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Case Study 3 – Annex

Danube River Basin – harmonising inland, coastal and marine ecosystem management to achieve aquatic biodiversity targets[1]

[1]See full case study report for author and project information. Further information at https://aquacross.eu/content/case-study-3-danube-river-basin-harmonising-inland-coastal-and-marine-ecosystem-management

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Annex 1: Danube tributaries: Impact of hydropower

Southeast Europe (SEE) represents one of the hotspots of aquatic biodiversity worldwide (Griffiths, Kryštufek, & Reed, 2004). In the same time, the area sees a boom of hydropower development, with more than 2500 dams being planned, even in nature conservation areas (EU Natura 2000 areas). Thus, the construction of hydropower dams represents a clear threat to the regional aquatic biodiversity and ecosystem services, while there is hardly any data available so far on the environmental effects of hydropower plants in that region featuring high aquatic biodiversity.

So far, there is no nationally available overviews on the number of existing and planned HP plants for the most countries of SEE Europe. As data on the operation type of HP plants are often lacking, too, as well as the environmental flows provided, the impacts of existing HP plants on the flow regimes of rivers are largely unknown, and in consequence the ecological impacts, too. Especially, potentially valuable hydrological and ecological studies comparing the situations before and after dam construction are rare. There are missing national strategies for hydropower development which are legally binding.

Selection of the relevant indicators, metrics and indices for assessing the pressure induced by hydropower activity

Based on data availability for Danube tributaries indicators for the D-P-S analyses in SEE were selected according with the AQUACROSS concept on drivers, human activities, pressures and ecosystem state, which was specified for indicators, metrics and indices in WP4 and WP5.

Water abstraction, water flow changes and interruption of longitudinal river continuity for energy production by hydroelectric dams were selected as indicators for physical changes by human activities (Table AI 1), and fish communities were selected to describe state/ecosystem components (Table AI 2)

Table AI 1 Available integrative indicators describing selected pressure induced by hydropower activity

Pressures	Indicator	Available metric/Index	Data availability
Water flow rate changes, Water abstraction	Water flow changes, hydrological alteration - local, including sediment transport considerations	Extent of area affected by permanent hydrographical alterations River water bodies significantly affected by impoundments, water	Slovenia, Croatia, Montenegro, Serbia, Bosnia and Herzegovina, Bulgaria, Romania

		abstraction or hydropeaking	
	ditto	Collated database of future infrastructure projects (hydrological alteration)	Slovenia, Croatia, Montenegro, Serbia, Bosnia and Herzegovina, Bulgaria, Romania
Water flow rate changes, Water abstraction	Water flow changes, hydrological alteration	The ecodifference method (ecodeficit and ecosurplus metrics)	5 rivers in Slovenia and Croatia affected by hydropower operation in different ways
	ditto	The Indicators of Hydrologic Alteration model	5 rivers in Slovenia and Croatia affected by hydropower operation in different ways
	ditto	Method for the assessment of flow alteration by hydropeaking	5 rivers in Slovenia and Croatia affected by hydropower operation in different ways

Table AI 2: Available integrative indicators describing state/ecosystem components.

State	Component /indicator	Metric/Index examples	Data availability
Biological state	Fish	composition, abundance; population	Romania

Mapping the pressures represented by hydroelectric dams in SEE

The known locations of current and planned dams based on available data sets, which are partially known to be incomplete (e.g. for Romania), were mapped (Figure AI 1).The map hence shows the minimum extent of potential effects of hydropower on rivers in SEE, which hence may hamper or prevent reaching the goals of the Water Framework Directive (WFD) and Natura 2000 Directive there.

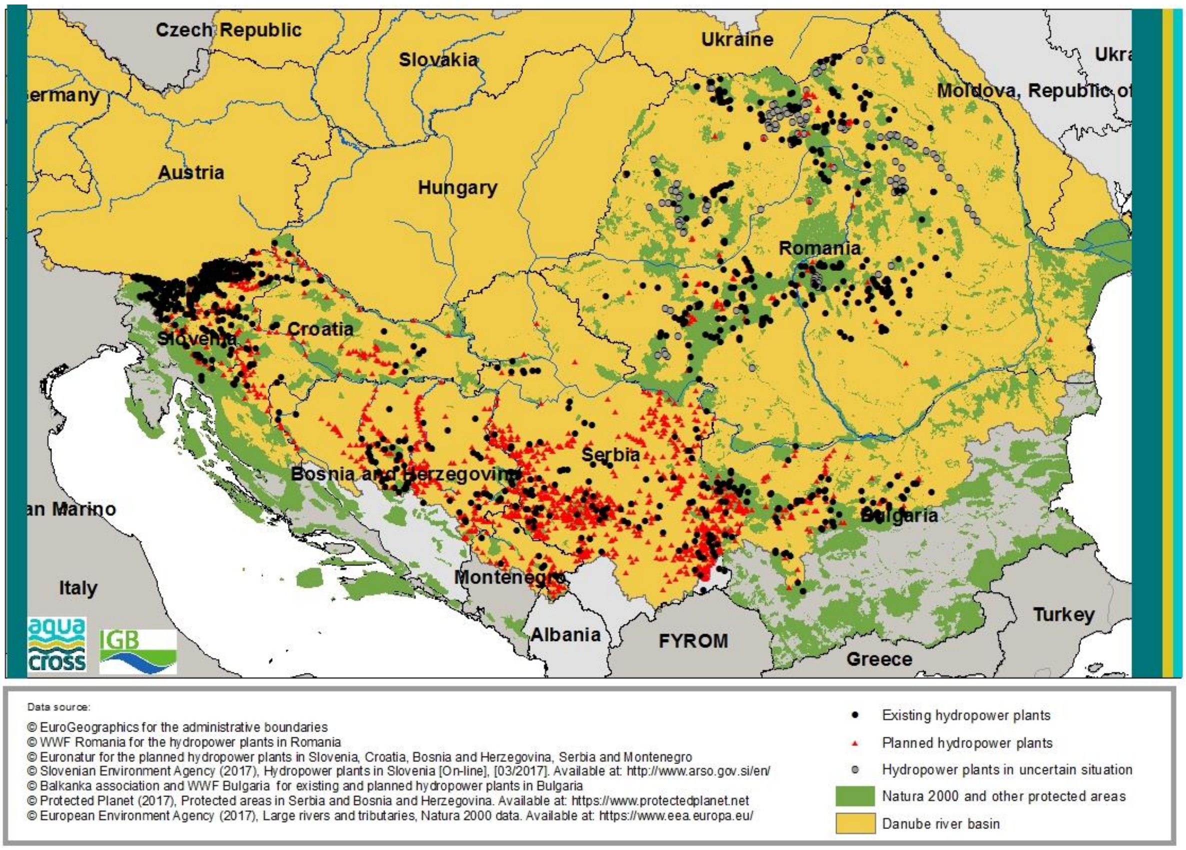


Figure AI 1: Map of operating and planed hydropower plants in Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Bulgaria and Romania. Please note that shown available data are probably incomplete, especially for Romania.

The map is based on a database with 2372 hydropower plants in various stages of approval, construction, or operation which was collated based on various information sources from Euronatur, Slovenian Environment Agency (www.arso.gov.si/en/), http://balkanka.bg), WWF Romania based on information provided by the Romanian Environmental Protection Agency (http://www.raurileromaniei.ro/harta/), Balkanka association (https://dams.reki.bg/Dams/Map), WWF Bulgaria (http://www.wwf.bg/) and others which cover 7 countries situated in the middle and lower Danube catchment (Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Bulgaria and Romania).

An analysis of this database shows that from 1044 operational HP plants, 333 (32%) are located in Natura 2000 areas, and from 1501 planned HP plants, 345 (23 %) would be located in Natura 2000 or other protected areas (Table AI 3).

Table AI 3: Number of the operating and planned HP plans in 7 countries from SEE (based on available data)

SEE countries	Existing	Planned	In Natura 2000 areas and other protected areas	Planned in Natura 2000 and other protected areas)
Bulgaria	84	82	51	42
Slovenia	419	150	110	67
Croatia	23	106	22	57
Romania	326	64	116	31
BiH	68	266	9	18
Serbia	113	780	25	126
Montenegro	11	53	0	4
Total	**1044**	**1501**	**333**	**345**

The fact that 23% of all new HP projects are planned in protected areas shows that this practice is in a contradiction to some guidelines for hydropower development that are highlighting protected sites as “no-go” areas such as the “Sustainable Hydropower Development” approach in the Danube Basin (ICPDR, 2014). The territory of protected areas in Bosnia and Herzegovina and Serbia is low and significantly below the European average (aprox. 2%) (Appleton et al. 2015), therefore percentage of planned HP projects in protected area there is lower than for example in Croatia or Slovenia.

Hydropower installed to date on rivers in the Danube basin in Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro

Large HP facilities provide a dominant share (95%) of total installed capacity in the rivers from the studied area (Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro) which sums up to 5148 MW. This capacity is contributed by only 7% of the total number of HP plants. Small HP plants represent 82% of the total number and provide only 2% of total installed capacity (Figure AI 2).

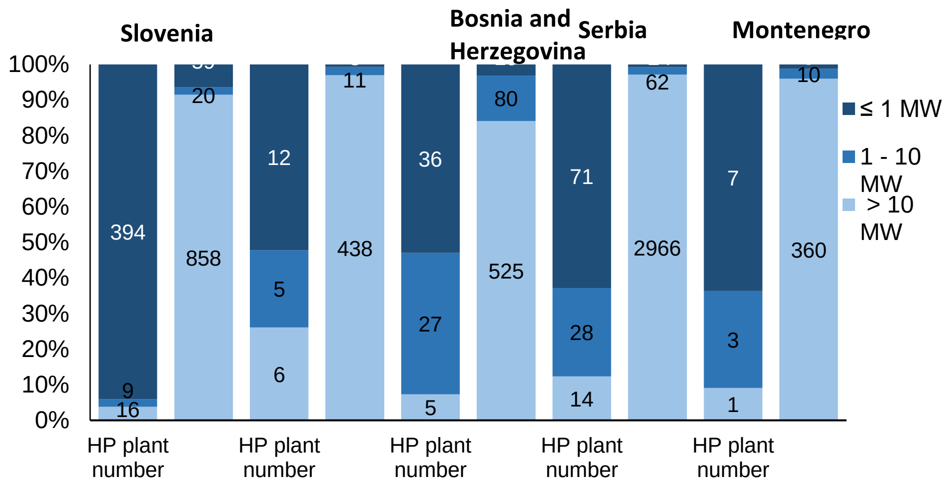


Figure AI 2: Country-specific distribution of installed electricity generation capacity (MW) among hydropower size classes, as compared to the respective distribution of the numbers of hydropower plants in Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro in 2017. The numbers represent the respective numbers of HPPs. For Bulgaria and Romania such analyses were not possible because of data lack.

The high number of small HPPs with small electricity output raises the question whether these financial incentives provided at national level for small HPPs are efficient to increase the share of renewable electricity production (Abbasi & Abbasi, 2011). Most planned HPPs in the study region are small sized, although they cause significant damage since they extend to almost every river and are unfortunately often projected on rivers with high ecological value (Kelly-Richards et al. 2017; Schwarz, 2015).

The construction of hydropower plants of a certain size in last years may be determined by several factors, as the availability of so far unused hydropower potential, by regional electricity demand, by the availability of a high voltage electric grid, and by the structure of financial subsidy programs (IRENA, 2017; Liu, Masera, & Esser, 2013). In order to achieve the objectives from the EU Renewable Energy Directive, most EU member states have established financial support schemes for renewable electricity production, as fixed feed-in tariffs and feed-in premiums. These financial incentives are the most beneficial for small HPPs (Bosnia and Herzegovina Government, 2016; Croatia Government, 2013; Montenegro Government, 2014; Republic of Serbia Government, 2013; Slovenia Government, 2010), and seem to be sufficiently attractive to trigger the present boom of small sized HP facilities in the study area (Schwarz, 2015). According to a study of the International Monetary Fund (IMF), Serbia and Bosnia and Herzegovina are among the world's top ten countries with the highest percentage of energy subsidies in the Gross Domestic Product (Coady, Parry, Sears, & Shang, 2015).

Analysis of the impact of hydropower plants on river hydrology in Slovenia and Croatia

Assessments of assumed environmental effects of future HPPs in SEE are hampered by the fact that even the basic effects of HPPs on the hydrology of rivers have hardly been studied in that region (Bonacci & Oskoruš, 2010; Bonacci, Tadic, & Trninic, 1992; Globevnik & Mikoš, 2009; Žganec, 2012).

The alteration of flow regimes is often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands (Sparks, 1995; Tockner, Pennetzdorfer, Reiner, Schiemer, & Ward, 1999). All species of the fauna and flora of rivers and their floodplains have adapted during their evolution to specific flow regimes. Correspondingly, the biotic communities colonizing certain river systems have been shaped by adaptation to their typical discharge levels, as well as to specific short-term and long-term dynamics of flow (Allan, 1995; Bunn & Arthington, 2002; Lytle & Poff, 2004; Townsend & Hildrew, 1994). Hydrological alterations may result in reduced or increased water levels, flow velocities and in artificial short-term or seasonal dynamics of those variables, which have direct effects on habitat features and availability both in the river channel and in the floodplain, as well as on sediment transport and sediment colmation (Magilligan & Nislow, 2005; Nislow, Magilligan, Fassnacht, Bechtel, & Ruesink, 2002). These impacts usually result in the alteration and homogenization of aquatic and water-dependent habitats in the affected river corridor, in the loss of lateral and longitudinal connectivity, leading to a disruption of life cycles (Kinsolving & Bain, 1993; Scheidegger & Bain, 1995). In consequence, the diversity of typical riverine biota decreases, exotic species spread, and many ecosystem dwindle not only at the reservoir site, but are additionally significantly degraded in most of the downstream river sections (Bunn & Arthington, 2002; Grill et al., 2015; Renöfält, Jansson, & Nilsson, 2010).

Knowledge on the impacts of planned HPPs on the hydrological regime of rivers in SEE would also represent a pre-requisite to develop approaches aiming at the mitigation or optimization of HPP operation to reduce environmental effects of flow regime alterations (B. Gao, Yang, Zhao, & Yang, 2012).

The study covers several river sub-basins within the Danube river basin located in Slovenia and Croatia which were selected due to the relatively good availability of gauging data there (Table AI 4, Figure AI 3). The hydrology of the studied rivers in Slovenia and Croatia is shaped by the Alpine and Continental climate components of the area, the marked orography, and by the widespread karstification of the river catchments. Rivers range from Alpine (e.g. Drava, Sava) to Continental karstic rivers (e.g. Gojacka Dobra).

Hence, for Slovenia and Croatia a complete database of the existing HPPs and gauging stations including their precise positions was collated. From there, longstanding hydrological gauging stations were chosen that are located downstream of the HPP, with daily data before and after HPP construction. If available, sub-daily (hourly) data were obtained. Data were provided by

Slovenian Environment Agency (www.arso.gov.si/en/) and Croatian Meteorological and Hydrological Service (http://meteo.hr/index_en.php).

Discharge data were available for 11 river reaches located downstream of several HPP types (Table AI 4, Figure AI 3). Among them, there are depleted river reaches (DR), reaches downstream of storage dams either with water withdrawal (STW), reaches downstream of diversion storage either with water withdrawal (STDW), or without water withdrawal (STD), and reaches downstream of run-of-river (RoR) HPP types (Table AI 4). The length of the daily discharge records for pre-impact periods (9 - 52 years) and post-impact (6 - 54 years) periods varied among hydrological gauging stations. For 13 presumably impacted gauging stations, sub-daily (hourly) data were available. Additionally, sub-daily data from 7 unimpacted gauging stations were obtained, which represent in total 106 years of non-altered discharge.

For three gauging stations with relatively short hydrological records, there were data for longer time spans available from nearby other gauging stations, which were hence included into analyses (Jesenice and Blejski Most (6U and 6D), Medno and Sentjakob (10U and 10D), and Varazdin and Dubrava (15U and 16D)) (Table AI 4). These stations were combined as there are no tributaries entering in between, and as the distance is max. 15 km, so that no significant difference in flow dynamics is assumed. During the gauging station selection process it became apparent that most gauging stations were constructed concurrently with HPPs, and many of these stations were decommissioned soon after HPPs were completed or they are operated by HPP owner, which thus greatly limits the number of acceptable data sets.

Table AI 4: Hydrological gauging stations selected due to assumed flow alterations by upstream hydropower plants, and hydrological basic information. Abbreviations: DR depleted river reach; STW - river reach downstream of storage hydropower plant which withdraw water from other rivers. STDW - reach downstream of diversion storage hydropower plant (after confluence of diversion and river bed) which withdraw water from other rivers; STD - reach downstream of diversion storage hydropower plant after confluence of diversion and river bed; RoR - reach downstream of run-of-river hydropower plant.

ID	HPP name	Gauging station	River (Country)	Location	River type	Pre-impact period	Post-impact period	H(m a. s. l.)	Catchment area [km2]
1	Formin	Borl	Drava (SI)	DR	Alpine nival-pluvial	1954-1977	1978-2016	322	14 662
5	Golica	Muta	Bistrica (SI)	DR	Alpine pluvial-nival	1954-1990	1991 - 2011	326	146
6A	Moste	Jesenice	Sava Dolinka (SI)	STW	Alpine high mountain nival-pluvial	1918-1952	6B	566	258

6B	Moste	Blejski most	Sava Dolinka (SI)	STW	Alpine high mountain nival-pluvial	6A	1953 - 2015	428	505
7G	Gojak	Lesce	Gojacka Dobra (HR)	STDW	Continental pluvial-nival	1946-1959	1960-2010	140	608
7L	Lesce	Lesce	Gojacka Dobra (HR)	STW	Continental pluvial-nival	1946-1959	2010-2016	140	608
8G	Gojak	Stative	Gojacka Dobra (HR)	STDW	Continental pluvial-nival	1946-1959	1960-2010	117	1 008
8L	Lesce	Stative	Gojacka Dobra (HR)	STW	Contineтal pluvial-nival	1946-1959	2010-2016	117	1 008
10A	Medvode	Sentjakob	Sava (SI)	RoR	Alpine medium mountain nival-pluvial	1926-1953	10B	267	2 201
10B	Medvode	Medno	Sava (SI)	RoR	Alpine medium mountain nival-pluvial	10A	1953 - 2015	300	2 285
11	Maribor-ski otok	Maribor	Drava (SI)	RoR	Alpine nival-pluvial	1926-1948	1949-2012	364	13 415
13	Zlatolicje	Ptuj	Drava (SI)	STD	Alpine nival-pluvial	1959-1968	1969-2014	335	13 664
14	Formin	Ormoz	Drava (SI)	STD	Alpine nival-pluvial	1962-1974	1991-2009	308	15 356
15	Varazdin	Varazdin	Drava (HR)	STD	Alpine nival-pluvial	1954-1974	1975-1982	166	15 616
16	Dubrava	Donja Dubrava	Drava (HR)	STD	Alpine nival-pluvial	15	1982-2015	130	16 000

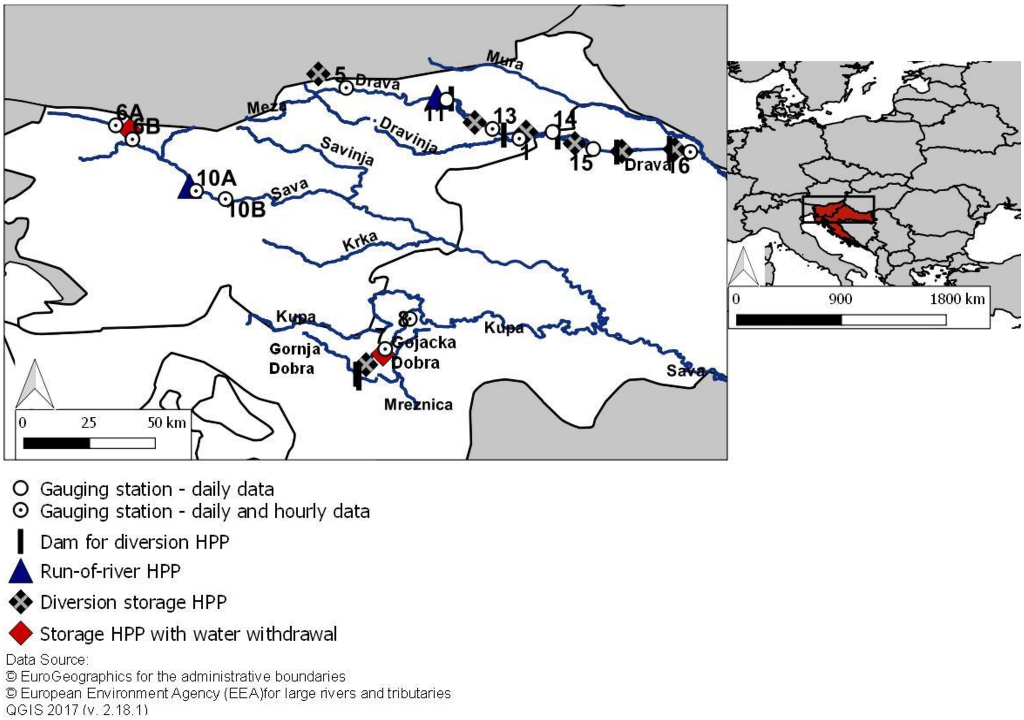


Figure AI 3: Hydrological gauging stations selected due to assumed flow alterations by upstream hydropower plants, and hydrological details

We analysed the type, magnitude, and direction of hydrological shifts across several types of hydropower plants (run-of-river, storage, diversion) based on gauging data at different temporal scales with three approaches, as (1) the ecodifference method (ecodeficit and ecosurplus metrics), (2) the Indicators of Hydrologic Alteration model and (3) a method for the assessment of hydropeaking flow alteration. Thereby, we applied these analyses to 5 rivers in Slovenia and Croatia affected by hydropower operation in different ways.

The methods differ in respect to data resolution and the time-scale of hydrological alterations which may be detected. Required data are short term (at least one year) daily discharge data for pre- and post-impact periods for method (1), long term (preferable more than 10 years) daily data from pre- and post-impact for method (2) and short term (at least one year) sub daily data for method (3).

The Ecodifference metrics (Vogel et al. 2007), including the ecodeficit (ED) and ecosurplus (ES) parameters, evaluate alterations to the flow regime of a river based on flow duration curves (FDCs). FDCs are calculated from daily stream flow data and provide a measure of the percentage of time duration that stream flow equals or exceeds a given value (Y. Gao, Vogel, Kroll, Poff, & Olden, 2009). Available hydrological time series were subdivided into the period before HPP construction and the period after that, and consequently two FCDs can be obtained for each HPP, i.e., a regulated FDC and an unregulated FDC. The ecodeficit is the percent area between the FCDs where the regulated FDC is below the unregulated FDC (Zhang et al., 2016a), while the ecosurplus is the percent area where the regulated FDC is above the unregulated.

Finally, the ecodifference, which mirrors the total change of flow regime, was computed as the sum of the ecodeficit and ecosurplus (Y. Gao et al., 2009; Zhang, Huang, & Huang, 2016).

When calculated on an overall percentage basis, ecodifference provides a measure of relative change from the unaltered condition. If ecodifference is higher than 15%, this river section is estimated as highly altered.

The Indicators of Hydrologic Alteration (IHA) method (IHA 7.1 software) may demonstrate the hydrologic alterations associated with HPP operation which will clearly affect the functioning of river ecosystems (Richter, Baumgartner, Powell, & Braun, 1996). Based on daily discharge data, IHA calculates more than 30 indices which describe the hydrologic regime of a certain gauging station. The indices generated by IHA consist of five major categories: (1) magnitude of monthly flows; (2) magnitude and duration of annual extreme and base flow conditions; (3) timing of annual extreme conditions; (4) frequency and duration of high and low pulses; and (5) rate and frequency of flow changes (Table AI 5) (Richter et al., 1996).

Thereby, non-parametric statistics were applied to skewed data distributions, which is common in hydrological data. In order to compare impacts of HPPs on quantitative way, we calculated for each HPP median value and degree of hydrological alteration (D) which was calculated according to (Richter, Baumgartner, Braun, & Powell, 1998).

Thereby, it is suggested that a level of D < 33% compared to the unaltered flow regime represents little or no alteration, 34% > D < 67% moderate alteration, and D > 68% high alteration (Richter et al., 1998).

Table AI 5: Output parameters for the IHA model (the 32 output parameters are grouped into five major categories; see Richter et al., 1996)

Indicator category	Description of categories	Indicators of Hydrological Alteration
Category 1	Magnitude of monthly flow	Average/Median flow of each calendar month
Category 2	Magnitude and duration of annual extreme flows, and the base flow conditions	Annual minimum 1-, 3-, 7-, 30-, 90-, day means/medians. Annual maximum 1-, 3-, 7-, 30-, 90-, day means/medians. Base flow index. Number of zero days
Category 3	Timing of annual extreme flow conditions	Julian date of annual 1-day minimum. Julian date of annual 1-day maximum
Category 4	Frequency and duration of high and low pulses	Number of low pulses each year. Mean duration of low pulse with each year. Number of high pulses each year. Mean duration of high pulse with each year
Category 5	Rate and frequency of flow changes	Up- and down rate. Number of flow reversals

The HP indicators software and method developed by Carolli et al., (2015) considers two of three indicators proposed by Meile, Boillat, & Schleiss, (2011), as HP1, which is a dimensionless measure of the magnitude of hydropeaking, and HP2 which reflects the temporal rate of discharge change. For both metrics the thresholds TRHP1 and TRHP2 were established based on the analysis of natural or near-natural flow series which enabled to identify the presence of hydropeaking. Thereby, the degrees of hydropeaking intensity were identified, as hydropeaking class 1 (absent or low alteration), hydropeaking class 2a and 2b (medium alteration) and hydropeaking class (strong alteration), following Carolli et al., (2015).

Results show that the various hydropower plant types have generally strong but varying effects on flow regime, producing a flow regime differing from the pre-impact natural flow regime. Flow regime was detected to be altered at all investigated river reaches downstream of hydropower plants (HPPs), according to the overall degree of hydrological alteration of the IHA model. However, degree of alteration vary: 8 river reaches were characterized as highly altered, and five as medium altered (Table AI 6). Medium altered river stretches are located downstream of diversion storage HPPs (STD) and run-of-river (RoR) HPPs (Table AI 6), while highly altered river stretches are located in depleted river reaches and downstream of storage HPPs with water withdrawal (STW and STDW) (Figure AI 4).

Flow regime within downstream of STW and STDW is the most severely changed as compared to the pre-impact flow regime. There are observed the highest degree of hydrological alteration of all IHA model's categories as compared to other HPP types (Figure AI 4). The most severe changes across these investigated sites occur in the rate and frequency of flow changes (Figure AI 4). Moreover only rate and frequency of flow changes is highly altered downstream of STD and ROR HPPs while other IHA model's categories downstream of these HPP types are medium altered (Figure AI 4). Within DRs magnitude of monthly flows is the most altered by drastic decrease of monthly discharge throughout all months (Figure AI 4, Table AI 6). Furthermore, there is a discharge reduced up to 11% of average pre-impact annual flow.

Similar results were revealed by ecodifference method where river reaches downstream of diversion storage and run-of-river HPPs exhibit less alteration than river reaches located in depleted river reaches and downstream of STW and STDW HPPs. Depleted river reaches reveal a strong change of flow duration curve resulting in a very high ecodeficit values. STW, STDW HPPs cause an increase in ecosurplus metric, while STD and RoR HPPs show increase in ecodeficit metric as compared to pre-impact conditions.

Moreover, hydropeaking (i.e. rapid variations of flow regime) was evident only at sub-daily scale downstream of storage, diversion storage and run-of-river hydropower plants (Table AI 6). Even 50 km downstream of STW HPP, hydropeaking is very strong (Table AI 6; GSs 8L, 8G). RoR HPPs in our study area produce hydropeaking, even that it is technically not possible to store large amounts of water in RoR HPPs. Therefore we explain our findings by the presence of HPPs with hydropeaking operation mode upstream of the RoR HPPs, which therefore still show discharge fluctuations shaped by hydropeaking. In contrast, depleted river reaches are not altered by hydropeaking (Table AI 7).

Thus, the total extent of flow alteration only gets visible with the availability of sub-daily hydrological data. As only a small fraction of all current gauging stations in the study area is actually recording at a sub-daily scale, the actual fraction of gauged river reaches which is affected by hydropower plants cannot be estimated to date. The combination of several methods could provide a practical and objective method for the analysis of hydrological alterations. Hydropeaking flow alteration method could be used complementary to other two used methods (Meile et al., 2011; Richter et al., 1996) in order to detected sub-daily changes which are obviously not detectable with other methods.

Table AI 6: The hydropeaking indicator values (HP1, HP2) and overall hydropeaking values for each gauging stations; gauging stations 11, 14 and 15 do not measure hourly data; THP1 = 0.4; THP2 = 1.6; *: Significant difference between unaltered and altered periods at the 5% level.

Gauging Station (GS)	1	5	6	7G	7L	8G	8L	10	13	15/16
HPP Type	**DR**	**DR**	**STW**	**STDW**	**STW**	**STDW**	**STW**	**RoR**	**STD**	**STD**
HP1	0.2*	0.1	0.8*	1.2*	1.3*	0.9*	1.2*	0.5*	1.3*	0.7*
HP2	3.1*	0.1*	5.2*	7.1*	15.6*	4.1*	12.2*	12.0*	94.2*	40.5*
Overall	2b	1	3	3	3	3	3	3	3	3

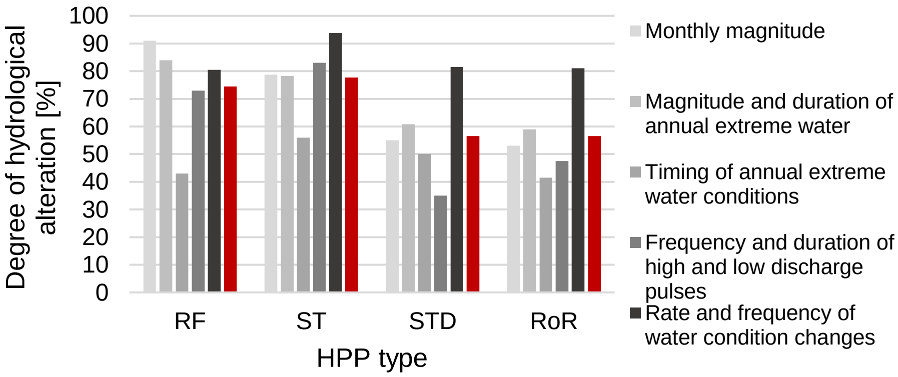


Figure AI 4: The degree of hydrological alteration of the IHA model's flow categories of different HPP types

Table AI 7: Degree of hydrological alteration of a flow regime (Equation 2); (1) ≤ 32% representing little or no alterations; (2) 33-66% representing moderate alteration; (3) 67-100% representing a high degree of alteration

Gauging Station (GS)/ parameters	1	5	6	7G	7L	8G	8L	10	11	13	14	15	15/16
Type of HPP	**DR**	**DR**	**STW**	**STDW**	**STW**	**STDW**	**STW**	**RoR**	**RoR**	**STD**	**STD**	**STD**	**STD**
October	100	100	80	80	100	35	61	8	23	33	26	88	12

November	100	43	30	65	100	86	100	70	41	67	13	63	21
December	100	14	78	61	67	30	61	19	15	50	13	63	24
January	100	62	86	70	61	56	100	5	41	50	24	25	21
February	100	81	100	24	22	30	61	26	36	83	26	100	56
March	100	43	78	80	61	72	61	32	4	67	13	25	16
April	90	62	86	70	61	91	61	22	2	33	13	13	29
May	100	62	77	61	67	53	61	8	62	33	38	36	24
June	100	100	72	73	100	21	100	8	49	17	26	13	6
July	90	43	86	25	4	31	100	2	69	67	38	13	12
August	100	81	69	16	42	55	71	39	20	33	26	29	47
September	100	62	83	30	67	62	100	5	23	33	26	63	21
Overall_Cat_1	99	83	89	68	83	74	90	52	54	68	32	77	43
1-day min	100	82	52	83	61	12	53	44	16	100	13	25	47
3-day min	100	81	56	52	61	7	61	51	2	67	1	25	3
7-day min	100	100	64	26	42	39	61	57	15	33	1	25	13
30-day min	100	100	100	54	100	67	22	62	15	83	73	25	29
90-day min	100	81	100	65	61	11	17	39	23	50	49	25	29
1-day max	30	5	53	83	100	49	100	73	77	67	36	50	24
3-day max	40	24	85	49	61	35	100	66	49	50	11	13	29
7-day max	80	43	85	90	61	7	61	53	28	50	26	63	74
30-day max	100	43	95	85	100	91	100	53	2	67	26	25	38
90-day max	100	62	100	85	61	86	61	26	28	100	26	13	6
#zero days	0	0	17	14	3	8	8	0	0	0	0	0	0
Base flow Ind.	50	5	45	70	22	81	61	5	62	50	75	63	65
Overall_Cat_2	88	80	87	78	83	70	82	60	58	82	56	49	56
Date of min	60	14	12	89	100	55	17	42	49	83	7	50	68
Date of max	7	43	50	9	61	12	17	22	36	17	38	13	24
Overall_Cat_3	49	37	41	71	91	45	17	37	46	69	31	42	58
#Low pulse	70	71	60	96	100	86	61	58	62	33	1	25	65
Low pulse L	93	14	100	42	17	92	100	54	12	40	13	59	9
#High pulse	94	73	80	65	100	12	61	1	4	0	13	13	21
High pulse L	52	23	20	53	48	38	74	24	29	27	11	75	35
Overall_Cat_4	86	60	84	82	85	77	88	48	47	33	12	61	34
Rise rate	92	81	5	70	100	75	100	100	36	33	7	63	74
Fall rate	90	81	98	85	100	100	100	21	87	83	26	36	85
#reversals	90	5	100	70	100	97	100	100	49	50	100	100	100

Overall Cat_5	91	70	97	80	100	95	100	88	74	71	77	85	93
Overall	83	66	80	76	88	72	75	57	56	65	41	63	57

1.1.1 Analysis of the impact of hydropower on fish communities in upper lotic systems in Romania

This section analyses the impacts of the small HPP on fish communities in rivers situated in the trout zone (upper lotic systems) in Romania.

Even small hydropower plants can have significant environmental impacts, which start during the construction phase: with habitat degradation, loss of riparian zone and destruction of wetlands (Başkaya, Başkaya, and Sari 2011).

The disruption of longitudinal connectivity by dams can have severe impacts on migratory fish, especially salmonids (Stakėnas and Skrupskelis 2009). Significant reductions in the numbers of salmonids were observed after the construction of small hydropower plants on small mountain rivers (Almodóvar and Nicola 1999, Ovidio et al. 2004).

The populations in upstream river reaches separated by dams from the lower reaches of the same river are often characterized by lower genetic diversity and a lower effective population size compared with populations below dams (Morita and Yokota 2002).

Another problem associated with small hydropower plants is the reduction of stream flow, which may cause profound ecological impacts. Flow abstractions to HPPs often result in a 90–95% reduction of the average annual discharge, which hence usually substantially affects key physical characteristics of the affected stream (e.g. water velocity, water temperature, suspended solids, fine particles and nutrients). Thereby, HPPs will also alter the quantity and quality of aquatic habitat, with cascading impacts on stream biota (Anderson, Freeman, and Pringle 2006, Vaikasas, Bastiene, and Pliuraite 2015).

The fish fauna of Romanian Carpathian first and second order streams (according to the Horton-Strahler classification system) has been studied by several ichthyologist generations, starting with Antipa (Antipa 1909), Bănărescu (Bănărescu 1964, Bănărescu 1969) and followed by others e.g. (Bănăduc et al. 2012).

In order to assess the impacts of a HPP, reference sites are needed to compare impacted with reference fish communities. In case the necessary reference sites are not present or accessible for sampling in the same stream system, an alternative solution is chosen by switching to other similar streams which must be located within the same ecoregion and also in the same longitudinal fish community zone. The Carpathians areas fortunately still harbor such river sectors or even rivers which can be used as reference rivers or river sectors (Bănăduc et al. 2012).

The available scientific information on Romanian ichthyofauna before the 1960's offer the possibility of a comparison of these documents fish communities, which are taken as reference data, with the present situation in order to assess the impact generated by the construction of the HP plants.

A review of scientific publication for Romania was conducted in order to assess the impact of HP plants on the biodiversity. We identified 44 relevant publications analyzing the effects of hydropower on Romanians rivers in terms of fish, 9 on macroinvertebrates and 4 on other biota.

Starting from the review of the scientific publications for Romania, a database for 55 hydropower plants situated in various rivers from Romania was created with information related to the presence and dominance of the fish species from these river reaches in historic reference time (Bănărescu 1964) and after the construction of the hydropower (upstream and downstream) (Bănăduc 1999, 2000, 2005, 2006, 2010, Bănăduc, Mărginean, and Curtean-Bănăduc 2013, Bănăduc et al. 2014, Curtean-Bănăduc, Costea, and Bănăduc 2008, Curtean-Bănăduc et al. 2014, Davideanu et al. 2006, Florea 2017, Momeu et al. 2007, Momeu et al. 2009, Voicu and Bănăduc 2014, Pricope et al. 2009, Telcean and Cupsa 2015, Ureche, Battes, and Pricope 2004, Voicu and Merten 2014, Voicu et al. 2016, Voicu et al. 2017). The database was completed by data provided by personal communication from the experts who published the mentioned studies (Bănăduc personal communication).

From these 55 HP plants situated in various river types in terms of fish zonation, 32 are situated in the trout zone after (Bănărescu 1964). For analyses that river type was selected because:

- the sampling methodology was similar in all case studies,

- in this river type other human pressures, as water pollution, bias are less frequent than in larger streams,

- there is a similar type of micro hydropower plant with diversion which has a installed power < 10 MW which is commonly installed on the streams in the trout zone.

Recorded dominances of the present fish species were assessed according to (Šorić 1996): ED - eudominant (> 20% of total fish number), D - dominant (10 - 20%), SD - subdominant (4 - 10%), R - recedent (1 - 3%), SR - subrecedent (< 1%).

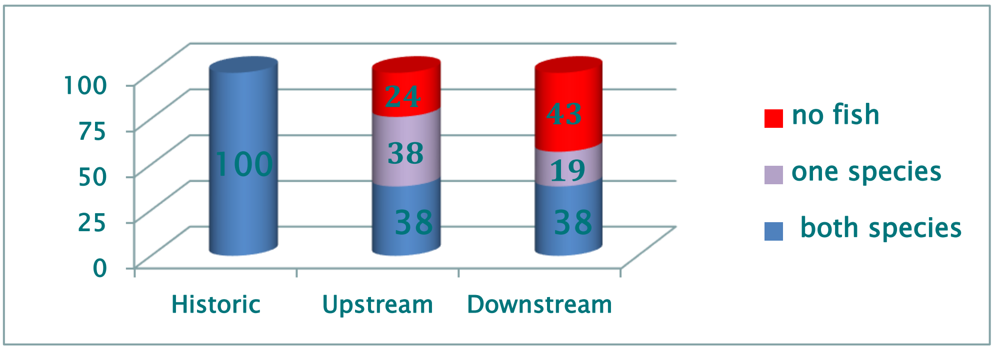
For statistical evaluation these dominance were coded into numbers 5 to 1, and the nonparametric Wilcoxon signed rank test for paired data was applied.

Two fish species are characteristic for the trout zone: brown trout (*Salmo trutta fario*) and bullhead (*Cottus gobio*). Brown trout was found in the reference state (based on the historic data) in all 32 stations, and the bullhead in 21 (60%) of the stations. Analyses of presence-absence data reveal that among the latter 21 stations harboring both species in the reference state, only in 38% both species remained either in the upstream or downstream stations after the construction of the HP plants (

Figure AI 5).

Hence, both the upstream and the downstream reaches of these streams near hydropower plants have clearly less fish species than in reference state: 24% - 43% lack one fish species, and 62% lack both fish species which can be expected there (

Figure AI 5). Presence of brown trout and bullhead in the reference state and presently in upstream and downstream reaches of HPPs at 21 selected sites where in the reference state



both species occur.

Figure AI 5: Comparative analyses of presence-absence data reveal among the 21 stations harbouring both fish species in the reference state with upstream and downstream reaches of HPPs

Analyses dominance records of both fish species at the same sites show that the dominances both of brown trout and bullhead are significantly decreased ($p < 0.005$) both in upstream and downstream reaches near HPPs in comparison with the historical reference state (Table AI 8, Figure AI 6, Figure AI 7). Thereby, the dominance of both species did not differ significantly between upstream and downstream reaches.

In the studied headwater streams other human impacts are improbable, so that the demonstrated relative effects on the fish communities (alteration of dominance) and the absolute reduction of the number of fish species may be mainly attributed to the micro hydropower plant constructed there.

Table AI 8: Wilcoxon signed rank test for paired data on dominance data of Salmo trutta fario and Cottus gobio

Wilcoxon signed rank test for paired data	Salmo trutta fario	Cottus gobio
	P value	P value
Reference state versus upstream	0.00222	0.000851
Reference state versus downstream	0.0003	0.000186
Upstream versus downstream	Not significant	Not significant

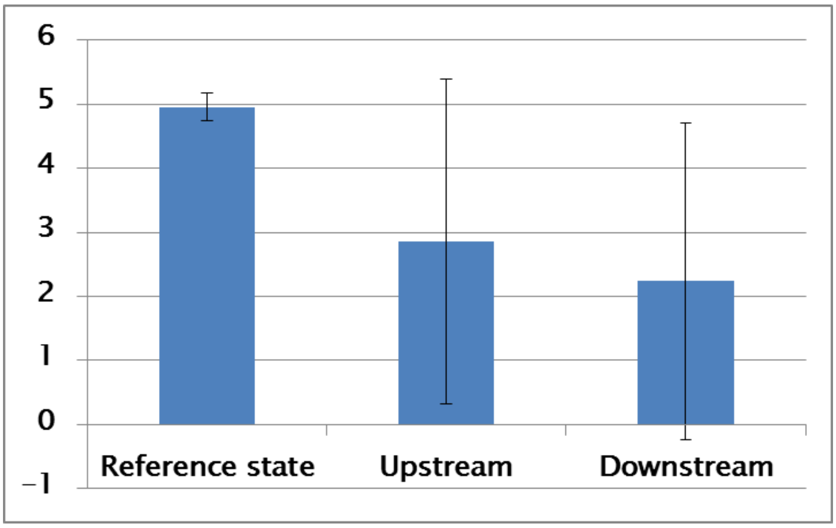
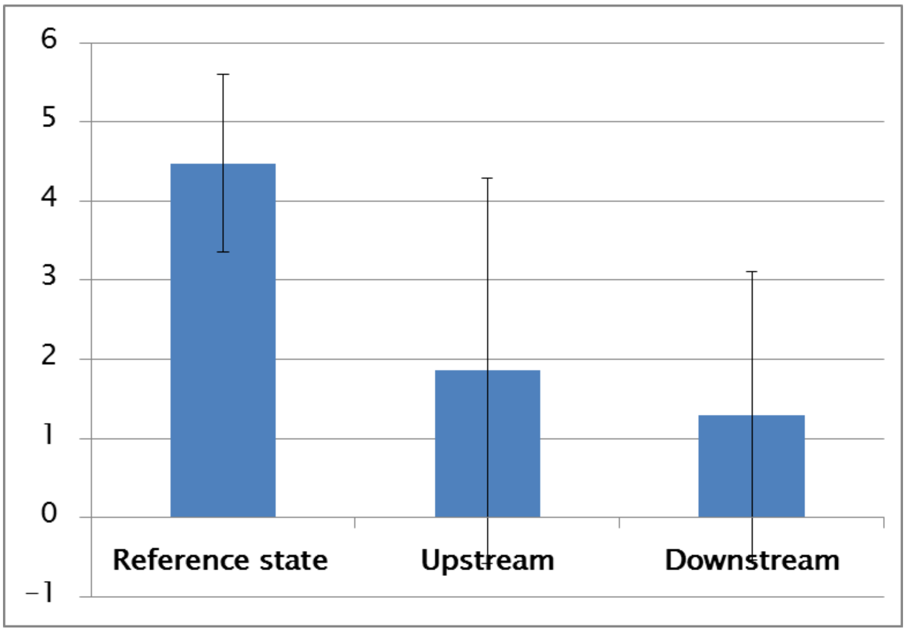


Figure AI 6: Dominance (average and standard deviation) of Salmo trutta in 32 Romanian streams of the trout zone in the historic reference status (left) and according to current records in the upstream and downstream reaches of HP plants located there. Dominance values were coded as follows: ED – eudominant (> 20% number) = 5, D – dominant (10 – 20%)= 4, SD – subdominant (4 – 10)= 3, R – recedent (1 – 3%)= 2, SR – subrecedent (< 1%)= 1, EX-extinct from that river streach = 0

Figure AI 7: Dominance (average and standard deviation) of Cottus gobio in 21 Ro streams of the trout zone in the historic reference status and according to current records in the upstream and downstream reaches of HP plants (right) located there. Dominance values were coded as follows: ED – eudominant (> 20% number) = 5, D – dominant (10 – 20%)= 4, SD – subdominant (4 – 10)= 3, R – recedent (1 – 3%)= 2, SR – subrecedent (< 1%)= 1, EX-extinct from that river streach = 0



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Annex 2: Impact of cyanobacteria blooms on the social-ecological system of the Danube Delta

This chapter summarises the supply and demand side for ecosystem services in the Danube Delta. Further, a specific analysis was accomplished on the current state of biodiversity conservation of aquatic ecosystems in the Danube Delta, by engaging stakeholders in the knowledge, combat or mitigation of eutrophication, climate change and the most visible effects in surface waters: algal (Cyanobacteria) blooms.

Building the knowledge base of the socio-ecological system

The reference configuration of the Inland Danube Delta-Socio Ecological System based on an integrated model of socioeconomic biodiversity drivers, pressures and impacts have:

• a high degree of complementarity between local socioeconomic metabolism and major ecosystem and landscape functions, e.g. over 50% of the region's total supply with resources and services are delivered by the local natural capital, and less than 10% of the total amount of energy (high quality energy content of the biomass which reflects the useful work that can be performed) accumulated by primary producers (NPP) was directly or indirectly diverted towards humans.

• a strong resilience against local and catchment-wide socioeconomic drivers and pressures and the hydrological pulse of the Danube river (Haberl H. *et. al.* 2009).

Despite growing recognition of their societal and ecological importance, deltaic flood plains are declining worldwide at alarming rates (Tockner K. *et al.* 2008). Loss of wetland ecosystem services is strongly related to the climate change and eutrophication, two major anthropogenic stressors that work dependently to favour cyanobacterial blooms in freshwater bodies (Moss *et al.* 2011; Mantzouki *et al.* 2014).

When it comes to manage the occurrence of this major problem in freshwater ecosystems, the socio-economic dimensions of cyanobacteria blooms and the benefits of mitigation measures on ecosystem services in the delta are being totally ignored.

The assessment of Danube delta's ecosystem services and trends was accomplished under Norwegian-Romanian cooperation, emphasizing two periods characterized by fundamentally different socio-political and economic frames: the socialist period (1960-1989) where policies focused on economic development and the market-economy period where policies shifted towards ecological restoration after 1990.

The Danube Delta provides critically important services which benefits accrue from local communities to humanity. In this respect, over 60% of the Delta's ecosystem services have declined over the studied period. The socio-economic benefits from ecological restoration policies are already becoming apparent (***, 2013), but must be improved because of the nitrogen cycling in Danube Delta lakes (Figure AII 1) which will continue to maintained high pressure on the capacity of aquatic ecosystem to produce ecosystem services.

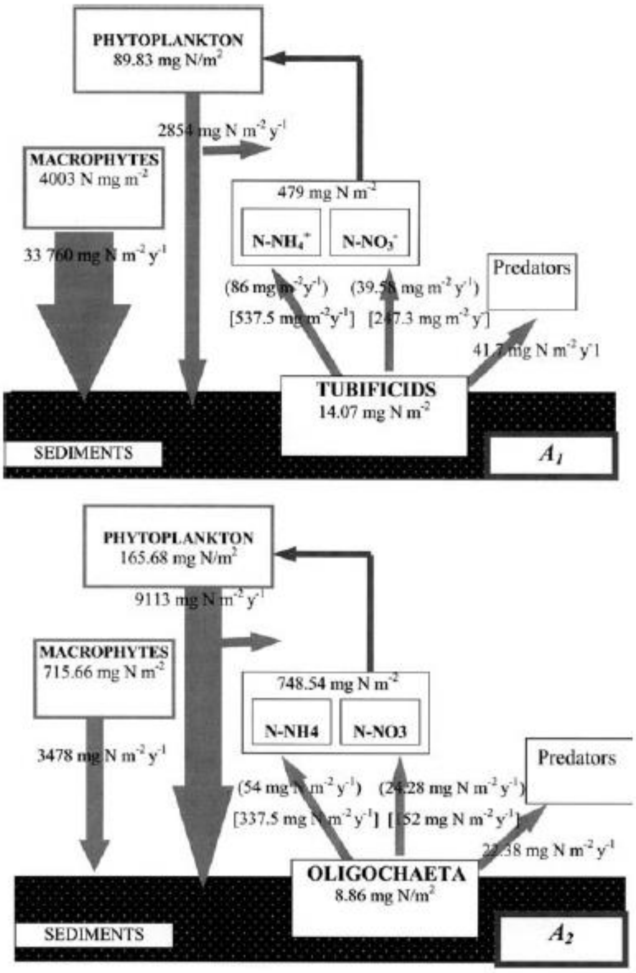

Figure AII 1: Nitrogen cycling in Danube Delta lakes (sources: Rîșnoveanu et. al. 2004)

A characteristic feature of the Delta socio-economic system, as part of the socio-ecological system, is the scarcity of Delta settlements (only 23) and the alternation of low populated areas with unpopulated areas, lack of waste disposal platforms and presence of drinking water networks in only six settlements, lack of services to meet the locals' and the tourists' demands and the high migrations of population (Petrișor *et al.* 2016; Tătar *et al.* 2017).

The interdiction of industrial-scale fishing, failure to fit into the job market due to little access to education and the absence of professional facilities, refusal to attend requalification courses offered by the Labour Employment Tulcea County Agency make this area one with a low income among the population. Poverty in the Delta shows up in poor health and high the risk for disease, due to pollution over the past decade which make the water improper for drinking, lack of collection and evacuation of domestic waste waters and uncontrolled waste dumping; reduced life expectancy due to heart diseases and improper diet (Damian N. & Dumitrescu B., 2009).

Apart from these, there are a small number of local entrepreneurs, with neither the expertise nor the funds to embark upon the development of local sustainable and eco-friendly ventures.

In the Danube Delta the industrial activities are poorly represented and the private agricultural production is taking place in various forms: intensive, organic, traditional-primitive for the subsistence of its inhabit-ants (Lup *et al.* 2016).

Agricultural land accounts 21.6% of the territory of Danube delta (see Table AII 1). In the structure of agricultural land use, the largest share belongs to permanent pastures with agricultural use (24,8%), followed by agricultural land without vegetation (6,87%) and shrub areas used for agriculture (3.05%). The vineyards and orchards occupy insignificant areas (2.67%), on the private land of the inhabitants (***, 2007).

Agricultural land used	Surface	
Land cover classes	hectares	% of used agricultural area
wheat and rye	6,060	5.73
barley and two-row barley	6,464	6.11
maize	6,464	6.11
potatoes	0	0.00
sunflower	8,080	7.63
soy	2,424	2.29
grain legumes	0	0.00
tomatoes and other fresh vegetables	0	0.00
temporary artificial pasture	2,424	2.29
orchards	0	0.00
vineyard	2,828	2.67
other agricultural crops including greenhouses	0	0.00
uncultivated land	29,896	28.24
agricultural lands without vegetation (fallow land)	7,272	6.87
permanent grassland, used for agriculture	26,260	24.81
areas with shrubs used for agriculture	3,232	3.05
woodlands, used for agriculture	0	0
Wetlands, used for agriculture	4,444	4.20
Total agricultural area	105,848	100,0

Table AII 1: Surface situation at the delta level of the main land cover, grouped on agricultural land (data taken from the Statistical Survey on land use in 2005)

Most industrial facilities are concentrated in urban areas adjacent to Danube Delta Biosphere Reserve. In the Danube Delta Biosphere Reserve area is developing an industry based on exploitation and valorisation of natural resources, primarily fisheries, agricultural and reed. (***, 2013)

Aquaculture in the Danube Delta was established in 1961 on an area of 560 ha but due to the poor results obtained in terms of productivity the development of this sector has declined significantly. The yield in fish farms is between 100-200 kg/ha, while the yield of the carp under natural conditions can exceeds 700 kg/ ha (Lup *et al*. 2016).

Case study specific analysis going beyond: D -P -S Danube Delta and Co-Design

Danube Delta is facing serious cyanobacteria bloom risks due to eutrophication and climate change, thus being vulnerable to ecological decline, which also involves challenging issues of biodiversity conservation, restructuration of the wetlands and improving the human well-being. Due to the hydro-morphological structure of the delta, to the release of sedimentary phosphorus and the opportunity of cyanobacteria to use nitrogen from atmosphere as a nutrient source cyanobacteria have been spread in all available niches (Török *et al.* 2017). Further, aggregation of cyanobacteria - concentrated by wind activity - could have high impact on aquatic biodiversity- considering its potential toxic effect, which increases the risk of toxin related health problems - in resting or feeding areas of the wildlife protected species if no action to mitigate their effect is taken.

Hence, the focus of the Danube Delta case study has been co-designed with 24 stakeholders divided in 6 groups, such as public authorities (12 persons), natural resource management (2 persons), Danube Delta Biosphere reserve authority (1 person), research and education (2 persons), NGO's (1 person), inspection and environmental control (6 persons). The authorities were represented by mayors from Local Councils, Tulcea Environmental Protection Agency. The natural resource management institutions were the Romanian Waters - Dobrogea Water Branch and Danube Delta Biosphere Reserve Authority, mean-while the research institutions engaged were National Institute for Marine Research and Development "Grigore Antipa" and National Institute for Research and Development in electrical Engineering, which is currently developing and validating viable solutions for the production of biogas from algal biomass in the Danube Delta Biosphere Reserve in collaboration with Danube Delta National Institute. National Environmental Guard is a specialized inspection and environmental control body that can take action to halt or suspend activity as a result of pollution and environmental damage.

This study analysed the perceptions of stakeholders on algal bloom in aquatic systems in the Danube Delta in order to apprehend potential adaptation and mitigation strategies for the future, and to highlight what type of political support is required for the adoption of these measures. The results could be used in other lakes and coastal waters coastal sites to help plan and mitigate algal blooms in the future.

The participants responded to the designed algal bloom questionnaire through person to person questionnaire deliveries. Based on used stakeholder expertise was created a draft of

Bow Tie diagram (Figure AII 2) to visualise the cause-control-mitigation measures-consequences for the phenomena of algal bloom to the aquatic ecosystems in Danube Delta.

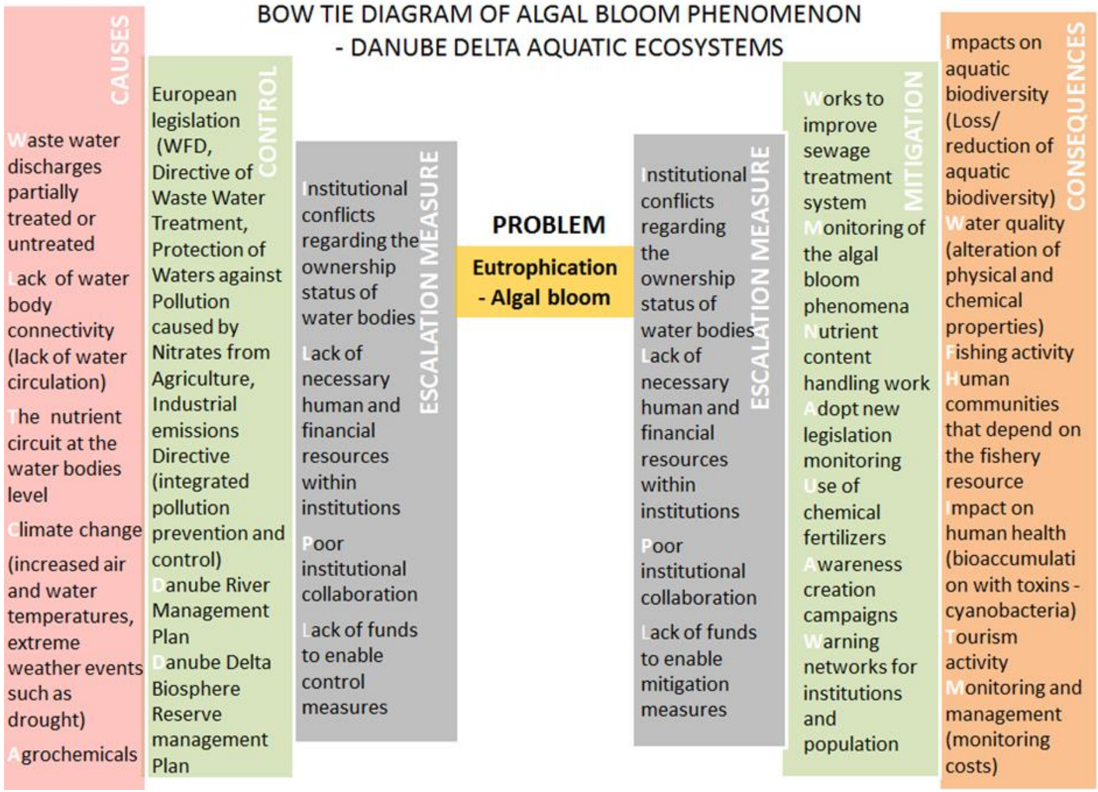

Figure AII 2: Bow Tie Diagram of algal bloom in Danube Delta Aquatic Ecosystems

A Bow Tiw diagram consists of a fault tree on the left side identifying the possible events causing the top event and an event tree on the right side showing the possible consequences of the top event based on the failure or success of safety barriers (Liu Z, 2017). In our case, the top event is represented by loss/reduction of aquatic biodiversity due to eutrophication. In the left side were mentioned the potential causes such as waste water discharges partially threatened or untreated, lack of water body connectivity, increase in water temperature, factors which favor the occurrence of algal bloom) and in the right side are the consequences resulting from the event. The algal bloom problem can result in many interlinking consequences. The controls measures positioned on the left are the solutions preventing the issue form occurring, meanwhile the mitigation column represent the measures which should be considered in order to recover once the event took place. Both control and mitigation measures use a mixture of legislation, water management plans and changes in behaviour and mentalities in order to manage the risk. Control and mitigation measures are specific to a certain cause or consequence and may not be applicable to all of them. In this phase of the analyse there were not drawn linking lines between these components of the diagram.

The escalation factors can be considered as restrictive ones that can damage the efficiency of both control and mitigation measures, such as institutional conflicts regarding the ownership status of water bodies that put barriers to the implementation of control or mitigation measures.

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Annex 3: Analysis of causal linkages for the navigable Danube

Table AIII 1: Selected metrics and indices per indicator related to hydro-mophological alterations for the modelling approach

Code	Description of metric	Indicator	Source
Driver			
Hydropower	river stretch is situated within the reservoir area upstream of a hydropower plant	impact of hydropower plant	https://danubis.icpdr.org/
navigation1	navigation class according to the "Classification of European Inland Waterways"	status of waterway	(Economic Commission for Europe, 2012)
navigation2	critical locations for inland navigation where the fairway depth of 2.5m at Low Navigable Water Level was not achieved	status of waterway	(Fairway, Danube, 2014, 2016)
urban	percentage of the potential floodplain area covered by urban structures	Land cover/Land use	Copernicus Land Monitoring Services (land.copernicus.eu)
agriculture	percentage of the potential floodplain area covered by agricultural land	Land cover/Land use	Copernicus Land Monitoring Services (land.copernicus.eu)
Pressure			
Bank stabilization	Extent of reach affected by artificial bank material (% of bank length)	hydro-morphological assessment	Schwarz, 2014
planform	Planform of the River channel	hydro-morphological assessment	Schwarz, 2014
erosiondeposition	Erosion/deposition character	hydro-morphological assessment	Schwarz, 2014
engineeringstructures	Impacts of artificial in-channel structures within the reach (impoundments, groynes)	hydro-morphological assessment	Schwarz, 2014
flooding	Degree of lateral connectivity of the river and the floodplain (Extent of floodplain not allowed to flooded, regularly owing to engineering)	hydro-morphological assessment	Schwarz, 2014
connectivity	Degree of lateral movement of the river channel	hydro-morphological assessment	Schwarz, 2014
State			
Aspius	Conservation status of *Aspius aspius* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Bombina	Conservation status of *Bombina sp.* (amphibian)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu

Gymnocephalus_bal	Conservation status of *Gymnocephalus schraetzer*(fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Gymnocephalus_sch	Conservation status of *Gymnocephalus baloni* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Lutra	Conservation status of *Lutra lutra* (mammal)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Misgurnus	Conservation status of *Misgurnus fossilis* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Rhodeus	Conservation status of *Rhodeus amarus* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Triturus	Conservation status of *Triturus dobrogicus* (amphibian)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Zingel_st	Conservation status of *Zingel streber* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Zingel_zi	Conservation status of *Zingel zingel* (fish)	conservation status according to HBD	Natura 2000 database, www.eea.europa.eu
Haliaeetus	Population status of *Haliaeetus albicilla* (bird)	population according to HBD	Natura 2000 database, www.eea.europa.eu
Alcedo	Population status of *Alcedo atthis* (bird)	population according to HBD	Natura 2000 database, www.eea.europa.eu

Table AIII 2: Probabilities in the Bayesian Network on the P-S link (links with a probability >0.5 are shown in bold) for selected species. Causal links were calculated via bootstrapping following the approach of Friedman et al. (1999). For abbreviations see Table AIII 1.

	bank-stabilization	planform	erosion-deposition	engineering-structures	connectivity
Aspius	**0.66**	**0.70**	0.35	0.30	0.37
Bombina	0.13	**0.55**	**0.86**	**0.22**	0.57
Gymnocephalus_bal	0.34	**0.74**	**0.73**	0.32	**0.68**
Gymnocephalus_sch	0.49	**0.60**	**0.96**	**0.68**	0.43
Lutra	0.03	**0.77**	**0.76**	0.36	**0.50**
Misgurnus	0.08	**0.82**	0.25	0.38	**0.51**
Rhodeus	0.05	**0.93**	0.47	0.48	**0.54**

Triturus	0.18	**0.65**	**0.89**	0.48	**0.50**
Zingel_st	0.25	**0.73**	**0.51**	0.18	0.37
Zingel_zi	0.06	**0.83**	**0.78**	0.65	**0.55**

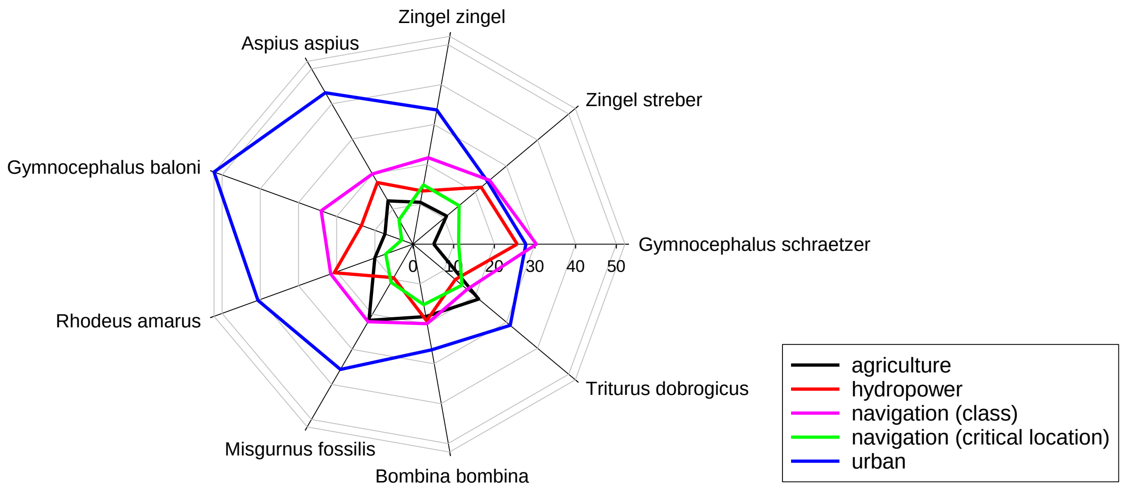
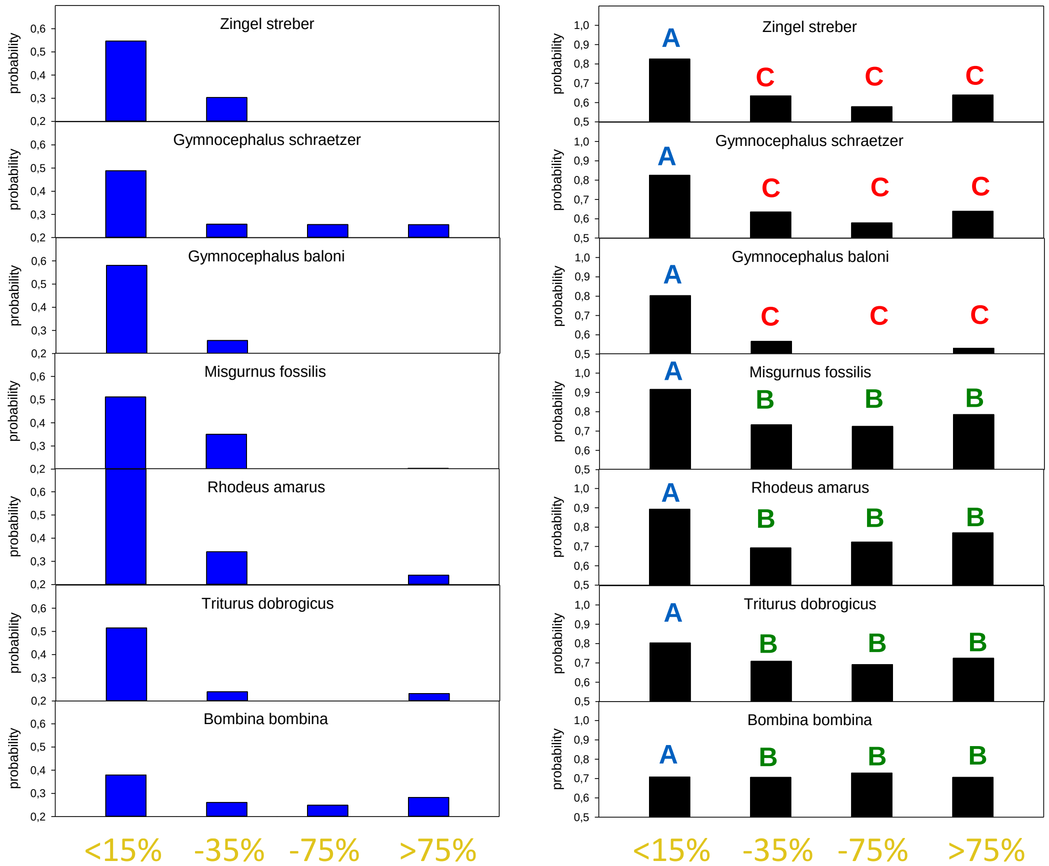


Figure AIII 1: Relative importance of drivers for the conservation status of selected species. Results of sensitivity analysis based on the boosted Bayesian networks for the D-P-S data for the selected species (see Table AIII 1).

Figure AIII 2: Conditional probabilities of the excellent conservation status (blue bars) and at least good conservation status (black bars) for selected species ranging from rheophilic (top graphs) to stagnophilic (lower graphs) species for the different levels of impact on the planform of the river (expressed in percentage of length of a stretch that has an altered planform). Capital letters mark highest probabilities for A: „excellent“, B: „good“, C: „average or reduced“ conservation status respectively.



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