INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE
ISSN: 2067-533X Volume 5, Issue 2, April-June 2014: 243-252 www.ijcs.uaic.ro

ECOLOGICAL FEATURES AND CONSERVATION PROPOSAL FOR THE LARGEST NATURAL DAM LAKE IN THE ROMANIAN CARPATHIANS – CUEJDEL LAKE

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Abstract

Cuejdel Lake is the largest aquatorium among the Romanian natural dam lakes and one of the top 5 largest natural dam lakes in the Romanian Carpathians (surface – 13.88ha, max. depth – 14.9m, total volume – 815,986m^3 *in 2013). The lake was generated by a large landslide that dammed the Cuejdel brook (in Ştânişoarei Mountains, Eastern Carpathians) during the summer of 1991. Cuejdel Lake was officially designated a national natural reserve by the Governmental Decision 2151/2004 regarding the creation of new protected areas and the conservation of natural flora and fauna habitats. Since 2011, our team has monitored the lake and studied the evolution of this limnosystem at the level of the lacustrine depression and its reception basin. Our research results indicated that, after 20 years of evolution and negative changes in the value of its morpho-bathymetric parameters (surface – 2.37ha, max. depth – 2.3m, total volume –* $26.77 \cdot 10^4 m^3$*), the lake is now in a relative hydrodynamic equilibrium with the obstructive dam. This paper is aimed to highlight the ecological features of this limnosystem that could further help to identify better solutions for the conservation of the lacustrine cuvette, in the context of an increasing anthropic pressure (deforestations, water pollution, uncontrolled tourist impact etc). The research indicates that the integration of the Cuejdel natural reserve and its reception basin within the Vânători-Neamţ Natural Park could be the best solution to preserve this hydro-morphological site and its biodiversity.*

Keywords: *Natural dam lake; Limno-ecological index; Biodiversity conservation; Cuejdel Lake.*

Introduction

Natural dam lakes are generated by geomorphological processes that obstruct water courses. The composition of the obstructive dams vary: e.g. lava flows, landslides, icedams, fluvial dams, eolian dams, dams formed in coastal areas, organic dams formed bioaccumulation or biogenetic activities (such as beaver dams). Sometimes, the water volume accumulated behind the dam can represent a hydrological risk factor for the riverain population and settlements [1, 2]. But the most complex transformations in landscape are asoociated with the lakes generated by landslides. These are usually concentrated in the mountain areas with narrow valleys and steep slopes, where the water accumulation needs a realtively low volume of

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obstructive materials [3, 4]. The temporary dependency of the water accumulations is proportional to the relation between the natural dam sustainability and the valley shape [5].

In Romania, natural dam lakes generated by landfalls and gravitational landslides are best represented. These are mainly concentrated in the Eastern Carpathians, the Curvature and Moldavian Subcarpathians and some scarce areas in the Moldavian Plateau. In this regard, the Carpathian flysch area presents the best geological conditions: the alternation of permeable and impermeable deposits with various toughness levels and the high declivity generate are responsible for the frequent slope processes [6].

The scientific literature mentions the existence of about 20 natural dam lakes in Romania, in various stages of conservation [6, 8]. Among these, the Red Lake is the most famous one. It was formed in 1837, as result of a landslide that detached from the western slope of Ucigasu Mountains and dammed the Bicaz brook [6]. Iezerul Sadovei (in the Feredeu Mountains) is the oldest natural dam lake in Romania and it was also generated by a landslide that obstructed an affluent of Sadova brook (left tributary of Moldova river) about 500 years ago. The lake is now very clogged up with silt and a large part of the initial water volume has been drained because of the dam sectioning, sustained also by anthropic intervention [7].

The subject of the present study is Cuejdel Lake – the newest and also the largest natural dam lake in the Romanian mountain area. The lake is situated in the South-Eastern part of Stânișoarei Mountains, in the Central area of the Eastern Carpathians (in North-Eastern Romania). The lacustrine depression was formed in 1991, in the superior basin of Cuejdiu brook (a tributary of Bistrita river), at about 1.5km uphill of its left tributary – Cuejdel, at 661m of altitude, as result of a landslide that dammed the valley. The lake is at 21km north-west of Piatra Neamt (in Neamt County), within the administrative territory of Gârcina rural commune. The lake coordinates are: 47º01’54” and 47º02’21” latitude, and within 26º13’02” and 26º13’07” longitude. Given its only 23 years of age, there are very few studies on this Cuejdel Lake and most of them descriptive [6, 9, 10] (Fig. 1a-f).

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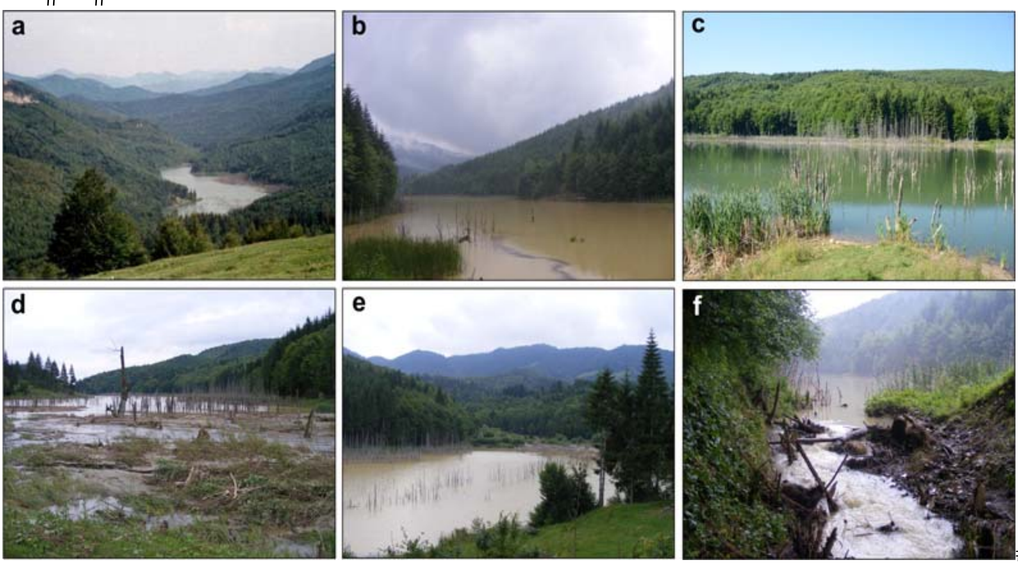

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Fig. 1. Cuejdel Lake from Stânișoarei Mountains (Eastern Carpathians):
a - View from Gârcina Massif; **b** - Inferior sector (with the maxim depths); **c** - Middle sector;
d - Inflow of lake (fan-delta area); **e** - Superior **s**ector; **f** - Outflow of lake

This study is aimed to highlight the importance of Cuejdel lake as a natural reserve of hydro-geomorphological interest and as a lacustrine habitat with a very high potential to preserve a specific biodiversity of mountain wetlands. On the other hand, given the accidental spatial occurrence of natural dam lakes and their relatively short existence, especially because of the anthropic interventions on their lacustrine cuvette and reception basin, we wanted to identify several solutions for the lake conservation within a least altered ecological context. Thus, these research findings were intended to represent an intermediary phase in the development of an integrated monitoring programme of natural dam lakes in Romania.

Materials and Methods

Cuejdel Lake has been the subject of a 4 years seasonal monitoring programme. Non-invasive technical instruments and methods were used to study the hydro-geomorphological stability and the ecologic potential of this lacustrine ecosystem [11-13]. The research was based on an interdisciplinary approach and high performance instruments used in similar international hydrological studies [11-13]: GPS-Valeyport Midas Ecosounder, Total Station Leica TCR 1200, GPS-Leica 1200 TCR, GPR Malå Ramac X3M, Hack Lange multiparameters etc. All the monitoring activities, investigation areas and monitoring frequency, as well as the technical equipments and methods are summarized in Table 1.

Table 1. Summary of the monitoring activities on Cuejdel Lake between 2011-2014

Types of activities	Investigated area	Techniques/device used	Monitorised parameters	Frequenci of monitoring
Bathymetric measurements	Lake basin	GPS-Valeyport Midas Echo-Sounder	Underwater morphology	1/year (2011)
Topographic measurements	Water level/ Aquatic surface	Total Station Leica TCR 1200; GPS-Leica 1200 TCR	Aquatic surface	1/year (2011 – 2013)
Bathymetric measurements	Lake basin	GPR Malå Ramac X3M – 100 mHz Antenna	Initial and actual underwater morphology	1/year (2013)
Sampling	Lacustrine sediments	Mecanic dispositive with tubs for sampling with vacuum method	Sediments thickness/ Lamination of lacustrine deposits	1/year (2013)
Sampling	Lacustrine sediments/ Biota	Bentonic dredger	Macrozoobenthos	2/year (2012; 2013)
Insitu evaluation of physico-chemical parameters	Water	Hack Lange multiparameters	pH, T(°C), LDO 101, CDC 401	4/year (2011 – 2014)
In labour analysis evaluation of physico-chemical parameters	Water	Labour equipments	pH, DO, BOD, NO_3, NH_4, PO_4	1/year (2012; 2013)
Sampling	Water	Nansen bottle	Water quality	2/year (2013; 2014)
Sampling	Water/ Biota	Nansen bottle/ Macrophytes net	Fhytoplancton	2/year (2012; 2013)

A Geographical Information System was realized for the entire study area, using specialized spatial analysis softwares such as: TNTmips 6.9 & 7.3, ArcGIS 9.3 & 10.1, (ArcMap; ArcScene; ArcCatalog). The cartographical materials used in the research were: topographical plans (1:5.000), forest management plans (1:10.000), topographical maps (1:25.000), ortorectified aerial photos (ed. 2005, 2010), satellite images etc. The study area was integrated within the limits of the Sites of Community Importance (SCIs and SPAs) provided on the website of the Romanian Ministry of Environment and Climate Changes [14].

Results and Discussions

Morpho-bathymetric parameters of the lacustrine basin

The first investigations on the lacustrine cuvette started in 2011, with the bathymetric measurements made with the aid of a high precision Echo-Sounder (Bathy-500DF Dual Frequency Hydrographic Echo-Sounder). Then, a 3D modelling of the lacustrine depression was realised, using 45.000 depths points at 0.25cm of equidistance. In 2013, a second bathymetric scanning was made with the aid of a GPR (ground-penetrating radar). This allowed the digital remodelling of the initial cuvette with a 0.3m/pixel DEM. The overall measurements results indicated that in 1991, the water volume behind the obstructive dam had the following parameters: $16.22 \cdot 10^4 m^2$ of surface, $122.3 \cdot 10^4 m^3$ of volume, -18.8m maximum depth and 1,170m of length. Twenty years later, despite the decreasing of the lake dimensions (the lake surface was reduced with 2.37ha, its maximum depth with 2.3m and the volume with $26.77 \cdot 10^4 m^3$), Cuejdel aquatorium still remained the largest natural dam lake known in the Romanian mountain area.

In order to highlight the high values of the morpho-bathymetric parameters for Cuejdel Lake, we compared 95 of the most important natural lakes in the Romanian Carpathians [6, 8, 15], including various genetic categories (glacial, nivation, volcanic, landslide). Thus, the ratio between the surface and the maximum depth indicates a relative equilibrium in the shape of the Cuejdel lacustrine depression, compared to 15% of the lakes analysed, which have high depths but smaller surfaces (e.g. Zanoaga glacial lake, with a surface of 6ha and a 29m maximum depth), or to 5% of the lakes, which have larger surfaces but lower depths. Besides several exceptions, the majority of the lakes have depths up to 5-7m and their water surface does not exceed 5ha (Fig. 2a).

As regards the altitudinal distribution of lakes, those situated above 1500m (most of them glacial), have small surfaces (0.1 – 7ha). The natural lakes formed in the low and medium mountains (500 – 100 m) have complex genesis and their surfaces rarely exceed 5 ha. The only natural lake largest than Cuejdel is the volcanic lake of St. Ana (surface – 19.5ha, max. depth – 7m), and, similar values has also the Red natural dam lake (surface – 12.6ha, max. depth – 10.5m)(Fig. 2b). As for the altitudinal distribution of the maximum depths, only three lakes have higher values: Tăul fără fund (17.5m), Galeșul (19.5m) and Zănoaga (29m), all glacial lakes situated at about 2000m of altitude (Fig. 2c).

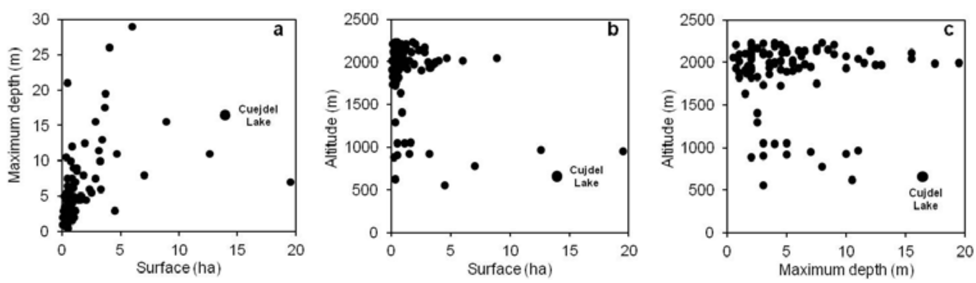

Fig. 2. Comparative analysis of morpho-bathymetric parameters for 95 natural lakes in the Romanian Carpathians: **a -** The ration between the total surface and maximum depth; **b -** Altitudinal distribution of water surfaces; **c -** Altitudinal distribution of maximum depths

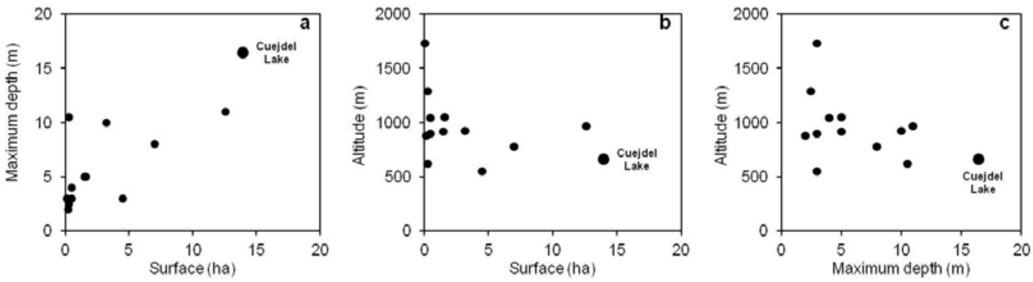

Fig. 3. Comparative analysis of morpho-bathymetric parameters for 13 natural dam lakes in the Romanian Carpathians: **a** - The ration between the total surface and maximum depth; **b** - Altitudinal distribution of water surfaces; **c** - Altitudinal distribution of maximum depths

Compared to all the natural dam lakes in Romania, at the end of 2013, Cuejdel lake had the highest values for the surface (13.88ha) and maximum depth (14.9m)(Fig. 3a). The unusual dimensions and the resistance in time are most probably the result of the relatively low altitude (661m), compared to other natural dam lakes formed at higher altitudes and presenting smaller surfaces: e.g. Răchitiș Lake (surface – 0.1ha, max. depth – 3m) or Black Lake (surface – 1.6ha, max. depth – 5m)(Fig. 3b). The higher frequency in the spatial distribution of natural dam lakes is between 500 – 1000m of altitude, which largely corresponds to the flysch area where the occurrence of geomorphological processes and the probability of deluvial damming water courses are higher. As regards the maximum depth, this one decreases indirectly proportional to the altitude. Thus, the highest values appear in the case of the lakes situated under 1000m (Iezerul Ighiel – 10m, Red Lake – 10.5, Tăul fără Fund – 10.5, Bălătău-Ponoare – 7.9m)(Fig. 3c).

Limno-ecological index

If, according to the topographical and morpho-bathymetric parameters, Cuejdel Lake is in the top 5 of the largest natural lakes in the Romanian Carpathians, according to the limno-ecological parameters, it has similar features to the lakes situated at higher altitudes. On the other hand, the biogeographical context shows capacity of Cuejdel Lake to develop like a limnosystem with features specific to the lakes situated at medium mountain altitudes, and within a topoclimate specific to the intra-mountain valleys, adjusted by a high forestation level (mixed forests) and sustained by a hydrographical network with a high water quality level [16].

At the level of the lacustrine biotope, the water volume (815,986m^3 in 2013) presents the thermic features of a dimictic rezervoir, with a direct layering during spring, summer and autumn, and inverse during winter. The temperature at water surface reaches about 23°C during summer and it is maintained all over the lake surface because the low river discharge reduces the water dynamic. The low temperature during winter favours the formation of an ice-bridge reaching 25-90cm thickness. The minimal temperatures during spring and autumn reach 13°C. At higher depths (10 – 15m), the temperature remains constant at 5°C.

The medium value of the water pH is 7.0 - 8.0, with low changes on a vertical level directly manifested during spring and winter. In autumn, there is an inversion of values: the pH increases in depth, up to 7.2-8. Over the year, the water pH is slightly alkaline, ranging between 7.5 and 8.0, and very rarely and in specific conditions, reaching circumneutral values. The quantity of dissolved oxygen at the water surface level reaches a maxim value of 8.2mg/L during summer and spring and a minimum of 4.5mg/L during winter. The quantity of dissolved oxygen decreases from 6 m depth, completely lacking on the bottom of the lake. In winter, when an ice-bridge is formed, the vertical distribution of these values is more uniform. The biochemical oxygen demand (BOD_5) or the level of organic pollution are low, with a 2.2mg/L average value, and largely follow the same vertical distribution pattern, thus indicating the lack of organic pollutants [13, 17].

Regarding the level of anthropic pollution of the Cuejdel lacustrine ecosystem, the concentrations of nitrates (NO_3^-) is very low, with an average of 0.5mg/L. The concentrations of ammonium ions (NH_4^+) (ranged between 0.25-0.38mg/L) are within the normal limits, caused by the waste of animal origin and the incomplete decomposition of underwater flora and fauna. Insitu biodegradation also adjusts the quantity of total organic carbon (TOC) and humic acides in the lacustrine benthos (organic carbon – 1.5-4g/100g, humus – 2.8-6.9g/100g) through the decay of vegetal wastes accumulated on the bottom of the lake. The concentration of phosphates (PO_4^{3-}) is under the average limit of natural waters (0.1mg/L), varying between 0.03-0.04mg/L. All these values indicate a natural regime of the physical-chemical processes and, thus, a water environment not altered by anthropic activities, with a medium trophicity (mesotrophic) (Table 2).

Table 2. Physico-chemical parameters and trophic state of Cuejdel Lake in 2011

Variable	Value	Variable	Value
pH (cold season)	7.2 – 8.0	NO_3^--N mg/L epilimn.	0.721
pH (warm season)	8.0 – 8.6	NO_3^--N mg/L hipolimn.	0.331
T°C epilimn. (cold season)	20 – 23	NO_2^- mg/L epilimn.	0.25
T°C epilimn. (warm season)	0.0	NO_2^- mg/L hipolimn.	0.38
T°C hipolimn. (year)	4 – 5	PO_4^{3-} - P mg/L epilimn.	0.041
Ice bridge in winter (cm)	30 – 90	PO_4^{3-} - P mg/L hipolimn.	0.038
O_2 mg/L epilimn. (cold season)	8.0 – 8.2	TOC mg/L (low depth)	4.00
O_2 mg/L epilimn.(warm season)	4.5 – 5.0	TOC mg/L (high depth)	1.50
O_2 mg/L hipolimn. (year)	0.0 – 0.2	Humus mg/L (low depth)	6.90
BOD_5 mg/L (average)	2.2	Humus mg/L (high depth)	2.80
CDC 401 mg/L epilimn.	185 – 190		
CDC 401 mg/L hipolimn.	345 – 350		

On the biodiversity level, the research was aimed to identify limno-ecological index for the communities of phytoplankton and macrozoobenthos. The algae community within the water volume indicates a preliminary phase, represented by some cosmopolite species from the families of: *Cyanophyta, Bacillariophyta, Chlorophyta, Dinophyta, Euglenophyta*. For the benthos communities, several species and subspecies of macrozoobenthos were identified, such as: *Tubifex tubifex, Potamothrix hammoniensis, Limnodrilus hoffmeisteri, Chironomus plumosus, Tanypus punctipennis, Bezzia* sp., *Chaoborus flavicans*. All these communities mentioned above are specific to lakes where the water quality score varies between 4.2 and 10 [18]. This indicates an ultra-oligotrophic aquatic environment (Table 3).

Table 3. Trophicity of several lakes in the Eastern Carpathians

Lake	Genetic type	Water stream	Usage	Water quality (category)	
				Nutrients (total nitrogens, total phosphorus)	Biology
Buhăescu	Glacial	-	-	M-E	O
Colibița	Human made	Bistrița	Complex	E-H	O
Lala	Glacial	-	-	UO	UO
Sfânta Ana	Volcanic	-	Tourism	M	M
Brădișor	Human made	Lotru	Complex	M	H
Măneciu	Human made	Teleajen	Complex	H	O
Paltinu	Human made	Doftana	Water supply	E-H	O
Bâtca Doamnei	Human made	Bistrița	Energy	E	O
Poiana Uzului	Human made	Uz	Water supply	E-H	M
Siriu	Human made	Buzău	Complex	E	O
Roșu	Natural barrage	Bicăjel	Tourism	M-E	UO
Cuejdel	**Natural barrage**	**Cuejdel**	**-**	**M**	**UO**

H - hypertrophic; E - eutrophic; M - mesotrophic; O - oligotrophic; UO - ultra-oligotrophic

Habitats and species conservation

The genesis of Cuejdel Lake presents a multiple scientific and economic interest. Thus, it allows biologists and geographers a better understanding of the genesis, evolution and impact of natural dam lakes in Romania. At the same time, the local public administration is directly interested in the preservation and management of the lake. In 2004, a governmental decision included Cuejdel Lake in the list of national protected areas [19]. But the scientific studies preparing the elaboration of a Management Plan for Cuejdel Lake [20] began only in 2010 (2010-2012) and they were financed by the Ministry of Environment and Climatic Changes with the support of the European Union. According to these studies, in the Cuejdel Lake nature reserve, 38 species of birds, 8 species of amphibians, 2 of reptiles and 11 habitats were identified. Among these, there are only 5 habitats, 8 species of birds, 3 of amphibians and one of reptiles that are mentioned in the 2006 modified version (2006/105/CE) of the Habitats (92/43/EEC) and Birds Directives (79/409/EEC) (Table 4 and 5).

Table 4. Habitats indentified in the Cuejdel nature reserve, according to the Romanian and Natura 2000 classifications

Romanian classification [21]	Natura 2000 habitat classification	International regulations
R2202: Danubian communities with *Lemna minor, L. trisulca, Spirodela polyrhiza* and *Wolffia arrhiza,* R2206: Danubian communities with *Potamogeton perfoliatus, P.gramineus, P. lucens, Elodea canadensis* and *Najas marin*; R5304: Danubian communities with *Sparganium erectum, Berula erecta* and *Sium latifolium*;	3150 Natural eutrophic lakes with *Magnopotamion* or *Hydro-charition*	**Habitats Directive (92/43/EEC) modif. 2006/105/CE**
R4101: South-east Carpathian forests with spruce *(Picea abies)*, beech *(Fagus sylvatica)* and fir *(Abies alba)* with *Pulmonaria rubra*	91V0 Dacian beech forest (Symphyto-Fagion)	**Habitats Directive (92/43/EEC) modif. 2006/105/CE**
R4402: Dacian-getic forest on hilly meadows with black alder *(Alnus glutinosa)* and *Stellaria nemorum*	91E0*Alluvial forest with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)	**Habitats Directive (92/43/EEC) modif. 2006/105/CE**

Table 5. Species mentioned in the Birds and Habitats Directives

Species names	**Type**	**Birds Directive (79/409/EEC)** **Habitats Directive (92/43/EEC) modif. 2006/105/CE**
Picus canus	bird	Annex 1 Bird
Turdus merula	bird	Annex 1 Bird
Turdus philomelos	bird	Annex 1Bird
Bonasa bonasia	bird	Annex 1 Bird
Columba palumbus	bird	Annex 1Bird
Dendrocopos syriacus	bird	Annex 1 Bird
Garrulus glandarius	bird	Annex 2 Bird
Anas platyrhynchos	bird	Annex 2 Bird
Bombina variegata	amphibian	Annex 2 Habitat
Rana temporaria	amphibian	Annex 5 Habitat
Triturus cristatus	amphibian	Annex 2 Habitat
Lacerta agilis	reptile	Annex 4 Habitat

Despite the existence within the Cuejdel Lake national reserve of an important list of habitats and species for which the prseent legislation indicates the necessity of creating a site of Community importance (SCI), a special area of conservation (SAC) and a special protection area (SPA), the national authorities did not take any measures in this aim.

Thus, Cuejdel Lake was not included in the vector shapefile, containing SCIs and SPAs limits published in 2011 on the website of the Romanian Ministry of Environment and Climatic Changes. Still, two important SCIs and SPAs were delineated in the near proximity of the lake, at about 1.7km North (Fig.4). Also, according to our interdisciplinary research, the territory of Cuejdel nature reserve fulfils the criteria specified in the EU Directives, thus deserving the status of official integration within the Natura 2000 European network. Another solution for a better local conservation and sustainable capitalization is the integration of this area within the extended limits of the ROSCI 0270 or ROSPA 0107 Vânători Neamţ Natural Park. The park is already a model of sustainable management for protected areas and good implementation of European funds, a benefit that could be extended to the area of Cuejdel Lake. Furthermore, within the limits of Vânători Neamţ Natural Park, also designated as SCI and SPA (ROSCI 0270 and ROSPA 0107), there is a population of European bison *(Bison bonasus)* grown in semi-captivity. In 2012, five bisons were released from captivity, as a first step in the efforts of the park administration to repopulate the forests with this species. In this context, the proximity of the Cuejdel Lake could be capitalized to further extend the park limits and to provide a water reservoir needed for the future spatial expansion of the European bisons.

Our research highlighted a complex scientific interest in Cuejdel Lake, as well as a series of scientific superlatives such as: *the youngest*, *the biggest*, *the deepest and the wider natural dam lake* known in the Eastern Carpathians. All these enhance the tourist potential of this area and another important direction for future development that could further support its conservation and sustainable capitalization. The very low anthropic intervention adds to the eco- and geo-tourist appeal of this area. An ecotourist route integrating both Cuejdel Lake and Vânători Neamt Natural Park would benefit local managers as well as tourists in search of educational or nature-based experiences.

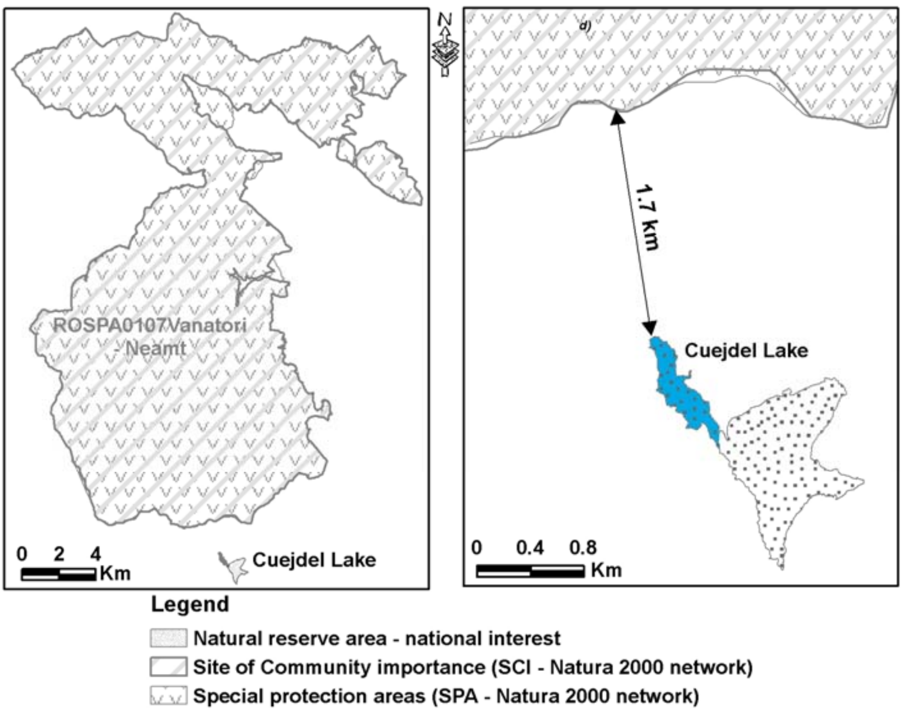

Fig. 4. Cuejdel Lake natural reserve (according to HG 2151/2004 - left), Vânători-Neamț Natural Park and the new Southern limit proposed (right)

Conclusions

Overall, this interdisciplinary research underlined key features of Cuejdel Lake area that enhance its scientific value. Our study provided scientific arguments to include the Cuejdel nature reserve in the Natura 2000 EU network, in order to ensure a better preservation and conservation of the habitats and species protected at EU level. Furthermore, the development of ecotourism could provide a consistent support for the future conservation and capitalization of Cuejdel Lake, enhancing and promoting the scientific value of this area. To fulfil this purpose, an integrated ecotourism development strategy should be set up, including other neighbouring protected areas with similar scientific and tourist value. Thus, given the rapid growth of ecotourism market and the increasing general interest for environmental issues, the near proximity of Vânători Neamţ Natural Park (only 1.7km) or of two SCIs and SPA at the northern limit of Cuejdel Lake could be better capitalized, enhancing both environmental preservation and tourism benefits.

Acknowledgements

This work was supported by the strategic grant POSDRU/159/1.5/S/133391, Project "*Doctoral and Post-doctoral programs of excellence for highly qualified human resources training for research in the field of Life sciences, Environment and Earth Science"* co-financed by the European Social Fund within the Sectorial Operational Program Human Resources Development 2007 – 2013. Our thanks also go to the Geoarchaeology Laboratory within the Faculty of Geography and Geology, "Alexandru Ioan Cuza" University of Iasi, which provided the equipment for data processing.

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Received: January, 29, 2014
Accepted: May, 27, 2014