SZENT ISTVÁN UNIVERSITY

THESES OF DOCTORAL (PHD) DISSERTATION

EFFECTS OF LOCAL- AND LANDSCAPE-SCALE FACTORS ON THE DISTRIBUTION OF NON-NATIVE FISHES IN STREAMS OF THE CATCHMENT AREA OF LAKE BALATON

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1. BACKGROUND AND OBJECTIVES

Nowadays, biological diversity experiences a drastic decline. The main causes of this decline are habitat alteration and spreading of non-native species. Non-native species are ones that occur outside of their natural biogeographic range associated to a certain temporal scale. Beyond natural active and passive dispersal mechanisms, species can get out of their natural range by some kind of anthropogenic mediation such as accidental or intentional introductions or modification of their biogeographic barriers (e.g. building channels between two originally separated river catchment). Species becoming extremely abundant during their spreading process are termed invasive species. Invasive species can cause significant economic and ecological effects in the new area which they arrived at. The economic effects of invasive species can be manifested as, on the one hand, decreasing the yield of plant cultures, livestock and ecosystem services, and on the other hand, as the monetary costs of the protection against invasive species themselves. The ecological effects of invasive species result from competition, predation, hybridization, spreading diseases and pathogens, which ultimately leads to the alteration of biological diversity.

Fishes are one of the most frequently introduced or translocated groups of aquatic organisms. They have been introduced intentionally or accidentally to several places worldwide due to fisheries and aquaculture, sport fishing, biological control, and aesthetic motive (ornamental fishes). All of these human activities involve the opportunity for non-native fishes to escape into natural water bodies where they were not intentioned to be introduced. Although we have already seen many examples for the unwanted economic and ecological effects of non-native fishes, their translocations and introductions will likely continue in the future due to socio-economic interests. However, many ecological and evolutionary effects and characteristics of the spreading of non-native species have been only slightly understood, hence it is hard to confidently predict the outcome and risks of the appearance of a certain non-native species in a certain region. Consequently, prevention and the precautionary principle applied to the arrived non-native species should play a dominant role in stopping the spreading. In order to manage effectively the already emerged unwanted effects, we need well established knowledge on the ecological behaviour of the non-native species observed along variable spatio-temporal scales. In this knowledge gathering process, beside the population ecological studies, there is a need for community ecological research too, because the effects of non-native species originated from interspecific interactions are indicated in the modification of the community structure. The community ecological effects of non-native species have far more complex and occasionally emergent features than their population ecological effects do, hence processes taken place at the higher levels of the hierarchic biological organization always are more complex than the lower-level processes. This contrast can especially be true for anthropogenically modified regions and regions possessing many non-native species at the same time. Therefore, the higher-level effects can be known and understood only by the study of the community forming role of the non-native fish species.

1.1 Objectives

In the dissertation we presented the ecological importance of non-native fishes in small watercourses in the catchment area of Lake Balaton, Hungary, using the results of seven investigations. Our specific tasks and questions were as follows.

1. Study the sample representativeness of the wading electrofishing method.
    (a) How did the accuracy, the precision and the ecological similarity of the independent samples taken from the same stream reach change in the function of the sampled stream length, and with the single- *vs.* double-pass electrofishing?

2. Up to date fish faunistical survey of the whole catchment area of Lake Balaton (excluding the lake itself); compiling a record on the non-native fishes of the catchment area.

3. Revealing the general structure of the fish stock at the regional level (catchment area of Lake Balaton).
    (a) What kinds of positions did the non-native fishes have in the occurrence and abundance based textural structure of the fish assemblage?

4. Identification of the relevant environmental variables determining the spatial distributional pattern of the local (reach scale) fish assemblages within the catchment area of Lake Balaton; comparison of the descriptive power of the environmental and spatial variables.
    (a) Which were the most relevant environmental variables describing the community structure?
    (b) How large was the relative importance of the spatial and environmental variable groups in describing the community structure?
    (c) How large was the relative importance of the local- and landscape-scale environmental variable groups in describing the community structure?
    (d) Did the non-native fishes influence all of those relative importance relationships?

5. Describing the relationships between the spatial distributional pattern of the non-native fishes and the relevant environmental variables within the catchment area of Lake Balaton.
   (a) What kinds of environmental variables could explain the spatial distribution of the occurrence (presence-absence), relative abundance and species number of the non-native fishes in a stream reach (hereafter we refer to these three response variables as ecological state variables)?

6. Comparing the spatial and temporal dynamics of non-native fishes within a stream.
   (a) How did the relative abundance of non-native fishes change along the source–mouth longitudinal spatial gradient from early spring to late autumn in streams modified by fish ponds?
   (b) How much variance of the relative abundance could be associated with the spatial variability of the sampling sites (source–mouth gradient) and the temporal variability of survey time?

7. Investigation of the species pool modifying effect of the non-native fishes.
   (a) Could biological homogenization / differentiation take place in the taxonomical composition of the fish assemblages within two decades?
   (b) How reliable could be the conclusions reached from the comparison of only two snapshot surveys data?

2. MATERIALS AND METHODS

2.1 Study of the sample representativeness

2.1.1 Data acquisition

We surveyed the middle and lower sections of seven streams, altogether at eight sampling sites in April 2008 to investigate the sample representativeness.

At each site, we divided a 200 m long stream reach into ten 20 m long sampling units. Sampling units were blocked with a small meshed net, and then electrofished with a backpack electrofishing gear (Hans-Grassl IG200/2B, PDC, 50–100 Hz, 350–650 V, max. 10 kW); a dip net was also used to collect the stunned fish. Collected fish were identified taxonomically and counted, and after that released back to the stream far downstream from the sampling unit. These data constituted the single-pass electrofishing data. After approximately 15 minutes, when the initial turbidity of the stream was regained, the sampling unit was electrofished again by the same method. This second sampling yielded the repeated sampling data. The whole process (blocking, single-pass and the repeated sampling) was applied to all of the ten sampling units. Double-pass electrofishing data were obtained by pooling the single-pass data and the repeated sampling data in a cumulative way. Because of the characteristic of the sampling design, measuring of the sampling effort by the length of the stream sampled and number of the sampling units was equivalent.

2.1.2 Data analyses

To investigate the sample representativeness, we used sample-based rarefaction curves, and applied two similarity-based approaches (computing the accuracy and precision of the estimation, and computing the autosimilarity of independent samples). Single-pass and double-pass data were analysed separately.

2.2 Fish fauna of the catchment area of Lake Balaton

2.2.1 Data acquisition

Fish faunistical surveys of 43 streams were conducted between 2006 and 2010 at 94 sampling sites. A backpack electrofishing gear (Hans-Grassl IG200/2B, PDC, 50–100 Hz, 350–650 V, max. 10 kW) was utilized for both the faunistical and all the other type of our surveys. If a sampling site was wadable, sampling was done by wading upstream direction along a 150 m long reach, but where circumstances (e.g. aquatic vegetation, thickness of the fine particulate deposit of the bottom) made wading difficult sampling sampling was done along at least a 100 m long reach. Fishes were collected for identification and counting by the person who operated the fisheries gear, and he was occasionally helped by one or two persons with a dip net as well. Where the water depth of the streams was too large for wading, sampling was conducted from a dinghy from upstream to downstream along a 200–300-m long reach depending on the average wet width of the site. Fishes were released back to the streams after taxonomical identification.

2.2.2 Data evaluation

Throughout our investigations we used the term non-native fish species to refer to species of which presence in the catchment area of Lake Balaton could be associated with a deliberate or accidental anthropogenic activity. Besides the non-native fishes, we recorded the protected fish species as well.

2.3 Ichthyological status of the non-native fishes in the streams of the catchment area of Lake Balaton

2.3.1 Data acquisition – The three-year data set

Fish assemblages were monitored between 2008–2010 with seasonal frequency (spring, summer, autumn; altogether nine surveys) at 40 sampling sites selected from the sites sampled in 2006–2007, and at each selected site a 150 m long reach was sampled by one pass electrofishing. Environmental condition of the sites was characterized by 11 landscape- and 20 local-scale variables. Hereafter we will refer to this data set as the three-year data set.

2.3.2 Data analyses

On the one hand, we averaged and rounded to the nearest larger integer of the number of specimens of the species among the nine surveys of the three-year data set, in order to mitigate the effect of the temporal variability of the abundance. We refer to this data set as the averaged three-year data set. After that, the commonness of the fish species within the regional (i.e. the whole catchment area of Lake Balaton) fish assemblage was assessed by the ordination of species according to their spatial occurrence frequency and abundance in the averaged three-year data set.

On the other hand, to examine the temporal variability of the compositional position of the species, we compiled a unified frequency index from the occurrence rank and abundance rank of the species (rank-based frequency index), and examined the fluctuation of this index among the surveys of the three-year data set.

2.4 Relative importance of the local-, the landscape-scale and the spatial variables

2.4.1 Data acquisition

The tree-year data set and the averaged three-year data set were used to this investigation.

2.4.2 Data analyses

We studied the relative descriptive power of the different scaled environmental (local- and landscape-scale) variables and the spatial variables embracing the topology of the spatial geographic configuration of the sampling sites at two community levels: total assemblage containing all species, and native assemblage containing only the native ones.

We analysed first the nine surveys of the three-year data set, then the averaged three-year data set at both community level.

Moran's Eigenvectors Maps (MEM) were used as spatial variables in the data analyses.

In the main data analysis, the relevant spatial and environmental variable groups (selected by a forward selection procedure *a priori*) were introduced into variance partitionings with redundancy analysis (RDA) to decompose the variability of the fish assemblages. Variance partitionings were conducted in two successional steps in a hierarchic design. In the first step, the total variability of an assemblage was partitioned into a pure spatial [S], a pure environmental (local- and landscape-scale variables together) [E], a spatially and environmentally shared [SE], and a residual [R] variance fractions. In the second step, the pure environmental variance fraction [E] was partitioned further into a pure landscape [Ela], a pure local [Elo], and a landscape and local shared [Elalo] variance fractions, while the spatial variables were taken into consideration as covariates of the RDA model.

2.5 Descriptive modelling of the spatial distribution of the non-native fishes

2.5.1 Data acquisition

We used the averaged three-year data set for this investigation in order to mitigate the temporal variability of the different surveys.

2.5.2 Data analyses

Spatial occurrence (presence-absence), relative abundance and species number of non-native fishes (ecological state response variables) were modelled with classification and regression tree based models (decision trees [TREE] and Random Forests [RF]). Different models were made with the landscape-scale and the local-scale environmental variables for each response variable.

2.6 Short-time dynamics of the non-native fishes in two streams

2.6.1 Data acquisition

This investigation was conducted on two streams (Eger-víz, length: 32 km, catchment area: 365 km^2; Marót-völgyi-csatorna, length: 32.9 km, catchment area: 178 km^2). We made surveys at 12 sampling sites (seven sites on Eger-víz and five sites on Marót-völgyi-csatorna) along the longitudinal profile, at nine times within one vegetational period in 2009. Both streams were modified by fish ponds: a reservoir was located between Monostorapáti and Hegyesd on the Eger-víz, and another reservoir at the source region of Marót-völgyi-csatorna near Tapsony village.

2.6.2 Data analyses

In this investigation, the collective relative abundance of the non-native fish species was the studied response variable. We examined and compared the variability of the relative abundance originated from the differences among the sampling sites and from the differences among the survey times by applying a Generalised Linear Mixed Model (GLMM with logit link and Restricted Maximum Likelihood estimation) which contained the streams as a fix factor with two levels.

2.7 Species pool modifying effect of the non-native fishes – study of the biological (taxonomic) homogenization

2.7.1 Data acquisition

We utilized the data collected by Przybylski *et al.* (1991)[1] in July 1987, and also used our own data collected in July 2007 and July 2008.

2.7.2 Data analyses

We examined the taxonomic homogenization by comparing the year 1987 with the year 2007 and with the year 2008 too, and, further, comparing the year 2007 with the year 2008. Taxonomic homogenization (TH) / differentiation (TD) taken place between two survey times was estimated by the difference of the average pairwise ecological similarities (Jaccard index) computed from the two actually compared survey times data separately. The statistical significance of the estimated homogenization / differentiation was tested by a non parametric paired randomization test.

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[1] Przybylski, M., Bíró, P., Zalewski, M., Tátrai, I., Frankiewicz, P. (1991): The structure of fish communities in streams of the northern part of the catchment area of Lake Balaton (Hungary). *Acta Hydrobiologica* 33(1–2):135–148.

3. RESULTS

3.1 Study of the sample representativeness

There were 27 fish species collected in total from the eight sampling sites. The number of species caught by the double-pass electrofishing of the 200-m sampling reach (applied maximal sampling effort) varied between 6–17. Compared to the double-pass sampling of the 200 m, the single-pass sampling of the 200 m long sampling reach yielded 95.7% ($\pm$ 4.9 SD) of species number and 71.1% ($\pm$ 5.1 SD) of the specimens.

Rarefaction curves showed that the expected number of species increased sharply with the length of the sampled stream reach, but there was not considerable difference between the single- and the double-pass sampling, except for one sampling site.

We found that the estimation accuracy and the precision was the same for the species number and also for the species pool (i.e. the presence-absence based species composition). In case of a short sampling reach ($< \approx 60$ m) the estimation of the relative abundance was more accurate and precise than that of the species number or the species pool. As compared to the 200-m double-pass sampling, single-pass sampling of a 100 m long stream reach (28 times the average stream wet width) produced more than 80% accurate estimations with less than 9% CV (Coefficient of Variation) precisions of the community structure variables, both for the species number / species pool and the relative abundance.

The autosimilarity of the three community structure variable differed slightly, but not significantly: irrespective of the sampled stream length, the average autosimilarity was the largest for the species number, the lowest for the species pool, and it was between the values of these two variables for the relative abundance. The average autosimilarity of the samples taken from a 100 m long stream reach by single-pass fishing was 85.2%, 70.9% and 80.7% for the species number, the species pool and the relative abundance, one after the other.

No significant difference was detected neither between the estimations of the community structure variables calculated from the single-pass and double-pass sampling data, nor between the autosimilarity of the community structure variables calculated from the single-pass and double-pass sampling data.

Table 1: Non-native fish species proved by faunistical surveys of the streams of the catchment area of Lake Balaton between 2006–2010.

Common name	Scientific name
Black bullhead	*Ameiurus melas*
Brown bullhead	*Ameiurus nebulosus*
Eel	*Anguilla anguilla*
Prussian carp	*Carassius gibelio*
Grass carp	*Ctenopharyngodon idella*
Eastern mosquitofish	*Gambusia holbrooki*
Silver carp	*Hypophthalmichthys molitrix*
Bighead carp	*Hypophthalmichthys nobilis*
Pumpkinseed	*Lepomis gibbosus*
Monkey goby	*Neogobius fluviatilis*
Rainbow trout	*Oncorhynchus mykiss*
Chinese sleeper	*Perccottus glenii*
Tubenos goby	*Proterorhinus semilunaris*
Stone moroko	*Pseudorasbora parva*
Brown trout	*Salmo trutta fario*

3.2 Fish fauna of the catchment area of Lake Balaton

Out of the 94 sampling sites, which were located on 43 streams, fishes were observed at only 75 sites (35 streams). Total number of the identified fish species was 43. Among them, there were 15 species considered as non-native for the catchment area of Lake Balaton (Table 1). We proved the occurrence of eight protected and one strictly protected species (Table 2).

3.3 Ichthyological status of the non-native fishes in the streams of the catchment area of Lake Balaton

The total number of the specimens and the number of species in the three-year data set were 71 291 and 39, respectively. Out of these, the total number of non-native specimens and the number of species of them were 14 377 and 12.

There was a positive association between the spatial occurrence frequency and abundance of the species in the averaged three-year data set.

Pumpkinseed was the most frequently occurred non-native species (26 sampling sites). It was followed by the Prussian carp with a frequency of 23 sampling sites.

Table 2: Protected fish species proved by faunistical surveys of the streams of the catchment area of Lake Balaton between 2006–2010.

Common name	Scientific name	Protection status
Stone loach	*Barbatula barbatula*	protected
Spined loach	*Cobitis elongatoides*	protected
Gudgeon	*Gobio obtusirostris*	protected
Sunbleak	*Leucaspius delineatus*	protected
Weatherfish	*Misgurnus fossilis*	protected
Minnow	*Phoxinus phoxinus*	protected
White-finned gudgeon	*Romanogobio vladykovi*	protected
Bitterling	*Rhodeus sericeus*	protected
European mud-minnow	*Umbra krameri*	strictly protected

Stone moroko and black bullhead also had a remarkable frequency of occurrence (19, and 18 sampling sites, respectively). The remaining non-native species occurred at eight or less sampling sites.

As for the abundance, stone moroko (715 specimens) and Prussian carp (677) were the most dominant non-native species. Compared to these two species, pumpkinseed showed a more moderate but still considerable abundance (151 specimens). The abundance of the black bullhead and monkey goby was an order of magnitude less (< 100 specimens); the abundances of the other non-native species were less than ten specimens.

3.4 Relative importance of the local-, the landscape-scale and the spatial variables

According to the first variance partitioning of the nine surveys, the average totally explained variance of the fish assemblages was 38.98% (± 3.46 SD) for the total community level, and 41.03% (± 3.46 SD) for the native community level. The pure spatially explained variance [S] varied between 1.81–8.21 (mean ± SD: 4.87 ± 2.27%) for the total, and between 0–7.68% (mean ± SD: 4.76 ± 2.44%) for the native assemblages. By contrast, pure environmentally explained variance [E], which varied between 21.41–31.90% (mean ± SD: 25.01 ± 3.38%) at the total community level, and between 16.46–37.75% (mean ± SD: 27.79 ± 5.86%) for the native assembles, was considerably greater. The shared spatial and environmental variance fraction [SE] ranged between 4.35–11.14% (mean ± SD: 9.10 ± 2.09%) for the total assemblages, and between 5.03–11.49% (mean ± SD: 8.48 ± 2.42%) for the native assemblages.

Interestingly, the residual variance fraction [R] of the native assemblages was slightly less than that of the total assemblages (one-tailed paired Wilcoxon signed rank test, V = 36, p = 0.004). Further, the pure environmental variance [E] was slightly greater for the native assemblages than for the total assemblages (V = 36, p = 0.004). The distribution of the pure spatial variance [S] did not differed significantly between the two community levels (V = 26, p = 0.156).

In the second variance partitionings of the nine surveys, the pure landscape explained environmental variance [Ela] varied between 2.02–9.55% (mean ± SD: 5.93 ± 2.11%) for the total assemblages, and between 3.17–9.88% (mean ± SD: 6.17 ± 2.56%) for the native assemblages. Compared to these values, the pure local explained environmental variance [Elo] was greater, which ranged between 6.40–17.06% (mean ± SD: 11.58 ± 3.50%) in case of the total assemblages, and between 7.38–21.28 (mean ± SD: 13.39 ± 4.68%) at the native community level. The shared variance fraction explained jointly by the landscape and local variables [Elalo] varied between 2.46–11.33% (mean ± SD: 7.50 ± 2.98%), and between 2.41–14.11% (mean ± SD: 8.22 ± 3.86%) for the total and the native assemblages, respectively.

There was not a significant difference between the pure landscape explained environmental variances [Ela] of the two community levels (one-tailed paired Wilcoxon signed test, V = 19, p = 0.674). However, we detected that the pure local explained environmental variance [Elo] of the native assemblages was slightly greater than that of the total assemblages (V = 37, p = 0.049).

3.5 Descriptive modelling of the spatial distribution of the non-native fishes

Descriptive power of the spatial variables was negligible for both the occurrence (classification RF model, misclassification error rate = 17/39, Cohen's κ = –0.28, Hand's H = 0) and the species number of the non-native fishes (regression RF model, pseudo-R^2 = –27.29%). However, the relative abundance pattern was moderately explainable by spatial effects (regression RF model, pseudo-R^2 = 21.75%), but taking into consideration of the effect of the environmental variables, significant spatial autocorrelation was not detectable in the model any more (Moran's I = 0.08, p = 0.29).

Non-native fishes occurred at 31 out of the 39 sampling sites. Their probability of occurrence increased with the average water depth and wet width of the streams, and decreased with the altitude (classification RF model, misclassification error rate = 6/39, Cohen's κ = 0.53, Hand's H = 0.29) (Table 3).

Where the non-native fishes occurred, their local (i.e. within reach) relative abundance varied between 0.32–68.87%. The most important descriptor of the relative abundance was the total area of ponds located on the catchment area of the stream segment, which affected positively the relative abundance (regression RF model, pseudo-R^2 = 46.39%) (Table 3).

Where the non-native fishes occurred, their local species number ranged from one to seven. Species number was associated only to landscape-scale environmental factors (regression RF model, pseudo-R^2 = 55.38%) (Table 3), from which the altitude was the most relevant one. Species number of the non-native fishes decreased substantially as altitude changed already only to a small extent from its starting value (from 107 m, altitude of water level of Lake Balaton, to approximately 125 m).

Table 3: Environmental variables describing the spatial occurrence, the relative abundance and the species number of the non-natives fishes. Numbers are the variable importance measures of the *Random Forests* (RF) models. These measures indicate the increment rate of the prediction error (misclassification error rate for classification; mean squared error for regression) of the model when the values of a certain variable are permuted randomly among the sampling sites.

Occurrence data	**Increase in misclassification error rate (%)**
water depth	29.89
wet width	28.11
altitude	11.90
Relative abundance data	**Increase in mean squared error (%)**
pond area	94.65
forest (%)	91.07
altitude	90.31
current velocity	82.65
silt (%)	79.44
Species number data	**Increase in mean squared error (%)**
altitude	219.01
artificial surface (%)	150.56
forest (%)	133.25

3.6 Short-time dynamics of the non-native fishes in two streams

Non-native fishes were detected at the sampling sites being directly downstream form the fish ponds at every survey time in both streams. However there was a considerable difference between the relative abundance of the non-native fishes in the two streams, the estimated values were 1.06% and 14.27% for the Eger-víz and the Marót-völgyi-csatorna, respectively (GLMM model).

The variance of the relative abundance originating from the differences among the sampling sites was approximately six times greater ($\hat{\sigma}^2 = 2,975$) than the variance associated to the differences among the survey times ($\hat{\sigma}^2 = 0,478$) (GLMM model).

3.7 Species pool modifying effect of the non-native fishes – study of the biological (taxonomic) homogenization

In the pooled data of the three survey times (1987, 2007, 2008) the regional (i.e. the eight sampling sites together) species number was 30, from which eight was the number of the non-native fish species. Taking the survey times separately such as 1987, 2007 and 2008, the regional species number and the number of the non-native species were as follows 22, 23, 24, and five, six, six, respectively.

The estimated measure of the taxonomic homogenization / differentiation taken place between two survey times were 8.86% for the comparisons of 1987 *vs.* 2007 (TH; non parametric paired randomization test p = 0.026), 3.33% for the comparison of 1987 *vs.* 2008 (TH; non parametric paired randomization test p = 0.230), and –5.53% for the comparison of 2007 *vs.* 2008 (TD; non parametric paired randomization test p = 0.130).

4. CONCLUSIONS AND RECOMMENDATIONS

Our results demonstrated that not just the occurrence and abundance distribution of the species, but the ecological indices used to measure the compositional similarity could influence remarkably the relative representativeness of the different community structure variables.

Compared to the single-pass electrofishing sampling, the double-pass sampling did not seem to improve sample representativeness significantly. At the same time, sampling a short (< 60–80 m) stream reach yielded a quite biased sample even in case of a double-pass sampling. Consequently, the single-pass sampling of a reasonably long stream reach is much more favourable sampling strategy for monitoring the spatio-temporal variability of stream fish assemblages than the more time consuming and labour intensive double-pass sampling.

Sampling fish assemblages in the wadable streams of the catchment area of Lake Balaton, a stream reach of length, at least, 100–120 m can already produce a sufficiently representative sample, but representative sampling of fish stocks containing many rare species, such as habitat-foreign and non-native ones, requires longer sampling reach. At other catchment areas, due to the regional differences (e.g. habitat complexity, fish fauna, abundance distributions), the evaluation of the optimal length of the stream reaches to be sampled may make the intensive sampling of some sites on the spot necessary, especially before starting of great spatial extended studies.

Our faunistical investigation contributed a great deal of recent knowledge to the fish fauna of the catchment area of Lake Balaton, especially due to the first investigation of many small streams in the River Zala catchment.

The temporal variability of the frequency occurrence varied from species to species. Because of this temporal variability, depending on the protocol to be applied, more than one surveys may be necessary for the ecological status assessment (bioassessment) of a single stream or stream system even if the survey design is spatially intensive, in order to reveal the realistic frequency relationships of the species (i.e. compositional structure) in a reasonably depth. Hence, a fish database of a relatively large catchment that was compiled by field surveys of its subcatchments conducted at different times (e.g. in different years) may provide a biased picture of the compositional structure of the fish assemblage. When spatio-temporal occurrence frequency and abundance were taken into consideration together, stone moroko, Prussian carp and pumpkinseed out of the non-native fish species of the streams of Lake Balaton took up a place in the most dominant part of the compositional structure of the regional fish assemblage.

Our study demonstrated that different unique spatial and environmental variables could play relevant roles in the description of the assemblage structure depending on the temporal variability. Because the descriptive power of the spatial, local and landscape environmental variables varies in time, the assessment of their relative importance in shaping the community structure on the basis of only one single field survey can be misleading. These suggest that studies based on a single field survey can be suitable to reliably investigate the descriptive efficiency and metacommunity dynamics primarily in case of a great spatial extent (e.g. catchment area of a large river) or organisms with weak dispersal ability (e.g. forest herbs). However, investigating organisms with high dispersal ability like fishes, particularly when the spatial extent of the investigation matches with the dispersal ability of the studied organisms, it seems that only data set originated from systematic monitoring may provide realistic information on the pattern shaping effect of the spatial and environmental factors and metacommunity dynamics of the studied organism group.

Relationship between the variance measures associated to the differences among the sampling sites and to the differences among the survey times of the relative abundance of the non-native fishes appeared to demonstrate that the position along the longitudinal profile affects more the relative abundance of the non-native fishes than the time of the field survey does. The effect of the longitudinal position tended to originate primarily from the ponds located on the streams. The gradual decline of the relative abundance with the increasing distance from the ponds implies that the dynamics of the instream distribution of the non-native fishes might be driven primarily by the passive dispersion from the ponds and instream reproduction may act only a secondarily mechanism in shaping this dynamics.

Our results suggested that non-native fishes could alter primarily the diversity of fish assemblages of lowland streams on which fish ponds are operated. Therefore, in our opinion, fish introductions into these ponds should be more strictly controlled for non-native fishes, and outflow locks of the ponds should be installed with more effective wire-netting in order to decrease the spreading and establishment possibilities of the non-native fishes.

Results seemed to show that taxonomical homogenization (TH) could take place or be observed at small spatially extended region during a few decades. Although, it appears to be challenging to yield a reliable estimate for the measure of the TH on the basis of only two snapshot surveys data, because the structural variability of the fish assemblages can be considerable among the years. Detection of long-term changes, such as temporal trends in the similarity relationships of the local species pools seems to require long-term monitoring with standardized methodology due to this remarkable between-year variability.

4.1 New scientific results

1.1. According to our knowledge, we have applied at the first time the autosimilarity-based approach to evaluate the sample representativeness in Hungary. In case of wading electrofishing of small lowland streams, we determined that the double-pass sampling did not improve significantly the sample representativeness as compared to the single-pass sampling when wadable lowland streams are sampled by a backpack electrofishing gear. Sampling a short stream reach could result in a sample with low representativeness even using double-pass electrofishing, consequently, increase the sampled stream reach could be a more promising way to improve sample representativeness than the more labour intensive double-pass sampling of a shorter reach when monitoring fish assemblages.

1.2. We proved that the sampling strategy used currently by the Hungarian Biodiversity Monitoring System, single-pass electrofishing a 150 m long stream reach, ensures sufficient sampling effort for monitoring highland and lowland fish assemblages in wadeable streams.

1.3. It was highlighted that the ecological similarity indices could influence remarkably the relative representativeness of the community structure variables of fish assemblages. When sample representativeness is evaluated by the approach of similarity between a reference sample established by an intensive sampling and the actual sample, the species number of the sampling units expressed as the percentage of the reference species number (i.e. similarity measured by the Ruzicka index) is the same as the representativeness of the species pool (i.e. presence-absence based composition) measured by the Jaccard index. In comparison with the case when the similarity of the species pool is measured by the Jaccard index, the representativeness of the species pool is always higher than the representativeness of the species number, and at the same time, the difference between the representativeness of the species pool and that of the relative abundance is lower when the similarity of the species pool is measured by the Sørensen index.

1.4. We concluded that using the Ruzicka-index, the autosimilarity-based evaluation of sample representativeness of the species number could be misleading due to the spatial species turnover, if the species density in the studied stream reach is spatially homogeneous.

2.1. The first ichthyo-faunistical survey of 20 small streams were conducted. Most of these streams were located in the catchment area of River Zala; new occurrence localities of many protected fish species were discovered due to these surveys.

2.2. Our investigation was the first which proved the presence of Chinese sleeper (*Perccottus glenii*) in the catchment area of Lake Balaton, and at the same time, this was the first occurrence detection of the species in the Transdanubian Region of Hungary.

3.1. We studied at the first time the relative importance of the spatial, local- and landscape-scale environmental variables in describing the community structure of fish assemblages in the high- and lowland streams of the Pannon Ecoregion. We found that both the explanatory power (descriptive efficiency) and the relative importance of the spatial, local and landscape variables explaining community structure vary in time. In the mainly agriculturally utilized catchment area of Lake Balaton, the spatial assembly of the local fish assemblages is driven basically by environmental factors as against the spatial factors; and local environmental variables play a more important organizing role than landscape environmental variables do.

3.2. We demonstrated that non-native fish species could decrease the explainability of the spatial variability of assemblage structure described by spatial and environmental variables. It seemed that this decrease resulted from a lower descriptive efficiency of the local environmental factors.

4.1. Our research showed that the relative importance of the spatial factors, the local-, and landscape-scale environmental factors in describing the spatial distribution of non-native fishes tends to vary depending on the type of the ecological state variable (i.e. presence-absence, relative abundance and species number of the non-native fishes in a stream reach). The occurrence was primarily affected by local environmental factors, the relative abundance was associated to landscape environmental and spatial factors, whereas the species number showed relationship with the landscape factors.

5.1. We concluded that local- and landscape-level habitat gradients associated to altitude and total area of the ponds located on the catchment area had a highlighted importance to the description of the spatial structure of fish assemblages. We showed the significant modifying effect of the fish ponds on the composition of the stream fish assemblages.

6.1. We examined and found that in streams modified by fish ponds, the abundance of the non-native fishes could follow a source-sink dynamics between the pond and the stream. Fish ponds could serve as permanent source regions of non-native fishes getting into the streams.

7.1. Applying a recently introduced approach (Olden 2006[1]) at the first time in Hungary to study the biological homogenization we ascertained that taxonomical homogenization could be observed in a small spatially extended region over two decades, but the estimation on the basis of only two snapshot surveys data of the homogenization occurred was not reliable at stream reach spatial resolution. At small spatio-temporal scales, stochasticity (e.g. temporal environmental fluctuation) and habitat-history appeared to have much greater importance to taxonomic homogenization / differentiation of the fish assemblage than non-native fishes did.

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[1] Olden, J.D. (2006): Biotic homogenization: a new research agenda for conservation biogeography. *Journal of Biogeography* 33(12):2027–2039.

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Journal articles

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Book, passage in a book

Passage in a book in Hungarian

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