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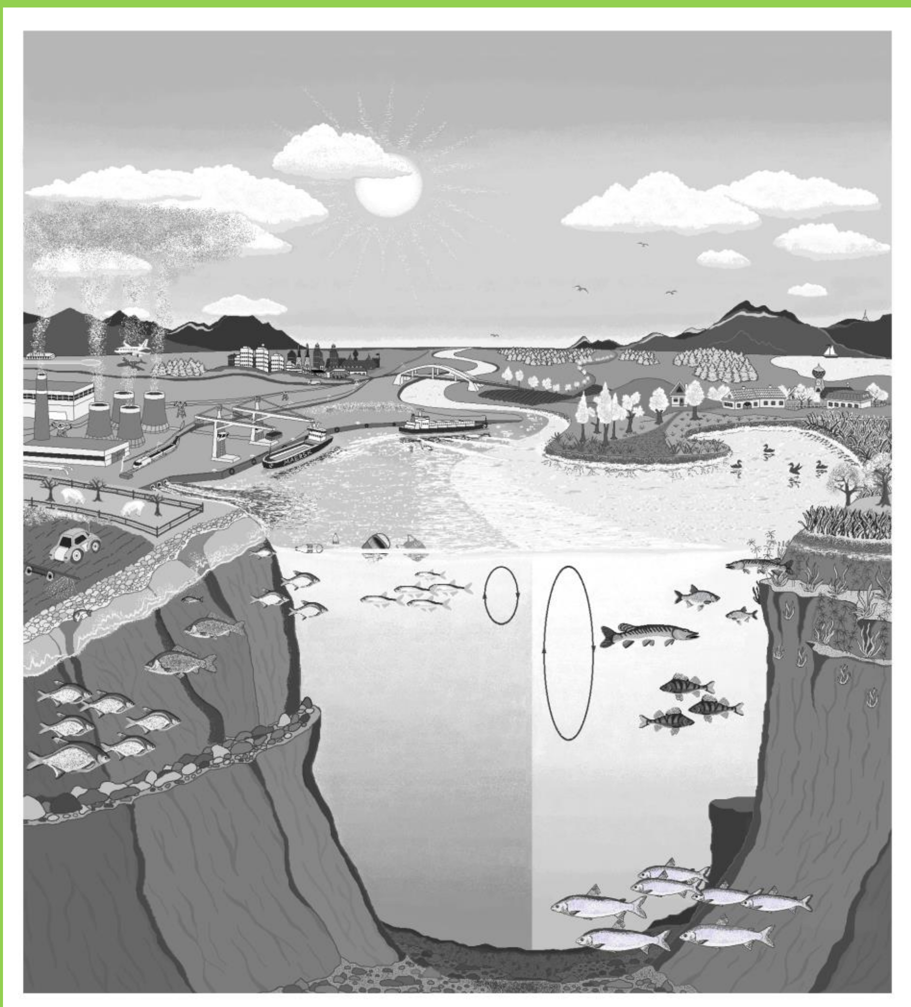
Petr Blabolil

Assessment of Czech water-bodies ecological potential based on fish community



School of Doctoral Studies in Biology Sciences

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Assessment of Czech water-bodies ecological potential based on fish community

Ph.D. thesis

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Annotation

Ongoing environmental changes and increasing pressure on freshwater habitat require that we understand the ecological quality of freshwater ecosystems across a wide range of habitat types. This Ph.D. thesis addresses the utility of fish as ecological indicators in heterogeneous reservoir ecosystems. In the first section, I develop suitable indices and calculate ecological potential in two case studies, one using common fish guilds and traits at a large continental scale and another using species-specific indicators for a country-specific dataset. In the second section, I compare the assessment of fish communities across a large geographical region and identify anthropogenic stressors with the highest impact on fish communities. In the third section, I discuss the issue of optimal gillnet sampling design for reliable fish indicator values to increase the utility of assessment methodologies and to reduce sampling effort and fish mortality required to obtain reliable data. In the fourth section, I compare estimates of fish recruitment based on different sampling methods and develop a novel statistical approach to analyse factors affecting fish recruitment. This work provides an initial step towards the improvement of ecological quality of freshwater reservoirs.

Declaration [in Czech]

Prohlašuji, že svoji disertační práci jsem vypracoval samostatně pouze s použitím pramenů a literatury uvedených v seznamu citované literatury.

Prohlašuji, že v souladu s § 47b zákona č. 111/1998 Sb. v platném znění souhlasím se zveřejněním své disertační práce, a to v úpravě vzniklé vypuštěním vyznačených částí archivovaných Přírodovědeckou fakultou elektronickou cestou ve veřejně přístupné části databáze STAG provozované Jihočeskou univerzitou v Českých Budějovicích na jejích internetových stránkách, a to se zachováním mého autorského práva k odevzdanému textu této kvalifikační práce. Souhlasím dále s tím, aby toutéž elektronickou cestou byly v souladu s uvedeným ustanovením zákona č. 111/1998 Sb. zveřejněny posudky školitele a oponentů práce i záznam o průběhu a výsledku obhajoby kvalifikační práce. Rovněž souhlasím s porovnáním textu mé kvalifikační práce s databází kvalifikačních prací Theses.cz provozovanou Národním registrem vysokoškolských kvalifikačních prací a systémem na odhalování plagiátů.

Blabolil

České Budějovice, 18. 4. 2017 RNDr. Petr Blabolil

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Cover image drawn by Zuzana Sajdlová.

List of papers and author's contribution

This Ph.D. thesis is based on the following papers and a manuscript (listed thematically):

Blabolil, P., Logez, M., Ricard, D., Prchalová, M., Říha, M., Sagouis, A., Peterka, J., Kubečka, J., Argillier, C. (2016) An assessment of the ecological potential of Central and Western European reservoirs based on fish communities. Fisheries Research 173: 80–87, DOI 10.1016/j.fishres.2015.05.022,
Impact Factor (2015): 2.230. 5-Year Impact Factor: 2.263
Petr Blabolil participated in field sampling and catch processing in Czech reservoirs, he was responsible for data analyses, statistical evaluation, and writing the manuscript.

Blabolil, P., Říha, M., Ricard, D., Peterka, J., Prchalová, M., Vašek, V., Čech, M., Frouzová, J., Jůza, T., Muška, M., Tušer, M., Draštík, V., Sajdlová, Z., Šmejkal, M., Vejřík, L., Matěna, J., Boukal, D.S., Ritterbusch, D., Kubečka, J. (submitted) A simple fish-based approach to assess the ecological quality of freshwater reservoirs in Central Europe.
Petr Blabolil participated in field sampling, catch processing, he was responsible for data analyses, statistical evaluation, and writing the manuscript.

Poikane S., Ritterbusch D., Argillier C., Białokoz W., Blabolil P., Breine J., Jaarsma N. G., Krause T., Kubečka J., Lauridsen T. L., Nõges P., Peirson G., Virbickas T. (2017) Response of fish communities to multiple pressures: development of a total anthropogenic pressure intensity index. Science of the Total Environment 586: 502–511, DOI 10.1016/j.scitotenv.2017.01.211
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Petr Blabolil participated in field sampling and catch processing in Czech reservoirs, he was responsible for Czech environmental and pressure data collection and analyses, he attended common meetings and discussions resulting in the manuscript, he contributed by comments during manuscript preparation and writing.

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Co-authors agreement

The co-authors listed below fully acknowledge that Petr Blabolil is the first author of three papers and a manuscript presented. Most of the processing as well as the statistical analyses was performed by Petr Blabolil. He also made a major contribution in writing to the manuscripts. All papers contain the original results. The co-authors consent to the publication of the papers in the Ph.D. thesis of Petr Blabolil and support this statement with their signature.

RNDr. Jiří Peterka, Ph.D.

As. Prof. Ing. MgA. David Boukal, Ph.D.

Prof. RNDr. Jan Kubečka, Ph.D.

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE
Institute for Environment and Sustainability (Ispra)

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Declaration of contribution

I confirm that Petr Blabolil participated in field sampling and catch processing in Czech reservoirs, he was responsible for Czech environmental and pressure data collection and analyses, he attended common meetings, discussions and comments on the article Poikane S., Ritterbusch D., Argillier C., Białokoz W., Blabolil P., Breine J., Jaarsma N. G., Krause T., Kubečka J., Lauridsen T. L., Nõges P., Peirson G., Virbickas T. (2017) Response of fish communities to multiple pressures: development of a total anthropogenic pressure intensity index. Science of the Total Environment 586: 502–511 doi: 10.1016/j.scitotenv.2017.01.211.

Yours sincerely,

Dr. Sandra Poikane

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Contents

Introduction

Human influence on aquatic ecosystems

Human alteration of the Earth is substantial and increasing (Vitousek et al. 1997). The effect is particularly evident in freshwater ecosystems, which provide essential services to human societies including water for drinking, irrigation, navigation, industrial uses, aquaculture, energy production, flood prevention, recreation, and waste disposal (Wetzel 2001). Despite their paramount importance, human impact on water ecosystems is mostly negative and leads to their degradation through nutrient and organic enrichment (eutrophication), acidification, salinization, contamination with toxic waste, channelization and fragmentation, impoundment by dams, dredging and filling of wetlands, water withdrawal for irrigation and industrial use, and introduction of alien species (EEA 2012). Global human population consumes more than half of the accessible freshwater supplies, mostly for agriculture, which causes rapid depletion of underground water resources, habitat loss, biodiversity loss and environmental degradation in many areas (EEA 2015). This is particularly evident in densely populated, developed countries including most of the Europe.

While some stressors such as airborne emissions and the resulting acidification receded in recent decades (Vrba et al. 2016), others remain a serious issue (Birk et al. 2012). For example, widespread eutrophication leads to increase of phytoplankton biomass, shifts towards toxic or inedible species, changes in macrophyte communities, decrease in water transparency, oxygen depletion, decline of desirable fish species, and overall decrease in the perceived aesthetic value of the water bodies (Carpenter et al. 1998). These negative alternations also limit the use of water bodies by human society (Karr and Chu 1997). Evaluation of freshwater ecosystem responses to stressors and the assessment of their ecological quality is therefore needed in order to guide restoration actions and minimize negative anthropogenic effects (Scheffer and Carpenter 2003).

Environmental monitoring and improvements

Problems with access to water resources and water quality forced people to identify pollution sources and strive to improve water quality for centuries. The growing awareness of the severity and ubiquity of problems associated with freshwater resources led to the development of a legal framework intended to prevent and mitigate the consequences. Directives or regulations of concentration limits were developed to curb chemical pollution, e.g., in the European community Directive 76/464/CEE, Directive 82/176/CEE, Directive 84/491/CEE. However, this approach reflected the status of the inputs for primary production or environmental toxicity, while the most direct and efficient assessment of ecological integrity is the status of inhabiting organisms (Karr 1981) that can diagnose chemical, physical and biological impacts as well as cumulative environmental effects.

One of the first attempts to use living organisms as bioindicators happened long before when Frič (1872) developed the so-called fish zones to characterize running waters in the temperate region. This classification was based on the observation that communities at localities sharing similar environmental parameters should also be similar and any different warrant the question why this is so. Soon thereafter, Kolkowitz and Marsson (1902, 1908) used diatoms to indicate water quality in streams and many other studies using other taxa in different areas of the world followed suit (e.g., Liebmann 1960, Thomas 1975, Sládeček et al. 1981).

The rise of ecological awareness meant that ecological quality assessment was incorporated in legal instruments such as the Clean Water Act in the United States of America (CWA 1972), South African law (RSA 1998), Australian law (ANZECC 2000), and the European Water Framework Directive (WFD) that was implemented in all member states of the European Union (EC 2000). WFD takes a holistic approach by requiring the assessment of whole river catchments and the evaluation of several key organismal groups from different trophic levels (phytoplankton, macrophytes, benthic fauna and fish). The assessment criterion is a deviation from a theoretical reference status that represents the original habitat, unaltered by human activity. Most of the work based on WFD so far focused on natural ecosystems including rivers, coastal waters, lakes and transitional waters (Birk et al. 2012) but largely neglected artificial and heavily modified water bodies such as reservoirs, whose ecological potential should be assessed separately under WFD.

Reservoir characteristics

Reservoirs are created by damming river valleys and represent highly modified running water ecosystems characterized by interference of natural fluvial processes, habitat fragmentation, and reduction of traditional fisheries including the extinction of native, especially migratory species and the introduction of non-native species (McCluney et al. 2014, Agostinho et al. 2016). On the other hand, reservoirs provide valuable social and economic benefits such as water storage, flood control, hydropower generation, and recreational use that are inherently linked to the negative alterations. If the negative effects cannot be mitigated without reduction of reservoir functions or significant adverse effects on the wider environment, they cannot be considered as pressures in the sense of WFD (EC 2000). On the other hand, stressors independent of primary purposes negatively affecting reservoir ecosystems and ecosystem functions (e.g., eutrophication) should be improved whenever possible.

Interest in artificial ecosystems is surprisingly low compared to natural water bodies, given that more than 60 % of standing waters in Belgium, Bulgaria, the Czech

Republic, France, Hungary, Italy, the Netherlands, and the United Kingdom, are classified as artificial (EEA 2012). Moreover, more than 6000 large dams have been built worldwide (Lehner et al. 2011). One reason for this lack of interest is the difficulties with studying heterogeneous ecosystems such as reservoirs that represent a transitional type between lakes and rivers, but usually share more similarities with lakes (Irz et al. 2006). In comparison to natural lakes, reservoirs are much younger, but the most obvious difference is in the morphology affecting hydrological processes.

Reservoirs usually have one or a few inflowing rivers, elongated shape, steep shores, relatively low mean depth and maximum depth near the dam (Duncan and Kubečka 1995). The canyon-shaped morphology drives longitudinal gradients in sedimentation and nutrient concentration (Hejzlar and Vyhnálek 1998). The most productive upper zone with high plankton and fish production is enabled by a slowdown of water flow, while the lowest productivity is in the dam part (Sed'a and Devetter 2000). In addition, the vertical gradient of environmental variables occurs in thermally stratified reservoirs with higher productivity, in which the oxygen can be quickly depleted and hypoxic or anoxic zones establish at grater depths under the thermocline. Most organisms including fish thus stay in warmer, oxygen-rich upper layers (Sed'a and Devetter 2000, Prchalová et al. 2009a).

Due to the canyon shape, benthic habitats in reservoirs are usually found mainly deep under the photic zone and in the off-shore littoral area that is poorly developed in many reservoirs due to water level fluctuation (Duncan and Kubečka 1995). Open-water pelagic habitat, on the other hand, represents a majority of water volume in steep-bank water bodies. These underlying gradients and habitat types make simple characterizations of reservoir ecosystems challenging.

Last but not least, fish populations in reservoirs are often exploited by anglers or commercial fisheries. Rare species are thus often protected by law, while commercially important species are actively managed (Boukal et al. 2012). All these external drivers should be reflected in the assessment of ecological potential.

Fish as ecological indicators

To assess ecological quality, the WFD emphasizes fish as one of four key taxonomic groups that also include phytoplankton, aquatic flora and benthic invertebrate, because fish communities are among the best studied indicators of ecological quality in freshwater ecosystems. Most relevant species are easily identified in the field and their ecological characteristics are well understood. Moreover, fish are a highly visible component of aquatic resources for the general public. Many fish sampling methods were developed to catch fish in different habitats (CEN 2006) and provide a "true picture" of the fish community (Kubečka et al. 2009). After filling a reservoir, the fish community composition stabilizes and reflects the environmental conditions (Kubečka 1993), and fish communities do not have to be sampled very often because of the relatively long lifespan of most species.

Fish communities can strongly impact ecosystem processes (Hrbáček 1958, Hrbáček et al. 1961) and are also affected by the environment, because fish growth and reproductive strategies are strictly dependent on the surrounding conditions (Karr 1981, Karr and Dudley 1981). Therefore, water bodies should be well characterized based on their surrounding environmental conditions (Belpaire et al. 2000, Mehner et al. 2005, Garcia et al. 2006, Ritterbusch et al. 2014) and when using fish as indicators of ecological quality, natural environmental factors should be accounted for as well (Argillier et al. 2013, Paper I).

Fish are highly sensitive to changes in the environment and a wide variety of environmental disturbances (Karr et al. 1986). The condition of the fish community is generally representative of environmental conditions, even though maximum stresses might have occurred at times other than the sampling dates. Both acute toxicity (missing fish) and stress effects (depressed growth or reproductive success) can be evaluated. Nevertheless, fish communities are usually able to recover from natural disturbances depending on the frequency, magnitude, and duration of the effect and the inherent sensitivity of the system. Stable and "well balanced" fish communities characterize water bodies in good condition, as species with different food preferences form feeding guilds and use much of the available resources (Karr and Dudley 1981). Similarly, natural reproduction along with wide age or size spectrums and absence of ill or anomalous individuals indicate a lack of significant stressors that would affect the local fish populations (Benejam et al. 2009).

Local fish communities can be assessed in many ways. Fish can be divided into groups of tolerant species with a broad ecological niche or sensitive species with a narrow ecological niche. In stratified lakes, most salmonids are indicators of good ecological quality (Gassner et al. 2003, Carol et al. 2006, Garcia et al. 2006). Other indicators of good ecological quality include stenotherm species such as burbot (*Lota lota*), bullheads (*Cottus* sp.) and common minnow (*Phoxinus phoxinus*) (Gassner et al. 2003). On the other hand, indicators of an altered environment are mainly large-bodied cyprinids, such as common carp (*Cyprinus carpio*) in southern Europe and common bream (*Abramis brama*) in central Europe (Mehner et al. 2005, Carol et al. 2006, Garcia et al. 2006). Mehner et al. (2005) and Garcia et al. (2006) also included pikeperch (*Sander lucioperca*) and ruffe (*Gymnocephalus cernua*) as species that increase with eutrophication. Beside general classification based on tolerance to the most common stressors, taxonomic identity, reproductive, trophic and feeding habitat guilds can be used to classify the fish communities (Argillier et al. 2013, Paper I).

Moreover, fish indicators can be based on standardized abundance and biomass or as a relative proportion in the community. For example, abundance and biomass of fish, particularly omnivores, increases with eutrophication (Garcia et al. 2006, Launois et al.

2011a, Argillier et al. 2013). Fish diversity provides another view on the ecological integrity. A water body with a dominance of alien and invasive species cannot be considered as being in good ecological health (Belpaire et al. 2000, Benejam et al. 2009).

Ecological quality assessment

Fish community indicators were used to assess anthropogenic alternation of many types of water bodies including running waters (Pont et al. 2007), caves (Poulson 1992), wetlands (Uzarski et al. 2005), estuaries (Coates et al. 2007) and salt waters (Henriques et al. 2008). The utility of fish-based indicators for standing waters was confirmed across the world including Asia (Zhang et al. 2014), North America (Whittier and Hughes 1998) and South America (Maggioni et al. 2012). In Europe, indices were developed in country-specific studies in, e.g., Austria (Gassner et al. 2003), Belgium (Breine et al. 2015), the Czech Republic (Paper II), Denmark (Søndergaard et al. 2005), France (Launois et al. 2011b), Finland (Olin et al. 2013), Ireland (Kelly et al. 2012), Lithuania (Virbickas and Stakėnas 2015), Spain (Lara et al. 2009), Sweden (Holmgren et al. 2007), and on a continental scale (Argillier et al. 2013, Paper I).

The amount of data and site-specific conditions highly affect data analyses and the applicability of developed methodologies. Within a small and specific dataset, researchers can identify important drivers in each ecosystem (Gassner et al. 2003, Ritterbusch et al. 2014), but at the same time can provide only limited scope for general conclusions. Small datasets often lack power for sophisticated statistical analyses and ensuring assessments hence they requires expert judgment and empirical understanding (Gassner et al. 2003), which are prone to subjectivity and could reduce the credibility of the results in scientific as well as stakeholder communities. This contrasts with the potential of larger datasets to cover more countries and larger environmental gradients to yield site-specific predictive models (Argillier et al. 2013, Paper I). Extrapolation beyond the range of available environmental conditions, which is more robust for large datasets, can also solve the conundrum of pristine reference conditions, which are extremely rare in natural water bodies (e.g., historical records, Gassner et al. 2005) and absent in artificial ones (Paper II).

Comparison of assessment methodologies

'Good ecological status' in natural water bodies and 'Good ecological potential' in artificial and heavily modified water bodies represent the target value that European surface water bodies should achieve by 2027. This presents formidable challenges at the continental scale due to strong gradients in physical geography, human activities and attitudes toward water resources across the 27 Member States of the European Union (Birk et al. 2013). In particular, development of assessment methodologies of the ecological status/potential will always be area specific. To ensure compatibility, different methodologies should therefore be compared and class boundaries harmonized to ensure consistent management objectives via the so called intercalibration process (EC 2000). As a result, one of three possibilities for intercalibration is chosen (1) direct comparison of similar data, (2) indirect comparison using common indicators if different sampling methods are used, or (3) common boundary settings based on a common database using the same assessment metrics (Poikane et al. 2015).

Passing all intercalibration criteria (i.e., establishing the biological reference condition, assessment of fish community composition, abundance and age structure, comparison of addressed pressures, habitats, sampling methods and background data availability) in fish assessment methods is difficult because of the high diversity of sampling methods, impacts of fisheries management, locally dependent effects of environmental pressures, natural variability of fish indicators, fish mobility and buffering capacity dependent on fish conditions and ontogeny (Kelly et al. 2012, Paper III). All these issues can obscure the relationships between specific pressure indicators and fish communities (Olin et al. 2013, Breine et al. 2015). Therefore, only a combination of pressures clarify the fish community composition. Comparison of assessment methodologies reveals the importance of combination of stressors and their effects on water ecosystems.

Fish sampling efficiency and final recommendations

Many fish sampling methods have been developed (CEN 2006). One of the most commonly used methods for fish sampling in Europe and other parts of the world are gillnets (CEN 2005, Bonar et al. 2009, Argillier et al. 2013). Gillnets are popular for their simplicity, low cost, applicability in different habitats and the existence of standard sampling protocols (CEN 2005, Bonar et al. 2009). On the other hand, this method provides only relative data on fish abundance and biomass, is selective and its efficiency depends on fish activity (Kurkilahti et al. 2002, Prchalová et al. 2009b) and gear saturation (Prchalová et al. 2010), and it has a very destructive impact on fish populations (Winfield et al. 2009, Žydelis et al. 2013). Because of all these controversial issues, applying the lowest sampling effort possible is imperative (Paper IV).

The last step in the process to improve of ecological quality is the restoration of damaged ecosystems. This can include bottom-up approaches such as the reduction of nutrient load from point sources (wastewater treatment plants) and across the catchment (agriculture management). Top-down restoration approaches are primarily represented by biomanipulation, i.e., the addition of top predators with cascading effects on the entire food web through the reduction of planktivorous fish (Carpenter 1985, Mehner et al. 2004). Successful biomanipulation requires a long-term presence of a sustainable population of piscivorous species, which cannot be achieved solely by stocking in larger waters and requires successful recruitment of the predators. However, the assessment of species-specific recruitment in reservoirs is challenging since traditional stock-recruitment models can be difficult to apply, especially due to limited data availability. Moreover, multiple factors such as the condition of the parental stock (Worm et al. 2009), spawning substrate availability (Paulovits et al. 2007), temperature (Jonsson and Jonsson 2009), predation (Dörner et al. 1999), food quality and quantity (Ljunggren 2002) can affect fish recruitment. Non-orthodox statistical methods are thus needed to find the critical factors driving recruitment, which could support management decisions (Paper V).

Aims of the study

This Ph.D. thesis addresses the utility of fish as ecological indicators in the heterogeneous ecosystems of freshwater reservoirs. The first section focuses on the development of suitable indicators and the quantification of the ecological potential in two case studies, one using common fish guilds and traits at a large continental scale (Paper I) and another using species-specific indicators for a country-specific dataset (Paper II). In the second section, the assessment methodologies of fish communities across a large geographical region are compared and anthropogenic stressors with the highest impact on fish communities are identified (Paper III). The third section addresses the issue of optimal gillnet sampling design for reliable fish indicator values to increase the utility of assessment methodologies and to reduce sampling effort and fish mortality in order to obtain reliable data (Paper IV). In the fourth section, estimates of fish recruitment based on different sampling methods are compared and a novel statistical approach to analyse factors affecting fish recruitment is developed (Paper V). The specific objectives of the individual papers were to:

Paper I (i) Select functional fish community indicators significantly reacting to proxies of eutrophication, (ii) combine them into a fish-based index applicable in Central and Western Europe by combining benthic gillnets data from French and Czech reservoirs, and (iii) adapt a hindcasting approach that enables the prediction of expected indicator values in the absence of pressure data for each reservoir depending on their environmental characteristics.

Paper II (i) Select new easy-to-use fish indicators, adapting a simple approach to the compiled data from benthic and pelagic gillnets across Czech reservoirs, and (ii) combine the indicators into an index validated by a multi-step procedure including evaluation of the pressure response, quantification of interannual stability, sensitivity analysis and comparison of the results with the index developed in Paper I.

Paper III (i) Explore fish community responses to multiple pressures, (ii) compare different assessment methodologies within the Central Baltic ecoregion and (iii) identify the best relationship between results of fish assessment methodologies and combination of the stressors for common mitigation and/or restoration measures.

Paper IV (i) Test the performance of different reduced sampling scenarios along the longitudinal and depth gradients in heterogeneous temperate reservoirs, (ii) identify scenarios which minimize the loss of information while substantially reducing sampling effort and fish mortality by lowering the number of sampling sites to find the best, cost-effective gillnet sampling design.

Paper V (i) Compare species-specific estimates of recruitment based on fry survival and commonly used fish sampling methods and (ii) determine the critical drivers in the early life-history of the selected species in a reservoir using a novel statistical approach.

Results

This Ph.D. thesis includes the following five papers – four published (Paper I, III, IV and V) and one submitted (Paper II) in international scientific journals. All the papers are appended and referred to in the text by their Roman numerals.

Paper I

An assessment of the ecological potential of Central and Western European reservoirs based on fish communities

Blabolil, P., Logez, M., Ricard, D., Prchalová, M., Říha, M., Sagouis, A., Peterka, J., Kubečka, J., Argillier, C. (2016) An assessment of the ecological potential of Central and Western European reservoirs based on fish communities. Fisheries Research 173: 80–87, DOI 10.1016/j.fishres.2015.05.022

In this study we developed a novel methodology based on fish communities to assess the ecological potential of central European reservoirs. Using the hindcasting approach, our index predicts values that could be observed in the absence of pressures for each reservoir depending on their environmental characteristics. Fish data were collected from 144 French and Czech reservoirs between 2005 and 2013 by standardized benthic gillnet sampling and transformed to functional and taxonomical metrics. After all validation by multiple testing of models redundancy and pressure-response, the final index was composed of three metrics: total biomass of fish, abundance of invertivores/piscivores, and abundance of planktivorous fish. The index accurately identifies reservoirs that are lightly, moderately and heavily affected by eutrophication. In addition to French and Czech reservoirs, this index could be a useful tool for countries with few reservoirs and the basis for further collaborative studies.

Paper II

A simple fish-based approach to assess the ecological quality of freshwater reservoirs in Central Europe

Blabolil, P., Říha, M., Ricard, D., Peterka, J., Prchalová, M., Vašek, V., Čech, M., Frouzová, J., Jůza, T., Muška, M., Tušer, M., Draštík, V., Sajdlová, Z., Šmejkal, M., Vejřík, L., Matěna, J., Boukal, D.S., Ritterbusch, D., Kubečka, J. (submitted) A simple fish-based approach to assess the ecological quality of freshwater reservoirs.

The assessment of ecological quality in freshwater ecosystems is a key issue in many countries, but conditions for the development of assessment methodologies are country-specific. This study proposes a simple methodology for the assessment of the ecological potential of reservoirs based on fish communities using a dataset covering major gradients in reservoirs in the Czech Republic. Fish data obtained by gillnet sampling were correlated with a proxy of eutrophication as a key indicator of anthropogenic pressure for selecting appropriate fish-based indicators, establishing scoring criteria and developing the final index of ecological quality. Expert judgement was also used to select potential indicators. Nine indicators were selected for the final fish-based index, fulfilling the criteria required by the Water Framework Directive. Three steps were used to validate the final fish-based index: evaluation of its response to an independent pressure index, quantification of its interannual stability, and sensitivity analysis of individual indicators. Finally, we compared the final index to a previously developed general biological index for Central and Western Europe. Our study demonstrates that a combination of expert judgement and strict validation methods can result in an informative assessment of the ecological conditions of reservoirs, which can help identify conservation and restoration priorities.

Paper III

Response of fish communities to multiple pressures: development of a total anthropogenic pressure intensity index

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Lakes in Europe are subject to multiple anthropogenic pressures, such as eutrophication, habitat degradation and alien species which are frequently inter-related. Therefore, effective assessment methods addressing multiple pressures are needed. In addition, these systems have to be harmonised (i.e., intercalibrated) to achieve common management objectives across Europe.

Assessments of fish communities inform environmental policies on ecological conditions integrating the impacts of multiple pressures. However, the challenge is to ensure consistency in ecological assessments through time, across ecosystem types and across jurisdictional boundaries. To overcome serious comparability issues between national assessment systems in Europe, we develop a total anthropogenic pressure intensity (TAPI) index as a weighed combination of most common pressures in European lakes that is validated against 10 national fish-based water quality assessment systems using data from 556 lakes.

The best-performing index combines eutrophication, hydromorphological alterations and human-use intensity of lakes. For specific lake types also biological pressures may constitute an important additional pressure. The developed best performing index can be used in lake management for assessing total anthropogenic pressure on lake ecosystems and creates a benchmark for comparison of fish assessments independent of fish community composition, size structure and fishing-gear.

We argue that fish-based multiple-pressure assessment tools should be seen as complementary to single-pressure tools offering the major advantage of integrating direct and indirect effects of multiple pressures over large scales of space and time.

Paper IV

Optimal gillnet sampling design for the estimation of fish community indicators in heterogeneous freshwater ecosystems

Blabolil, P., Boukal, D.S., Ricard, D., Kubečka, J., Říha, M., Vašek, M., Prchalová, M., Čech, M., Frouzová, J., Jůza, T., Muška, M., Tušer, M., Draštík, V., Šmejkal, M., Vejřík, L., Peterka, J. (2017) Optimal gillnet sampling design for the estimation of fish community indicators in heterogeneous freshwater ecosystems. Ecological Indicators 77: 368–376, DOI 10.1016/j.ecolind.2017.02.036

Monitoring of biota in heterogeneous ecosystems requires sampling in different habitats and across environmental gradients. The resulting multivariate community data are typically aggregated into one or several indicator values for the entire ecosystem, but the relationship between the robustness of such indicators and sampling effort, including the identification of minimum acceptable sampling designs, is not fully understood.

We address this issue for multi-mesh gillnet sampling of freshwater fish communities in deep-valley reservoirs, using data from 29 detailed annual surveys in eight reservoirs in the Czech Republic that account for the inherent longitudinal and depth gradients and the qualitatively different benthic and pelagic habitats. We evaluate the performance of eight sampling scenarios, created by variously reducing the full dataset. To this end, we use 31 fish-based, community-, size- and species-level indicators calculated separately for benthic and pelagic habitats, and fit the relationships between the indicator values based on the reduced and full sampling design using Bayesian generalized linear models.

The ability of reduced data to estimate the “true” indicator value across the entire dataset, expressed as the adjusted R^2 value of the best model for the given indicator, increased with sampling effort. However, the relationships differed between indicators: R^2 values were higher for abundance-based than for biomass-based indicators. We identified three suitable reduced sampling designs: (1) sampling the entire longitudinal profile in the epilimnion, yielding on average the highest R^2 values (0.97), (2) same as before but limited to one sampling layer closest to the surface (R^2 = 0.91), and (3) sampling all depth strata at the farthest points of the longitudinal gradient (i.e., dam and tributary, $R^2 = 0.83$). These results demonstrate that, in order to obtain robust estimates of fish community indicators, current gillnet sampling protocols can be optimized to reduce effort and minimize unwanted fish mortality.

Paper V

Predicting asp and pikeperch recruitment in a riverine reservoir

Blabolil, P., Ricard, D., Peterka, J., Říha, M., Jůza, T., Vašek, M., Prchalová, M., Čech, M., Muška, M., Seďa, J., Mrkvička, J. Boukal, D.S., Kubečka, J. (2016) Predicting asp and pikeperch recruitment in a riverine reservoir. Fisheries Research 173: 45–52, DOI 10.1016/j.fishres.2015.08.003

Fish recruitment in riverine reservoirs is not fully understood because the long-term data series required for standard stock–recruitment models are often lacking. In this study, two unrelated piscivorous species with different ecologies, asp (*Leuciscus aspius*) and pikeperch (*Sander lucioperca*), were investigated over a 14-year period in a reservoir in the Czech Republic using a novel informative statistical approach based on dimension reduction methods. This method is useful for situations in which potential predictors are equal to, or exceed, the length of the time series. Recruitment of asp fry was affected by zooplankton abundance, predator density and temperature. Recruitment of pikeperch fry measured with seine and trawls was only affected by the number of predators, while recruitment of pikeperch fry estimated with gillnet data was also affected by temperature and water level fluctuation. Although gillnets are commonly used sampling method, it seems to be inappropriate for developing fry predicting model. This research also highlights the use of a novel approach to dimension reduction for analysis of factors affecting recruitment using shorter time series (in our case 13 years).

Discussion

The Ph.D. thesis contributes to the improvement of ecological quality in freshwater reservoirs. Two fish-based indices differing in the composition of indicators, statistical approaches, spatial extent and validated procedures were developed. The total anthropogenic pressure intensity index was selected as a weighted combination of the most common pressures in European lakes that is validated against 10 national fish-based indices. Cost-effective sampling designs were identified using statistical analyses of available data and finally a novel approach for studying fish recruitment was proposed.

Development of fish-based indices

The first fish-based index developed in collaboration with French researchers is applicable at least to Central and Western European reservoirs (Paper I). This work extends a previous study by Argillier et al. (2013), who developed an index for natural lakes across Europe. In that study, functional indicators were preferred due to species differences between communities across large spatial scales. However, species- or trophic guild-based indicators that can be used across smaller spatial scales have the advantage of extensive ecological knowledge available for each species, which can lead to better understanding of the links between stressors and fish-based indices (Gassner et at. 2003). One should, of course, combine species-specific indicators with community-level characteristics such as the increase of total fish abundance and biomass with productivity (Belpaire et al. 2000, Søndergaard et al. 2005, Kelly et al. 2012). Biomass is a more direct parameter than abundance since it integrates productivity in the whole food-web and hence it was used separately in different productivity localities (dam and tributary) in Paper II.

The first selected indicator in Paper I, abundance of planktivorous fish, consisted mainly of common bream. This species was used in several fish indices as a single-species indicator of ecosystem degradation because its abundance increases with productivity (Mehner et al. 2005, Garcia et al. 2006, Kelly et al. 2012, Paper II). Abundance of six species of invertivorous and piscivorous fish, the second indicator in Paper I, was driven mainly by European perch (*Perca fluviatilis*) and pikeperch. Pikeperch is typical for lowland, nutrient-rich waters (Gassner et al. 2005) and its populations increase with eutrophication (Kitchell et al. 1977, Mehner et al. 2005). In the Paper II pikeperch as a species-specific indicator was not included due to a low correlation coefficient with total phosphorus concentration, this is probably due to smaller gradients in the Czech subset compared to the whole Czech-French dataset. Abundance of European perch, when small individuals were evaluated, also generally increases with productivity (Mehner et al. 2005). However, when compared across a shorter productivity gradient from meso- to eutrophic condition, European perch biomass decreases (Vašek et al. 2016, Paper II).

The other species-specific indicators (i.e., relative abundance of ruffe and biomass of rudd *Scardinius erythrophthalmus*) and an indicator grouping salmonids suggested specific species richness in Czech reservoirs. The last indicator, presence of 0+ fish of six common species (Paper II), captures the natural reproduction and indirectly evaluates age structure as required by WFD. Indirect assessment of age structure (e.g., based on size distribution) is common across indices since its direct assessment is difficult, expensive and time consuming. However, the relationships between size structure and anthropogenic pressures such as eutrophication are inconclusive (Kelly et al. 2012, Emmrich et al. 2014). Therefore, our approach to consider age structure in Paper II makes easy to determine and provides a reliable proxy for the presence of young fish beyond current recruits.

In summary, the nine fish indicators used in Paper II are close to the European average of eight per index (Birk et al. 2012). Functional indicators are useful for comparison of fish communities on large geographical scales, but separate species-specific indicators can provide results that are directly interpretable for fisheries managers. Both indices were validated using several approaches. In particular, the verification of a pressure-response relationship is a key, but often neglected, issue in the development of an assessment methodology (Birk et al. 2012). The index in Paper I was validated during the process of indicator selection for a strong relationship with pressures and avoidance of redundant indicators. Paper II with a simpler approach to indicator selection can be seen as subjective. Therefore more effort than in Paper I was dedicated to proper validation using an independent pressure index covering multiple pressures without eutrophication, quantification of interannual stability and sensitivity analysis of the index to the exclusion of individual indicators. Classification based on both indices were compared with the main difference in the assessment being stricter in Paper I was than in Paper II. This difference results from a larger gradient of pressures used for index development in Paper I than within the Czech subset as demonstrated by better condition in the comparison of separate Czech and French reservoirs. Czech reservoirs are in better condition as they are on relatively small rivers and in colder climate, especially when compared to some French reservoirs in the Mediterranean.

The results in Paper I and II confirmed that the composition of local fish communities closely reflects the intensity of eutrophication even if they are further impacted by hydro-morphological stressors associated with water use and influenced by fisheries management (Boukal et al. 2012, Vašek et al. 2013). Moreover, only a few Czech reservoirs were classified as reaching the maximum ecological potential, whereas most were of moderate or poor ecological potential. This is not surprising given the intensity of human impacts on freshwater habitats and particularly reservoirs in Central and Western Europe. Fortunately, very few reservoirs fell in the category of bad ecological potential. This means that although reservoirs suffer from eutrophication and the situation in the majority of them deserves our attention, the issue is not critical.

Comparison of assessment methodologies

Comparison of reservoirs with natural lakes revealed similar responses of fish communities to stressors within the Central-Baltic ecoregion (Paper III). Despite the Czech assessment developed with data from reservoirs and focusing on eutrophication (Paper II), the common intercalibration exercise identified hydromorphological alteration and direct lake-use intensity as two other important drivers. All three stressors were previously identified to have impact on whole freshwater ecosystems (Jeppesen et al. 2012). On the other hand, acidification, chemical pollution and contamination, fishing and stocking and estimates of alien species were not included in the best-performing total anthropogenic pressure intensity index (TAPI). Some of these stressors can be masked in the assessment of lake-use intensity covering recreation activities and human population density. When compared the provided datasets, the Czech one covers a sufficient gradient from minor to highly degraded reservoirs that is highly advantageous in contrast to Belgian lakes under high pressure of non-native species (Belpaire et al. 2000) and the French dataset covers a sufficient gradient of only eutrophication (Argillier et al. 2013). Response of fish communities to environmental change is better detected on the level of multiple-pressure intensity rather than from single stressors (Schinegger et al. 2013, Nõges et al. 2016). The development of TAPI by combination of the most important pressures is highly important as a non-biological tool for the comparison of biological elements on a large spatial scale. This will help in the implementation of the WFD because 230 methods from 28 countries so far were officially intercalibrated and published in the EC Decision (EC 2013), including five for fish in lakes (Poikane et al. 2015).

Optimal gillnet sampling design

Fish-based indices developed in this Ph.D. thesis rely heavily on standardized gillnet data. Depth-stratified gillnet sampling in randomly chosen localities is required by European as well as North American standard sampling protocols (CEN 2005, Bonar et al. 2009), but this approach is not efficient in heterogeneous reservoirs with predictable gradients (Prchalová et al. 2008, Prchalová et al. 2009a, Vašek et al. 2016). In Paper IV, optimal gillnet sampling design was proposed to highlight the use of existing environmental gradients in reservoirs. With respect to previous parts of this study 31 fish-based, community-, size- and species-level indicators calculated separately for benthic and pelagic habitats were used to test the estimates across eight sampling scenarios. The community-level indicators were standardised abundance and biomass for the whole fish community used also in Paper I and II and biomass divided to small, medium-size and large fish species to compare sensitivity of different size categories (Šmejkal et al. 2015). The last community-level indicator was species richness to demonstrate species habitat association. To compare species-specific indicators, five common and widespread species (Kottelat and Freyhof 2007) with different ecological requirements in terms of habitat productivity (Vašek et al. 2016) and different body shape were selected. These selected species overlap with indices in Paper II (common bream, European perch and ruffe) and were extended by roach (*Rutilus rutilus*) and bleak (*Alburnus alburnus*) because of their common distribution and bleak´s small body-size. The reduced sampling designs differed in the number of localities (all, dam and tributary, and dam) and depth strata (all, epilimnion above the thermocline, and one sampling layer closes to the surface) to cover the main environmental gradients in the reservoirs. Among the eight reduced sampling designs, the highest estimability (expressed as goodness-of-fit statistic, R^2) was achieved when the sampling covered the entire longitudinal gradient of each reservoir but was restricted to the epilimnion layers in vertical profile. Sampling of the entire longitudinal gradient restricted only to the uppermost layer yielded the second best estimability and provided an alternative optimal scheme if reduction in both sampling effort and fish mortality is desired or required (Paper IV).

Fish communities in nutrient-rich reservoirs in Europe are dominated by cyprinids, the most abundant and diverse fish family in Europe (Kottelat and Freyhof 2007). Most of the species prefer the warm, well oxygenated epilimnetic layer (Prchalová et al. 2008, Prchalová et al. 2009a). Selection of the upper layers in thermally stratified reservoirs is therefore reasonable. When reduction of fish mortality (or reduction of time spent processing the samples) is the main priority, possibly at the expense of lower estimability of the indicators, sampling of all strata at the tributary and the dam is the most appropriate strategy.

Last but not least, we found that fish-based indicators varied in their sensitivity to the reduction of sampling design (Paper IV). Biomass indicators were more variable than abundance indicators because of the often random presence or absence of a few large individuals (Šmejkal et al. 2015). When indicator estimability in benthic and pelagic habitat was compared, the estimates based on benthic gillnets were more variable due to the higher reduction of sampling effort and stronger association of the fish with this heterogeneous habitat (Prchalová et al. 2008, Prchalová et al. 2009a). Bream-based indicators had the poorest estimability among all species-specific indicators, probably due to its tall laterally compressed body shape and relatively large size that result in its low catchability by standard gillnets relative to other small- and medium-bodied species (Šmejkal et al. 2015). This undermines the current use of common bream as an indicator species (Gassner et al. 2005, Jeppesen et al. 2005, Emmrich et al. 2014). Attained outcomes contribute to optimization of gillnet sampling protocols and minimization of effort and unwanted fish mortality.

Development of population recruitment predictive models

Successful recruitment is a prerequisite for the long-term persistence of a fish population, but factors affecting recruitment of many fish species in freshwater reservoirs are poorly understood. Paper V attempts to develop a novel statistical approach to evaluate the relationship between year-class-strength and environmental factors when the time series is short relative to the number of possible explanatory variables. The method was applied to two species with different early life history, asp (*Leuciscus aspius*) and pikeperch. First of all estimates based on different sampling methods were evaluated. For asp associated with shallow littoral (Jůza et al. 2014), only fry beach seine data were used resulting in a highly predictable model. The second species, pikeperch, inhabits different habitats with size-dependent changes (Frankiewicz et al. 1996). Despite the combination of fry sampling methods (fry beach seine and pelagic trawl) or gillnet sampling (benthic and pelagic gillnets), the models provided rather poor fits to the data. The recruitment of both species was negatively affected by an abundance of piscivorous European perch as previously demonstrated by Dörner et al. (1999) who identified European perch as a significant predator of fish larvae and juveniles. Although parental stock is a basic element of traditional stock–recruitment models (Quinn and Deriso 1999), in our models we did not detect a significant positive relationship probably because of unreliable estimates. The expected positive effect of temperature (Hokanson 1977) and opposite negative effect of water level fluctuation (Paulovits et al. 2007) was not clearly confirmed as well. Finally, a positive trend between year-class-strength and zooplankton availability was confirmed only for asp, despite its high importance for pikeperch too (Ljunggren 2002). This could be caused by inherent stochasticity in fish recruitment, high spatiotemporal heterogeneity of key environmental drivers of the recruitment, which cannot be covered by regular field sampling (usually restricted to the dam or tributary part). Although the results are limited by the short time series of available data, they provide valuable insights that can guide further research.

Perspectives and conclusion

The whole planet is changing dramatically. Human population growth and rising energy demand will increase the pressure on freshwater resources. Global warming will cause shifts in freshwater ecosystems including fish fauna. New species will profit from the changes and the populations of others will suffer. Currently dominant problems such as eutrophication might become less acute, while new stressors will appear. The ecosystems may behave differently under more extreme conditions such as increasing water temperatures, water scarcity and droughts, and altered rainfall patterns and flooding. This will also result in more water- and health-related issues impacting both economic sectors and freshwater ecosystems (EEA 2015).

One can assume that good ecological quality will increase the resilience of local ecosystems to additional adverse pressures (EEA 2012). This creates an urgent need to link science with improved water management. Better monitoring, assessment and forecasting of water resources will help allocate water more efficiently among competing needs (Jackson et al. 2001).

Additional stressors that are likely to play a more important role in the future should be addressed in the next steps of ecological quality assessment. Water level fluctuation is a ubiquitous stressor in regulated reservoirs. Excessive water level fluctuation leads to the destruction of littoral zones with well-developed macrophyte communities, which provides spatial refugia for zooplankton and benthic macroinvertebrates, and feeding and spawning habitats for most fish species (Belpaire et al. 2000, Wantzen et al. 2008, Duncan and Kubečka 1995).

Recreational fishing also affects fish communities in reservoirs, primarily by the selective removal of large fish and highly prized species. Overfishing can result in a complete collapse of parental stock, as known from commercially important marine species (Hutchings 2000). Local fisheries authorities often stock fish for recreational fishing and the overall trends are to stock more over time (Boukal et al. 2012). This can put additional stress on the local, naturally reproducing fish populations. Moreover, stocking of artificially bred fish erodes genetic diversity (Weiss et al. 2001, Gum et al. 2006) and often brings non-native species that compete with native fauna and disrupt the community (Belpaire et al. 2000, Gassner et al. 2003, Launois et al. 2011b).

Fish integrate past and present conditions due to their relatively long lifespan and their communities can thus be used as indicators of specific pollutants (acidification, oil products, metabolites of drugs, heavy metals, PCBs), environmental changes (e.g., in temperature), and biological degradation. Long-term stress can result in external deformities, eroded fins, lesions, tumours and excessive parasitisation of individual fish, as demonstrated in common carp (Benejam et al. 2009).

Moreover, the existing methodology should embrace other datasets to provide more inclusive assessments of ecological status. Data from fish-friendly methods other than gillnets, such as hydroacoustics (Guillard et al. 2014, Martignac et al. 2015), use of environmental DNA (Ward et al. 2009, Valentini et al. 2016), electrofishing in the littoral or purse seining (CEN 2006) should be used along with the standard gillnet methodology. Fish-based indices can and should be combined with other biological elements (e.g., algae, macrophytes and macro-invertebrates) and fish biomarkers (stress and enzymatic responses, endocrine disruptors, trophic tracers, energy and bile metabolites, genotoxic indicators, histopathological and behavioural alterations, and genetic and cutting-edge omic markers) to enable detection of early signs of ecosystem disturbance (Colin et al. 2016).

Despite the relatively small size of the Czech Republic, where most of the reservoirs studied in this Ph.D. thesis are located, its position in the heart of Europe enables to achieve results that are directly applicable in other nearby countries aiming to improve ecological quality. Moreover, the approaches for development assessment indices, optimal sampling design as well as predicting models can be transferred to other continents and heterogeneous ecosystems.

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Blabolil, P., Říha, M., Ritterbush, D., Ricard, D., Kubečka, J., Assessment of the ecological potential in Czech reservoirs based on fish communities. 2nd International LakeFish Intercalibration Meeting Central Baltic Group, 24-25 October 2013, Berlin, Germany

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- oral presentations (Czech)

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Blabolil, P., Říha, M, Peterka, J., Prchalová, M., Vašek, M., Jůza, T., Čech, M., Draštík, V., Kratochvíl, M., Muška, M., Tušer, M., Frouzová, J., Ricard, D., Mrkvička, T., Sajdlová, Z., Vejřík, L., Šmejkal, M., Borovec, J., Matěna, J., Boukal, D., Kubečka, J., What do the fish say about the quality of aquatic ecosystems. Konference vodní nádrže 2013, 25-26 September 2013, Brno, Czech Republic

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Blabolil, P., Peterka, J., Čech, M., Jůza, T., Draštík, V., Frouzová, J., Kubečka, J., The dispersal of larvae and early juveniles of pikeperch (*Sander lucioperca*) in the deep canyon shaped reservoir. XII. Česká ichtyologická konference, 19-20 May 2010, Vodňany, Czech Republic

- poster presentations

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Blabolil, P., Říha, M., Kubečka, J., Opatřilová, L., The intercalibration results of the methods of assessment of the biological element fish in the Central Baltic Lake Group. XV. Česká rybářská a ichtyologická konference (RybIKon 2016), 4.-5. February 2016. Prague, Czech Republic

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Blabolil, P., Peterka, J., Frouzová, J., Kubečka J., Comparison of three methods of age determination of pikeperch (*Sander lucioperca* L.) larvae and early juveniles during their 60 days post-hatch period. Digital Imaging in Fisheries Biology, 20-23 September 2010 Písek, Czech Republic

- passive participation

Dynamics of Inland Fish and Fisheries, 13.-16. September 2010 České Budějovice, Czech Republic

Fish Stock Assessment Methods for Lakes and Reservoirs, 11.-15. September 2007 České Budějovice, Czech Republic

5th conference of the Czech Society for Ecology, 23.-25. October 2015 České Budějovice, Czech Republic

Curriculum vitae

Date of birth:

20. January 1987, Čáslav

Education and academic employment:

since 2012 Ph.D. student at the Faculty of Science University of South Bohemia in České Budějovice, Czech Republic (Assessment of ecological potential of Czech water bodies based on fish community, supervisor: RNDr. Jiří Peterka, Ph.D.)

2016 RNDr. Thesis at the Faculty of Science University of South Bohemia in České Budějovice, Czech Republic (Predicting asp and pikeperch recruitment in a riverine reservoir, supervisor: RNDr. Jiří Peterka, Ph.D.)

2010-2012 MSc. student at the Faculty of Science University of South Bohemia in České Budějovice, Czech Republic (The factors affecting survival of pikeperch (*Sander lucioperca*) and asp (*Aspius aspius*) in the deep canyon shaped reservoir, supervisor: RNDr. Jiří Peterka, Ph.D.)

2006-2010 BSc. student at the Faculty of Science University of South Bohemia in České Budějovice, Czech Republic (The factors affecting early survival of pikeperch larvae and juveniles in the deep canyon shaped reservoir, supervisor: RNDr. Jiří Peterka, Ph.D.)

since 2007 part-time job as a student assistant worker at the Institute of Hydrobiology, Biology Centre Czech Academy of Sciences, České Budějovice

2013/14 work placement at IRSTEA, Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, UR HYAX, Hydrobiologie, Aix-en-Provance, France

since 2016 part-time job at Soil and Water (SoWa) Research Infrastructure, Biology Centre Czech Academy of Sciences, České Budějovice

participation in sampling of more than thirty lakes, reservoirs and rivers in Austria, France, Czech Republic and the Netherlands, some of them repeatedly

Scientific projects:

- principal investigator

Research program Diversity of life and ecosystem health, Strategy AV21, activity Monitoring of cryptic species having indicative value using harmless sampling methods (2015-2016, Czech Academy of Sciences)

- co-investigator

15-01625S - Changes in fish isotopic signals: linking land use and reservoir food webs (2015-2017, Czech Science Foundation)

158/2016/P - Ecological interactions in aquatic and terrestrial habitats: implications for community and ecosystem functioning (2016-2017, Grant Agency of the University of South Bohemia)

145/2013/P - Evaluating the impacts of biotic interactions and abiotic stressors on populations and communities (2013-2015, Grant Agency of the University of South Bohemia)

CZ.1.07/2.3.00/30.0032 - Promotion of post-doctoral positions in the Biology Centre of the Czech Academy of Sciences aimed to build the global competitiveness (2012-2015, co-financed by the European Social Fund and the state budget of the Czech Republic.)

CZ.1.07/2.3.00/20.0204 - Centre for ecological potential of fish communities in reservoirs and lakes (2012-2015, co-financed by the European Social Fund and the state budget of the Czech Republic.)

05611212 - Methods for the assessment of the ecological potential of heavily modified and artificial water bodies (2012-2013, The State Environmental Fund of the Czech Republic)

QH81046 - Optimalisation of the biomanipulative effect of predatory fish in ecosystems of water reservoirs (2008-2012, National Agency for Agriculture Research)

CZ 0091 - Monitoring of the fish stock of Czech reservoirs (2008-2010, Grant from Iceland, Liechtestein and Norway through the EEA financial mechanism and the Norwegian financial mechanism)

1QS600170504 - Limnological basis of sustainable management of reservoirs (2005-2009, National Agency for Agriculture Research)

International cooperation:

National representative in Central Baltic Lake Fish Geographical Intercalibration Group
National representative in European Committee for Standardization (CEN)

Reviewer for scientific journals:

African Journal of Environmental Science and Technology, Belgian Journal of Zoology, Ecosystems, Fisheries Research, Hydrobiologia, Journal of Applied Ichthyology, Lakes & Reservoirs: Research and Management, Water management

Teaching and supervision experiences:

Lectures at Faculty of Science University of South Bohemia: Agriculture Zoology, Animal Ecology (seminar), Biology of Water Organisms II, Field Course of Alpine Zoology, Field Course of Marine Biology, Field Practice I and II, Hydrobiology - Field Excursion, Practicum in Vertebrate Zoology, Special Zoology, Vertebratological Excursion

Lectures at Hydrobiological institute BC CAS: practical workshops, public seminars, Open day, Day of open laboratories

Consultant of MSc. thesis at Czech University of Life Sciences Prague: Ichthyofauna of the Brdy Protected Landscape Area in Central Bohemia (Ťuláková A.) and Bc. thesis at University of South Bohemia: Growth analysis of perch (*Perca fluviatilis*) in Czech reservoirs (Křížová M.)

Educating young students in the Club of young anglers in Golčův Jeníkov

Special awards:

Ph.D. conference winner in 2017, 3rd place in Ph.D. conference in 2016

3rd place in national and the winner in the Region Central-Bohemia round competition of secondary-school professional activity (SOČ) in 2006 (Ecological status of Brslenka brook after launching water treatment plant Čáslav-central; supervisor: MSc. Martin Šlais)

Society membership:

American Fisheries Society, Czech Anglers Union, Czech Limnological Society, Czech Zoological Society

Language skills:

Czech (mother tongue), English (fluent, certificate TOEFL ITP), German (passive), French (beginner)

Computer skills:

MS Windows, MS Office, ArcGIS, pgAdmin, statistical software: R, Canoco, Statistica

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