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BIOLOGICAL MONITORING IN CAVES

BIOLOŠKO ZASLEDOVANJE STANJA (MONITORING) V JAMAH

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David C. Culver & Boris Sket: Biološko zasledovanje stanja (monitoring) v jamah

Leta 1999 sva opisala 20 jam in kraških vodnjakov, v katerih živi po 20 ali več na podzemlje vezanih vrst živali. Pet izmed teh jam je ali pa je bilo urejenih za turistično izrabo: Postojnsko-planinski jamski sistem (Slovenija), Sistem Baget - Sainte Catherine (Francija), Shelta Cave (Alabama, ZDA), Mammoth Cave (Kentucky, ZDA) in Vjetrenica (Bosna in Hercegovina). Prav dejstvo, da imajo lahko močno preurejene jame z visokim številom obiskovalcev tudi pestro favno, kaže, da se oboje ne izključuje. Številne standardne tehnike za vzorčevanje, so uporabne le v maloštevilnih jamah. Te metode so le omejeno uporabne. Onesnaženje je lahko za jamske živali neposredno pogubno ali pa omogoča površinskim živalim, da tudi v podzemlju izpodrivajo. Zato moramo zasledovati tako gostoto favne, kot tudi spremembe v njeni taksonomski sestavi. Ob načrtovanju novih posegov je treba pred kakršnim koli urejanjem raziskati krajevno favno, tako površinsko kot podzemeljsko. Za biološko zasledovanje stanja priporočava naslednje: 1. vzorčenje skozi daljše obdobje; 2. nastavljanje vab v kopenskih in v vodnih habitatih; 3. nastavljanje lončastih pasti v kopenskih habitatih.
Ključne besede: speleobiologija, speleobiološki monitoring, favna v turističnih jamah.

Abstract UDC: 551.44.001.4

David C. Culver & Boris Sket: Biological Monitoring in Caves

In 1999, we described the twenty caves and karst wells that have 20 or more species of obligate cave organisms living in them. Among these caves five are developed as tourist caves — Postojna-Planina Cave System (Slovenia), Baget - Sainte Catherine System (France), Shelta Cave (Alabama, USA), Mammoth Cave (Kentucky, USA), and Vjetrenica Cave (Bosnia & Herzegovina). For these and other tourist caves, there is a special responsibility to protect this fauna. The very fact that caves with large numbers of visitors and with modifications to the cave can have high species diversity shows that the two are not incompatible. Many of the standard sampling techniques, may work in some caves only; they are of restricted use. Pollution may be either directly detrimental to the cave fauna or may enable surface species to outcompete the endemic cave fauna. Therefore, changes in the quantity of fauna have to be monitored as well as changes in its taxonomic composition. In the case of new tourist installations, the local cave and surface fauna has to be investigated prior to any modifications. For biological monitoring, we recommend one of the following: 1. minimum-time census, rather than minimum-area census; 2. baiting in both terrestrial and aquatic habitats; 3. pitfall traps (baited or unbaited) in terrestrial habitats.
Key words: speleobiology, speleobiology monitoring, fauna of touristic caves.

TYPES AND DISTRIBUTION OF BIODIVERSITY IN CAVES

The first step in monitoring biological diversity in caves is to consider the kinds of biological diversity that may exist in a cave. In general, species who utilize caves fall into three broad categories. The first are mammals that utilize caves either on a seasonal or daily basis. The best known of these are bats, many species of which use caves as hibernacula, maternity roosts, and as summer roosts. Many species of bats have an obligate dependence on caves even though they regularly leave caves (McCracken 1989). Bats are not the only mammals to regularly use caves—dormice (*Myoxus glis*) routinely use caves during the day in Slovenia (Polak 1997) and wood rats (*Neotoma)* frequently nest in North American caves. The cricket family Rhaphidophoridae includes a number of daily and a number of seasonal inhabitants-migrants (Novak and Kuštor 1983). The second broad category of organisms that utilize caves are those that inhabit the entrance area of caves, in reduced light conditions. A wide range of species are found in the entrance zone, including nesting birds (the eastern phoebe, *Sayornia phoebe* in North America; ferns, mosses, and algae possibly adapted to the low light conditions of the entrance; and a range of invertebrates characteristic of the entrance zone (*e.g.,* some widely distributed spider species, like *Meta* spp. and *Metellina* spp.). The presumed reasons for their presence in the entrance are as diverse as the species themselves but include avoidance of predation, avoidance of competition, and avoidance of environmental extremes. The third category of species that utilize caves are those that spend their entire life cycle in caves, especially those species that are found nowhere else. Worldwide there are between 10,000 and 100,000 species (Culver and Holsinger 1992) of obligate subterranean terrestrial species (troglobionts) and aquatic species (stygobionts). A few fish and salamanders are in this group but the vast majority are invertebrates, especially arachnids, beetles, and crustaceans.

The distribution of subterranean biodiversity both within and among caves is highly heterogeneous. First consider the within-cave pattern. An obvious point of concentration is in the entrance area. In addition to the species specialized for this zone, it is also the entrance and exit point for those species, including bats, that pass in and out of the cave. This zone might be critical in Slovenia where reforestation of karst areas over the past century has significantly reduced the amount of bare rock available for some species of mosses and ferns that require this habitat. Hibernacula and maternity colonies of many bat species in caves occur in very restricted environmental conditions. For example the endangered Indiana bat, *Myotis sodalis* hibernates in caves colder than most in the area and in chambers with ceilings 10 m or more in height (Barbour and Davis 1969) which restricts them to a small fraction of caves and a small fraction of the space within a suitable cave. Because food is nearly always in very short supply in caves, stygobites and troglobites tend to be clumped around food, which in turn is usually very unevenly distributed in both space and time. In terrestrial habitats, transitory organic matter in the form of carcasses and guano is often especially important (Poulson and Lavoie 2000). Many aquatic species are limited to small pools and trickles of water and are absent from the main watercourses of a cave probably because they are unable to survive in the stronger current of the larger streams. Finally, many stygobites and troglobites are hidden in inaccessible crevices perhaps because of a thigmotaxy or because of more favorable environmental conditions such as higher humidity in the case of terrestrial habitats. One obvious example of this is the strongly thigmotactic behavior of the European cave salamander *Proteus anguinus.* Frequently, only their heads are visible from the small cracks and crevices that they prefer.

If anything, the heterogeneity of distribution of stygobites and troglobites among caves is even more striking. Perhaps the best example of this is the distribution of the world's most diverse caves. Culver and Sket (2000) found that six of twenty caves and wells with 20 or more species were in the Dinaric Mountains, and five of these were in Slovenia. Among the 6 caves with 40 or more species, four are in the Dinaric Mountains (Table 1). While there are other areas of high diversity, there is little doubt that globally the most important subterranean biodiversity hotspot is the Dinaric Mountains (Sket 1999). Any show caves in this region are likely to be an important site of subterranean biodiversity. It is both interesting and encouraging to note that three of the six most diverse caves are or have been show caves.

Table 1: The number of stygobites and troglobites in the world's most diverse caves. These are the only caves known to have 40 or more species. Those marked with an asterisk are or were show caves. Data are from Culver and Sket (2000).

Cave	No. of Species
Sistem Postojna-Planina, Slovenia*	84
Vjetrenica, Bosnia & Hercegovina	60
Peşera de la Movile, Romania	47
Križna jama, Slovenia	44
Logarček, Slovenia	43
Mammoth Cave, USA	41

THREATS TO BIODIVERSITY FROM SHOW CAVES

It is probably the case that in most cave regions, the greatest threat to biodiversity in the cave comes not from human activities inside the cave, but human activities outside the cave. These include logging, water pollution, quarrying, etc. But show caves create potential problems. The first is the possible disruption of bat hibernacula and maternity colonies by visitor traffic. Bats may also face problems because of alteration or disruption of entrance access (Dwyer and Hamilton-Smith 1965). Given that many bat species are at risk, these problems need special attention.

For stygobionts and troglobionts show caves have a negative impact as the result of habitat destruction as the result of construction and compaction of trails and eutrophication especially by the autotrophs of the lampenflora (Aley *et al.* 1985). There can be other factors that may be unique to particular caves. Sket (manuscript) reports that some stygobionts have disappeared from parts of Vjetrenica because of leakage from batteries discarded by visitors. The microclimate of caves is also affected by visitors, especially in terms of elevated CO_2, but its impact on the cave fauna is unknown. Elliott (2000) and Humphreys (2000) give overviews of the impact of human activities on the cave biota.

THE FAUNA OF ŠKOCJANSKE JAME

An example of the fauna of one cave—Škocjanske jame—and the site of the International Workshop on Monitoring Karst Caves is listed in Tables 2 and 3. Of the six bat species known to inhabit Škocjanske jame, all but *Nyctalus noctula* are listed in Annex II of the Council Directive 92/43/EEC of 21 May 1992 as species "Whose Conservation Requires the Designation of Special Areas of Conservation and Indicated as Special Priority Species". Bat protection can be especially difficult in show caves since many maternity and hibernating colonies of bats are especially sensitive to human disturbance (Tuttle 1979) and the gates on many show caves can interfere with the flight of bats but there are effective "bat-friendly" designs for gates (Elliott 1996). The monitoring of bats themselves is best done by non-invasive counts of bats leaving the cave using video or infrared sensing devices or by direct counts of hibernating colonies.

Table 2: Bats roosting in Škocjanske jame. Data courtesy of Maja Zagmajster.

širokouhi netopir	Barbastella barbastellus (Schreber 1774)
dolgokrili netopir	Miniopterus schreibersii (Kuhl 1819)
dolgonogi netopir	Myotis capaccinii (Bonaparte 1837)
navadni mračnik	Nyctalus noctula (Schreber 1774)
veliki podkovnjak	Rhinolophus ferrumequinum (Schreber 1774)
mali podkovnjak	Rhinolophus hipposideros (Bechstein 1800)

Although Škocjanske jame is not a cave particularly rich in stygobionts and troglobionts by Slovenian standards, its 23 species would make it one of the most diverse caves anywhere else in the world. The species list (Table 3) provides a convenient way to consider some of the general problems faced in the attempting to monitor cave faunas. The majority of 12 aquatic species are tiny crustaceans found in percolating water, water that enters the cave through ceiling drips (Petkovski and Brancelj 1985). Estimating their population size or monitoring water quality in their habitat would require continuous or frequent sampling of ceiling drips. The main stream of the cave has no stygobites which is not surprising both because of the direct connections to the surface and the strong currents in the stream. The terrestrial isopods *Titanethes* and *Alpioniscus* are in fact amphibious, but otherwise water quality of the Reka river as it flows through the cave will have little if any impact on the cave fauna. The 11 terrestrial species are generally concentrated—if at all—in two kinds of places:around areas of organic matter that result from activities of bats, dormice, and other regular cave visitors and around plant debris left by receding waters of the Reka river. Some species are even more heterogeneous in their distribution. The collembolan *Oncopodura cavernarum*, like many collembola in caves (Christiansen 1965) is typically found on the surface film of small pools where it is presumably feeding on organic matter trapped on the surface.

Table 3: List of stygobites and troglobites from Škocjanske jame. Copepods are from Petkovski and Brancelj (1985).

Haber monfalconensis Hrabe 1966	Annelida: Oligochaeta	a
Acanthocyclops hypogeus (Kiefer, 1930)	Crustacea: Copepoda	a
Acanthocyclops hypogeus Kiefer, 1930	Crustacea: Cyclopoida:	a
Acanthocyclops venustus stammeri (Kiefer)	Crustacea: Copepoda	a
Diacyclops clandestinus (Kiefer, 1926)	Crustacea: Copepoda	a
Speocyclops infernus (Kiefer, 1930)	Crustacea: Copepoda	a
Elaphoidella cvetkae Petkovski, 1983	Crustacea: Copepoda	a
Elaphoidella jeanneli (Chappuis, 1928)	Crustacea: Copepoda	a
Elaphoidella kieferi Petkovski & Brancelj, 1985	Crustacea: Copepoda	a
Moraria stankovitchi Chappuis, 1923	Crustacea: Copepoda	a
Morariopsis scotenophila (Kiefer, 1930)	Crustacea: Copepoda	a
Niphargus cf. stygius (Schioedte, 1847)	Crustacea: Amphipoda	a
Zospeum spelaeum spelaeum Rossmaessler, 1839	Mollusca: Gastropoda:	t
Alpioniscus (Illyrionethes) strasseri Verhoeff, 1927	Crustacea: Isopoda:	t
Androniscus stygius tschameri Strouhal, 1935	Crustacea: Isopoda:	t
Titanethes (T.) dahli Verhoeff, 1926	Crustacea: Isopoda:	t
Trichoniscus stammeri Verhoeff, 1932	Crustacea: Isopoda:	t
Typhloiulus (Stygiiulus) illiricus Verhoeff, 1929	Myriapoda: Diplopoda	t
Oncopodura cavernarum Stach, 1934	Insecta: Collembola:	t
Onychiurus canzianus Stach	Insecta: Collembola:	t
Onychiurus variotuberculatus Stach,1934	Insecta: Collembola:	t
Anophthalmus schmidti trebicanus Mueller, 1912	Insecta: Coleoptera:	t
Bathysciotes khevenhuelleri tergestinus Mueller, 1922	Insecta: Coleoptera:	t

DIFFICULTIES WITH STANDARD MONITORING TECHNIQUES IN CAVES

As other contributions to this symposium amply demonstrate, the physical-chemical monitoring of caves can be very sophisticated. Nevertheless, except in the case of the continuous sampling, these methods can only give accurate data for the moment of sampling. The sampled fauna may carry the stamp of the situation which escaped the physical or chemical analysis. For biota, a short wave of a high pollutant concentration or a long period of a weak pollution may be deciding - depending on the kind of both, biota and pollutant. On the other hand, for physical and chemical monitoring to have relevance in the assessment of biological resources, several problems need to be addressed. First, there is the question of where to monitor. This is illustrated by the copepods found in percolating water in Škocjanske jame. No amount of monitoring of the stream will be relevant to these populations. Second, there is the question of what parameters to measure and how frequently to measure them. For aquatic species, there are two general kinds of threats. One is the one time release of a toxic chemical as the result of illegal dumping, an accident, or even storm events. We include storm events because many pesticides and herbicides accumulated in the soil get flushed through a cave with the first few minutes of precipitation (Quinlan and Alexander 1987). The difficult is that we do not know what the toxic chemical will be in advance and its residence time may be short. The other kind of threat is from accumulation of pollutants over time, particularly organic pollutants. This can be monitored but the parameters, such as nitrates and dissolved organic carbon, may be both expensive and difficult to measure. For terrestrial species, threats would include eutrophication, and paradoxically, from a restriction of food. Entrance gates may restrict the movement of bats, dormice, etc. and consequently reduce food input (Culver 1999). Neither of these situations is amenable to physical-chemical monitoring. There is one possible circumstance where physical monitoring may be useful. Many troglobites are especially sensitive to drying and cannot survive in conditions where relative humidity is not at or near saturation. Changes in gates and entrance doors may alter relative humidity. However, it is our contention that in most cases, the problems listed above make such monitoring of very limited use. For both, terrestrial and the aquatic cave specialized biota, the slight organic pollution may be favorable if their surface competitors have no acces; it is detrimental, if the richer food resources anables surface species to penetrate underground and to compete with them (Sket 1977). On the other hand, this makes the composition of fauna and particularly its changes a suitable “monitoring device”. The source of water “enrichment” may be a slight municipal pollution, for terrestrial habitats the lampenflora or organic debris brought by visitors (“natural” or men).

There are also problems with many of the standard techniques for biological monitoring when applied to cave populations. For example, randomly placed quadrats for terrestrial sampling are of limited utility. The sampling area and thus available habitat changes as water levels change and most of the animals are likely in inaccessible cracks and crevices. The situation is the same for aquatic habitats. Many aquatic species, including those found in Škocjanske jame, are not found in the stream at all but in small drip pools and trickles of water.

SOME RECOMMENDATIONS FOR BIOLOGICAL MONITORING

We have found several effective techniques for assessing and monitoring the status of stygobites and troglobites in caves. The first of these is what might be called “minimum-time censusing”. When a general survey of stygobiotic and/or troglobiotic species is needed, one effective way is to spend a fixed number of person-minutes looking in suitable habitat. This avoids the problems of looking in unlikely areas because of a spatial sampling scheme. We suggest that 100 person minutes is probably a minimum amount of time for a census even in a very small cave.

Baiting in both aquatic and terrestrial habitats often produces many more individuals, but the results are difficult to quantify, but it at least allows for confirmation that a species is still present. Among the effective materials that have been used for baits are dung, aromatic cheeses and rotten meats in terrestrial habitats and raw shrimp and yogurt in aquatic habitats. Pitfall traps, either baited or unbaited, provide a way to have long-term samples. However, since these may kill many individuals, especially baited ones, we cannot recommend their general use.

An underutilized technique is that of mark-recapture, widely used in ecology. The concept is very simple. A total of N_M animals are collected and marked. After they are released and sufficient time for mixing with the population has elapsed, some N_R are recaptured, N_{MR} among them are marked. The population size, N, is then

$$N/N_M = N_R/N_{MR} \text{ or } N = N_M N_R/N_{MR}$$

This has been used on a wide variety of stygobionts and troglobionts, including beetles (Delay 1978) and amphipods (Knapp and Fong 1999).

A final caveat needs to be raised about the interpretation of mark-recapture studies. It is obvious that decreases in population sizes of stygobionts and troglobionts need to be viewed with concern, but so should large increases. In the food-poor environment of caves, population increases usually mean increases in available food, which in turn is usually a sign of eutrophication (as mentioned above). The usual sequence of eutrophication in caves is one of increased population sizes of stygobites and troglobites, followed by increased population sizes of non-specialized species usually accompanied by a decline in population sizes of stygobionts and troglobionts, and finally the extirpation of stygobites and troglobites. More attention needs to be paid at the early and more reversible stages of eutrophication when population sizes of stygobites and troglobites are increasing.

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BIOLOŠKO ZASLEDOVANJE STANJA (MONITORING) V JAMAH

Povzetek

Leta 1999 sva opisala 20 jam in kraških vodnjakov, v katerih živi po 20 ali več na podzemlje vezanih vrst živali. Od raziskanih je tako bogatih gotovo manj kot 0,1 % jam, njihov dejanski delež pa mora biti še nižji. Te jame so pravi biotski zaklad.

Pet izmed teh jam je ali pa je bilo urejenih za turistično izrabo: Postojnsko-planinski jamski sistem (Slovenija), Sistem Baget - Sainte Catherine (Francija), Shelta Cave (Alabama, ZDA), Mammoth Cave (Kentucky, ZDA) in Vjetrenica (Bosna in Hercegovina). Posebej smo odgovorni za zavarovanje jamske favne v teh jamah. Zaradi povsem izjemnega bogastva, pa še zaradi nekaterih zgodovinskih slučajnosti, to še posebej velja za slovenske jame. Prav dejstvo, da imajo lahko močno preurejene jame z visokim številom obiskovalcev tudi pestro favno, kaže, da se oboje ne izključuje. Glavni razlog je, da je turistična izraba skoraj vedno omejena le na del jamskega sistema. Če ni tako, bo favna nedvomno prizadeta.

Načeloma uporabne so številne fizikalne, kemijske in biološke tehnike za zasledovanje stanja (monitoring). Ker razne okoljske katastrofe včasih pustijo le malo kemijsko ugotovljivih sledi, so biološke analize bistvene. Številne standardne tehnike za vzorčevanje, kot je na primer uporaba raznih okvirjev pri vzorčevanju rečnega dna, so uporabne le v maloštevilnih jamah. Te metode so le omejeno uporabne, (1) ker se možnosti za vzorčenje prav neverjetno spreminjajo od jame do jame in tudi s časom v isti jami; (2) ker je struga vodotoka celo v posamezni jami lahko izredno raznolika; (3) ker so živali pogosto zbrane na posameznih mestih (na primer okoli organskih ostankov ali pa v ponvicah). Onesnaženje je lahko za jamske živali neposredno pogubno (ob močnem organskem ali ob neorganskem onesnaženju), ali pa omogoča površinskim živalim, da tudi v podzemlju izpodrivajo podzemeljske (v primeru rahlega organskega onesnaženja). Zato moramo zasledovati tako gostoto favne, kot tudi spremembe v njeni taksonomski sestavi. Ob načrtovanju novih posegov je treba pred kakršnim koli urejanjem raziskati krajevno favno, tako površinsko kot podzemeljsko.

Za biološko zasledovanje stanja priporočava naslednje:

1. dolgotrajnejše vzorčenje (kar je pomembnejše kot širše območje);
2. nastavljanje vab v kopenskih in v vodnih habitatih;
3. nastavljanje lončastih pasti (z vabo ali brez) v kopenskih habitatih.

Pri uporabi lončastih pasti je treba zagotoviti, da bi z vzorčenjem ne prizadeli populacij. Če nas posebej zanima določena živalska vrsta, je neredko uporabna metoda z označitvijo in ponovnim ulovom. Tako so uspešno raziskovali majhne vrste, kot na primer postranice, mokrice in hrošče.