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POPULATION VIABILITY ANALYSIS AND POTENTIAL OF ITS APPLICATION TO DANUBE STURGEONS

I. JARIĆ[1], MIRJANA LENHARDT[2], G. CVIJANOVIĆ[1], and T. EBENHARD[3]

[1]*Institute for Multidisciplinary Research,* 11000 Belgrade, Serbia
[2]*Siniša Stanković Institute for Biological Research,* 11060 Belgrade, Serbia
[3]*Swedish Biodiversity Center (CBM), Box 7007,* S-750 07 Uppsala, Sweden

Abstract — Sturgeon species in the Danube River basin have experienced severe decline. Besides overexploitation, habitat loss, and pollution, they are further endangered by lack of efficient policy and management, as well as by serious lack of knowledge about their life history. Although population viability analysis (PVA) could represent an extremely valuable tool to cope with these problems, it has not so far been applied to Danube populations. This paper represents an assessment of different PVA methods and models developed for sturgeon species. It analyzes their results, main advantages, drawbacks, and problems, and discusses the possibility of applying PVA to sturgeon populations in the Danube River basin.

Key words: PVA, extinction risk, life history, *Acipenser, Huso*

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INTRODUCTION

The majority of fisheries worldwide are today either fully exploited, overharvested, or completely depleted (Botsford et al., 1997). As species of great economic interest, sturgeons (family Acipenseridae) have experienced the same fate, with only a very small number of populations still abundant enough to be the object of commercial fisheries (Birstein et al., 1997; McDowall, 1999). Besides overexploitation, their worldwide decline is further promoted by river fragmentation, habitat degradation, and pollution (Birstein et al., 1997; Pikitch et al., 2005).

The Danube River basin and the Black Sea, originally inhabited by six sturgeon species, are considered to be the key habitat of European sturgeons (Williot et al., 2002; Lenhardt et al., 2006a). However, due to a whole range of anthropogenic impacts, Atlantic sturgeon (*Acipenser sturio*) and ship sturgeon (*Acipenser nudiventris*) have nowadays almost disappeared from the region, while populations of beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*), stellate sturgeon (*Acipenser stellatus*), and sterlet (*Acipenser ruthenus*) are experiencing severe decline (Williot et al., 2002; Reinartz, 2002; Lenhardt et al., 2006b). All impacts are further exacerbated by the present lack of knowledge on basic demography, life history, and the effects of different negative influences, as well as by the lack of efficient policy, management measures, and their implementation (Williot et al., 2002; Pikitch et al., 2005). The main problem is that managers most often do not have enough time to wait for better knowledge, and management decisions must be based on available information, even when it is limited, which is often the case for endangered species (Grogan and Boreman, 1996). Some important factors will never be completely predictable, and many managers are disinclined to make choices in view of such uncertainties (Ludwig, 1999).

Population viability analysis (PVA) represents a method that is able to cope with uncertainties present in ecological data, and it is an indispensable tool in conservation biology (Boyce, 1992; Akçakaya and Sjögren-Gulve, 2000). The given method is widely used to predict extinction risks for threatened species and to compare alternative options for their management (Brook et al., 2000). So far, this method has not been applied to sturgeons that inhabit the Danube River basin.

This paper represents a review of different PVA methods and models, with emphasis on those developed for sturgeon species. It analyzes their results, main advantages, drawbacks, and problems, and discusses the possibility of applying PVA to sturgeon populations in the Danube River basin.

OVERVIEW OF PVA METHODS

There is a lack of consensus on the definition of PVA, and it has been used to designate methods that range from qualitative and verbal processes to mathematically sophisticated simulation models (Reed et al., 2002). However, all methods have in common the fact that they represent some form of examination of the interacting factors that place a population or species at risk (Shaffer, 1990). The outcome of a PVA model can be an estimation of the risk of extinction or decline, quasi-extinction probability, expected time to extinction, chance of recovery, future population size, various impacts of human activities, or efficacy of different management scenarios (Boyce, 1992; Ludwig, 1999; Akçakaya and Sjögren-Gulve, 2000; Reed et al., 2002; Reed et al., 2003).

The simplest PVAs are deterministic models (Boyce, 1992). Dulvy et al. (2004) labelled this group as time-series approaches, and they can be, for instance, models that use deterministic population growth rates to make population projections (Dulvy et al., 2004) or models using sighting frequency, which can be useful when the only available information is in the form of sighting records (Solow, 1993). However, these models do not consider the stochasticity of the system and thus can create significant bias, proportional to the degree of intrinsic variance in the system (Boyce, 1992; Burgman et al., 1988). They can therefore be useful only for heuristic purposes or as a preliminary tool, for example in rapid assessments of a large number of populations (Boyce, 1992; Dulvy et al., 2004).

Spatial models, such as different occupancy models, are used for PVA of metapopulations and, besides the spatial dimension, they can include parameters like dispersal between subpopulations and habitat suitability (Sjögren-Gulve and Hanski, 2000).

Demographically structured models group individuals into distinct classes, either according to their age (age-structured models) or certain stages (stage-structured models), e.g., according to size, weight, or developmental state (Akçakaya, 2000). They are often employed and can be very useful for analysis of larger populations or populations with simple dynamics or social organization (Akçakaya, 2000).

Individual-based models (IBMs) represent simulations where each individual, behavior of that individual and its fate are separately modeled (Akçakaya and Sjögren-Gulve, 2000). They are often performed through computer programming (Lacy, 1993), and as simulations became more feasible, use of IBMs became much more frequent (Chambers, 1993). Such models have the flexibility to represent individual differences in age, size, spatial location, and other relevant attributes (Uchmański, 1999; Jager et al., 2000) and provide a basis for merging genetics with demography (Chambers, 1993). They are the only PVA methods that can successfully model genetic changes in a population or effects of inbreeding depression (Jager, 2001, 2005).

Stochastic processes that are relevant to population viability can be categorized into demographic, environmental, and genetic stochasticity, and catastrophic events (Lacy, 1993). Individual-based models, demographically structured ones, and spatial models often do have stochasticity included within the model, but not necessarily. Development of models that consider stochasticity of the system is considered crucial in order to increase reliability of the PVA (Boyce, 1992).

Program packages for PVA have become very popular in the field of conservation biology, and some programs like the RAMAS series and VORTEX are being widely used (Lacy, 1993; Akçakaya and Raphael, 1998; Brook et al., 2000); for example, VORTEX is now routinely used by the World

Conservation Union (IUCN) to establish quantitative classification of endangered species (Brook et al., 1997). Brook et al. (2000) found a surprising accuracy of most commonly used program packages with very high concordance in their results. It is considered that the main potential of PVA program packages is the ability to compare the efficacy of different management scenarios (Ebenhard, 2000; Reed et al., 2002).

STURGEON PVA

So far, PVAs conducted on sturgeons were mostly aimed at assessing the impact of different harvest levels on population viability or the influence of fishing regulations, such as length or slot limits (Beamesderfer et al., 1995; Quist et al., 2002; Bajer and Wildhaber, 2007; Colombo et al., 2007; Heppell, 2007; Kennedy and Sutton, 2007). Certain studies assessed the mitigative value of hatchery supplementation (Jager, 2005) and the value of habitat improvements that target specific life stages (Bajer and Wildhaber, 2007). Some studies dealt with the problem of fragmented river habitats and assessed the impact of habitat size or loss (Jager et al., 2001) and different levels of dispersal among fragments (Jager, 2006a, 2006b). All PVAs have so far been conducted on North American sturgeons, mostly on *Scaphirhynchus platorhynchus*, *Scaphirhynchus albus*, *Acipenser oxyrhynchus*, *Acipenser transmontanus*, and *Acipenser medirostris*.

Most sturgeon PVAs have been based on age-structured models (Beamesderfer et al., 1995; Pine et al., 2001; Bajer and Wildhaber, 2007; Heppell, 2007; Kennedy and Sutton, 2007). Only Henriëtte I. Jager and her coauthors have applied individual-based models in sturgeon PVAs (Jager, 2001, 2005, 2006a, 2006b; Jager et al., 2000, 2001).

Some authors used simpler approaches in their PVAs. Beamesderfer et al. (2007) used a life table model, which designates age-specific demographic parameters such as weight, sex ratio, maturity, and natural and fishing mortality, and uses them to project outcomes in terms of population size, biomass, optimum harvest, etc. While it requires certain assumptions, such as population equilibrium, stable size, age structure, and lack of density dependence, which are seldom met in natural conditions, this method can be the very appropriate for evaluating population sensitivity to changes in demographic rates (Beamesderfer et al., 2007).

Model parameterization

Many age-structured models were solely restricted to females (Bajer and Wildhaber, 2007; Kennedy and Sutton, 2007), which assumes equal numbers of males and females in the population, the same age-specific survival rates for both sexes, and that male abundance is sufficient to fertilize eggs (Bajer and Wildhaber, 2007). Models with both sexes included usually set the sex ratio in the population as equal (Pine et al., 2001).

According to Jager (2001), sturgeons are known to experience fluctuations in year class strength, and are unlikely to ever reach a truly stable age distribution (Heppell, 2007). Beamesferder et al. (2007) found that the majority of individuals in a population at stable age distribution consisted of subadults, representing as much as 63% of the population, with adults and juveniles representing only 12 and 25% of the population, respectively.

Sturgeons do not spawn every year (Reinartz, 2002). Because the egg development process (vitellogenesis) typically requires more than one year, only a small fraction of the total population takes part in spawning in a given year (Beamesderfer et al., 2007). Fecundity is usually estimated by considering the mass of ovaries as a constant proportion of fish mass and dividing it by the average weight of an egg (Bajer and Wildhaber, 2007).

The mortality from egg to age 1 class was assigned similar values in all models and all studied sturgeon species; it ranged from 0.9996 to 1.0 (Pine et al., 2001; Jager, 2006a; Bajer and Wildhaber, 2007; Kennedy and Sutton, 2007). The natural mortality for subadults and adults varied from case to case, but it mostly ranged between 0.07 (Quist et al., 2002; Bajer and Wildhaber, 2007) and 0.1 (Kennedy and Sutton, 2007). Heppell (2007) claimed that research efforts should be focused on the estimation of fishing and natural mortality rates.

Bajer and Wildhaber (2007) estimated the carrying capacity by multiplying the total river length by the average density of the species for periods before commercial exploitation began.

Since there is often a lack of data on important life history parameters, authors sometimes use the available information for other populations of the same species (Beamesderfer et al., 2007) or even for different sturgeon species (Bajer and Wildhaber, 2007).

All age-structured models and IBMs were subjected to sensitivity analysis. It usually consisted of increasing or decreasing different parameters from their nominal values by a series of ratios, e.g., 5, 10, and 20% (Bajer and Wildhaber, 2007) in order to assess the influence of each parameter on model outcome.

PVA outcomes

All sturgeon PVAs generally produced the conclusion that slow physical growth and discontinuous spawning of sturgeons result in low intrinsic population growth rates, slow recovery from exploitation, and high sensitivity to harvest (Heppell, 2007). Harvested populations are likely to collapse due to the removal of reproductively viable adults (Colombo et al., 2007), and age-specific maternal effects on offspring survival emphasize the importance of maintaining large, old females in the population (Heppell, 2007).

Kennedy and Sutton (2007) determined the exact value of minimum length limits for fisheries that would offer balance between the optimum protection and harvest in a studied population. The minimum length limit should be at least several cm longer than the length at which individuals reach maturity in order to enable at least one or two spawning events to occur prior to harvest.

In a fragmented river habitat, the size of each fragment proved to be the major factor influencing population persistence (Jager et al., 2000). Due to the source and sink effect, it is necessary to ensure sufficient upstream passage through dams proportional to the downstream migration (Jager, 2006a).

A genetic model by Jager (2005) revealed that stocking can represent only a temporary measure, and restoring the spawning habitat remains the only long-term solution for maintaining viable populations.

There is at present a need for wider use of genetic models, which could, in addition to modeling the effects of inbreeding, provide information on the costs and benefits of supplementing fish populations with hatchery-reared stock (Jager et al., 2000). A study by Reisenbichler and Rubin (1999) showed that progeny of hatchery fish were often characterized by substantial reductions in fitness in the wild when compared to the progeny of wild fish.

PVA APPLICATION TO DANUBE STURGEONS

Danube sturgeon populations have experienced such serious decline over the past decades that there is an urgent need to implement efficient conservation strategies. This is hindered by the present lack of knowledge on the status of populations, extinction risks, the impact of various endangering factors, and efficiency of different management scenarios. So far, these questions were answered mostly by "rule of thumb" or through transfer of experiences from well-studied populations. Decision makers in the Danube River basin have so far often been forced to act with limited resources for management activities which, combined with the absence of clear assessments of the possible outcomes of different management alternatives, have made them reluctant to make choices. In such a state of affairs, PVA could prove to be an extremely valuable tool.

Due to an expressed need for urgent conservation measures, the development of Danube sturgeons PVAs should not wait for better data. On the contrary, PVA can provide insights regarding which parameters have the strongest impact on population persistence and thus direct investigators to the research activities of greatest importance.

The availability of PVA program packages like VORTEX, which have already proved their usefulness and reliability (Brook et al., 2000), could diminish the need for experience in programming and developing PVA models.

Future development of PVAs on sturgeon populations in the Danube River, besides assessment of population viability and future extinction risks, should be oriented towards three main issues: 1) estimation of impacts of different life history parameters on population persistence; 2) identification of key life history parameters on whose determination future research should be concentrated; and 3) prediction of the likely effects of different management scenarios on population persistence and recovery.

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REFERENCES

Akçakaya, H. R. (2000). Population viability analyses with demographically and spatially structured models. *Ecol. Bull.* **48,** 23-38.

Akçakaya, H. R., and *M. G. Raphael* (1998). Assessing human impact despite uncertainty: viability of the northern spotted owl metapopulation in the northwestern USA. *Biodivers. Conserv.* **7,** 875-894.

Akçakaya, H. R., and *P. Sjörgen-Gulve* (2000). Population viability analyses in conservation planning: an overview. *Ecol. Bull.* **48,** 9-21.

Bajer, P. G., and *M. L. Wildhaber* (2007). Population viability analysis of Lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon. *J. Appl. Ichthyol.* **23,** 457-464.

Beamesderfer, R. C. P., Rein, T. A., and *A. A. Nigro* (1995). Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the Lower Columbia River. *Trans. Am. Fish. Soc.* **124,** 857-872.

Beamesderfer, R. C. P., Simpson, M. L., and *G. J. Kopp* (2007). Use of life history information in a population model for Sacramento green sturgeon. *Environ. Biol. Fish.* **79,** 315-337.

Birstein, V. J., Bemis, W. E., and *J. R. Waldman* (1997). The threatened status of acipenseriform species: a summary. *Environ. Biol. Fish.* **48,** 427-435.

Botsford, L. W., Castilla, J. C., and *C. H. Peterson* (1997). The management of fisheries and marine ecosystems. *Science* **277,** 509-515.

Boyce, M. S. (1992). Population viability analysis. *Annu. Rev. Ecol. Sci.* **23,** 481-506.

Brook, B. W., Lim, L., Harden, R., and *R. Frankham* (1997). Does population viability analysis software predict the behavior of real populations? A retrospective study on the Lord Howe Island woodhen *Tricholimnas sylvestris* (Sclater). *Biol. Conserv.* **82,** 119-128.

Brook, B. W., O'Grady, J. J., Chapman, A. P., Burgman, M. A., Akçakaya, H. R., and *R. Frankham* (2000). Predictive accuracy of population viability analysis in conservation biology. *Nature* **404,** 385-387.

Burgman, M. A., Akçakaya, H. R., and *S. S. Loew* (1988). The use of extinction models for species conservation. *Biol. Conserv.* **43,** 9-25.

Chambers, R. C. (1993). Phenotypic variability in fish populations and its representation in individual-based models. *Trans. Am. Fish. Soc.* **122,** 404-414.

Colombo, R. E., Garvey, J. E., Jackson, N. D., Brooks, R., Herzog, D. P., Hrabik, R. A., and *T. W. Spier* (2007). Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? *J. Appl. Ichthyol.* **23,** 444-451.

Dulvy, N. K., Ellis, J. R., Goodwin, N. B., Grant, A., Reynolds, J. D., and *S. Jennings* (2004). Methods of assessing extinction risk in marine fishes. *Fish Fisheries* **5,** 255-276.

Ebenhard, T. (2000). Population viability analyses in endangered species management: the wolf, otter and peregrine falcon in Sweden. *Ecol. Bull.* **48,** 143-163.

Grogan, C. S., and *J. Boreman* (1998). Estimating the probability that historical populations of fish species are extirpated. *N. Am. J. Fish. Manage.* **18,** 522-529.

Heppell, S. S. (2007). Elasticity analysis of green sturgeon life history. *Environ. Biol. Fish.* **79,** 357-368.

Jager, H. I. (2001). Individual variation in life history characteristics can influence extinction risk. *Ecol. Model.* **144,** 61-76.

Jager, H. I. (2005). Genetic and demographic implications of aquaculture in white sturgeon (*Acipenser transmontanus*) conservation. *Can. J. Fish. Aquat. Sci.* **62,** 1733-1745.

Jager, H. I. (2006a). Chutes and ladders and other games we play with rivers. I. Simulated effects of upstream passage on white sturgeon. *Can. J. Fish. Aquat. Sci.* **63,** 165-175.

Jager, H. I. (2006b). Chutes and ladders and other games we play with rivers. II. Simulated effects of translocation on white sturgeon. *Can. J. Fish. Aquat. Sci.* **63,** 176-185.

Jager, H. I., Chandler, J. A., Lepla, K. B., and *W. Van Winkle* (2001). A theoretical study of river fragmentation by dams and its effects on white sturgeon populations. *Environ. Biol. Fish.* **60,** 347-361.

Jager, H. I., Lepla, K., Chandler, J., Bates, P., and *W. Van Winkle* (2000). Population viability analysis of white sturgeon and other riverine fishes. *Environ. Sci. Policy* **3,** S483-S489.

Kennedy, A. J., and *T. M. Sutton* (2007). Effects of harvest and length limits on shovelnose sturgeon in the upper Wabash River, Indiana. *J. Appl. Ichthyol.* **23,** 465-475.

Lacy, R. C. (1993). VORTEX: a computer simulation model for population viability analysis. *Wildlife Res.* **20,** 45-65.

Lenhardt, M., Jarić, I., Bojović, D., Cvijanović, G., and *Z. Gačić* (2006a). Past and current status of sturgeon in the Serbian part of the Danube River. 36th International Conference of IAD, Austrian Committee Danube Research/IAD. Vienna - Klosterneuburg, 04-08 September 2006, 148-151.

Lenhardt, M., Jarić, I., Kalauzi, A., and *G. Cvijanović* (2006b). Assessment of extinction risk and reasons for decline in sturgeon. *Biodivers. Conserv.* **15,** 1967-1976.

Ludwig, D. (1999). Is it meaningful to estimate a probability of extinction? *Ecology* **80 (1),** 298-310.

McDowall, R. M. (1999). Different kinds of diadromy: different kinds of conservation problems. *ICES J. Mar. Sci.* **56,** 410-413.

Pikitch, E. K., Doukakis, P., Lauck, L., Chakrabarty, P., and *D. L. Erickson* (2005). Status, trends, and management of sturgeon and paddlefish fisheries. *Fish Fisheries* **6,** 233-265.

Pine, W. E. III, Allen, M. S., and *V. J. Dreitz* (2001). Population viability of the Gulf of Mexico sturgeon: inferences from capture-recapture and age-structured models. *Trans. Am. Fish. Soc.* **130,** 1164-1174.

Quist, M. C., Guy, C. S., Pegg, M. A., Braaten, P. J., Pierce, C. L., and *V. H. Travnichek* (2002). Potential influence of harvest on shovelnose sturgeon populations in the Missouri River system. *N. Am. J. Fish. Manage.* **22,** 537-549.

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D., and *R. Frankham* (2003). Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biol. Conserv.* **113,** 23-34.

Reed, J. M., Mills, L. S., Dunning Jr., J. B., Menges, E. S., McKelvey, K. S., Frye, R., Beissinger, S. R., Anstett, M.-C., and *P. Miller* (2002). Emerging issues in population viability analysis. *Conserv. Biol.* **16 (1),** 7-19.

Reinartz, R. (2002). *Sturgeons in the Danube River. Biology, Status, Conservation. Literature Study*. 150 pp. International Association for Danube Research (IAD), Bezirk Oberpfalz, Landesfischereiverband, Bayern.

Reisenbichler, R. R., and *S. P. Rubin* (1999). Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. *ICES J. Mar. Sci.* **56,** 459-466.

Shaffer, M. L. (1990). Population viability analysis. *Conserv. Biol.* **4 (1),** 39-40.

Sjögren-Gulve, P., and *I. Hanski* (2000). Metapopulation viability analysis using occupancy models. *Ecol. Bull.* **48,** 53-71.

Solow, A. R. (1993). Inferring extinction from sighting data. *Ecology* **74,** 962-964.

Uchmański, J. (1999). What promotes persistence of a single population: an individual-based model. *Ecol. Model.* **115,** 227-241.

Williot, P., Arlati, G., Chebanov, M., Gulyas, T., Kasimov, R., Kirschbaum, F., Patriche, N., Pavlovskaya, L. P., Poliakova, L., Pourkazemi, M., Kim, Y., Zhuang, P., and *I. M. Zholdasova* (2002). Status and management of Eurasian sturgeon: an overview. *Int. Rev. Hydrobiol.* **87 (5-6),** 483-506.

АНАЛИЗА ВИЈАБИЛНОСТИ ПОПУЛАЦИЈА И МОГУЋНОСТ ЊЕНЕ ПРИМЕНЕ НА ДУНАВСКЕ ЈЕСЕТРЕ

И. ЈАРИЋ[1], МИРЈАНА ЛЕНХАРДТ[2], Г. ЦВИЈАНОВИЋ[1] и T. EBENHARD[3]

[1]*Институт за мултидисциплинарна истраживања,* 11000 Београд, Србија
[2]*Институт за биолошка истраживања "Синиша Станковић",* 11060 Београд, Србија
[3]*Swedish Biodiversity Center (CBM), Box 7007,* S-750 07 Упсала, Шведска

Популације јесетарских врста у басену Дунава су доживеле озбиљан пад бројности. Поред прекомерног излова, губитка станишта и загађења, додатно су угрожене недостатком ефикасне легислативе и управљања, као и озбиљним недостатком знања о њиховом животном циклусу. Иако анализа вијабилности популација (PVA) може представљати веома користан метод у решавању ових проблема, до сада није примењивана на дунавске популације. Овај рад представља процену различитих PVA метода и модела развијених за јесетарске врсте. У раду се анализирају њихови резултати, главне предности, недостаци и главни проблеми на које се наилазило, и дискутује се о могућности њихове примене на популације јесетри у басену Дунава.