A brief overview of the development of the ES-HIPPO model for assessing the sustainability and conservation priorities of fish, fish resources, and inland water habitats

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Abstract This chapter contains a brief overview of the development of models for assessing the sustainability and conservation priorities for fish, fish resources, and inland water habitats in Serbia and the region. The basic version of the ES–HIPPO model consists of two elements. The first, Ecological Specialization (ES), reflects the level of taxon specialization in relation to habitat, diet, reproduction strategy, life cycle, body size, degree of endemism, and degree of isolation. The second factor, "HIPPO", refers to the impact of factors such as H- habitat alterations, I- invasive species, P- pollution, P- human population growth, and O- overexploitation on populations in the spatial and temporal dimensions. From the general model, advanced models were developed: *ES–HIPPOfish* intended for assessing the viability of fish species that are important for fishing, ES–HIPPOcrayfish to assess the sustainability of decapod crustacean populations, and the latest version of *ESE-HIPPOriverbasin* to assess the degree of habitat conservation for a sustainable fish community in a river basin.

Keyword: Serbia; ES–HIPPO model; *ES–HIPPOfishing*; ES–HIPPOcrayfish; *ESE–HIPPOriverbasin*

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1 Introduction

Successful protection and conservation of ecosystems can only be achieved if there is a good diagnosis of ecosystem health (Pitcher 2015). Apart from the assessment of environmental conditions (biota), the assessment of the stability of the biotic component is necessary. In current conditions, when ecosystems are exposed to numerous stressors, mostly of anthropogenic origin, inland waters are susceptible and quickly lose ecological sustainability and loss of ecological services (Bănăduc et al. 2022). Fish, as the last or top members of the food chain, are good indicators of the health of aquatic ecosystems. The assessment is two–way, which means that the assessment of the condition of fish communities and populations reflects the health and sustainability of the ecosystem, and on the contrary, poor habitat conditions are often the cause of low sustainability of populations and fish stocks (Karr 1981, 1987; Jepsen and Pont 2007; Pont et al. 2007; Stojković et al. 2011, 2013; Radinger et al. 2019). However, the unsustainable fish community in good ecological habitat conditions is often a consequence of the overexploitation of the fish stocks by fishing.

Furthermore, while there are well–developed methods for assessing the state of fish stocks in marine ecosystems due to very intensive commercial fishing and the increasing depletion of fish and other biological resources, for inland waters, there are significantly fewer developed methods (Cooke et al. 2016). Often, methodology for marine is also used for inland fish resources with certain modifications (e.g., methods in the software packages FISAT 1 and 2). The European Water Directive (WFD) developed the European Ichthyological Index based on the Ichthyological Biotic Indices (IBI) in order to assess the ecological status of inland waters, leaving the possibility for each member state to develop modifications under the local and regional specificities of the fish fauna (Jepsen and Pont 2007). These methods have been significantly improved using eDNA methods (Pont et al. 2019).

Our long–term experience in assessing the state of the fish stocks and the water ecological status, using generally accepted WFD methods and assessment models (primarily FISAT 1 and 2) (Gayanilo et al. 2005), indicated that the hydrogeographic heterogeneity of the inland water habitats of Serbia requires certain modifications or the development of new assessment model. The next reason for the development of new models is the chronic lack or irregularity of data regarding the catches of commercial and recreational fishermen. That significantly complicates the development of sustainable management programs because the data can hardly be used in the above–mentioned methods and models, especially for the assessment of fishing pressure. Finally, an important reason for developing new models is the more efficient implementation of conservation efforts and measures for the sustainable use of the fish stocks in accordance with the ecosystem approach to fisheries in inland waters (Kolding et al. 2016). Considering the stated reasons, the ES–HIPPO model system is designed not only for scientists but also for experts in managing fishing areas and fish stocks. It enables the management of fish stocks by all social actors and not only by the "top–down" system (Welcome 2016).

1.1 The ES–HIPPO basic model and its importance in the conservation of fish stocks

The ES–HIPPO model (Simić et al. 2007) was created to supplement the assessment results of the degree of endangerment of aquatic organisms at the national level, which are obtained at the expense of the global IUCN criteria (IUCN 2022). The primary goal was expanded by assessing the degree of sustainability and priority for conservation at the national and population levels. The model is based on the ecological specialization of taxa, which is the result of adaptation through evolution and the ability to resist specific modern multiple stressors (Fisher and Owens 2004). The model has two elements; the first is the Ecological Specialization of taxa (ES) in relation to habitat, diet, breeding strategy, life cycle, body size, degree of endemism, and degree of isolation (Fisher and Owens 2004). The second factor, "HIPPO" refers to the impact of factors such as H – Habitat alterations, I – Invasive species, P – Pollution, P – human Population growth, and O – Overexploitation on population in spatial and temporal dimensions (Brennan and Withgott 2005). The degree of ecological specialization is evaluated on a three–level scale: 1 – high ecological specialization of the taxon, 3 – moderate, and 5 – low specialization (cosmopolitan species). The sum of the ES + HIPPO factors for each population (∑ES+HIPPO.np) of the taxon gives information regarding the degree of sustainability and the level of conservation priority. The higher sum indicates lower ecological sustainability and higher conservation priority (PP). The model was designed to assess the degree of sustainability of aquatic habitat taxa in general but has been most used for fish. The results obtained for the assessment of the degree of sustainability of fish species and the level of conservation priorities significantly helped in the implementation of the NATURA 2000 program for Serbia and the preparation of red books. Apart from this, the results were also used to propose taxa of macroalgae, macroinvertebrates, and fish for the national list of strictly protected species (Anonymous 2016) and the list of fish that need a permanent ban on fishing (Regulations on measures for the conservation and protection of fish stocks). The current list of autochthonous fish species with a certain degree of sustainability and conservation priority level based on the ES–HIPPO model is shown in Table 1. Particular conservation efforts should be focused on species characterized as High priority based on the ES–HIPPO model on the territory of Serbia (Table 1). Within those species, some have economic (e.g., Acipenseridae) or fisheries significance (e.g., huchen), but the model also implies that species with small–sized bodies and rare in Serbia but without economic value should be prioritized in conservation (e.g., vairone (Veličković et al. 2020) and Romanian golden loach (Marić et al. 2022)).

Table 1. Level of sustainability and priorities for fish conservation based on the ES–HIPPO model and in relation to global and official national status.

Family/Fish species valid name according to Fishbase	**Global IUCN***	**Appendix I and II of the Rulebook****	**ES–HIPPO**
Petromyzontidae			
Lamprey *Eudontomyzon danfordi* (Regan, 1911)	LC	I	No data
Drin brook lamprey *Eudontomyzon stankokaramani* (Karaman, 1974)	LC	I	No data
Ukrainian brook lamprey *Eudontomyzon mariae* (Berg, 1931)	LC	I	No data
Danubian brook lamprey *Eudontomyzon vladykovi* (Oliva & Zenandrea 1959)	LC	I	No data
River lamprey *Lampetra fluviatilis* (before *Petromyzon fluviatilis*) (Linnaeus, 1758)	LC		No data
European brook lamprey *Lampetra planeri* (Bloch, 1784)	LC		No data
Sea lamprey *Petromyzon marinus* (Linnaeus, 1758)	LC		No data
Acipenseridae			
Danube sturgeon *Acipenser gueldenstaedti* (Brandt and Ratzeburg, 1833)	CR	I	High
Fringerbarbel sturgeon *Acipenser nudiventris* (Lovetsky, 1828)	CR	I	High
Sterlet sturgeon *Acipenser ruthenus* (Linnaeus, 1758)	EN	II	High
Starry sturgeon *Acipenser stellatus* (Pallas, 1771)	CR	I	High
Sturgeon *Acipenser sturio* (Linnaeus, 1758)	CR	I	High
Beluga sturgeon *Huso huso* (Linnaeus, 1758)	CR	I	High
Salmonidae			
Peled *Coregonus peled* (Gmelin, 1789)	LC	/	No data
Huchen *Hucho hucho* (Linnaeus, 1758)	EN	II	High
Marble trout *Salmo marmoratus* (Cuvier, 1829)	LC	I	No data
Brown trout *Salmo trutta* (Linnaeus, 1758)	LC	II	High–moderate
Salmo farioides (Karaman, 1938)	/	/	No data

Macedonian trout *Salmo macedonicus* (Karaman, 1924)	DD	/	Moderate
Arctic char *Salvelinus alpinus* (Linnaeus, 1758)	LC	/	
Brook trout *Salvelinus fontinalis* (Mitchill, 1814)	/	/	
Rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792)	NE	/	
Thymalidae			
Grayling *Thymallus thymallus* (Linnaeus, 1758)	LC	II	Moderate
Angulidae			
European eel *Anguilla anguilla* (Linnaeus, 1758)	CR	I	High
Clupeidae			
Caspian shad *Alosa caspia* (Eichwald, 1838)	LC	/	High
Pontic shad *Alosa immaculata* (Bennet, 1835)	VU	I	High
Esocidae			
Northern pike *Esox lucius* (Linnaeus, 1758)	LC	II	Moderate
Umbridae			
European mudminnow *Umbra krameri* (Walbaum, 1792)	VU	I	High–moderate
Cyprinidae			
Zope *Ballerus ballerus* (before *Abramis ballerus*) (Linnaeus, 1758)	LC	II	Low
Bream *Abramis brama* (Linnaeus, 1758)	LC	II	Low
White–eye bream *Ballerus sapa* (before *Abramis sapa*) (Pallas, 1814)	LC	II	Moderate
Barbel *Barbus barbus* (Linnaeus, 1758)	LC	II	
Round–scaled barbel *Barbus cyclolepis* (Heckel, 1837)	LC	I	High
Danube barbel *Barbus balcanicus* (Kotlík, Tsigenopoulos, Ráb and Berrebi, 2002)	LC	II	Low
Crucian carp *Carassius carassius* (Linnaeus, 1758)	LC	I	High
Carp *Cyprinus carpio* (Linnaeus, 1758)	VU	II	Low?

Goldfish *Carassius auratus* (before *Carassius auratus auratus*) (Linnaeus, 1758)	LC	/	
Prussian carp *Carassius gibelio* (before *Carassius aurata gibelio*) (Bloch, 1782)	/	/	
Gras carp *Ctenopharyngodon idella* (Valenciennes, 1844)	LC	/	
Xenocyprididae			
Silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844)	NT	/	
Bighead carp *Hypophthalmichthys nobilis* (Richardson, 1844)	DD	/	
Gobionidae			
White–finned gudgeon *Romanogobio albipinnatus* (before *Gobio albipinnatus*) (Lukasch, 1933)	LC	II	High
Gudgeon *Gobio gobio* (Linnaeus, 1758) *Gobio obtisirostris*	LC	II	Low
Kessler's gudgeon *Romanogobio kessleri* (Dybowski, 1862)	LC	II	Moderate
Danube longbarbel gudgeon *Romanogobio uranoscopus* (Agassiz, 1828)	LC	II	High
Topmouth gudgeon *Pseudorasbora parva* (Temminck and Schlegel, 1842)	LC	/	
Leuciscidae			
Spirlin, schneider *Alburnoides bipunctatus* (Bloch, 1782)	/	II	Low
Italian bleak *Alburnus albidus* (Costa, 1838)	VU	/	/
Bleak *Alburnus alburnus* (Linnaeus, 1758)	LC	/	Low
Alburnus scoranza (Bonaparte, 1845)	LC	/	/
Danube bleak *Alburnus chalcoides* (Güldenstadt, 1772)	/	I	No data
White bream *Blicca bjoerkna* (Linnaeus, 1758)	LC	/	Low
Nase *Chondrostoma nasus* (Linnaeus, 1758)	LC	II	Low
Aral asp *Leuciscus aspius* (before *Aspius aspius*) (Linnaeus, 1758)	LC	II	Low
Belica *Leucaspius delineatus* (Heckel, 1843)	/	I	No data
Chub *Squalius cephalus* (before *Leuciscus cephalus*) (Linnaeus, 1758)	LC	II	Low–moderate
Ide, orfe *Leuciscus idus* (Linnaeus, 1758)	/	II	Low–moderate

Common dace *Leuciscus leuciscus* (Linnaeus, 1758)	LC	/	No data
Vairone *Telestes souffia* (Risso, 1826)	LC	I	High
Pachychilon macedonicus (Steindachner, 1892)	DD	/	No data
Pachychilon pictum (Heckel & Kner, 1858)	LC	I	No data
Sichel *Pelecus cultratus* (Linnaeus, 1758)	LC	II	Nigh
Common minnow *Phoxinus phoxinus* (Linnaeus, 1758)	LC	/	High–moderate
*Leucos basak (*before *Rutilus basak)* (Heckel, 1843)	LC	/	No data
Pigo *Rutilus pigus* (Lacepede, 1804)	LC	II	Moderate
Rutilus virgo (Heckel, 1852)	LC	/	No data
Rutilus or common roach *Rutilus rutilus* (Linnaeus, 1758)	LC	/	Low
Scardinius erythrophthalmus (Linnaeus, 1758)	LC	/	Moderate
Scardinius graecus (Stephanidis, 1937)	CR	/	No data
Scardinius knezevici (Bianco and Kottelat, 2005)	LC	/	No data
Vimba *Vimba vimba* (Linnaeus, 1758)	LC	II	Low
Macedonian vimba *Vimba melanops* (Heckel, 1837)	DD	/	High ?
Acheilognathidae			
Ammur biterling *Rhodeus sericeus* (Pallas, 1776)	LC	I	Low
Tincidae			
Tench *Tinca tinca* (Linnaeus, 1758)	LC	I	High–moderate
Cobitidae			
Balkan loach *Cobitis elongata* (Heckel & Kner, 1858)	LC	I	moderate
Spined loach *Cobitis taenia* (Linnaeus, 1758)	LC	II	moderate
True loach *Misgurnus fossilis* (Linnaeus, 1758)	LC	I	moderate
Balkan spined loach *Sabanejewia balcanica* (Filippi, 1865)	LC	I	moderate

Sabanejewia bulgarica	LC	I	No data
Romanian golden loach *Sabanejewia romanica* (Băcescu, 1943*)*	NT	/	High?
Nemacheilidae (before Balitoridae)			
Stone loach *Barbatula barbatula* (Linnaeus, 1758)	LC	/	moderate
Struma stone loach *Oxynoemacheilus bureschi* (before *Barbatula bureshi*) (Drensky, 1928)	LC	I	High
Siluridae			
Wels catfish *Silurus glanis* (Linnaeus, 1758)	LC	II	Low
Ichtaluridae			
Brown bullhead *Ameiurus nebulosus* (Le Sueur, 1819)	LC	/	
Black bullhead *Ameiurus melas* (Rafinesque, 1820)	LC	/	
Lotidae (before Gadidae)			
Burbot *Lota lota* (Linnaeus, 1758)	LC	II	Moderate
Syngnathidae			
Bleack–striped pipefish *Syngnathus abaster* (Risso, 1826)	LC	/	
Gasterosteidae			
Three–spined stikleback *Gasterosteus aculeatus* (Linnaeus, 1758)	LC	/	No data
Southern ninespin stikleback *Pungitius platygaster* (Kessler, 1859)	LC	/	No data
Percidae			
Balon's ruffe *Gymnocephalus baloni* (Holčik & Hensel, 1974)	LC	I	High
Ruffe *Gymnocephalus cernua* (before *Gymnocephalus cernuus*) (Linnaeus, 1758)	LC	/	Low
Schraetzer *Gymnocephalus schraetser* (Lin-naeus, 1758)	LC	II	Moderate
European perch *Perca fluviatilis* (Linnaeus, 1758)	LC	II	Low
Pikeperch *Sander lucioperca* (Linnaeus, 1758)	LC	II	Low
Volga pikeperch *Sander volgensis* (Gmelin, 1788)	LC	II	Moderate

Danube streber *Zingel streber* (Siebold, 1863)	DD	I	High
Zingel *Zingel zingel* (Linnaeus, 1766)	LC	I	Moderate
Centrarchidae			
Pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758)	LC	/	
Largermouth black bass *Micropterus salmoides* (Lacepede, 1802)	LC	/	
Gobiidae			
Monkey goby *Neogobius fluviatilis* (Pallas, 1811)	LC	/	
Racer goby *Babka gymnotrachelus* (Kessler, 1857)	LC	/	
Bighead goby *Ponticola kessleri* (Gunther, 1861)	LC	/	
Round goby *Neogobius melanostomus* (Pallas, 1811)	LC	/	
Tubenose goby *Proterorhinus marmoratus* (Pallas, 1811)	LC	/	
Blennidae			
Freshwater blenny *Salaria fluviatilis* (Asso, 1801)	LC	II	No data
Cottidae			
European bullhead *Cottus gobio* (Linnaeus, 1758)	LC	I	Moderate
Odontobutidae			
Chinese sleeper *Perccottus glenii* (Dybowski, 1877)	LC	/	

*IUCN (2001) Red List categories and criteria, version 3.1 Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD). **Rulebook on declaration and protection of protected and strictly protected wild species of plants, animals, and fungi (Official Gazette of RS No. 5/2010, 47/2011, 32/2016, and 98/2016). Appendix (I – strictly protected, II – protected species).

2 A model adapted to assess the sustainability of commercially important fish species *ES–HIPPOfishing*

The *ES–HIPPOfishing* model (Simić et al. 2014) is a modification of the basic model (ES–HIPPO) designed to assess the sustainability of fish species exploited through commercial and recreational fishing in inland waters. A significant adjustment to this goal was achieved by introducing a new sub–element in the model, Index of Local Sustainability of Fish Populations (ILSFP). Spatial and temporal indicators of populations of commercially important fish species were used to estimate ILSFP, and they included dominance, frequency, biomass, maturity of females (%), number of age classes, the average length of fish stocks, and percentage of population located in protected areas. The ILSFP is estimated based on the trend of the mentioned indicators during ten years and spatially along the river courses of a catchment area. Stream sections with the highest ILSFP values for a particular fish species are designated as critical habitats for the sustainability of that species throughout the basin. The model has certain similarities in some elements with the work of Giam et al. (2011), Chantepie et al. (2011), Linke et al. (2012), and Chester and Robson (2013).

The results obtained for the sustainability of commercially important fish species based on the *ES–HIPPOfishing* model from the creation period in 2013/14 and the present (2021/22) are shown in Table 2.

Table 2. Degree of sustainability of commercial fish species in Serbian waters (Low – L, Moderate – M, High – H) based on calculated values of the *ES–HIPPOfishing* model during 2013/14 and estimates during 2021/22. Abbreviations: VL (Very Low), ML (Moderate Low)

Fish species	***ES–HIPPOfishing* 2014**	***ES–HIPPOfishing* 2022**
Huchen *Hucho hucho*	54 – VL	56 – VL
Sterlet sturgeon *Acipenser ruthenus*	54 – VL	60 – VL
Grayling *Thymallus thymallus*	50 – L	54 – VL
Brown trout *Salmo trutta*	50 – L	54 – VL
Northern pike *Esox lucius*	50 – L	52 – L
Barbel *Barbus barbus*	49 – L	52 – L
Pikeperch *Sander lucioperca*	46 – L	40 – ML
Carp *Cyprinus carpio*	46 – L	46 – L
Bream *Abramis brama*	42 – L	32 – M
Wels catfish *Silurus glanis*	42 – L	34 – M
Nase *Chondrostoma nasus*	38 – M	38 – M
Chub *Squalius cephalus*	32 – M	40 – ML
Aral Asp *Leuciscus aspius*	–	28 – H
Prussian carp *Carassius gibelio*	30 – M	28 – H

After just under ten years, the sustainability of commercially important fish species obtained from the *ES–HIPPOfishing* model indicates some significant changes. The presented results show that the level of sustainability is decreasing for all salmonid species. In particular, this applies to brown trout, which have moved from a low sustainability level to a very low sustainability level. The reasons are multiple and highlighted in several chapters of this monograph. They include the habitat fragmentation due to the intensive construction of small hydro–power plants (SHPP), genetic contamination of the autochthonous Danubian genetic lineage with allochthonous Atlantic and Adriatic genes, climate changes affecting the hydrological and temperature regime of the salmonid area, pollution, and still present poaching. The model can be used to obtain key habitats for preserved autochthonous populations, which primarily include populations with unique haplotypes. Among the habitats where the viable and autochthonous trout populations are preserved, the Đetinja River and the upper reaches of the Temska River Basin in the Stara Planina National Park can be singled out. There is also observed the high sustainability of some populations contaminated with Atlantic lineage specimens, such as the Sokobanjska Moravica (South Morava Basin) and Gradac river (Kolubara basin) (Fig. 1).

Figure 1. Trout from the river Gradac (Kolubara Basin) (Photo by V. Simić)

In the case of cyprinid species, the model indicates reduced viability of chub populations (Fig. 2). Our research indicates that chub populations have a decreasing trend in the Morava basin, especially in the middle and lower reaches of larger tributaries (Simić et al. 2022).

Figure 2. Chub from the recreational catch from Studenica River (Biosphere Reserve Golija – Studenica) from August 2020 (Photo by V. Simić)

On the other hand, there is a certain increase in the level of sustainability of fishing species such as bream, pikeperch, and wels catfish. Populations of these species with a higher level of sustainability occur in reservoirs in the Morava and Drina basins and the Sava River (Fig. 3 and 4). In addition to these species, a higher level of sustainability of populations of Aral asp, a predatory species from the Cyprinidae family, which has been a frequent catch in recent years, was also measured by commercial and recreational fishermen in the Danube, Sava, and Morava.

Figure 3. Catch of a commercial fisherman on the Sava River near Šabac with a dominant bream (Photo by M. Vlajković)

Figure 4. Experimental fishing with standing nets for scientific research purposes in June 2020. The dominance of bream is evident in the Zavoj reservoir in the Stara Planina National Park (Photo by V. Simić)

3 A model adapted to assess the viability of the decapod crustaceans ES–HIPPOcrayfish

Unlike some European and Scandinavian countries, Serbia does not have a tradition of harvesting or consuming freshwater decapod crustaceans. The situation is similar in other Western Balkans countries, but there are also cases where crayfish from these areas are caught by foreign concessionaires and exported to Western Europe (Rajković 2004; Rajković et al. 2006, 2012; see Chap. No. 8, Đuretanović et al.). The crayfish plague decimated crayfish populations in Europe and only, to a slightly lesser extent, affected the Balkan Peninsula. Invasions of North American crayfish (*Pacifastacus leniusculus* and *Faxonius limosus*), pollution, and habitat destruction have further adversely affected crayfish populations. Research on the distribution of decapod crustaceans on the territory of Serbia by Simić et al. (2008), the first after 50 years, was a warning sign because it showed a critically endangered status for the noble crayfish *Astacus astacus*. In order to more effectively preserve decapod crustaceans in the area of the Balkan Peninsula, a modification of the ES–HIPPO model to *ES–HIPPOcrayfish* was formulated (Simić et al. 2015). The main modification was based on the introduction of the Index of the Local Adaptive Population of Crayfish (ILAP) element that assesses the level of the adaptive value of individual crayfish populations to local habitat conditions. ILAP indicators include genetic (phylogeny and nucleotide diversity), morphometric, and population data. The aim of the model was the determination of the level of sustainability of individual populations and the selection of the basic conservation unit and elemental conservation unit (ECU). The ECU represents the population that has priority in the conservation program. The model indicated very low sustainability of *A. astacus* populations in Serbia (Fig. 5), and the higher sustainability of *Austrpotamobius torrentium* populations compared to *Austropotamobius pallipes/italicus* populations that inhabit the rivers of the Adriatic basin. The model also indicated the unsustainability of *A. astacus* populations in the reservoirs of the headwaters of the Zeta River in Montenegro if the rate of exploitation by foreign concessionaires continues (Rajković 2004; Rajković et al. 2006; Petrović et al. 2013). Similar considerations on crayfish can be read in Souti–Grosset et al. (2003), Bonin et al. (2007), Klobučar et al. (2013), Schrimpf et al. (2014), Parvulescu and Zaharia (2014), Lovrenčić and Maguire (2021), and Lovrenčić et al. (2022).

Figure 5. Drying up of small rivers in Central Serbia due to climatic changes, but also excessive exploitation of water due to the capture of springs for water supply, and irrigation, threatens the survival of the remaining populations of *Astacus astacus*. The picture presents the upper course of the Lepenica River and the remaining ponds during the summer of 2021 (a). Crayfish probably survive in these remaining ponds and later probably burrow into the wet mud (b) (Photo by V. Simić)

4 A model for assessing the sustainability of river basins *ESE–HIPPOriverbasin*

The latest version of the ES–HIPPO – *ESE–HIPPOriverbasin* model (Simić et al. 2022) has significant modifications. The primary goal and purpose of the model have been changed. Instead of assessing the sustainability of populations of aquatic organisms, especially decapod crustaceans and fish, the model deals with assessing the stability and sustainability of individual aquatic habitats up to the overall sustainability of river basins. As in the previous variants, the model has two elements: Ecological Stability of the Ecosystem (ESE) and "HIPPO". At the core of the assessment of the first element of the model, now called ESE, is the structure of the fish community. The indicators for ESE that may differ in the time dimension are presented in Table 3.

Table 3. Structure of indicators of the *ESE–HIPPOriverbasin* model (taken from Simić et al. 2022). In cases that there are lack of data for the evaluation of the indicators, alternative information for the evaluation are provided and marked with an asterisk.

ESE indicators (code/abbreviation)	**Threshold and scoring system for each ESE indicator**		
	1 (low)	3 (medium)	5 (high)
Fish community composition (species diversity)			
(% Au/his): Total number of autochthonous taxa (deviation between present and historical condition)[1]	Deviation > 50%	Deviation < 50%	No or minor change ± 10%
The Shannon-Weaver Index (d)* (value d cannot be calculated when there is only one species)	d < 1	d (1-2)	d > 2
(Al. sp%): Total number of allochthonous species[2]	Allochthonous species > 50%	Allochthonous species (30-50 %)	Allochthonous species < 30%
The characteristics of target fish population which zonation concept is based on			
A (MF): Trend in abundance of target fish population in the past 10-20 years[3]	Decrease in abundance	Variation in abundance up to ±10%	Increase in abundance
B (MF): Trend in biomass target of fish population in the past 10-20 years	Decrease in biomass	Variation in biomass up to ±10%	Increase in biomass

Implementation of ABC (abundance biomass comparison) curves (Clarke and Warwick, 1994)*	The pattern in the abundance and biomass shows heavily disturbed assemblages	The pattern in the abundance and biomass shows moderately disturbed assemblages	The pattern in the abundance and biomass shows undisturbed assemblages
TL (MF): Trend in total length of target fish population in the past 10-20 years[4]	Decrease in total length	Variation in total length up to ±10%	Increase in total length
Comparison of analyzed specimen's length with a common length of the species (FishBase)*	More than 50% of specimens TL < common length (FishBase)	% of specimens containing the common length: 50% ± 5% (FishBase)	More than 50% of specimens TL > common length (FishBase)
nAge (MF): Trend in number age classes in the past 10-20 years	Decrease in number age classes (1-2)	Stagnation in the number of age classes (3-4)	Increase in number age classes (>4)
The characteristics of accompanying fish population in particular zone			
A, B, TL, nAge (SMF)[5]	The same scoring system as used for target fish species		
Predator fish species			
(nPF): Total number of predator taxa (deviation between present and historical condition)[6] (%)	Decrease < 50%	Stagnation or ≥ 1 species	Increase > 30%
(BPT): Trend in biomass predator fish population in the past 10-20 years	Decrease in biomass	Variation in biomass up to ±10%	Increase in biomass
Total number of predator taxa*	< 50% predatory fish characteristic for the fish zone	50% predatory fish characteristic for the fish zone	All / > 50% predatory fish characteristic for the fish zone
Biomass predator fish (BP) population in comparison to other fish populations (BO)*	BP/BO > 10%	BP/BO (10-30%)	BP/BO > 30%
Sensitive fish species			
(% SFT): Total number of sensitive fish species given in % and/or trend in the past 10-20 years [7-8]	ST ≤ 30 % and/or decrease M ≤ 50% [8]	ST 31- 60% or ST ≤ 30 % M >50%	ST > 60 % and/or increase

[1] Pančić (1860); Ristić (1972, 1977), Simonović (2001). [2] Modification of Site-specific Biological Contamination (SBC) (Panov et al. 2008).[3] Fish river zone (Thienemann et al 1928; Huet 1949, 1959), characteristics of typical zone fish species: autohtonous species, fishing species, frequency > 90%, dominant > 75%. [4] TL – Total body length. [5] Characteristics subtypical fish species: autohtonous species,

fishing species, frequency > 75%, dominant > 50 %. [6] Primary and secondary piscivore fish species (excluding *Anguilla anguilla*): *Silurus glanis, Esox lucius, Sander lucioperca, Aspius aspius, Hucho hucho, Perca fluviatilis,* and *Salmo trutta* TL>0,35m. [7-8] Fishbase data of Resillence (van Treeck et al., 2020); moderate fish species (%)

The first group of indicators (A set in the table) has a time dimension that imply that the value for each indicator of the structure of the fish community from a certain habitat can only be calculated if there is data on it for at least ten years (the longer the period, the more precise the data will be). In this case, a problem for model operation may be a lack of data. However, apart from scientists, the model is primarily designed for professional managers of fishing areas. If they use it, it requires constant monitoring of the state of the fish stock through real data collection on the catch of commercial and recreational fishermen. In this way, the model (if the manager uses it) can indirectly affect the chronic problem of lack of data on real catch and fishing pressure in freshwater fisheries. Another possibility enabled by the temporal version of indicator monitoring is alignment with ecosystem approaches to fisheries in inland waters. Primarily, this refers to the possibility of planning a balanced harvest in parts of the basin or the entire basin for certain fish species, several of them, or the total harvest. For example, by monitoring the trend of age classes and fish production in the waters exploited by fishing it is possible to assess the increased fishing pressure on the demographic structure (young fish, large older fish) in a certain time and accordingly make corrections in the management plans in terms of directing the pressure on the age classes with the largest current production (for further reading see: Kolding et al. 2003; Kolding and van Zwieten 2011; Garcia et al. 2012; Law et al. 2012, 2013; Welcomme 2016; Kolding et al. 2016). Suppose there is no continuous data for the selected indicators; the model can be used for the current assessment of the ecological sustainability of fishing waters in the basin using data set marked in bold (Table 3). The model's significant role in preserving the fish stock is based on the possibility of determining parts of the watershed that can be declared as freshwater ecological reserves. Freshwater protected areas (FPAs) are also part of the ecosystem approach to fisheries in inland waters. Based on the indicators of the structure of the fish community and the intensity of the influence of the "HIPPO" factor, the model estimates the degree of ecological sustainability of the habitat in the watershed. Habitats with a higher degree of sustainability also support a sustainable fish community and, indirectly, the condition and sustainability of fish species important to fisheries and the fish stock as a whole. By monitoring and analyzing the level of habitat sustainability in the watershed, the schedule of FPAs can be planned. FPAs can be declared on parts of the reserves, watersheds with naturally preserved fish communities, or individual fish species to recover the fish stock from overfishing and/or some other stressor. In both cases, the reserves are spared from fishing and other anthropogenic influences and, over time, become places from which the "spillover" effect maintains the stability and sustainability of fish communities and fish stocks beyond their borders (Hannah et al. 2019). In the example of the Morava basin, which covers the largest part of

Serbia, one can see the state of ecological sustainability of the basin and its units, which was obtained based on the *ESE – HIPPOriverbasin* model.

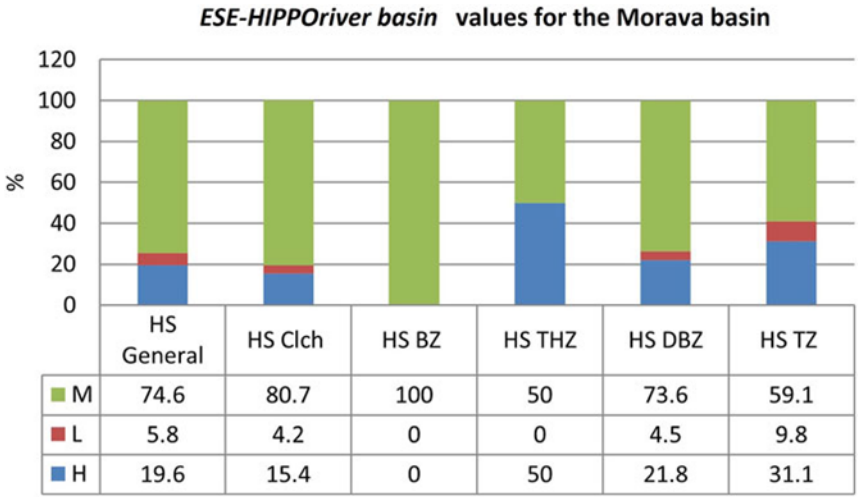

Figure 6. Ecological sustainability of habitats in the Morava basin (Serbia) based on the *ESE–HIPPOriverbasin* model. Abbreviations: H – high level of sustainability, M – medium level of sustainability, L – low level of sustainability. HS –% of the length of the catchment stream which has high sustainability in relation to the total length. HS Clch – % HS under the influence of climate change. HS BZ – HS barbel zone, HS THZ – HS grayling zone, HS DBZ – HS Danube barbel zone, HS TZ – HS trout zone (taken from Simić et al. 2022).

The results presented in Fig. 6 indicate an unexpectedly high percentage of habitats with a moderate and low level of ecological sustainability (about 50%) in the trout zone of this watershed. A careful analysis of the trend of the ESE and HIPPO factors shows major changes in brown trout populations in the last ten years, primarily due to massive habitat fragmentation, changes in the flow regime, and climatic factors that cause changes in temperature (greater warming of the water during the year) and hydrological regime (droughts or strong torrents).

Except for the basic ES–HIPPO model, all other modifications are supported by Kohonen artificial neural network (i.e., self-organizing maps - SOM) (Kohonen 1982).

For further reading on models that have been developed and used to assess fish stock status in freshwater ecosystems around the world, see Pitcher (2015). The model has certain similarities with the models and application of the Biotic Integrity Index for some river basins of China (Yang et al. 2021; Huang et al. 2022). In the Balkans area, proposals and applications of the model for assessing the state of the fish stock in the Danube can be found in the works of Jarić et al. (2014a) and Smederevac–Lalić et al. (2017), as well as for the assessment of the state of sturgeon species (Jarić et al. 2009, 2010, 2014b, 2016) and the assessment of floodplain and marsh habitats (Stamenković et al. 2021).

5 The application of fish in the assessment of the ecological status/potential of water bodies

In addition to the previously mentioned publications that focus on the use of fish in assessing the ecological sustainability of fish populations and inland water ecosystems, publications that utilize fish and/or fish communities as indicators of the ecological status and potential of water bodies are also important, in compliance with the Water Framework Directive (WFD 2000).

For the waters of Serbia, notable findings on this topic are presented in the work of Stojković et al. (2013), where the fish communities in the South Morava River basin were analyzed. Based on the SOM analysis (Stojković et al. 2013), three clusters with indicator fish species that are indicative of specific ecological characteristics of the habitat were established (Table 4). The methodology and results presented in this manuscript can be applied to assess the ecological status/potential as well as to select priority areas for the conservation of biodiversity and fish stocks of rivers.

Table 4. Species that differ by IndVal index, for cluster (I) and sub–cluster (Ks1, Ks2). Bold letters indicate the species representative for SOM clusters that have IndVal values greater than 25%. Species without significant IndVal values are included at the end of the columns (taken from Stojković et al. 2013)

Y		**X1**		**X2**	**Y**
Rutilus rutilus	75.0***	*Barbus balcanicus*	52.6***	*Salmo trutta*	86***
Alburnus alburnus	61.8***	*Alburnoides bipunctatus*	40.8***	*Cottus gobio*	12.0*
Chondrostoma nasus	59.8***	*Barbatula barbatula*	34.4***	*Oncorhynchus mykiss*	12.0*
Barbus barbus	50.0***	*Cobitis elongata*	21.3**		
Leuciscus cephalus	45.0**				
Carassius auratus	39.6***				
Vimba vimba	38***				
Gobio gobio	36.0***				
Silurus glanis	36.0***				
Rhodeus sericeus	33.0***				
Perca fluviatilis	23.0***				
Aspius aspius	11.1**				
Scardinius erythrophthalmus	9*				
Esox lucius	8.9*				
Cobitis teania					
Cyprinus carpio					
Lepomis gibbosus					

Leuciscus leuciscus	
Pseudorasbora parva	
Rutilus pigus	
Zingel zingel	

*Indicates the significance level: < 0.05** Indicates the significance level: <0.01***Indicates the significance level: < 0.001

The use of fish communities in the operational monitoring of water bodies in Serbia is discussed in the report by Simonović et al. (2018). The report uses both fish and macrophytes to evaluate the ecological status and potential of water bodies in Serbia. The ecological status assessment was conducted using the Fish Index Slovakia (National method for evaluating the ecological status of streams based on fish populations) (Kováč 2015).

The results indicate the significant possibilities of applying this index in assessing the ecological status/potential of water bodies in Serbia and the need for its adaptation and modification in relation to the local geographical, hydrological, and hydroecological conditions of Serbia.

One of the possible approaches in the use of fish and fish communities in the assessment of the ecological status/potential of water bodies was obtained based on our research aimed at monitoring the relationship of high, moderate, and low susceptibility fish species according to van Treeck et al. (2020) in the rivers and reservoirs of Serbia (Fig. 7).

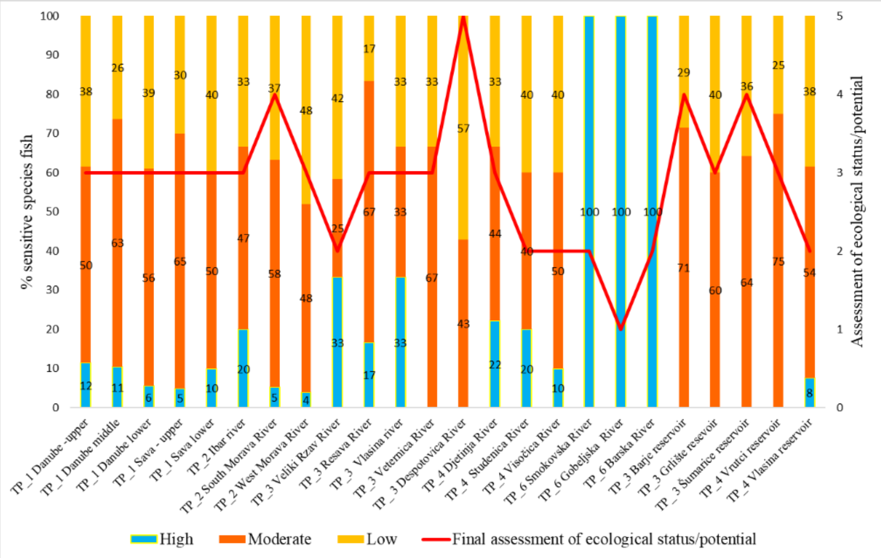

Figure 7. Percentage of sensitive fish species in selected rivers and reservoirs of Serbia: **H –** High sensitivity species: *Salmo trutta, Oncorhynchus mykiss, Thymallus thymallus, Barbus barbus*; *Leuciscus idus*. **M** – Moderate sensitivity species: *Cottus gobio, Abramis brama, Barbus balcanicus, Ballerus sapa, Cyprinus carpio, Chondrostoma nasus, Leuciscus aspius, Phoxinus phoxinus, Squalius cephalus, Rutilus rutilus, Vimba vimba, Hypophthalmichthys nobilis, Hypophthalmichthys molitrix, Vimba vimba, Ctenopharyngodon idella, Scardinius erythrophthalmus, Pelecus cultratus, Perca fluviatilis, Zingel zingel, Sander lucioperca, Sander volgensis, Gymnocephalus schraetser, Acipenser ruthenus, Silurus glanis, Esox lucius.* **L** – Low sensitivity species*: Carassius gibelio, Alburnus alburnus, Alburnoides bipunctatus, Gobio obtusirostris, Pseudorasbora parva, Rhodeus amarus, Blicca bjoerkna, Rutilus pigus, Zingel streber, Cobitis taenia, Sabanejewia balcanica, Barbatula barbatula, Lepomis gibbosus, Ameiurus nebulosus,* (according to van Treeck et al. (2020). Abbreviations: TP_1 – Type 1 – large lowland rivers; TP_2 – Type 2 – large river; TP_3 – Type 3 – small and medium watercourses (altitude up to 500 m); TP_4 – Type 4 – small and medium watercourses; (altitude over 500 m); TP_6 – Type 6 – small watercourses outside the area of the Pannonian Plain that are not covered by Type 3 and 4 (Anonymus 2010). Final assessment of ecological status/potential: 1 – high, 2 – good, 3 – moderate, 4 – poor, 5 – bad (Anonymus 2011)

The results obtained indicate a significant correlation between the presence of sensitive fish species and the final assessment of the ecological status/potential of water bodies in Serbia, as determined by the communities of aquatic macroinvertebrates and phytobenthos (diatoms) in accordance with the Water Framework Directive (WFD 2000).

In the large rivers Danube, Sava, and Morava, the ecological status ranges from good to moderate, and moderately sensitive fish species dominate, with some tolerant species present as well. In larger tributaries of these rivers, there is a stronger correlation between ecological status and the presence of sensitive fish species. Tributaries with poor ecological status, like the Despotovica (TP_3) are dominated by tolerant fish, while those with moderate status are medium sensitivity fish. Tributaries with good ecological status, such as (TP_3 Veliki Rzav and Vlasina rivers) and (TP_4 Djetinja, and Studenica rivers), have a significant presence of sensitive fish species. Sensitive fish species clearly dominate in salmonid rivers with excellent and good ecological status, such as the Gobeljska River, Samokovska River, and Barska River (TP_6). In the investigated lowland reservoirs (TP_3), where the ecological potential ranges from moderate to poor, moderately sensitive fish species dominate, with a smaller or larger share of tolerant ones depending on the degree of ecological potential. The presence of sensitive fish species is greater only in mountain reservoirs, such as the Vlasina reservoir (TP_4) (Fig 7).

6 Conclusion

All previous research and experience in utilizing fish to evaluate the ecological sustainability of fish stocks, the ecological status, and the potential of water bodies demonstrate the need for continued research and the creation of more effective models and methods that are adapted to the regional ecological conditions of Serbia, the Western Balkans, and the Balkan Peninsula in general.

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