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USE OF TERRESTRIAL MOLLUSCS FOR BIOINDICATION OF THE IMPACT OF THE GABČÍKOVO HYDRAULIC STRUCTURES (THE DANUBE RIVER, SLOVAKIA)

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The aim of this paper is (1) describe main methods using within the biomonitoring programme of the Gabčíkovo hydraulic structures along the Danube River, SW Slovakia; (2) present main results of the monitored long-term structural changes in alluvial molluscan fauna over the past ten years; (3) describe changes to surface and ground water dynamics on communities of terrestrial molluscs and (4) compare structure of molluscan faunas before the Danube damming and ten years on.

Bioindication abilities of terrestrial molluscs

The advantages of molluscs as a model group can be characterized as follows:

- Molluscs belong, within the scope of Central Europe, to well investigated animal groups from the viewpoint of community structure, distribution and habitat requirements,
- The species form well-defined communities and have strong ecological relationships to specific habitats and reliably react (although more slowly) to changes in soil moisture and the absence or presence of floods. In the Slovak part of the iuxta-Danubian area, the occurrence of 58 species of terrestrial molluscs has been confirmed, including species indicating relatively natural habitats, changes in soil moisture and different degrees of habitat degradation,
- Most Central European land snails are small (several millimetres) and little mobile animals with a strong dependence on habitat, unlike some insect groups and spiders. Small species penetrate into the adjacent habitats very slowly,
- With long-term monitoring of the changes in the natural environment, the changes in the mollusc community structure reflect rather long-term trends than short-term fluctuations in environmental parameters. For this reason, they are an ideal group for biomonitoring or surveillance,
- In river sediments rich in calcium, the mollusc conchs easily fossilize and form thanatocoenoses in situ and, in this way, make it possible to study the development of natural environment at sites where they occur from a very long-term perspective.

Calibration of indication properties

It is known that animals, hence also molluscs, can often have relatively different ecological requirements in different zoogeographical units. Thus, knowledge of habitat requirements of the iuxta-Danubian (close, at, beside the Danube) molluscs cannot be automatically applied for example to conditions of the Borská nížina lowland and not at all to more remote parts of Europe under the influence, for example, of the Atlantic climate. For this reason, results of monitoring from geographically and climatically distant areas are not fully comparable.

Prior to a monitoring investigation, a calibrating indication investigation must be carried out in each area where the local ecological requirements of individual species are not known in detail in order to determine (calibrate) them by means of the methods given below.

A brief description of methods and interpretation of results

Field and laboratory work

When evaluating changes in the natural environment by means of molluscan communities, the quantitative and semi-quantitative methods are used. The most applied method is the volume method, with which a standardised volume (mostly 5 litres) of litter and soil upper layers are taken from several places in a homogenous plot, approximately up to a depth of 3-5 cm. After washing, drying and subsequent sieving, the mollusc conchs are sorted from individual fractions, identified and counted. The proportion of individual species in a sample of the community determines its character (mutual proportion of hygrophilous, shadow-preferring, hygrotolerant or euryecious species). Another, less frequently used method is the qaudrat method, which differs just by collecting litter and soil substrate over a specific surface area (e.g. 50×50 cm). In this case the number of molluscs is related to the area unit.

Analysis and synthesis of data

Counting individuals in samples gives us absolute data, which should firstly be transformed (converted to a scale determined by experts, transformed logarithmically, etc.), to be prepared for statistical analysis. In addition, to usual descriptive quantitative characteristics like population density, relative abundance (dominance) and structural characteristics like diversity and equitability, data can be subjected also to different methods of multivariate analysis (cluster analysis, ordination), which helps us visualise the data structure and makes data interpretation easier. Results obtained in individual years can be continuously compared and the trends estimated.

Principles for selection of investigation plots and problems of data interpretation

Within the scope of the monitoring plots set by the monitoring coordinator, the structurally most homogeneous parts are to be selected, in which specific investigation plots are then established. Investigation plots of 50×50 m are suitable. The investigation plots should be situated as far from the stand margin as possible to eliminate the edge effects. It is important to ensure that the monitoring plots remain unaffected by silvicultural interventions (e. g. thinning or even timber exploitation) during the whole period of monitoring. Otherwise, we would be monitor the influence of silvicultural, but not the influence of changes to hydrological conditions.

Problems with sampling arise on those plots that are flooded by surface water several times a year. After a flood most molluscs are washed away from the plot or the local patchy structure of communities is mixed by water turbulence. For this reason the samples obtained 5-8 weeks after the flood are hardly interpretable from the viewpoint of moisture changes. Another problem of data interpretation arises in the habitats situated at a considerable distance from the flood zone and which remain for a long time out of the influence of floods, especially in habitats situated on elevated places (terrace platforms, fluvial levees), where the ground water table is deep and does not influence the hydropedological regime in the soil upper layers. In such a habitat it is mostly problematic to interpret changes in molluscan communities as a direct consequence of water regime changes.

Influence of changes to surface and ground water dynamics on communities of terrestrial molluscs

Molluscs, and their communities, reliably react to changes in soil moisture and the absence or presence of floods.

(a) Habitats frequently flooded by more or less destructive (streaming) surface floods are characterised by the exclusive presence of polyhygrophilous species and by a naturally low alpha-diversity of communities (in average 12 species). The poorest in the number of species are molluscan communities in the initial stages of floodplain forest (in average 6 species) [3, 4]. Only those species that are adapted to flood conditions survive there. They are represented especially by larger species that are able to escape from the rising water level by climbing onto trees (*Arianta arbustorum*, *Cepaea hortensis*, *Succinea putris*, *Oxyloma elegans*, *Trochulus hispidus*, *Trochulus striolatus danubialis*) or that are able to survive for a time directly in the water or in different water-bearing substrates, especially in deposits of plant material (*Zonitoides nitidus*, *Pseudotrichia rubiginosa*, *Carychium minimum*, and partly also probably *Trochulus striolatus danubialis* and *Trochulus hispidus*).

In recently flooded habitats, which are covered after an intensive flood by a silt crust, the polyhygrophilous species *Oxyloma elegans*, *Succinea putris*, *Zonitoides nitidus* and *Pseudotrichia rubiginosa* appear as pioneer species. Other strongly hygrophilous species, *Carychium minimum*, appears later, because it is a small species having a small dispersal power, and the oligotrophic type of substrate does not satisfy its trophic requirements.

(b) In sporadically flooded parts of the floodplain, which are influenced by surface waters only at high or very high water levels in the Danube, but which have a high level of ground water and a moist to waterlogged substrate, the dominant species are *Carychium minimum* and *Zonitoides nitidus*, while *Succinea putris*, *Arianta arbustorum*, *Trochulus striolatus danubialis*, *Trochulus hispidus*, *Deroceras laeve* or also *Euconulus praticola* occur as subdominant species.

(c) Habitats with the natural or semi-natural hydrological regime mentioned above, which see a sudden drop in the ground water level or the halting of the influence of floods, are at first penetrated by moderately hygrophilous species (*Semilimax semilimax*, *Cochlicopa lubrica*, *Succinella oblonga*, *Vitrea crystallina*), while the polyhygrophilous species start to decline and free up niches for mesohygrophilous or eurytopic forest species (*Alinda biplicata*, *Monachoides incarnatus*, *Fruticicola fruticum*, *Aegopinella nitens*) or even for euryecious or anthropotolerant species (*Punctum pygmaeum*, *Limax maximus*, *Helix pomatia*). According to the degree of moisture the new community gradually obtains a structure corresponding to a specifically drier habitat type, mostly characteristic of a degraded community with a certain portion of xenocenous and anthropotolerant species (*Limax maximus*, *Arion fasciatus*, *Arion lusitanicus*).

Influence of silviculture on molluscs

From the 48 species of terrestrial molluscs regularly occurring in the iuxta-Danubian floodplain forests, as many as 32 species also occur in older poplar lignicultures [1, 3]. According to existing data, the most constant species inhabiting the stands of poplar cultivars are *Monachoides incarnatus*, an eurytopic forest species, which reaches a dominant to subdominant position here, and *Fruticicola fruticum* having similar ecological requirements as *Monachoides incarnatus*, but only managing a subdominant to receding position here. Among the constant species, the forest mesohygrophilous *Aegopinella nitens*, forest hygrophilous *Arianta arbustorum* and forest eurytopic *Alinda biplicata* also should be named. *Cochlicopa lubrica*, *Cepaea hortensis* and *Trochulus striolatus danubialis*, having optimum conditions in moister sites in willow-poplar forests, and forest hygrophilous species *Vitrea crystallina*, *Urticicola umbrosus* and *Clausilia pumila*, as well as forest mesohygrophilous *Cochlodina laminata* occur here mostly as subdominant species [3]. Richterová [11] found 28 species in poplar ligniculture of the within-dike zone. The most frequent were forest hygrophilous species *Arianta arbustorum*, *Trochulus striolatus danubialis*, *Vitrea crystallina*, *Cepaea hortensis* and *Fruticicola fruticum*, mesohygrophilous forest species (*Aegopinella nitens*, *Monachoides incarnatus*) and polyhygrophilous *Carychium minimum*. As dominate species she gives *Aegopinella nitens*, *Punctum pygmaeum* and *Carychium minimum*, but the largest portion of the community consisted of euryecious species (22%) and eurytopic forests species (17%).

The above enumeration shows that the forest species of the Illyrian regiotype (sensu Lisický [6]) were able to successfully adapt to conditions of economic forest stands and to cyclical anthropogenous disturbances (clear-cuttings, overall soil preparation etc.). Even species of the regiotype of forest permanent dwellers do not represent an exception. The poplar cultivars have their moisture optimum in dry types of softwood floodplain forests (especially at sites of the *Salici-Populetum typicum* variety with *Swida sanguinea*), in transitional floodplain forests (*Fraxino-Populetum*) and in the surroundings of Bratislava also in sites of moister hardwood floodplain forests (*Ulmo-Fraxineta*). Hence, individual habitat types have a corresponding structure of molluscan communities. We do not exclude the potential occurrence of *Cochlicopa nitens*, *Succinella oblonga* and *Euconulus praticola* in moist habitats. They are present in this territory, but occur rarely. As to *Columella edentula*, to date it seems that it escapes medium-moist habitats (transitional floodplain forests and drier varieties of willow-poplar floodplain forests) and very moist habitats (it probably cannot tolerate floods) [3].

In young stands of poplar cultivars, in dependence on the habitat, usually *Trochulus hispidus* (in moister habitats) *Aegopinella nitens*, *Monachoides incarnatus* and *Urticicola umbrosus* (in drier habitats) predominate. Remarkable is also the occurrence of other forest species, for example *Cochlodina laminata* and *Trochulus striolatus danubialis*, whose occurrence in this type of stands was not originally expected. Insufficient shadowing by the tree canopy in the case of young stands is substituted by high and dense ruderal vegetation and, if stumps remained at the place of clear-cut plots, also "sprout enclaves", in which even some forest hygrophilous species are able to survive due to a favourable microclimate.

Long-term changes in the structure of iuxta-Danubian fauna

Structure of iuxta-Danubian mollusc fauna in the past (evaluated based on thanatocoenoses)

A knowledge of the history of development of hydrological and habitat conditions in individual plots is necessary foremost in order to produce an objective evaluation of the so-called zero state of the natural environment, but also for evaluation of the subsequent sequence of changes caused by the changed hydrological regime.

In spite of existing local investigations, the general question still remains as to when and how the present iuxta-Danubian geobiocoenoses originated? There is a relatively clear answer in the case of floodplain forests, especially for the strip of floodplain forests in the within-dike zone. The floodplain forests doubtlessly existed there already in the prehistoric period (younger Holocene) [5]. They were, however, probably much more extensive, and so the present strip in the within-dike zone is just a reduced relict of them.

In the Danube calciferous sediments, mollusc conchs preserve well and often form complete thanatocoenoses (death assemblages). According to thanatocoenoses, which can be dated, in addition to radiocarbon methods, also on the basis of old maps, the habitat conditions of specific localities can be relatively accurately reconstructed. Mostly a complete successive series of the habitat can be reconstructed.

According to existing findings of Holocene's mollusc fauna, it is probable that a border separating the wide zone of flooded floodplain forests from the elevated, drier and partly steppe-like interior of the Žitný Ostrov Island run approximately along the area of the present village of Vrakúň. Hence in the past (in younger Holocene), the floodplain on the present Slovak territory had a width of about 10 km (today in the widest part at the village of Baka it is only 3 km) [8]. The question of the steppe-like enclaves within the floodplain is dealt with in [8, 9]. As yet the dating of individual processes is missing, together with knowledge of the topographical distribution of individual geobiocoenoses, which can be made more accurate only by further investigation of recent and fossil mollusc fauna, prehistoric settlements and by searching for data in archive documents from this area.

From the perspective of the changes caused by the Gabčíkovo hydraulic structures, the period before the so-called Lanfranconi regulation of the Danube for the medium water (1886-1896) is of particular interest. The mollusc thanatocoenoses in the iuxta-Danubian area were studied by Pišút & Čejka [10]. According to historic maps, they dated the absolute age of sediments and by means of mollusc thanatocoenoses reconstructed the complete succession series of the floodplain forest from its initial stage to the present transitional floodplain forest (period of 1791–1999, i.e. 208 years). They confirmed the occurrence of similar types of floodplain forests as those occurring in the iuxta-Danubian area at present and the occurrence of thanatocoenoses, whose structure approximately corresponds to the structure of the most preserved forest molluscan communities occurring at present in the area between the villages Dobrohošť and Sap. The total area of the moistest types of softwood floodplain forests with corresponding malacocoenoses was, of course, much larger in the past than at present and showed a more natural structure of stands. This is obvious even upon comparison of phytocoenological relevés from the 1940-1950-s with the present ones [12, 13]. Unfortunately, there are no quantitative or semi-quantitative data available on molluscan communities in the iuxta-Danubian area from the first half of the 20th century. Therefore the only possibility of comparison is an extensive paleoecological investigation of recent Danube sediments.

Mollusc fauna structure before the Danube damming and ten years on

In the beginning it must be noted that before the Danube damming there were two principal types of molluscan communities: (1) molluscan communities of the softwood, willow poplar floodplain forests and (2) those of hardwood floodplain forests.

The iuxta-Danubian area can be divided from the viewpoint of molluscan communities into the following parts:

(1) the surroundings of the Čunovo reservoir on the stretch Bratislava – Dobrohošť,
(2) the by-passed area of the Gabčíkovo hydraulic structures on the stretch Dobrohošť – Sap,
(3) the stretch downstream from the mouthing of the tail-race canal (Sap – Klúčovec),
(4) the area of Čičov village out of the direct influence of the Gabčíkovo hydraulic structures.

In the first stretch, the level of ground water increased after the Čunovo reservoir was filled and the hydropedological regime became renaturalized. The habitats in this area were, however, void of any larger influence of the groundwater level and relied exclusively on rainwater. The original hygrophilous communities disappeared and the habitats in the course of revitalization are lacking in immigration sources of autochthonous mollusc populations due to the absence of the possibility of passive (drifting by floods) or active spreading [2, 3].

In the second stretch, after the damming, the groundwater level declined in the zone running along the Danube old main channel. The changes appeared first of all in the representation of individual subtypes of softwood floodplain forests with characteristic structure of molluscan communities. In the by-passed area molluscan communities of the moistest types of floodplain forest are disappearing, especially those bound to the subassociations *Salici-Populetum phragmito-caricetosum* and *Salici-Populetum myosotidetosum*. After the damming, most of these types of molluscan communities started to restructure on "drier" types bound to various degraded types of willow-poplar floodplain forests (*Salici-Populetum typicum*).

In the third stretch, the Danube riverbed bottom deepened, but the water levels were not significantly changed. For the moment this has not reflected on the communities of terrestrial molluscs, but in future we cannot exclude adaptive changes caused secondarily by vegetation changes resulting from the eventual changing of the ground water level.

The fourth stretch at the village of Čičov is out of the direct influence of the Gabčíkovo hydraulic structures.

Expected development of the molluscan communities structure while saving the present hydrological regime.

The existing hydrological regime is relatively satisfying only from the viewpoint of revitalization of ground water levels at the Čunovo reservoir (the floodplain stretch downstream from Bratislava). However, with some exceptions, this area is not regularly flooded. Upon high discharges in the Danube, some parts of the area in the stretch between the Prístavný Most Bridge and Čunovo are flooded (for example at the Rusovské Ostrovy Islands). Areas situated behind the flood protective dikes are not flooded. Accounting for the relatively high level of ground water, the conditions for terrestrial mollusc are potentially satisfying. However, the polyhygrophilous species have almost disappeared due to insufficient moisture and the absence of floods. These species are already unable to colonize these habitats either passively or actively. Some chance for the revitalisation of molluscan communities might be the relocation of polyhygrophilous species from areas situated more downstream (Kráľovská lúka, Erčéd).

A worse situation exists on the stretch Dobrohošť – Sap, where the absence of natural floods and results in negative structural changes in the molluscan communities. The floods can be partly simulated by leading water into the arm system from the intake structure at Dobrohošť, but there is not a sufficient will to carry out such flooding because of conflicts of interests. The disadvantages of simulated floods are dealt with in the monograph [7], which presents ideas about the revitalisation of the area. The present floodless situation is bad and the succession of most of the originally strongly moist habitats will stop in the stage of dry types of willows poplar floodplain forests, or even drier succession stages, which will concurrently influence the succession of respective molluscan communities.

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