citt. in Gessner et al. 2007*; In Rioni River *Reinartz 2002*; In Rioni River *Bloesch et al. 2006*; 8-20 *Birstein 1993*; 14 In Rhine River *De Groot 2002*; 14-15 in Guadalquivir River *Classen 1944 citt. in Gessner et al. 2007*; 15 Gironde *Williot et al. 1997*; 16-18 in Gironde *Magnin 1962 citt. in Rochard et al. 1991*; 16-20 in Gironde *Magnin 1963 citt. in Gessner et al. 2007*; southern populations mature 2-6 years earlier than in Gironde River *Holcik et al. 1989 citt. in Gessner et al. 2007*)

Age of first offspring for males: 12
> (7-9 in Rioni River *Ninua 1976 citt. in Gessner et al. 2007*; in Rioni River *Reinartz 2002*; in Rioni River *Bloesch et al. 2006*; 7-10 in Po River *Holcik et al. 1989 citt. in Gessner et al. 2007*; 7-12 in Rioni *Elanidze et al. 1970 citt. in Rochard et al. 1991*; 7-15 *Birstein 1993*; 8 in Rhine River *De Groot 2002* ; 10 Gironde *Williot et al. 1997*; 10-11 in Guadalquivir River *Classen 1944 citt. in Gessner et al. 2007*; 13-15 in Gironde *Magnin 1963 citt. in Gessner et al. 2007*; 14-18 in Gironde *Magnin 1962 citt. in Rochard et al. 1991*)

Maximum age of reproduction: 48
> (48 *Reinartz 2002*; in Gironde *Holcik et al. 1989 citt. in Gessner et al. 2007*; *Bloesch et al. 2006*; 100 in Gironde Estuary *Holcik et al. 1989 citt. in Gessner et al. 2007*; in 8th and 9th century 35-36, in Gironde 42 *Reinartz 2002*; life span of males is 12, that of females 20 *Bacalbaşa-Dobrovici and Holčik 2000*)

Maximum number of progeny per year: 560 (1 400 000 * 0.0004)
> (1 412 000 *Holcik et al. 1989 citt. in Gessner et al. 2007*; 1 820 000 in Rioni River *Reinartz 2002*; in Rioni River *Bloesch et al. 2006*; 0.0004 is the maximum natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Sex ratio at birth – in % males: 50

Density dependent reproduction: no
Percent adult females breeding: 33.3%
> (Every 3 years *Williot pers. comm.*)

Environmental variation in % adult females breeding: 4 percentage units
Distribution of offspring per female per year: normal distribution approximation
Mean number of offspring per year: 170 (851 000 * 0.0002)
Standard deviation in number of offspring per year: 50
> (851 000 *Holcik et al. 1989 citt. in Gessner et al. 2007*; 0.0002 is the average natural survival of age 0 to 1 *Pine et al. 2001; Jager 2005; Jager 2006; Bajer and Wildhaber 2007; Kennedy and Sutton 2007*)

Percent males in breeding pool: 50%
> (Every 2 years *Williot pers. comm.*)

Natural mortality fitted to the three different values of intrinsic population growth rate:

Natural mortality of females (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	86.0 ± 7.0	80.0 ± 10.0	74.0 ± 13.0
age 2 to 3	70.0 ± 15.0	60.0 ± 20.0	51.0 ± 20.4
age 3 to 4	50.0 ± 12.5	38.0 ± 9.5	30.0 ± 7.5
age 4 to 5	28.0 ± 7.0	16.0 ± 4.0	10.0 ± 2.5
age 5 to 14	6.7 ± 1.68	6.7 ± 1.68	6.7 ± 1.68
age 14+	6.7 ± 0.67	6.7 ± 0.67	1.0 ± 0.1

Natural mortality of males (age specific mortality as % ± SD due to environmental variation):

	r=0.05	r=0.10	r=0.15
age 0 to 1	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
age 1 to 2	86.0 ± 7.0	80.0 ± 10.0	74.0 ± 13.0
age 2 to 3	70.0 ± 15.0	60.0 ± 20.0	51.0 ± 20.4
age 3 to 4	50.0 ± 12.5	38.0 ± 9.5	30.0 ± 7.5
age 4 to 5	28.0 ± 7.0	16.0 ± 4.0	10.0 ± 2.5
age 5 to 12	6.7 ± 1.68	6.7 ± 1.68	6.7 ± 1.68
age 12+	6.7 ± 0.67	6.7 ± 0.67	1.0 ± 0.1

[a] Age 0 to 1 natural mortality is incorporated in the mean and maximum number of offspring; see chapter 1 for clarification.

4. Input values used in the sensitivity analysis scenarios in Vortex

This appendix contains values for different parameters that were applied in the sensitivity analysis. They are represented by either a range of values (value placed in bold was the starting value, that was used in basic scenarios), or by a percentage by which the original value was decreased or increased. All simulations that were part of the sensitivity analysis were run for 100 years and at the carrying capacity set at 2 000. Initial population size was basically set to N=50, but the effect of a change in this parameter was also tested in the sensitivity analysis (see values provided in the table).

Parameter	*Huso huso*	*Acipenser gueldenst.*	*Acipenser stellatus*	*Acipenser ruthenus*	*Acipenser nudiventris*	*Acipenser sturio*
Age of first offspring (♀)	13 / **15** / 18	12 / **14** / 16	7 / **10** / 12	4 / **5** / 7	10 / **13** / 17	8 / **14** / 20
Age of first offspring (♂)	10 / **11** / 16	7 / **12** / 13	4 / **6** / 8	3 / **4** / 5	6 / **8** / 10	7 / **12** / 18
Max. age of reproduction	60 / 80 / **100**	40 / **50** / 60	30 / **35** / 40	16 / **26** / 30	30 / **36** / 42	30 / **48** / 100
Max. No. of progeny / year[a]	180 / **360** / 540	80 / **160** / 240	80 / **160** / 240	22 / **43** / 65	260 / **520** / 780	280 / **560** / 840
Sex ratio (in percent of ♂)	25 / **50** / 75	25 / **50** / 75	25 / **50** / 75	25 / **50** / 75	25 / **50** / 75	25 / **50** / 75
Percent of ♀ breeding / year	14.29 / **17** / 20	16.6 / **21** / 25	20 / **25** / 33.3	33.3 / **70** / 100	33.3 / **42** / 50	25 / **33.3** / 50
Environmental variation in percent of ♀ breeding	0.5 / **1.5** / 2.5	1 / **2** / 3	1.5 / **2.5** / 3.5	7.5 / **15** / 22.5	2 / **4** / 6	2 / **4** / 6
Mean No. of progeny / year[a]	54 / **108** / 162	17 / **34** / 51	15 / **30** / 45	6 / **12** / 18	75 / **150** / 225	85 / **170** / 255
Environmental variation in mean No.	15 / **30** / 45	4.5 / **9** / 13.5	4.5 / **9** / 13.5	2.5 / **5** / 7.5	25 / **50** / 75	25 / **50** / 75

of progeny

Percent of ♂ breeding / year	14.29 / **20** / 25	20 / **25** / 33.3	25 / **29** / 33.3	50 / **75** / 100	33.3 / **50** / 70	33.3 / **50** / 70
Adult mortality (r=0.05)	0.5 / **1** / 1.5	3.35 / **6.7** / 10.05	6.5 / **13** / 19.5	15.85 / **31.7** / 47.55	4 / **8** / 12	3.35 / **6.7** / 10.05
Adult mortality (r=0.10)	0.5 / **1** / 1.5	3.35 / **6.7** / 10.05	6.5 / **13** / 19.5	15.85 / **31.7** / 47.55	4 / **8** / 12	3.35 / **6.7** / 10.05
Adult mortality (r=0.15)	0.5 / **1** / 1.5	0.5 / **1** / 1.5	2.5 / **5** / 7.5	14 / **28** / 42	2.5 / **5** / 7.5	0.5 / **1** / 1.5
Age 1-2, 2-3 and 3-4 mortality	± 10%[b]	± 10%	± 10%	± 10%	± 10%	± 10%
Mortality of age groups 4 to adult	± 10%	± 10%	± 10%	± 10%	± 10%	± 10%
Environmental variation in mortality for all age groups	± 50%	± 50%	± 50%	± 50%	± 50%	± 50%
Environmental variation in carrying capacity	**0** / 400 / 800	**0** / 400 / 800	**0** / 400 / 800	**0** / 400 / 800	**0** / 400 / 800	**0** / 400 / 800
Initial population size	40 / **50** / 60	40 / **50** / 60	40 / **50** / 60	40 / **50** / 60	40 / **50** / 60	40 / **50** / 60

[a] Through the mean and maximum number of progeny / year input variables, sensitivity analysis of both the age 0 to 1 natural mortality and the mean and maximum fecundity were performed, since the values for these two input variables were derived through combination of both life history parameters (for the explanation how the age 0 to 1 natural mortality was incorporated in the model, see the chapter 1).

[b] I.e. if the basic value was 20, ± 10% would mean variation from 18 to 22.

5. Results of the sensitivity analysis scenarios in Vortex

5.1. Assessment of the results of sensitivity analysis by the use of ranking technique

Following four tables include results of the ranking preformed on the outcome of the sensitivity analysis in Vortex simulation model. They present the influence of each life history parameters through the total rank value (where higher value signifies higher influence) for each of five resulting parameters – pseudo-extinction probability, heterozygosity level; deterministic population growth rate, stochastic population growth rate and the population recovery time. Parameters are sorted in each table according to the values in the column with the total ranking value, from the highest to the lowest one.

Legend: fem age – time needed for females to reach maturity; 1-4 mort – natural mortality of year 1-4 age groups; N – initial population size; fem breed – female spawning frequency; ad mort – natural mortality of adult individuals; mean offs – mean number of offspring (also represents egg to age 1 natural mortality); mort EV – environmental variation in natural mortality of all age groups; K EV – environmental variation in carrying capacity; max age – maximum reproductive age; male age – time needed for males to reach maturity; fem breed EV – environmental variation in female spawning frequency; mean offs EV – environmental variation in mean number of offspring; 4-ad mort – natural mortality of year 4 to adulthood age groups; male breed – male spawning frequency; max offs – maximum fecundity.

5.1.1. Pseudo-extinction probability

Extinction probability	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
fem age	121	157	165.5	148.5	173	111.5	876.5
1-4 mort	108	166.5	130.5	115	161.5	121.5	803
N	126.5	152.5	117	130.5	131.5	127.5	785.5
fem breed	107	124.5	164	137	137	103	772.5
ad mort	129.5	112.5	158	130.5	94.5	103.5	728.5
mean offs	105.5	125.5	153.5	126	104	98	712.5
mort EV	105	125.5	137.5	103.5	110.5	109.5	691.5

	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
K EV	112.5	94.5	63.5	96	117	80.5	564
sex ratio	104.5	76	134	106.5	47	91	559
max age	78.5	110	41.5	69.5	101.5	102	503
male age	74.5	65	50	60	124.5	86.5	460.5
fem breed EV	79	49.5	98	62	68.5	97	454
mean offs EV	86	65	67	79	52	73.5	422.5
4-ad mort	102.5	67	9	88	58.5	92	417
male breed	66.5	35	58	76	53.5	99	388
max offs	77.5	58	37	56	49.5	88	366

5.1.2. Heterozygosity level

Heterozygosity level	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
N	169	142	118.5	146	136	175	886.5
mean offs	143	139.5	154	140.5	133.5	174	884.5
fem age	127	150	169	167	151	96	860
ad mort	138	144	165	161	122	113	843
sex ratio	112	123	131	112	129	145	752
1-4 mort	85	167	137.5	93.5	146	118	747
mort EV	91.5	143	121	88	120	144.5	708
fem breed	114	79	167	115	110	59.5	644.5
K EV	112	91.5	44	120	143	86.5	597
male age	92	43.5	77	83.5	104.5	90	490.5
4-ad mort	88.5	86.5	9	103.5	82	67.5	437
max age	76.5	85.5	42	72	66.5	77.5	420
mean offs EV	68	54.5	73.5	57	58	68	379
male breed	61	46	67	59.5	24.5	65.5	323.5
fem breed EV	46.5	53	62.5	25	29	59	275
max offs	60	36	46	40.5	29	45	256.5

5.1.3. Deterministic population growth rate

Character	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
fem age	159.5	177	176.5	180	184	163	1 040
mean offs	182	166.5	168	175	162.5	177	1 031
sex ratio	182	166.5	168	175	162.5	177	1 031
1-4 mort	140	174	129	127.5	171	163.5	905
fem breed	144	135	166.5	144.5	144.5	144.5	879
ad mort	138	135	146	148	123.5	119	809.5
4-ad mort	125	117	9	121	119	127	618
max age	73.5	89	81	81	93	73	490.5
N	55	53	61	54	53	55	331
mort EV	55	53	61	54	53	55	331
K EV	55	53	61	54	53	55	331
male age	55	53	61	54	53	55	331
fem breed EV	55	53	61	54	53	55	331
mean offs EV	55	53	61	54	53	55	331
male breed	55	53	61	54	53	55	331
max offs	55	53	61	54	53	55	331

5.1.4. Stochastic population growth rate

Character	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
fem age	161.5	181.5	180	180.5	186	165.5	1 055
mean offs	185	169	168	177.5	163	180	1 042.5
sex ratio	176	158	156.5	169	147.5	169.5	976.5
fem breed	144.5	141	168	145	154	143.5	896
1-4 mort	142	159	129	128.5	170	163.5	892
ad mort	134	140.5	152.5	151.5	117	109	804.5
4-ad mort	124.5	109.5	9	118.5	104.5	119	585
mort EV	74	84.5	117	86.5	86	92.5	540.5
N	57	77.5	71.5	60	66.5	89.5	422
max age	57.5	77.5	47	71.5	55	72	380.5
K EV	57	61.5	67	59.5	70.5	47.5	363
fem breed EV	57.5	49	104	49.5	46.5	48.5	355
male breed	66.5	32.5	71.5	59.5	37.5	50	317.5
male age	41.5	49.5	41	42	95.5	42.5	312
max offs	57.5	51	48	43	40.5	44	284
mean offs EV	48	42.5	54	42	44	47.5	278

5.1.5. Population recovery time

Character	Russian sturgeon	Ship sturgeon	Sterlet	Stellate sturgeon	Atlantic sturgeon	Beluga	Total
fem age	164.5	172	169.5	179	183	168	1 036
mean offs	181.5	168.5	162	172	160.5	181	1 025.5
sex ratio	155.5	145.5	153.5	155	136.5	156	902
fem breed	146.5	140.5	162.5	147.5	152	145	894
1-4 mort	129.5	165	141	128	156	149	868.5
ad mort	117	123	156.5	140	102.5	85	724
N	118.5	87.5	84	113.5	69.5	131.5	604.5
K EV	91	105.5	68.5	91.5	134.5	67.5	558.5
4-ad mort	93	83	9	111	75.5	82.5	454
mort EV	61.5	73.5	112.5	72	56.5	76.5	452.5
max age	55	70.5	51	51	70	70.5	368
fem breed EV	56.5	46	87	46	52	55	342.5
mean offs EV	64	53.5	61	51	45	65.5	340
male age	40	38.5	59	45.5	97.5	48	328.5
male breed	55	69.5	55.5	40.5	45	55	320.5
max offs	55	42	51.5	40.5	48	48	285

5.2. Assessment of the results of sensitivity analysis by the use of regression analysis

Following two tables include results of the regression analysis preformed on the outcome of the sensitivity analysis in Vortex simulation model. They present the most influential life history parameters, for each resulting parameter (left column) and each simulated population growth rate (r=0.05, 0.10 and 0.15). Only up to four most important parameters were included per each simulated population growth rate, and only those regressions with statistical significance ($p<0.05$). The most influential parameters are bolded, and each two life history parameters that produced the same effect on the resulting parameters are placed in italics (e.g. as it was often the case for the mean number of offspring and the sex ratio).

	Beluga	Russian sturgeon	Stellate sturgeon	Sterlet	Ship sturgeon	Atlantic sturgeon
P — 0.05	**N** 1-4 mort EV fem age	**mean offs** sex ratio	**mean offs** sex ratio adult mort	**fem breed** fem age adult mort mean offs	**1-4** max age fem age	**1-4** fem age fem breed mean offs
P — 0.10	**N**	**K EV**	**K EV**	**fem age** fem breed mean offs sex ratio	**fem age** 1-4 N K EV	**fem age** 1-4 K EV male age
P — 0.15	**K EV**	**K EV**	**K EV**	**fem age** fem breed	**fem age** N mort EV 1-4	**K EV** fem age male age
r det — 0.05	**1-4** *mean offs* *sex ratio* fem age	*sex ratio* *mean offs* 1-4 adult mort	**fem age** *mean offs* *sex ratio* adult mort	**fem age** fem breed mean offs *sex ratio*	**1-4** *mean offs* *sex ratio* fem age	**1-4** fem age *mean offs* *sex ratio*
r det — 0.10	***mean offs*** ***sex ratio*** 1-4 fem age	***sex ratio*** ***mean offs*** fem age fem breed	**fem age** *mean offs* *sex ratio* adult mort	**fem age** fem breed *mean offs* *sex ratio*	**1-4** fem age *mean offs* *sex ratio*	**fem age** 1-4 *mean offs* *sex ratio*
r det — 0.15	***mean offs*** ***sex ratio*** fem age fem breed	***sex ratio*** ***mean offs*** fem age fem breed	**fem age** *mean offs* *sex ratio* fem breed	**fem age** fem breed *mean offs* *sex ratio*	**fem age** *mean offs* *sex ratio* 1-4	**fem age** *mean offs* *sex ratio* 1-4
r stoch — 0.05	**1-4** mean offs sex ratio fem age	**mean offs** sex ratio 1-4 fem age	**mean offs** fem age sex ratio adult mort	**fem age** fem breed mean offs adult mort	**fem age** mean offs adult mort 1-4	**1-4** fem age mean offs fem breed
r stoch — 0.10	**mean offs** sex ratio fem age 1-4	**mean offs** sex ratio fem age adult mort	**fem age** mean offs sex ratio adult mort	**fem age** fem breed mean offs sex ratio	**fem age** 1-4 mean offs sex ratio	**fem age** 1-4 mean offs sex ratio
r stoch — 0.15	**mean offs** fem age sex ratio fem breed	**mean offs** *sex ratio fem age* fem breed	**fem age** mean offs sex ratio fem breed	**fem age** fem breed mean offs sex ratio	**fem age** mean offs sex ratio 1-4	**fem age** mean offs sex ratio 1-4

	Huhu	Acgu	Acsl	Acru	Acnu	Acst
H	0.05: **1-4** N	0.05: **mean offs** adult mort 1-4 sex ratio	0.05: **mean offs** adult mort sex ratio fem age	0.05: **fem breed** mean offs fem age sex ratio	0.05: **1-4** adult mort fem age sex ratio	0.05: **1-4** adult mort mean offs fem age
	0.10: **mean offs** N mort EV sex ratio	0.10: **K EV** N adult mort	0.10: **adult mort** fem age mean offs K EV	0.10: **fem age** fem breed mean offs sex ratio	0.10: **1-4** K EV fem age adult mort	0.10: **K EV** 1-4 N adult mort
	0.15: **K EV** mean offs N	0.15: **K EV** mean offs N	0.15: **K EV** N fem age mean offs	0.15: **fem age** fem breed mean offs	0.15: **mean offs** N mort EV fem age	0.15: **K EV** mean offs fem age
RT	0.05: **1-4** mean offs sex ratio fem age	0.05: **mean offs** sex ratio 1-4 adult mort	0.05: **fem age** mean offs adult mort sex ratio	0.05: **adult mort** mean offs fem breed sex ratio	0.05: **1-4** fem age mean offs sex ratio	0.05: **fem age** 1-4 mean offs fem breed
	0.10: **mean offs** fem age 1-4 sex ratio	0.10: **K EV** mean offs	0.10: **K EV** mean offs fem age	0.10: **fem age** fem breed mean offs sex ratio	0.10: **K EV** fem age mean offs 1-4	0.10: **K EV** fem age mean offs 1-4
	0.15: **mean offs** fem age K EV	0.15: **mean offs** fem age fem breed	0.15: **fem age** mean offs sex ratio fem breed	0.15: **fem age** fem breed mean offs sex ratio	0.15: **fem age** mean offs 1-4 sex ratio	0.15: **fem age** mean offs K EV fem breed

P – pseudo-extinction probability; *r* det – deterministic population growth rate; *r* stoch – stochastic population growth rate; *H* – heterozygosity level; *RT* – population recovery time; N – initial population size; 1-4 – natural mortality for year 1-4 age group; mort EV – environmental variation in natural mortality of all age groups; fem age – time needed for females to reach maturity; mean offs – mean number of offspring (also represents egg to age 1 natural mortality); adult mort – natural mortality of adult individuals; fem breed – spawning frequency of females; K EV – environmental variation in carrying capacity; male age - time needed for males to reach maturity.

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