Hungarian University of Agriculture and Life Sciences

FISHERIES BIOLOGICAL STUDIES ON THE RÁCKEVE (SOROKSÁR) DANUBE BRANCH AND ITS ECOLOGICAL WATER QUALIFICATION BASED ON THE FISH FAUNA

Abstract of Doctoral (PhD) Thesis

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Gödöllő
2025

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1. BACKGROUND AND OBJECTIVES

The Ráckeve (Soroksár) Danube Branch (RSD) is a lentic, heavily modified watercourse, the second longest arm of the Hungarian Danube section and, at the same time, the country's only complex water management system.

The water quality problems of RSD are caused by its multiple uses (excess water storage, industrial, irrigation and aquaculture water supply, nature conservation, maintaining aquatic and wetland habitats, navigation, recreation, angling-oriented fisheries management). A further, albeit undesired function of the water body is the accommodation of treated wastewater. The largest daily load of 72,000 m^3 biologically treated wastewater comes from the South Pest Wastewater Treatment Plant of Budapest Sewage Works Ltd.

In EU member states, including Hungary, the rules of water management-related regulation and coordination are set by the Water Framework Directive (WFD). The deadline of implementing the WFD objective of reaching good status of surface and groundwaters may be extended until 2027 on the basis of a thorough justification.

Based on the concepts of biological indication, feasibility and cost-benefit ratio, WFD regards the study of five biological groups of high indicator value – *phytoplankton, phytobenthos, macrophytes, macrozoobenthos, fish* – essential and obligatory during the qualification and monitoring of the ecological status of surface waters.

Environmental disturbances (e.g. water pollution, habitat degradation) are better integrated, sooner and longer indicated by these taxa. Natural-water fisheries cannot be developed without knowing the biological potential of water bodies, the structure and functioning of their fish communities and food base. Fish, which are situated at higher levels of the food web of aquatic ecosystems and, as such, have a decisive role therein, are important indicators. As a result of a number of spatio-temporal characteristics less typical for other living organisms, such as their life cycle, relatively long life span, migration pattern, human-scale habitat size, and also their relatively easy collection and identification, these animals are perfectly suited for monitoring.

Accepting the watercourse status of RSD, I chose to apply the fish fauna-based ecological qualification from the five groups of living organisms required by WFD. Based on the emergency situations related to the lack of oxygen and inadequate water flow, RSD is the most endangered surface water of Hungary, where the high number of mass mortality events of fish and bivalves indicate that the water body is at the limits of its resiliency. RSD has been unable to cope with the phenomenon of water quality deterioration; moreover, the unfavourable situation is further aggravated by the need to comply with multifunctionality requirements.

The „channelization” of RSD, the stabilization of low water levels, the lower water discharge and water velocity require the fisheries manager to shift to a different type of fisheries management. A fisheries biological survey of the system is needed in order to optimize the structure of the fish stocks and make it more compliant with nature conservation requirements. The optimization of fish stocking structure and further treatments in fisheries waters requires the natural conditions of the water body (qualitative and quantitative characteristics of the fish community, natural fish production, food base, competitive interactions, presence or absence of potential spawning and nursery grounds) to be taken into account. With few exceptions, these data are generally unavailable to the water body manager or they require studies that are too extensive and costly to be feasible. Fish fauna studies, which are easier to perform, can yield much information relevant from a manager's point of view. I surveyed the fish stocks of RSD, which has a significant angling, touristic and environmental development potential, with the above in mind.

1.1. Objectives

My objectives were the following:

- to present the fisheries challenges of RSD through the evaluation of both available (Environmental Measurement Centre) and own measurement data;
- to study the impact of the South Pest Wastewater Treatment Plant of Budapest Sewage Works Ltd. and other significant pollution sources on the fish community structure of RSD;
- to study the structural relationships of fish fauna in the RSD reach between the Kvassay sluice and the Tass sluice;
- to survey the fish stock of RSD according to the WFD fish monitoring protocol in three different seasons of year 2018 (spring, summer, autumn);
- to compare the fish fauna of different reaches of RSD and follow its changes along the longitudinal profile;
- to analyze the structural composition of the fish stock of RSD using different diversity indices;
- to confirm whether the studied functional traits can be used to understand the relationships between the fish community structure and the functioning of RSD;
- based on the results, to formulate recommendations for an angling-oriented fisheries management of the registered fisheries area, with special regard to the revision of the fisheries management plan and the potential harmonization of the complex water uses;
- carp markings for regularly stocked 2-3-old common carp (*Cyprinus carpio*) and record size (15 kg+) individuals, and correlations with carp population growth and migration behaviour and patterns;
- based on the results, to formulate recommendations for the revitalization plans of RSD.

2. MATERIAL AND METHODS

Moving south from the capital, the gradually improving water quality is a basic trend distinguishing the 4 characteristic reaches of the water body of RSD. Based on my knowledge of the water body, 13 sampling areas were designated. During the designation of the sampling sites, special care was taken to study characteristic reaches and habitats of this unique water body. In all sampling areas, 2 subareas were sampled, each with one sampling group sampled at the same time. Each subarea was a section 1000 m long in agreement with the type of the watercourse. The sampling method corresponded to WFD requirements.

The sampling areas were fished on 3 occasions (2018 spring/summer/autumn), from a small motorboat using a SAMUS 1000 type battery-operated pulsating direct-current electric fishing gear. The radius of action of the fishing gear, i.e. the width of the sampled strip was established to be 2 m, and thus, the total fished water surface per sampling area was 2000 m^2. During the sampling events, the caught fish, after identification and counting, were released to the water at the place of their catching.

The data were recorded by sampling group on the spot using a digital voice recorder (OLYMPUS DM-1, OLYMPUS WS-200S). In each sampling area and at all three sampling events, a WTW multi 3430 SET F type instrument previously calibrated at an accredited laboratory was used to measure water quality parameters (instantaneous conductivity, instantaneous dissolved oxygen concentration, instantaneous pH and water temperature). Reports of the Environmental Measurement Centre on the water quality status of RSD, based on forthightly and, in the critical summer period, daily sampling events, were used to characterize the 2018 water quality of RSD.

After the sampling, the occurrence data retrieved from the voice recorder were ordered into a data matrix with a format corresponding to the Past and Species Diversity and Richness IV softwares. Knowing the time spent with active sampling and the number of individuals, the catch per unit effort (CPUE) was calculated. The classification of non-natural fauna elements occurring in the sampling areas was done on the basis of the fauna component concept system of SÁLY (2007).

The similarity of fish communities was studied by hierarchical clustering of the Jaccard and Bray-Curtis dissimilarity matrices with the UPGMA algorithm using the PAST 4.05 software after an arcsin transformation of the square root of the species' relative abundance within the sampling subunit. The differences in the fish assemblage structures between the groups were analyzed with the ANOSIM test. Of the diversity indices, the species richness, the Berger–Parker dominance index, the local Shannon–Wiener α-diversity index, the Routledge β-diversity index (ROUTLEDGE 1977), the effective number of species, the expected species number in a rarefied sample and, for the scale-dependent characterization of diversity, the Rényi one-parametric index family (RÉNYI 1961). The Routledge β-diversity index, stemming from information theory and based on presence/absence data, was used to quantify the mosaicity of fish communities along the longitudinal profile of the watercourse and the variability of species composition as an important inherent property of the biocoenoses. The diversity index was computed on the basis of the samples collected in the main channel of RSD. The effective number of species was determined as the exponential of the calculated Shannon-Wiener index. During the species richness intrapolation, the sample size of the sample with the lowest number of individuals among the compared samples was taken as the standard number of individuals (m). The diversity of fish communities was evaluated through the comparison of Rényi diversity profiles. The diversity indices were estimated with the Species Diversity and Richness IV software package. The significance of the difference between the diversities of two sampling areas was tested with SOLOW's (1993) statistical test.

The extent of change in species composition stemming from locally arriving and locally disappearing species in a fish community between two points in time was calculated with the species turnover (ST) index. The survey of the year 2010 was taken as the starting point of the time interval taken into account. The comparison of the pooled spring species composition data of my own survey and data from the 2007 (UGRAI és GYÖRE 2007) and 2010 (GYÖRE et al. 2012) studies was done on the basis of non-metric multidimensional scaling (NMDS). The derived data of the Bray-Curtis dissimilarity matrix used in the ordination were obtained through Wisconsin double standardization of the square roots of the numbers of individuals (SHEPARD 1980).

The season-specific mean species richness was determined as the simple average of the species richness values of the 13 sampling sites (26 sub-samples) in the given period. The mean values were compared on the basis of the one-sample Student t-distribution.

The fish community structure of RSD was also characterized by classifying the fish species in functional guild-like proups. The classification was done according to the biological trait groups proposed by SÁLY and ERŐS (2016). During the evaluation, the relative abundance of the species belonging to the same functional guild, pooled from the three sampling events in the same sampling site, was taken into account. The total species richness of the fish community was estimated using the so-called second-order jackknife (Jackknife 2) method, in a non-parametric way from the pooled species number data of the individual sampling areas (TÓTHMÉRÉSZ 2002).

The pooled relative abundance values of fish families by sampling periods were transformed by calculating their square root for each sampling area and plotted with PCA biplot ordination using the PAST 4.05 version software package. During the application of the PCA procedure with the SVD algorithm, the eigenvalues and eigenvectors of the variance-covariance matrix were taken into account (LEGENDRE és LEGENDRE 1998).

The extent of biotic homogenization or differentiation was studied along the scale of sampling areas, based on presence/absence (OLDEN és POFF 2003) and absolute abundance (ROONEY et al. 2004). The pairwise similarities of the species assemblages of the sampling areas based on the Jaccard and Bray-Curtis indices were evaluated using the PAST 4.05 version programme software, separately for the 2010 (GYÖRE et al. 2012) and 2018 data. The dissimilarity matrices of the pairwise similarity matrices were calculated in case of both indices. The extent of biotic homogenization or differentiation in the water area of RSD was estimated on the basis of the mean similarity value of the dissimilarity matrix. A paper by GYÖRE et al. (2012) where the authors collected fish samples in the same sampling areas of RSD with the same method was used as the basis for comparison.

2.2. Fish tagging study

I analysed catch (mark-recapture) data for carp weighing more than 15 kg from 2020 to 2024.

At the time of capture, I recorded the time and location of capture, the standard length and weight of the fish, and the type of bait used. Fish caught were tagged with a microtransponder (ISO 11784:2024) for tracking purposes. Captured specimens were checked with a chip reader (ISO 11785:1996) and, in the case of recapture, the new catch data were matched with the history data for the specimen.

I examined the absolute numbers and proportions of individuals caught/recaptured, indicators of the variation in location of each individual along the length-section of the river, the distribution of catches by month and by time of day, the variation in body weight of individuals, and the types of bait that resulted in successful catches.

Catch-recapture data were analysed for fish caught at least three times. Based on the body length and body weight data, I calculated the condition of the fish and its variation. I used the FROESE (2006) formula to evaluate condition. Correlation analysis at 95% significance level was used to explore the relationship between individual changes in body weight and condition and the time elapsed between catches, while a two-sample t-test was used to compare the condition at the first and last catch.

3. RESULTS AND DISCUSSION

3.1. Water quality, water quantity

The year 2018 was special in many respects, the increased risk of excess water inundation being the main problem on the catchment area in the beginning of the year.

For most of the year, the *dissonved oxygen concentration* did not reach the lower limit of good water quality set by WFD for standing waters (7 mg/l). In the sampling sites of the Kvassay sluice, Molnár Island, Dunaharaszti M0 bridge, Dunaharaszti railway bridge and Szigethalom, the water was typically of class III quality from the end of May to the beginning of August.

The pH of the water in the samples only occasionally exceeded the upper limit of good water quality according to WFD (pH=8.8), in general, it remained within the range characteristic of good water quality for standing waters. The water quality of the sampling areas ranged between classes I and II, the limit values for Class III were exceeded only on two occasions in the area near the Tass sluice.

The received excess water was demonstrated to increase the *electric conductivity* of the RSD water in April. This parameter showed extreme values (1000–1200 μS/cm) in the area of the Molnár Island, Dunaharaszti M0 bridge and Dunaharaszti railway bridge sampling points in autumn, which, even if to a small extent, exceeded the upper limit of good water quality. With the exception of the mentioned autumn period characterized by extreme values, the water quality of the sampling areas belonged to Class I on the basis of *conductivity*.

There was only one sampling area, at the Kvassay sluice, where *the ammonium ion concentration* did not exceed the limit corresponding to good water quality, the other sampling sites generally belonged to Class II for most of the year. Still, the water quality based on this component belonged only to classes III or IV around the Molnár Island, Dunaharaszti M0 bridge and Dunaharaszti railway bridge sampling points in spring and autumn, and it even deteriorated to Class V at Molnár Island on one occasion in spring and on two occasions in autumn. Of the nutrient balance parameters, the *nitrite ion concentration* exceeded the limit for Class II from mid-April to the end of the year and belonged to classes IV and V throughout the autumn and winter. The only occasion when the upper limit of good water quality based on *nitrate ion concentration* (1.8 mg/l) was not exceeded was in the lower reach (Ráckeve Bridge, Tass sluice) in autumn; in all other sampling areas and periods, this parameter defined a Class II water quality. Of the measured water quality parameters, trend changes were described only in case of conductivity and pH, as the dissolved oxygen concentration and temperature have a much more expressed daily fluctuation than the former two.

In the first quarter of 2018, which was characterized by a high hazard of groundwater inundations, the water level of RSD was strongly reduced so that the water body could receive the excess water of the surrounding areas by changing the flow direction of the double-use canals (which provide irrigation water during the summer). As a consequence of maintaining a water level of 80–120 cm instead of the 150 cm prescribed for the spring period, the generally shallow side arms and backwaters almost dried out in many places. There is a valuable floating island area 230 m long and 20 to 25 m wide north of Szigetszentmiklós, in the reach of RSD between the river kilometers 45.0 and 46.2. Individuals of *Umbra krameri* were registered here both in 2007 (UGRAI és GYÖRE 2007) and 2010 (GYÖRE et al. 2012). During the sampling events of 2018 and 2020, I could not confirm the occurrence of this strictly protected fish species in the side arm in any of the sampling periods. It is probable that the population of European mudminnow dropped below the minimum viable population size because of the habitat loss, even if it was limited in time and space. The normally shallow backwater ceased to be a suitable habitat for the fish. We can only guess if the population of European mudminnow, which had a stable self-sustaining stock for many years, has become definitively extinct in the given habitat or, in a more fortunate case, has managed to emigrate to a nearby refugium area from where it has not yet recolonized its former area. It can be stated that the population of European mudminnow was not prepared to and could not tolerate the destructive and extremely harmful disturbance of water level reduction.

3.2. Fish community structure of RSD

The occurrence of 26,589 individuals of 36 fish species belonging to 8 families was confirmed in the 26 sampling areas. The number of native species was only 23. The 13 adventive (intentionally or inadvertently introduced or immigrated) species were *Ctenopharyngodon idella, Pseudorasbora parva, Carassius auratus, Carassius gibelio, Hypophthalmichthys molitrix, Ameiurus nebulosus, Ameiurus melas, Lepomis gibbosus, Micropterus salmoides, Proterorhinus semilunaris, Neogobius fluviatilis, Neogobius melanostomus* and *Ponticola kessleri*. Only 6 of the 37 fish species legally protected in Hungary occurred in the sampled area: *Rutilus virgo, Gobio gobio complex, Romanogobio vladykovi, Rhodeus amarus, Misgurnus fossilis* and *Gymnocephalus baloni*. Of the endemic fish species living in the Hungarian faunal area, individuals of two, *Rutilus virgo* and *Gymnocephalus baloni* were confirmed to be present. In addition to species protected in Hungary, a population of asp (*Aspius aspius*), a NATURA 2000 indicator species was also detected. The occurrence of two indigenous species with a "non-catchable" status (*Carassius carassius, Gymnocephalus cernua*) was registered in the water body. And in 2023, the presence of a third "non-catchable" fish species, *Acipenser ruthenus*, was detected (UDVARI et al. 2023).

The number of common species in the species lists of the spring and summer sampling events was 24, the Jaccard index showed a high similarity (J=0.7742). The number of common species in the spring and autumn species lists was 27, the similarity is slightly lower, J=0.7500. The similarity of summer and autumn species lists is also high, J=0.7714. In the fish community structure-based clustering of the sampling areas according to the Bray-Curtis index, the first two samples to be ordered into one cluster were those of spring and summer, with a very high (0.9253) similarity index. The low distortion of pairwise ultrametrics is confirmed by the high value (0.9873) of cophenetic correlation. Based on the non-parametric, one-way ANOSIM test, the differences between the groups were not significant (p=0.3232), i.e. the structural relations of the fish assemblages sampled in three different periods did not differ. Taking into account only samples collected in the main channel, *β-diversity* showed an approximately linear gradient. Based on the spring sampling campaign, the Routledge diversity characterizing the variability of the species pool of the 13 sampling areas along the entire reach of the watercourse, in the direction RSD-1/B→RSD-13/B, was β_I=0.1787. According to the results of the autumn sampling events, this diversity index indicates a serious disturbing factor in the Soroksár reach of the water body, near the effluent channel of the South Pest Wastewater Treatment Plant. In other cases, the Routledge diversity indices of the pairwise comparisons of neighbouring sampling sites was not significantly high (β_I=0.0251–0.0926).

The qualitative and quantitative composition of the fish community in the „main channel" of RSD differed from that in the side arms, oxbow lakes and backwaters. Of the total of 36 species registered in the area, the presence of smaller or larger populations of 33 species was confirmed in the main channel and 30 species in the side arms. The fish community of the main channel lacked *Carassius carassius, Misgurnus fossilis* and *Micropterus salmoides,* which are all stagnophilic species. On the other hand, individuals of *Rutilus virgo, Squalius cephalus,* the *Gobio gobio* complex, *Romanogobio vladykovi, Carassius auratus* and *Hypophthalmichthys molitrix* were not found in the water bodies of the side arms and backwaters. The number of common species was 21, the Jaccard similarity index was relatively high, JQ = 0.75.

The structural similarity of the fish communities in the sampling areas was calculated with the Bray-Curtis percentage dissimilarity formula. Based on spring samples, 5 groups could be distinguished by cluster analyisis, „*cutting*" the dendrogram approximately at the similarity value of 0.650. Only 3 groups could be distinguished on the basis of the summer samples, and 7, according to the autumn samples.

Catch per unit effort (CPUE) was 450±555 fish per hour in spring. The CPUE value was somewhat lower, 439±289 fish per hour, in summer. In autumn, only 331±240 fish could be caught during an hour in the individual subareas. Neither the F-test, nor the T-test could detect any significant difference between CPUE values. The high CPUE values experienced in some subareas could be explained by the extreme dominance of *Alburnus alburnus.* An increasing trend of CPUE values was observed in downstream direction in all three periods.

It was my intention to prove whether the functional traits defined in the classification by SÁLY and ERŐS (2016) can be used to understand the relationships between the fish community structure and the functioning of RSD.

The 36 species recorded in the entire studied reach of RSD in 2018 could be classified into a total of 21 traits. The highest diversity was manifested by the fish community of the Czuczor Island main channel having 14 species, the lowest, by that of the reach downstream of Csepel-Királyerdő, with 13 species. Based on the pooling of the 26 spring samples, the Shannon-Wiener index of the fish community of RSD was 1.229, with a mean index of 1.345. The α-diversity of the fish community in the sampling area directly influenced by the „treated" wastewater of the South Pest Wastewater Treatment Plant was lower (at p=0.0007 and p=0.0067 significance levels) than those of the preceding and following reaches. The local Shannon-Wiener diversity of the fish community in the right-bank subarea of the reach in question showed the lowest value experienced in the spring period (H=0.295).

In some reaches, significant differences were found in the species richness and species diversity of the right- and left-bank subareas. The sampling areas designated between river kilometers 35.00 and 49.25 had high local diversity during the spring sampling campaign. The fish communities of the sampling areas characterized by high values of the Berger-Parker index were understandably dominated by only 1 or 2 species, one always being *Alburnus alburnus*, accompanied, on three occasions, by *Rutilus rutilus*, or, in one sub-area, by *Ponticola kessleri*. The species number by sampling area associated with the rarefied sample size was calculated at the abundance level (n=27) of the sampling site designated on the eastern side of Csupics Island at Szigetcsép. In comparison with the original number of species, the expected number was the lowest in the subarea downstream of Csepel-Királyerdő, with a difference of -83.1%. The difference between the expected and observed species numbers was the lowest in the Gubacsi-dűlő sampling subarea downstream of the Kvassay sluice, with a difference of only -4.44%.

During the summer sampling campaign, the dominance indices of the individual sampling subareas showed no significant difference from those experienced in spring (unequal var. Welch test p=0.162). In this period, too, the high value of the Berger-Parker index could be explained by the massive dominance of *Alburnus alburnus*. Based on the Shannon-Wiener indices of the fish communities in the two littoral regions of the RSD-1 sampling area, the species diversity of the left bank was higher than that of the right bank at a p=0.044 significance level. In the next sampling area (RSD-2), in contrast with what was experienced in spring, there was no difference between the diversities of the fish assemblages of the two bank sections in summer (p=0.392). However, based on the Solow test (p«0.0001), significant differences were again found between the diversities of the left-bank and right-bank fish communities in the lower subareas RSD-12/A and RSD/12/B in the area of Dömsöd and Makád. In summer, the fish communities of the sampling areas characterized by high values of the Berger-Parker index were dominated by at least 2 species, one still being *Alburnus alburnus*, which was accompanied, on three occasions, by *Rutilus rutilus*, in one subarea, by *Ameiurus nebulosus*, and in one more, by *Carassius* *gibelio*. The species number by sampling area associated with the rarefied sample size was calculated at the abundance level (n=91) of the left-bank subarea directly influenced by the "treated" wastewater of the South Pest Wastewater Treatment Plant. Based on the autumn sampling events, the right bank of the reach downstream of the Kvassay sluice (RSD-1/B) was found to be a species-rich area, where the occurrence of individuals belonging to 20 species was confirmed. The local species richness was also high in the main channel at Czuczor Island, in the Csupics Island backwater at Szigetcsép and in the area before the Kiskunság Main Canal and the Tass sluice.

The autumn fish community of all three subareas consisted of 18 species. The mean autumn number of species in the fish communities of the 26 sampling areas was 13.6, which did not significantly differ from those of either the spring or the summer. Similarly to summer, the highest local species diversity was registered in the 18-species fish community of the main channel at Czuczor Island (RSD-4/B), while the lowest was found in the subarea downstream of Szigetbecse-Királyrét (RSD-12/A), having 14 species. Based on all samples, the autumn α-diversity index was 1.733, the mean of diversity indices being 1.514, which was significantly higher (p=0.0004) than in summer, but did not significantly differ from the spring values (p=0.178). In autumn, too, the species diversity of the fish communities of the pooled sampling subareas RSD-2/A and RSD-2/B was lower than in the immediately preceding reach, the Solow-teszt confirming a significant difference in case of the RSD-1–RSD-2 pair (p«0.0001). No significant difference was detected between the α-diversities of the fish communities in the pooled RSD-2 and pooled RSD-3 sampling areas (p=0.209). Based on the autumn samples, the fish communities of the individual subareas were dominated by at least three species, with two exceptions (RSD-12/A and RSD/13/B). The diversity of fish communities in the sampling area directly influenced by the „treated" wastewater of the South Pest Wastewater Treatment Plant of Budapest Sewage Works Ltd. (RSD-2), as well as the RSD reaches lying immediately upstream (RSD-1) and downstream of it (RSD-3 and RSD4) was also studied by comparing their Rényi diversity profiles. This was deemed necessary as the generally used diversity indices assign different importance to the abundance of species. Based on the may sampling events, the diversities of the fish communities of the 4 sampling sites could be ordered using the Rényi diversity ordering method. The species diversity of the polluted reach (RSD-2) was visibly the lowest, the diversity profiles of all three fish communities run above it over the entire range of the scale parameter.

3.3. Tagging results for record-size carp

My dissertation contains data from 2515 catches of 1394 common carp individuals. There were two individulas caught 9 times, one individual caught 8 times, seven individuals caught 7 times, 22 fish caught 6 times, 29 fish caught 5 times, 84 fish caught 4 times, 148 fish caught 3 times, 282 fish caught 2 times, and 819 individuals caught only once.

The longest upstream migration length was 49 km, and the corresponding time between two detections was 369 days. The longest downstream length was 45 km and the corresponding time between two detections was 66 days. The fastest change of position, with an average speed of 5 km/day, was observed for a downstream swimmer.

The highest body weight gain, 9.8 kg, was recorded in only 105 days. The most extreme weight loss, 10.26 kg, was observed in an individual with 409 days between captures.

Most of the catches were in the 5 southernmost municipalities (Ráckeve 638, Szigetbecse 363, Dömsöd 602, Makád 352, and Tass 221), which represents a total of 86.5% of the total RSD catches of large carp in the period 2020-2024.

It is worth noting that 90% of the fish were caught with a single bait type, the boilie.

For fish caught at least three times, the average distance between the two furthest catch points was 4.97 km. More than 70% of fish moved a maximum of 5 km, but 93% of fish did not swim more than 16 km, indicating that fish use only a small part of the water system regularly.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Water quality, water quantity

The complex water management system typical of RSD today has not been able to cope with the phenomenon of water quality deterioration; moreover, the unfavourable situation is rather aggravated by the need to comply with multifunctionality requirements. The annual mean values of the parameters, e.g. the dissolved oxygen in most years between 2007 and 2017, can show a water quality that is excellent from the point of view of fish physiology. In the summer of 2018, the dissolved oxygen concentration permanently ranged between 4–6 mg/l in the morning hours, allowing to assume early morning anoxic conditions. Because of other physico-chemical parameters of the targeted fish physiological studies (NH_4^+, NO_2^- and NO_3^- concentration), the water body could not receive an overall „good" status according to WFD. Based on the data sets of the period between 2007 and 2017, the water of RSD did not reach a good ecological water quality status because of the high concentrations of nitrogen balance parameters. This was principally due to the elevated concentrations of ammonium-N and nitrate-N. This indicates the regrettable fact that the self-cleaning capacity of RSD is no longer sufficient to process the effects of the loads coming mainly from the wastewaters of Népjóléti ditch and Gyáli 1st canal.

For a future change (improvement) of the water quality conditions, I consider it important to intensify wastewater treatment, to eliminate the point- and non-point sources of domestic and agricultural pollution in the catchment area, to improve the water transmission capacity, but mostly the diversion of the treated wastewater of the South Pest Wastewater Treatment Plant, which is currently released into RSD, to the main channel of the Danube. The interventions would probably modify the species or community structure of fishes, and therefore, the evaluation of the necessity and the impacts of the projects should not only be placed into an economic policy context, but also should be made dependent of fisheries objectives.

4.2. Stock of species

Compared to the importance and surface area of RSD, there have been unduly few science-oriented fish faunal surveys in the history of the side arm. The study of the fish fauna of our waters should be an important task; however, it should be done with appropriate frequency in order to be able to identify the changes and their causes in every detail. Based on the species lists in the papers of the 1902–2020 period and the results of my 2018 survey, a total of 60 species has been known from RSD until now. The number of species recorded by myself is much lower than that, this may be due to the fact that the previous species lists included several taxa that only temporarily occurred in the watercourse or that have never been found ever since, such as *Eudontomyzon mariae*.

The total species richness of the entire RSD reach, estimated with the jackknife 2 method and rounded to the nearest integer, was 42. With other methods (Chao 2, jackknife 1, bootstrap), the upper limit of the theoretically possible number of species ranged between 38 and 40, i.e. was not much different. The species number extrapolation showed that a further 6 species not found during the 2018 sampling events could potentially occur in the community. In addition to the 5 gobiid species recorded to date (*Proterorhinus semilunaris, Neogobius fluviatilis, Neogobius melanostomus, Ponticola kessleri, Babka gymnotrachelus*), the appearance of *Perccottus glenii* can also be regrettably expected in the near future. Significant changes could have happened in the fish community of RSD during the study period. The enrichment of the species pool of RSD was mostly the result of the ill-calculated naturalizations and introductions of North American and Central and Eastern Asian fish species and the spreading and natural gradation of Ponto-Caspian goby species. I registered individuals of 9 adventive fish species in RSD during the 2018 sampling campaign. During the sampling of RSD, the only red-coloured individual of goldfish was caught in the Napospart reach at Dömsöd on 11 October 2018. The total share of alien goby species in the fish community of RSD was only 0.08% in 2007, 0.24% in 2010, while my studies showed that it already increased to 0.81% by 2018. One of the important causes of the changes in the fish species pool is the construction and existence of wing dams. Many rheophilic species, such as *Eudontomyzon mariae, Acipenser ruthenus, Squalius cephalus, Chondrostoma nasus, Barbus barbus, Zingel zingel* or *Zingel streber*, can occur in the slow-flowing side arm only as occasional guests. It is not only spawning, but also growing habitats that typical riverine species cannot found, not even in the main channel of RSD. The listed species can only enter the side arm when the sluice gates are opened, but it is unlikely that they move far from the sluices.

Taking into account all the individuals caught in the entire RSD reach, the 62.5% abundance share of *Alburnus alburnus* stood out strongly. The general „over-representation" of the species, also experienced in the fish communities of other water bodies, is often explained by the fact that it can be more efficiently caught by electric fishing gear because of it surface-dwelling way of life. At the same time, the high catch efficiency can also be explained by the species' tendency to form shoals. The second most abundant fish in the catches was *Rutilus rutilus* (18.08%). Comparing the sampling events of 2007, 2010 and 2018, it could be established that, of the five most abundant species of the samples collected in the same season (spring), *Alburnus alburnus, Rutilus rutilus* and *Abramis brama* were present in all three years. The populations of *Cyprinus carpio* (in 2007 and 2018), *Carassius gibelio* (in 2007 and 2010) and *Blicca bjoerkna* (in 2010) were also present with high numbers of individuals.

The decrease in electric fishing gear catches, as compared to previous years, was possibly due to the fact that the year 2018 was extraordinary in many respects (low water level, poor water exchange, nearly standing-water-like character), so there were much less individuals in the riparian habitats that fish are „accustomed to" in the spring period. The extremely high abundance share of *Alburnus alburnus* (80%) is also probably due to this fact, as, being a pelagic fish species, it entered into the abandoned riparian habitats.

The most frequent fishes of RSD were *Rutilus rutilus, Alburnus alburnus, Leuciscus aspius, Carassius gibelio, Cyprinus carpio* and *Lepomis gibbosus,* whose individuals were present in all of the 26 sampling areas during the three sampling periods, i.e. were continuously present along the entire side arm. Further frequent species (occurring in 24–25 sampling sites) were *Abramis brama, Silurus glanis, Esox lucius* and *Sander lucioperca*. Rare faunal elements of the water body were *Rutilus virgo, Squalius cephalus,* the *Gobio gobio* complex, *Carassius carassius, Carassius auratus* and *Misgurnus fossilis,* which were recorded only in one or two sampling areas with very low abundance. The single individual of gudgeon found during my studies after more than 60 years is the exclusive proving specimen of the species' occurrence in RSD. Crucian carp has become a very rare faunal element of RSD in the last 60 years. The decrease of the domestic and European stocks of this species have also been observed in other habitats and is generally attributed to the invasion of goldfish. The same cause is likely in the case of RSD, too. The increased water pollution is seen as another cause of the drastic stock reduction, as it results in an almost complete loss of the submerged vegetation where this species lives, feeds and spawns. I caught one individual of the stagnophilic weatherfish in 2018 in the side arm of Csupics Island, and another, in the shallow marshy water of the eastern side arm of the reed and cattail stands opposite Domariba Island. Based on the pooled data of the seasonal sampling events, asp was strongly overrepresented in the predatory fish stock. Pike, wels and pike-perch were present with nearly the same abundance shares. The share of largemouth bass and Volga pike-perch was negligible.

I confirmed the occurrence of individuals of a total of 21 fish species, which is 35% of the total species pool, in spring in the fish community of the sampling area directly influenced by the „treated" wastewater of the South Pest Wastewater Treatment Plant, as well as the RSD reaches lying immediately upstream and downstream of it. In the spring of 2007, the occurrence of 26 fish species was proven in the same 4 sampling areas of the same reach. Comparing the spring data of 2018 with the results of the spring sampling events of 2007, the extent of species turnover can be regarded as moderate. Instead of the seven „disappeared" species, *Rhodeus amarus, Umbra krameri, Gymnocephalus cernua, Gymnocephalus baloni, Sander volgensis, Proterorhinus semilunaris* and *Neogobius melanostomus,* only two, *Scardinius erythrophthalmus* and *Neogobius fluviatilis* appeared in the area in 2018.

4.3. Species and functional diversity

Based on the Jaccard similarity index, the percentage value of biotic homogenization between the RSD reaches from 2010 to 2018 was -6.89 (±10.92). The negative average percentage value of „homogenization" does not indicate a shift towards increasing similarity, but rather a minor extent of differentiation. When applying the Bray-Curtis index, the number of homogenization and differentiation cases was absolutely the same (39-39), there was no sampling site without a change of some direction. According to the Bray-Curtis metrics, the percentage value of biotic homogenization between the RSD reaches from 2010 to 2018 was 1.61 (±25.40). Based on the latter value, no significant homogenization could be detected in the species pool of the 26 sampling sites of RSD during the eight years. Both the extremely low homogenization and the negative similarity of the communities can be interpreted as that the last 8 years were too short a period to generate major changes. Based on the above, it can be stated that the fish communities in the subareas downstream of the Kvassay sluice (RSD-1/A and RSD-1/B) and the subarea of the sampling site downstream of the Csepel-Soroksár ferry (RSD-3/B) were two to three times more diverse during the spring sampling event than in the sampling areas affected by the „treated" wastewater of the South Pest Wastewater Treatment Plant (RSD-2/A and RSD-2/B). The fish community of the reach aroung the bridge of the M0 motorway was already five to six time more diverse.

The Berger-Parker index is a good indicator of the distribution of abundance being disturbed by some factor. The disturbed abundance distribution of the fish community in the polluted reach appeared evident. Dominance could be linked to the population of *Alburnus alburnus*. In this case, this can be explained by the fact that bleak likes visiting the surroundings of stream and channel mouths, even if they bring strongly polluted water.

Analyzing the functional guilds of RSD, it must be pointed out that the distribution of fish species among them is extremely unequal, some guilds contain spectacularly more species. Several functional guilds include relatively few species, and therefore, they have little impact on the diversity of the community. The frequency differences of the species partly explain why some functional guilds have relatively many species. It can be stated that taxa belonging to guilds with many species generally also have a large abundance in the fish community of RSD and occur in the reaches of the water body with high frequency. Based on the exceedingly high dominance of fish species with omnivorous feeding habits, belonging to the phyto-lithophilic reproduction guild and, in respect to water flow, to the eurytopic or stagnophilic groups, the fish community of RSD indicates a degraded lentic ecosystem.

It is difficult to find native predator species that can successfully reduce the population size of these adventive species. An attempt has been made to do so in Hungary (HORVÁTH et al. 2007), based on the assumption that artificially increasing predator fish populations in the food web implements top-down regulation. The structure of the RSD predator fish population (many *Aspius aspius*) needs to be changed by stocking *Sander lucioperca*, but especially *Esox lucius*.

4.4. Tagged record size common carps

In the analysis of the carp tagging studies for the years 2020-2024, I found that of the 1,394 carp (*Cyprinus carpio*) over 15 kg caught and tagged, there were 2 individuals of common carp caught 9 times (!) by anglers during the years. In the year 2024, 359 of the 693 individuals caught were first time registrants, indicating that the percentage of individuals (51.8%) first time registrants with a chip from the RSD waters remains high but statistically verifiable decreasing.

I have demonstrated that the largest proportion of the RSD carp population is concentrated in the section of the RSD below Ráckeve (86.5%), which may be explained by the ideal habitat conditions for the carp species (e.g. high biomass of mussels), but may also be due to the higher volume of stocking.

The results of my study, covering 1963 ha, showed a very similar pattern to that of RAAT's (1985) study of just over 3 months in two replicates on a 0.4 ha pond. The proportions of fish caught once in RAAT's (1985) studies were 50% and 73%, while in my case they were 58.75%, and the proportions of fish caught twice were 29% and 23%, while in my case they were 20.23%. For carp caught three times, the rates were 15%, 4%, and 10.61% in my study. The above results raise the possibility that there is some conservative pattern among carp, with equal proportions of shy and less shy individuals in the population, or that the learning process (bait avoidance) is very similar. It cannot be ruled out that mortality also plays a role in this pattern of recapture rates.

The data on the spatial distribution of catches partially support the findings of SPECZIÁR and TURCSÁNYI (2014) that common carp typically move only over a small area. In a two-year study by STUART and JONES (2006), nearly 80% of the fish were moved within 5 km, with an average distance of 19 km, while the average displacement in my study was 4.97 km. However, this distance is significantly smaller than the results of a survey of common carp in the same water area but at a younger age class, which showed an average distance of 12 km (VITÁL et al. 2022).

Looking at the body weight of the fish, it can be concluded that even in this very old age class there is still growth, with most fish ranging in age from 6+ to 28+ years according to WINKER et al. (2011). The average time between two catches is 210 days, a very similar value to the seven months reported in CZAPLA et al. (2023), which is the average time for which bait/hook avoidance after earlier catches was confirmed for common carp.

4.5. Recommendations

In order to protect the water quality, I consider it important, in general, to intensify wastewater treatment, to eliminate the point- and non-point sources of domestic and agricultural pollution in the catchment area and to improve the water transmission capacity. In detail:

- Mechanical treatment (screening removal, installation of an oil interceptor) of the wastewater mixed with rainwater that does not undergo full treatment at the South Pest Wastewater Treatment Plant.
- Construction of a new pumping station at the Kvassay sluice in order to attain an acceptable water quality in RSD while meeting the irrigation water demand.
- Definitive diversion of the treated (or, in case of intense rainfall, untreated!) wastewater of the South Pest Wastewater Treatment Plant of Budapest Sewage Works Ltd., currently released into RSD, to the main channel of the Danube.
- Dredging and utilization of the silt deposits of the main channel and side arms of RSD.
- Final and complete connecting of the holiday houses along the banks of RSD to the existing sewer network.

In order to protect the indigenous fish fauna and to develop an angling-oriented fisheries management, I recommend the following to the Ráckeve Danube Branch Angling Federation (RDHSZ) as the holder of fisheries rights:

- Stocking of native predatory fish species into RSD in order to decrease the stock size of alien fish species (*top-down* regulation).
- Modifying the current structure of the predatory fish stock of RSD (much asp) by stocking pike-perch and, especially, pike. By my suggestion, RDHSZ intends to put more emphasis on the propagation and stocking of predatory fish species in the future in order to reinforce their stocks, which was already manifested in the 2019–2021 period.
- The population of European mudminnow has probably dropped below the minimum viable size because of habitat loss in an important habitat of the species in RSD. I suggest to restock European mudminnow into the backwater using the fry of breeders from RSD and to improve the backwater’s water management in order to avoid, in the future, any low water level and harmful water quantity issues, which caused the species’ actual disappearance, in this habitat important from a conservational point of view.
- The chip tagging scheme I have introduced to protect the RSD large carp (15 kg+) stock should be maintained in the long term, as in addition to active protection against fish stealing, the resulting systematic statistical data provide important information on the structure of the large carp stock, growth and migration patterns of common carp and their long-term time series changes. These can be used as a basis for future management decisions (stocking planning, fish inspector).

5. NEW SCIENTIFIC RESULTS

1. I confirmed the occurrence of a total of 26,589 individuals of 36 fish species belonging to 8 fish families in the 26 sampling areas of RSD. The number of native fish species in the species pool was only 23. I could prove the presence of 13 adventive (intentionally or inadvertently introduced or immigrated) species. Only 6 of the 37 fish species legally protected in Hungary occurred in the sampled area: *Rutilus virgo*, the *Gobio gobio* complex, *Romanogobio vladykovi, Rhodeus amarus, Misgurnus fossilis* and *Gymnocephalus baloni*. I was able to confirm the presence of individuals of two endemic species inhabiting the Hungarian faunal area, *Rutilus virgo* and *Gymnocephalus baloni*. Of the NATURA 2000 indicator species, I found the population of *Aspius aspius*. I also confirmed the occurrence of two species (*Carassius carassius, Gymnocephalus cernua*) in the area that have the status of non-catchable indigenous fishes. I found the Molnár Island side arm and the reach downstream of the Tököl Park Forest to be poor in species (both having 8 species). The area before the Kiskunság Main Canal and the Tass sluice was found to be rich in species, with confirmed populations of 20 species. The Taksony oxbow lake also resulted to be a species-rich area, where I found 18 species. In 2018, I was the first to describe the occurrence an individual of the species *Carassius auratus* from the area, and in 2022, two specimens of *Acipenser gueldenstaedtii*.

2. I was the first to use the Bray-Curtis percentage dissimilarity formula to study the structural similarities of the fish community in RSD and I also prepared the seasonal (spring, summer, autumn) cluster diagrams of the sample areas. During the study of the temporal patterns of the fish community structure in RSD, I established that, on the basis of the clustering of samples collected in three different seasons of the same study year, the structural conditions of the fish assemblages collected in the three different periods did not significantly differ from each other.

3. The numerical expression of β-diversity offers a good approach to the quantification of the mosaicity of the fish community of RSD in the different sampling areas and the variability of species composition as an important inherent property of the biocoenosis. The variability index of species composition did not allow to emphatically prove the disturbance caused by the water of the South Pest Wastewater Treatment Plant in spring and summer. Acording to the results of the autumn sampling events, the diversity index showed a serious disturbing effect in the Soroksár reach of the water body in question, near the effluent channel of the wastewater treatment plant.

4. I also characterized the fish communities in the sampling sites of the water body according to their functional traits. It was my intention to prove whether the functional traits defined in the classification by SÁLY and ERŐS (2016) can be used to understand the relationships between the fish community structure and the functioning of RSD. The 36 species recorded in the entire studied reach of RSD in 2018 could be classified into a total of 21 traits. Of the six feeding traits, the *omnivorous* type was the most frequent in all sampling sites, reaching up to 96% in some places, while the *pelagic* type was, on average, the most frequent (63.5%) among the 3 functional traits of the feeding habitat. Of the seven reproductive groups, most individuals (84.5%) of the 36 fish species characteristic of RSD belonged into the *phyto-lithophilic* trait. From the point of view of preference for flow conditions, the relative frequency of *eurytopic* species is outstanding in the entire RSD. Based on the relative frequency of the two traits associated with biogeographic status (adventive and native), adventive species were rather typical of the upper reach of RSD, as if indicating the direction of immigration, mostly of Ponto-Caspian gobiid species. The relatively outstanding frequency value of alien species is mainly due to four species: pumpkinseed, black and brown bullhead and goldfish.

5. I surveyed the structure of the predatory fish stocks in RSD. Compared to previous surveys, the population size of asp (*Aspius aspius*) has become much bigger, while the share of pike (*Esox lucius*) within the predatory fish stock has dropped to nearly a quarter of the previous value. In order to change the structural relationships of the predatory fish stock, I recommended the fisheries rights owner to restock coldwater fishes, whose decreasing natural-water stocks supposedly indicate the impacts of climate change, namely pike-perch (*Sander lucioperca*) and, especially, pike (*Esox lucius*).

6. For the first time in Hungary, microtransponder tagging was used to monitor and statistically evaluate the growth and migration patterns of record-sized (15 kg+) common carp (*Cyprinus carpio*) in a large-scale fisheries are (RSD) over a longer period (5 years), analysing 2515 catches (tagging-retrieval) of 1394 common carp individuals.

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