Landslides and biodiversity conservation: the importance of an integrated approach. A case study: the Subcarpathian part of the Doftana watershed (Prahova County, Romania)

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Abstract. Over the last few years mass-movements have been more and more perceived from an ecological standpoint, as natural disturbance factors, which may raise the geo- and biodiversity of an area. Mass-movements create a diverse microtopography, through material redistribution (Gertseema & Pojar, 2007), which form conditions for the installation of a rich diversity of plant and animal species, with different ecological requirements, some of them protected at national or EU level. Furthermore, at landscape level, the aquatic habitats formed in different elements of the landslides' microtopography have a network layout (on landslides body and due to spatial extension of landslide process in Subcarpathian area), providing suitable habitats and good dispersion possibilities to pond-reproducing or pond-depending fauna. The rich geodiversity (diversity of relief microforms, of soils and of hydrological / hydrogeological conditions) of landslide prone areas determines a mosaic of extremely diverse natural habitats (Aleksandrowics & Margielewski, 2010), very important for biodiversity conservation. We chose as a case study the Subcarpathian part of the Doftana river valley for ilustrating the importance of studying, mapping and monitoring slow mass-movements for the conservation of insect, amphibian and reptile species, which depend on aquatic habitats for reproducing, developing and feeding.

Keywords: landslides, biodiversity, geodiversity, nature conservation

1. Introduction

Landslides are usually perceived as natural hazards (Alcantara-Ayara, 2002; De Blasio, 2011) or environmental hazards (Lee & Jones, 2004), being studied in relationship with the risks posed to the socio-economic system: land degradation, infrastructure or other material damages and sometimes human casualties. The ecological role and meaning of this kind o disturbance is rarely taken into account. It's a well known fact that the disturbances have an important role in nature, being a major source of temporal and spatial heterogeneity in the natural communities' structure and dynamics (Sousa, 1984). The role of this kind of disturbances – landslides – in maintaining a rich biodiversity was largely ignored (Geertsema & Pojar, 2007). Being slope-shaping processes, under the influence of climatic and geological factors, landslides induce an increase in the spatial heterogenity (through erosional and deposition processes), with areas of exposed parent material in the upper part (scarps of landslides), with a humidity deficit, and areas with water-logged colluvial material. So, these slope-processes move along the altitude gradient crucial elements for downstream ecosystems, like calcium and phosphorus, resulted from the erosional processes associated with landslides (Walker & Shiels, 2013). Thus, landslides have an important role in one of the crucial ecosystem service: nutrient cycling. Furthermore, landslides reset the "pedogenic clock" of areas affected by them back to Regosol-Brunisol-Podsol sequence, fostering the restart of ecological succesion processes (Gertseema & Pojar, 2007). Consequently, the effects of landslides go far beyond their physical limits, due to their role in sediment loading of water courses, as well as in maintaining a rich regional biodiversity and dispersion of organisms (Walker & Shiels, 2013). At the landscape level, landslides create habitat discontinuities in a background matrix, like forests, shrubs or grasslands (Walker & Shiels, 2013), ensuring an increase in spatial and functional diversity. They also create networks of aquatic habitats (ponds, puddles, wet areas, rivulets), important in maintaining viable populations of pond-depending fauna, especially in case of species which form metapopulational structures (amphibians).

The increase of structural heterogeneity, driven by landslides, is not always perceived as beneficial in maintaining a rich biodiversity, some studies emphasizing that landslides may facilitate the installation of invasive alien plant species (Restrepo & Vitousek, 2001), showing that landslides do not increase herbaceous species diversity, but rather decrease it (Koolaei et al., 2011), other arguing that landslides affect medicinal herb distribution (Lepcha et al., 2011), other showing that landslides affect the vegetation land-cover and biomass distribution, altering succesional trajectories, and thus transforming ecosystems in irreversible ways (Restrepo et al., 2003). Other studies in turn, argue that landslides, acting as perturbation factors, have important roles in imprinting a certain dynamic in the structure of forest vegetation and in biodiversity enrichment (Seiwa et al., 2012; Walker, 1996). Other studies show that geodiversity (understood as relief, soil and hydrologic diversity) creates conditions for the existence of a mosaic network of extremely diversified habitats (Alexandrowics & Margielewsky, 2010). Other authors emphasize that landslides influence several types of diversity: site diversity, soil diversity and ecosystem diversity, creating suitable habitats for aquatic fauna, denning/nesting habitats, escape terrain, cliff habitats for vertebrates (Geertsema & Pojar, 2007). Landslides may form - depending on the geological strata and sliding mode - aquatic habitats, as shown above, the geological structure allowing sometimes for the persistence of ponds, in spite of material movements (Fleming & Baum, 1999). It is acknowledged that modeling / patterns / power law identification regarding the ecology of structures and functions at landscape level are part of a young discipline (landscape ecology), a synthesis between abiotic and biotic processes being needed (Brown et al., 2010). The wide variation of patch sizes in different succession stages due to different landslide disturbances probably affects species diversity and ecosystem productivity at local to regional levels (idem). The aim of our study was to detail the influence of habitat structure created by landslides on pond-depending fauna species of conservation interest and its importance for biodiversity conservation.

The study area is located in the Curvature Subcarpathians, the subdivision of the Prahova and Buzău Subcarpathians, in the Doftana river basin. The Subcarpathian part of Doftana river basin was delimited eastwards and westwards by watersheds, southwards by Doftana – Prahova confluence and northwards by the geological limit between the Bobu Nappe (massive sandstones and conglomerates, sandstone-marl flysch) and the Teleajen Nappe (Curbicortical flysch, massive sandstones), which passes under the Paltinu storage reservoir and on which base the mountain unit may be delimited from the hill unit. The resulting study area covers 80.333 sq km, having a perimeter of 54.551 km, the lowest altitude of 360 m, highest altitude of 1.034 m and a mean altitude of 669 m a.s.l.. Using a DEM with a 30m pixel resolution and Slope analysis from ArcMap 10.1, we calculated the slopes angles within the study area, as following: minimum slope = 0.0027°, maximum slope = 35.84° and average slope = 8.89°, with a standard deviation of 5.0543°.

It is known from the scientific literature that most landslides from the study area are shallow (<1.5 m) or medium deep (2-5m), whereas deep-seated landslides (5-10m) occupy small areas (Armaş, 1999).

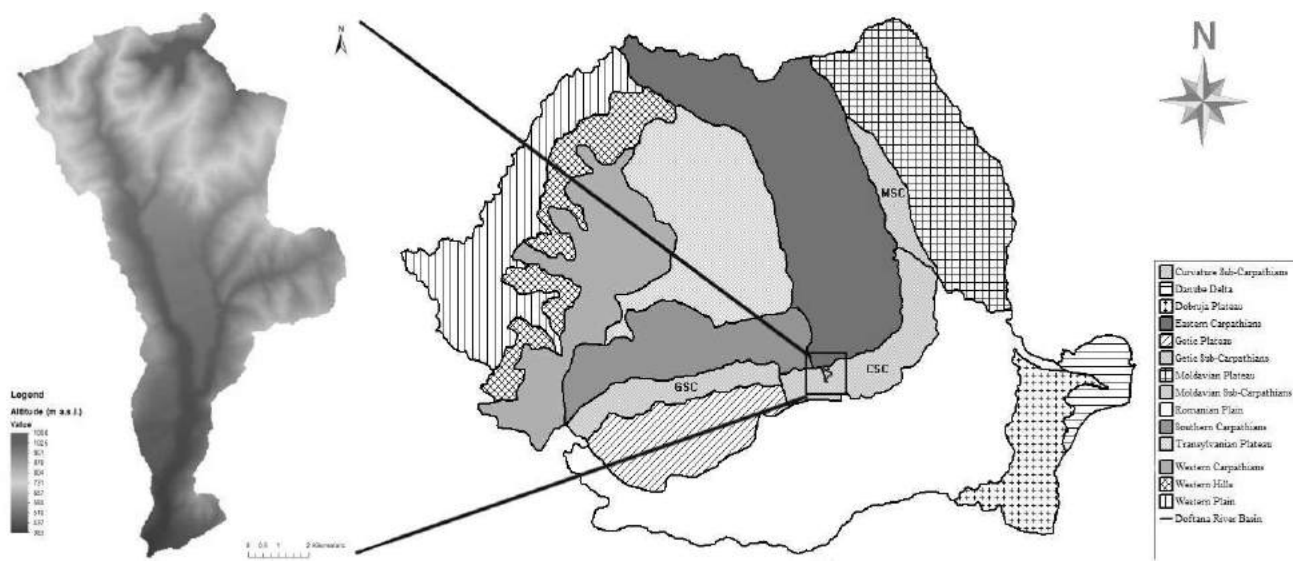


Fig. 1. **Study area location – Curvature Subcarpathians**

2. Materials and methods

The study was carried out during 2010 - 2013, in the above-mentioned study area. We mapped on field the active landslides on the basis of slope microrelief (cracks, slope discontinuities, wet habitats with hydrophilous vegetation, deranged material with pioneer vegetation), as well as of trees inclination. By using a GPS device from Garmin, model eTrex Legend Hcx, with a precision of up to 3 m, for field mapping, and by making use of photointerpretation of satellite imagery with a 0.3 m resolution (Bing Maps), as well as by analyzing topographic maps at a scale of 1:25 000 and geological maps 1:50 000 (Comarnic and Teleajen sheets), a number of 140 active landslides was successfully mapped. Aquatic habitats were also mapped in the field, using the same GPS device, in addition to a few aquatic habitats which were mapped through photointerpretation of satellite imagery due to their extent (exceeding 1000 m^2) or difficult access. Thus, a number of 193 aquatic habitats (temporary and permanent ponds, puddles and swamps, lakes, artificial basins) were mapped in the Subcarpathian part of Doftana valley. Out of 193 aquatic habitats, only 75 are formed on active landslides, the rest being formed on stabilized landslides, subsidence sinkholes or dissolution lakes (Brebu Lake) or representing artificial lakes/basins. The pond-depending fauna species were mapped on field, during the reproduction season (from March through July), using the scan searching method (Halliday, 2006), auditive transects (Cogălniceanu, 1997; Halliday, 2006) and for some aquatic habitats we used funnel traps, made from pet bottles of 2L, for newt species (Griffiths, 1985). Data were subjected to a spatial analysis using GIS-softwares, such as Global Mapper, SAGA GIS, Quantum GIS and ArcMap 10.1.

3. Results

The landslide inventory of the study area revealed the following types of landslides: slumps, mudflows and complex landslides. Of particular interest for the study were the landslides which may form aquatic habitats suitable for pond-depending fauna: slumps and complex landslides. Although we mapped the mudflows, they are not of interest for this study, because they do not form aquatic habitats, due to high dynamic of viscous material. We were interested in those slope-processes (slumps and complex landslides) that may lead to apparition of negative micro-forms, in which aquatic habitats may form depending on the presence of clays. Those processes have to be slow enough (1cm–1m / year) in order for the aquatic habitats to be suitable for the development of pond-depending species. Furthermore, the network of aquatic habitats formed on landslides have to be persistent through several years, allowing the development of metapopulational structures or at least of viable isolated populations, a crucial aspect for the long-term survival of the studied species.

Although the whole area is more or less prone to mass-movements, due to geological and climate conditions, the area affected by the mapped active landslides extends over 1 446 sq. km of the 80 333 sq. km large study area. We analyzed the spatial distribution of active landslides on different slope aspects and angles with the Zonal statistics histogram function of ArcMap 10.1, using the above-mentioned 30m resolution DEM and a binary raster with active landslides (1) and background matrix (0) with a cell grid of 0.00001 decimal degrees. The results are shown in the graphs of Figures 2 and 3:

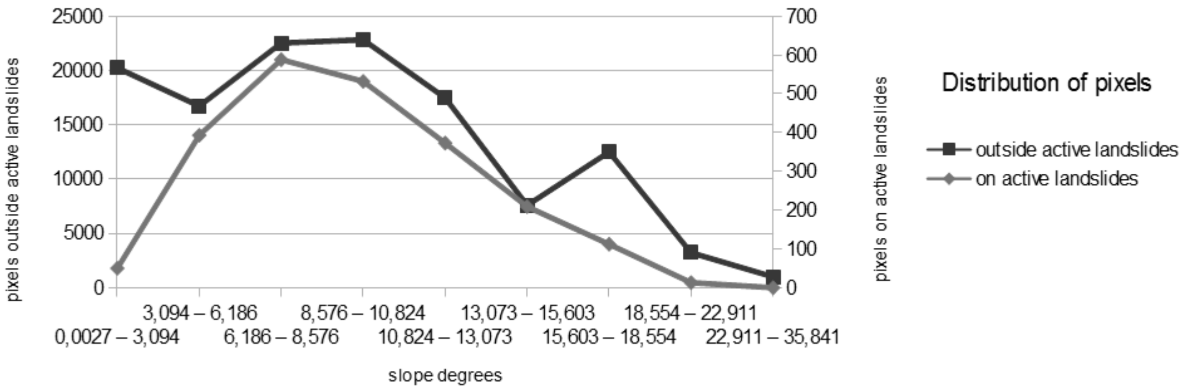


Fig. 2. **Distribution of pixels affected by active landslides and of background matrix** (area not affected by active landslides) **on slope angle categories**

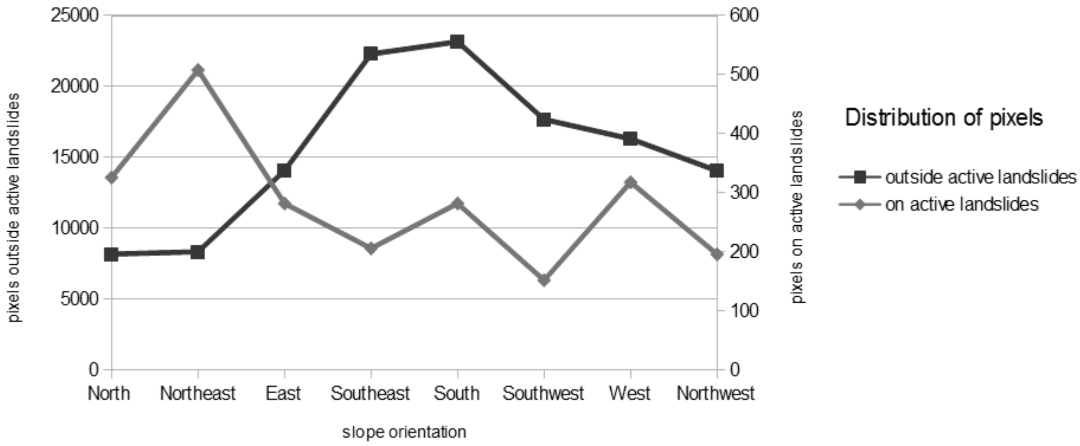
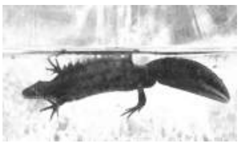


Fig. 3. **Distribution of pixels affected by active landslides and of background matrix** (area not affected by active landslides) **on slope aspect categories**

We identified during the study period (2010-2013) a number of 5 species (2 invertebrates: *Carabus variolosus*, *Lycaena dispar*, 2 amphibians: *Bombina variegata*, *Triturus cristatus* and 1 reptile: *Emys orbicularis*) listed in the IInd Annex of Habitats Directive (92/43/EEC), for the conservation of which special conservation area designation is required (as part of Natura 2000 pan-European protected area network), and another 3 species of community interest (amphibians: *Hyla arborea*, *Rana dalmatina*, *Bufo viridis*), listed in the 4th Annex of Habitats Directive, which need strict protection measures.

Table 1. **Pond-depending fauna species with a special legal protection status identified in the study area**

No.	**Species**	**Taxonomic Group**$^{+}$	**Habitats Dir. Annex II**	**Redlist conservation status**	**Ecological requirements and relations to aquatic habitats**
1	***Carabus variolosus*** 	I	II	VU-CR*	Semi-aquatic, strictly stenotopic species, indicating (semi-)natural woodland brooks and ponds, preferring high soil moisture, circumneutral pH and light woodland. Exhibits untypically low population sizes for insects (Matern et al., 2008; Matern et al., 2009). Uses wet habitats for reproduction and foraging.
2	***Lycaena dispar*** (Large Copper) 	I	II, IV	LC**	Occupies wet habitats (wet grasslands, puddles and ponds, fens), laying eggs on 3 species of a hygrophilous plant genus – *Rumex sp.* (docks). The larvae feed on docks, which grow in the above-mentioned wet habitats (Duffey, 1993; www.leps.it). The species is regarded as a low density species, with high dispersal ability – up to 5 km (Settele et al., 2000, *apud* Strausz, 2010)
3	***Bombina variegata*** (Yellow-belied toad) 	A	II, IV	NT***	The species breeds in temporary ponds and aquatic habitats with highly varying hydroperiod (Hartel, 2008). It can occupy virtually any pond or water accumulation, from little cattle imprints or small rivulets to more developed aquatic habitat, with aquatic vegetation (Cogălniceanu et al., 2000). Uses aquatic habitats mainly for reproducing and larval development, but sometimes also for foraging.

4	***Bufo viridis*** (European green toad) 	A	IV	NT***	This species is much more terrestrial than the above one, undertaking long migrations for breeding. Uses aquatic habitats mainly for reproducing and larval development. (Cogălniceanu et al., 2000). Forages on land.
5	***Hyla arborea*** (European tree frog) 	A	IV	VU***	This species represents the only tree frog from Romania. It possesses special adhesive structures at the tip of its fingers, by means of which it can climb on leaves of trees. It uses aquatic habitats mainly for reproducing and larval development (Cogălniceanu et al., 2000). Forages on land.
6	***Rana dalmatina*** (Agile frog) 	A	IV	VU***	It is the most common woodland frog from the plain and hilly area from Romania. It uses almost every spring pond for reproduction and larval development. Forages on land (Cogălniceanu et al., 2000).
7	***Triturus cristatus*** (Great crested newt) 	A	II, IV	VU***	It is the second largest species of newts from the plain and hilly area from Romania. It occupies fish-free aquatic habitats in an advanced stage of ecological succesion, with rich plant and animal communities (Oldham et al., 2000). The species has troughout the year both an aquatic stage, in which it reproduces and forages in water, and a terrestrial stage, in which it lives near water bodies (Cogălniceanu et al., 2000). The larvae develop in the above-mentioned aquatic habitats, with hydroperiods sufficiently long (permanent ponds, puddles and lakes, or temporary ponds which last from March through July at least).
8	***Emys orbicularis*** (European pond turtle) 	R	II, IV	VU***	The only aquatic species of turtles from Romania, occupies stagnant or slow flowing aquatic habitats, like meso- and eutrophic lakes, oxbow lakes, swamps, permanent ponds, stock ponds, requiring a certain aquatic vegetation, shore soil texture and basking sites. It reproduces, developes, forages, and hibernates in water (Fuhn & Vancea, 1961).

[+] Taxonomic Group of the Class rank: I = Insecta, A = Amphibia, R = Reptilia

* The hygrophilous species of ground beetle *Carabus variolosus* was not assessed in terms of conservation status, neither at global level (IUCN Redlist v. 2013.1), nor at EU or national level. Some EU member states assessed the species conservation status between VU ”vulnerable” and CR ”critically endangered”, in others the species went extinct (Switzerland, Italy), according to Matern et al. (2008);

** For the butterfly species *Lycaena dispar*, we used the European assessment of its conservation status (van Swaay et al., 2010), because Romania did not developed yet an invertebrate national Redlist;

*** For vertebrates (herpetofauna), we used the assessments from the Romanian Vertebrates Redlist, elaborated in 2005 by the National Museum for Natural History ”Grigore Antipa” (herpetofauna was evaluated by Iftime, 2005). NT means ”near threatened” species, VU means ”vulnerable” species.

We recorded a total of 265 occurrences of the 8 species above-mentioned, in or near aquatic habitats situated on active landslides, on stabilized landslides or on flat ground having other forming processes (dissolving, subsidence). Because stabilized landslides are much more difficult and expensive to map, we divided the occurrences in: occurrences in/near aquatic habitats on active landslides and occurrences in/near aquatic habitats outside active landslides, as presented in Table 2.

We identified 6 negative microforms, which may form aquatic habitats suitable for pond-depending fauna, due to the presence of clays in the slided material: slope discontinuities under the main scarp (1), slope and material discontinuities on the contact surface between the slided material and the fixed material (2), slope discontinuities on the landslide body, due to the sliding mode of the slumping blocks (3), transverse cracks in the landslide body (4), landslide foot, which is almost always water-logged (5), negative microforms lasting on stabilized landslides (6) (see numbers in Fig. 5).

Table 2. **Occurrences of pond-depending fauna species on and outside active landslide areas. Red colour is for HD Annex II species, for which special conservation area have to be designated; yellow colour is for HD Annex IV species, which need strict protection measures. I = Invertebrate, A = Amphibian, R = Reptile**

Occurences in aquatic	Car_var	Lyc_dis	Bom_var	Tri_cri	Hyl_arb	Ran_dalm	Buf_vir	Emy_orb
	I	I	A	A	A	A	A	R

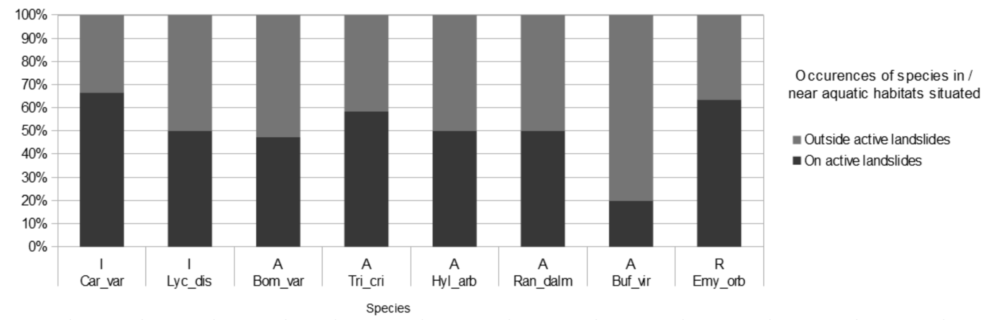


Fig. 4. **Percentage of occurrences of the 8 species on and outside active landslides areas**

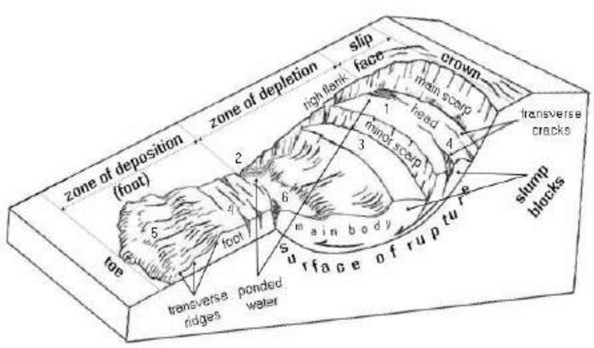


Fig. 5. **Diagram of landslide elements, modified after Cruden and Varnes** (1996)

Fig. 6. **Ponded water on the head of a landslide**

We present below which of the 8 species with a legal protection status were found on each of the 6 negative microrelief forms, with aquatic habitats installed on their surface.

a) Under the main scarp of slumps, on the first slumping block, ponds can be observed, which formed due to the reversed slope. This was the case for at least 6 landslides out of 140 landslides mapped in the studied area. Depending on the aquatic vegetation succesional stage, we could observe the following amphibian species: *Rana dalmatina, Hyla arborea, Bombina variegata, Triturus cristatus.*

b) On landslide flanks we could observe, depending on the sliding mode, material discontinuities between the slided part and the fix part (the slided material retires from one of the fix parts). On some landslides, through these longitudinal discontinuities small rivulets are drained and where these rivulets reach a slope discontinuity, water accumulates and ponds appear. These rivulets may fill also transverse crack or negative microrelief forms resulted from material accumulation. On the small rivulets situated along landslides flanks, we could observe adults and juveniles of yellow-belied toad *Bombina variegata*. On the ponds formed by those rivulets when encountering reverse slopes or accumulated material, we could observe both invertebrate species: the ground beetle *Carabus* (Hygrocarabus) *variolosus* and the butterfly *Lycaena dispar*, and 2 species of amphibians: *Bombina variegata* and *Triturus cristatus*.

c) On the landslide body of almost every landslide appear slope discontinuities due to slump-blocks, transverse ridges and hummocks. Depending on the clay presence in the soil and/or in the bedrock, the slumps, transverse ridges and hummocks may shelter ponds being in any stage of succession, from simple ponded water having small areas, to puddles and up to eutrophic ponds. All 8 species could be found in these ponds and puddles, due to their spatial distribution (up to 10 ponds and puddles on one single slump, of 2.79 ha), to the permanent character of some of the aquatic habitats and to their rich trophic offer.

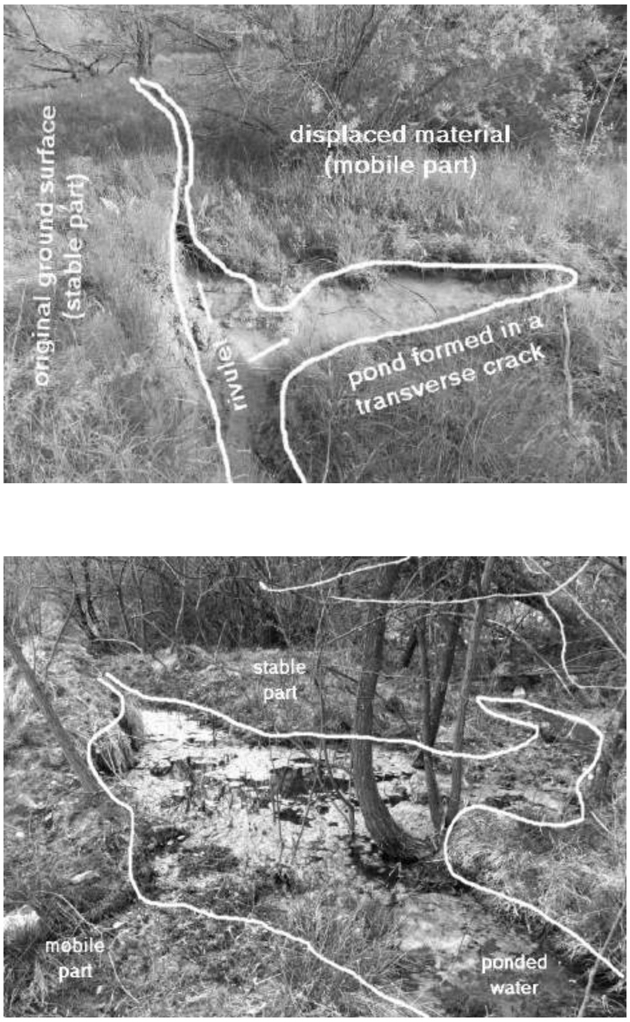


Fig. 7. **Temporary** (left) **and permanent** (right) **ponds formed between the stable part and the mobile part**

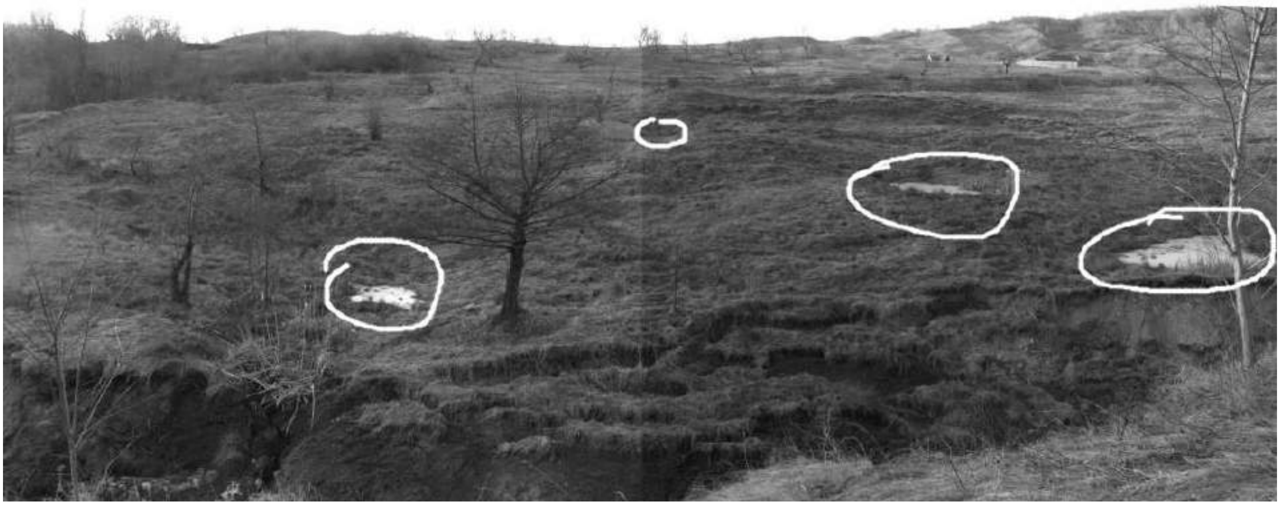


Fig. 8. **Network of permanent and temporary ponds formed in microdepressions, on a slow-moving landslide** (between 1-100 cm / year), **triggered by slope-base erosion**

d) Cracks appear on all landslides and some of them may retain water due to the presence of clays. Thus, small temporary ponds are formed, having no or scarce pond vegetation. On this kind of temporary aquatic habitats we could find only 2 species of amphibians, being known to be able to reproduce in very small temporary water bodies: *Bombina variegata* and *Rana dalmatina*.

e) The lower parts of landslides are almost always water-logged. Thus, ponds and puddles appear on the foot or toe of landslides, or even in front of landslides' toes. In this kind of aquatic habitats we observed the following amphibian and reptile pond-depending species: *Bombina variegata, Triturus cristatus, Rana dalmatina* and *Emys orbicularis*.

f) Negative micro relief forms may be observed on stabilized landslides (no cracks can be seen), especially towards the lower part of depletion zone or on slope discontinuities (reverse slopes, transverse ridges, zones with no slope gradient) remained after sliding. In such negative microforms rainwater and/or groundwater may accumulate and hydrophilous vegetation may colonize them (*Juncus sp., Carex sp., Epilobium sp., Potamogeton sp., Rumex sp. etc.*). In those ponds, which may be permanent, we could observe the amphibian species *Bombina variegata, Hyla arborea, Rana dalmatina, Triturus cristatus.*

In Table 3 we present a synthetic table of the 8 species with a special legal protection status that were observed in the study area and types of aquatic habitats within which they were observed.

Fig. 9. **Pond formed in a transverse crack**

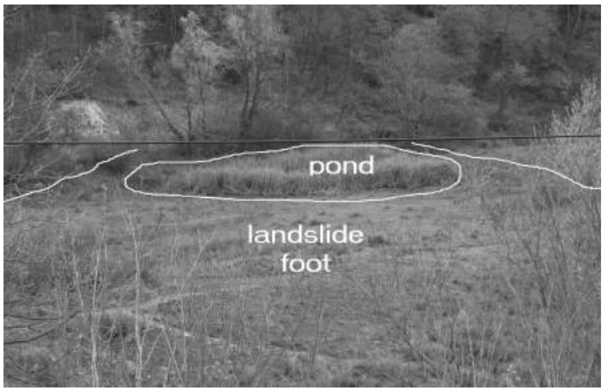


Fig.10. **A slump' zone of deposition**

Fig. 11. **Temporary pond formed in a negative relief form, on a stabilized landslide**

Table 3. **Species of fauna associated with aquatic habitats and types of microrelief in which they where observed**

No crt.	Species	Taxonomic Group	1	2	3	4	5	6
1	***Carabus variolosus***	I		●	●			●
2	***Lycaena dispar*** (Large Copper)	I		●	●			
3	***Bombina variegata*** (Yellow-belied toad)	A	●	●	●	●	●	●
4	***Bufo viridis*** (European green toad)	A			●			
5	***Hyla arborea*** (European tree frog)	A			●			
6	***Rana dalmatina*** (Agile frog)	A	●	●	●	●	●	●
7	***Triturus cristatus*** (Great crested newt)	A	●	●	●		●	●
8	***Emys orbicularis*** (European pond turtle)	R			●		●	

4. Discussions

Data gathered until now don't allow us to calculate degrees of correlation between species occurrences and aquatic habitats installed in negative microrelief forms. But taking into account that the area of active landslides sums up approximately 1.8% from the study area (1.446 sq km) and that the species occurrences on active landslides vary between 25% (European green toad) and 66.6% (*Carabus variolosus*), we may have an incipient image of the ecological importance of landslides, as far as the pond-depending fauna is concerned.

During our study, the area most rich in herpetofauna species from the study area became a Natura 2000 Site of Community Interest for 3 pond-depending species: *Bombina variegata*, *Triturus cristatus* and *Emys orbicularis* (Legal Act issued in November 2011 – Ministerial Order 2387). Since November 2011, we observed two other species listed in Annex II of HD: *Lycaena dispar* and *Carabus variolosus*. Those two invertebrate species are good indicators of the wilderness degree of the aquatic habitats formed on active landslides, at a landscape scale, as they are stenotopic species, with specific habitat requirements.

At a landscape level, the aquatic habitats created by active or stabilized landslides have a network structure, which is beneficial for maintaining viable populations of pond-depending fauna species on a long term. It is acknowledged that a network of sufficiently close aquatic habitats is beneficial to biodiversity for at least two reasons: 1) as far as the pond-depending species richness is concerned (aquatic snails, aquatic beetles, damselflies, dragonlies, amphibians), a network of ponds and puddles of smaller area has a greater conservation value than a large water-body with the same area as the summed areas of the smaller ponds and 2) a network of ponds and puddles sufficiently close may sustain metapopulational structures, in which if one sub-population goes extinct, recolonisation from the other sub-populations is possible (Marsh et al., 2001). Though, the disappearance of a breeding habitat for pond-depending fauna species (e.g., through desiccation) doesn't represent a major threat in a landscape where other options do exist. We further present a model of buffer zones of 100, 300 and 1 000 m around each aquatic habitat mapped in the field from an area of approximately 6 sq km, covering two patches of the above-mentioned Natura 2000 site (ROSCI0283 Cheile Doftanei), which reveals a certain connectivity between them with an important meaning for pond-related biodiversity. These units were modeled taking into account several maximal migration distances for amphibian and reptile species, according to the scientific literature. As far as the two invertebrate species are concerned, *Carabus variolosus* live in very small populations and have very short migration distances, not very well studied (several hundreds of meters, according to Matern et al., 2009), whilst *Lycaena dispar* may migrate several kilometers away (5 km according to Strausz, 2010).

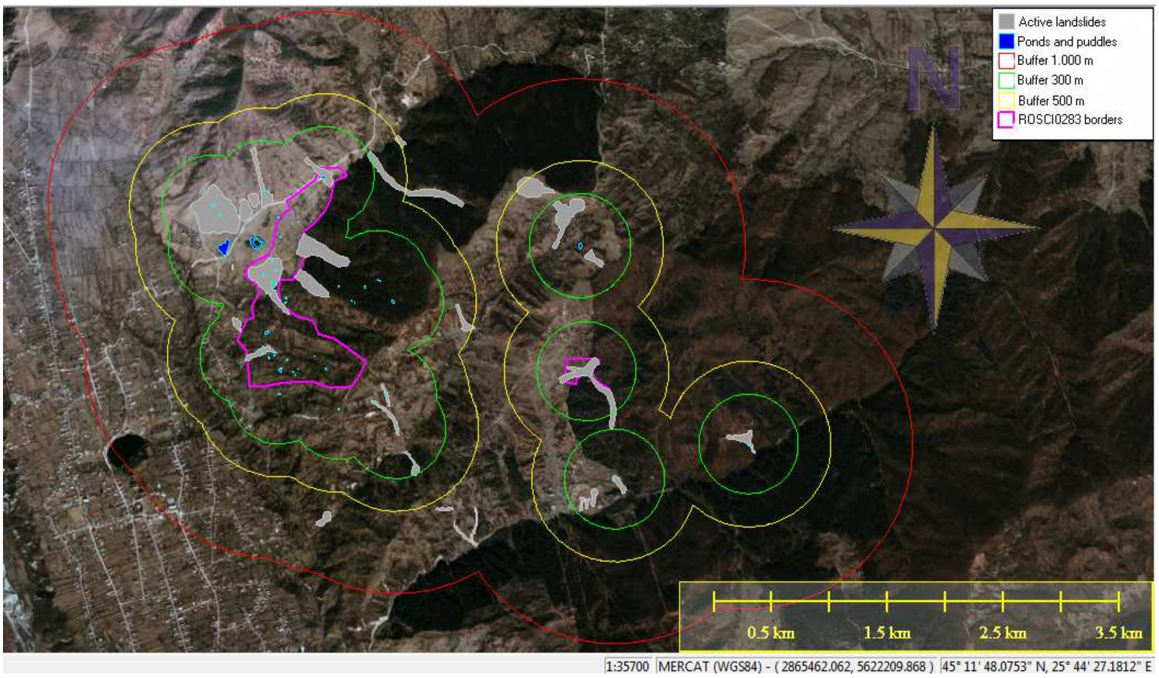


Fig. 12. **Modeling of buffer zones of 100, 300, 1 000 m around the ponds** (55 ponds and puddles in a 6 sq km area)

Besides the fact that landslides create aquatic habitats in a network disposal, some ponds formed by the sliding mode of slump blocks are deeper, having thus longer hydroperiods. We observed that even when evaporation exceeds precipitation (summer months), at least 10 ponds remain in the 6 sq km area, finally maintaining a similar theoretical connectivity (we didn't model a habitat permeability matrix for each of the 8 species, as presented by Ray et al., 2002), with a smaller area (8.88 sq km at 1 000 m buffer, instead of 14.33sq km at 1 000 m buffer), as presented in Fig. 13.

We propose, on the basis of our findings, that the further process of designating natural protected areas especially for hygrophilous plants, wetland habitats and pond-depending fauna in landslide prone areas (between 300 and 1.000 m a.s.l.) should take into account the following factors:

i) slope angles varying between 3 and 15 degrees;
ii) slope orientation: especially northeastern and western slopes;
iii) lithological composition: clays and marls (Quaternary deposits);
iv) precipitation amounts: over 600 mm/year;
v) landcover: secondary grasslands, orchards, woodlands, trees and shrubs.

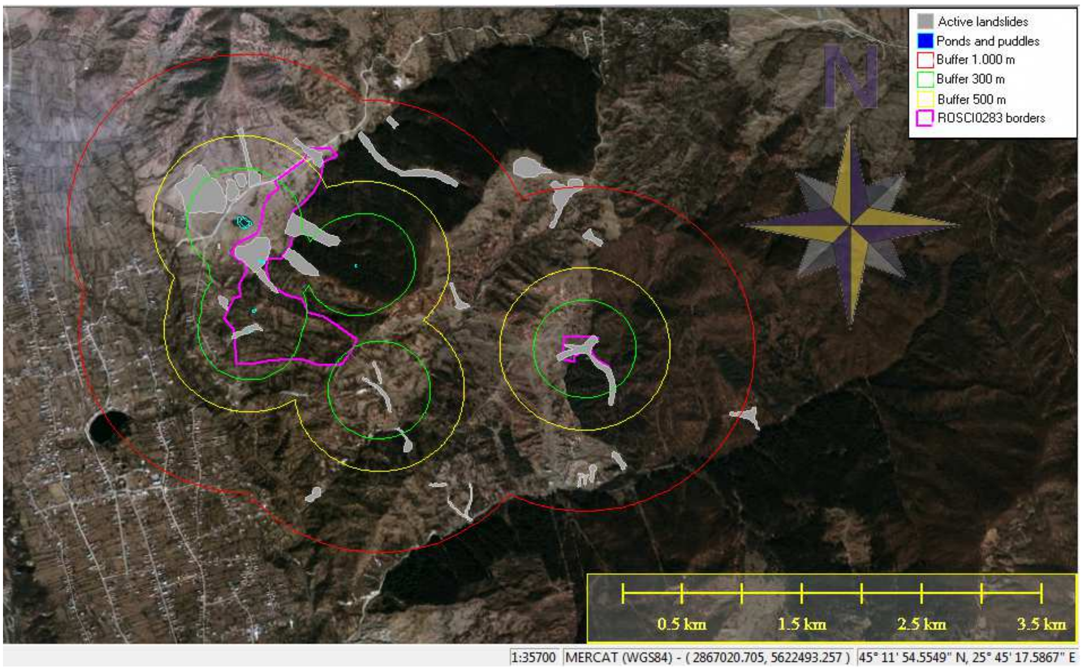


Fig. 13. **Modeling of buffer zones of 100, 300, 1 000 m around the ponds in the warm season** (June-August) (10 ponds and puddles in a 6 sq km area)

Studies should further detail conditions of landslides forming aquatic habitats, as a new branch of Ecology has emerged (Landslide Ecology, see Walker & Shields, 2013) and as more and more wetlands are lost (Gibs, 2000). Many pond-depending fauna species live in multiple local populations sustained by occasional migrations, which means through metapopulational structures (Hanski & Gilpin, 1991; Semlitsch, 1998; cited by Gibs, 2000). Protecting aquatic habitats formed by landslides means protecting local sub-populations of wider metapopulations and assuring long-term survival of endangered wetland animal species. Landslide mitigation should be balanced with ecosystem services preservation, where those two directions would come in a possible antagonism. Both are required for human well-being, an equilibrium of both action directions being a prerequisite of local and regional sustainable development. The more localized the landslide mitigation solutions are and the natural evolution of hillslope is taken into account, the more efficient are the ecosystem services preserved (through conservation of wet habitats and associated pond-depending species). Case-by-case judgement should ensure this balance between landslide mitigation projects and ecosystem services preservation (through biodiversity conservation), taking advantage of the coherence and framework of the EU-wide protected area network Natura 2000, which is very flexible in balancing development needs with conservation needs. Where landslide mitigation projects should prevail over biodiversity conservation interests, because of the importance of the infrastructure being threatened by landslides (overriding public interest of social or economic nature, according to EU Habitats Directive 92/43/EEC/1992, art. 6.4.), compensatory measures (e.g. in other Natura 2000 sites) will be taken in order to assure the overall coeherence of Natura 2000 protected area network, the ecosystem services preservation, and, finally, the human well-being.

5. Conclusions

Landslides produce spatial heterogeneity at the landscape level (Walker & Shiels, 2013) and create networks of aquatic habitats, due to geological and climate conditions. This geodiversity sustains suitable habitats for pond-depending fauna, especially for threatened wetland species, some of them being very rare at EU level and of particular interest for conservation measures (*Carabus variolosus*). Therefore, slow moving landslides should be taken into account in the process of designation of natural protected areas in the future, both for their suitable wet habitats and for migration dynamics.

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