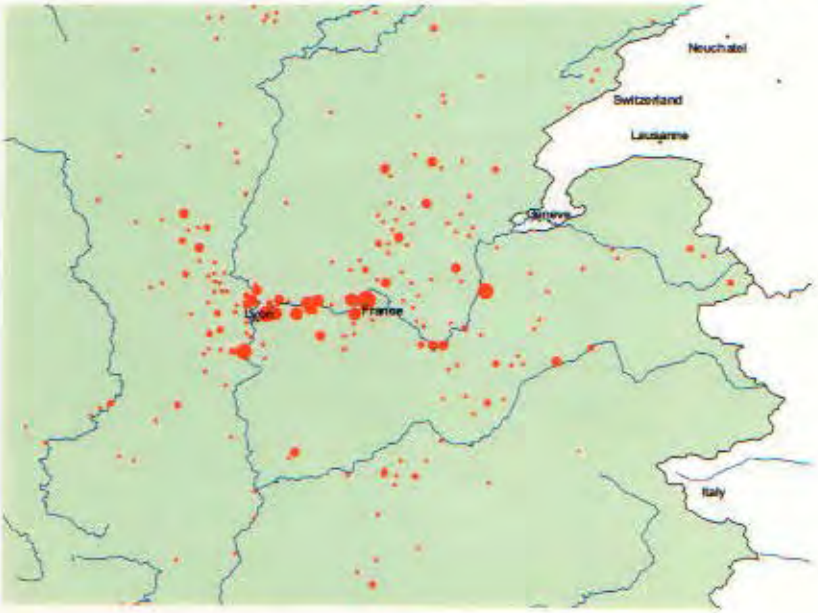
KARST WATERS INSTITUTE

LABORATOIRE SOUTERRAIN

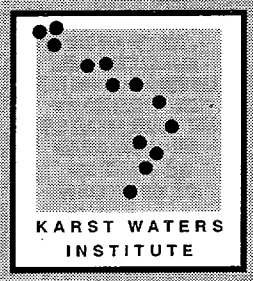
Special Publication 6

Mapping Subterranean Biodiversity
Cartographie de la biodiversité souterraine



Proceedings of an international workshop held
March 18 through 20, 2001
Laboratoire Souterrain du CNRS, Moulis, Ariege, France

Edited by
David C. Culver, Louis Deharveng, Janine Gibert, and Ira D. Sasowsky



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On the cover: Biodiversity of *Niphargus* in the vicinity of Lyon, France. See paper on page 63

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WORKSHOP SUPPORTERS

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Cave Conservancy Foundation
CNRS
Conseil Regional Midi-Pyrénées
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WORKSHOP ORGANIZERS AND STAFF

Workshop Organizers:
David C. Culver
Louis Deharveng
Janine Gibert

Local Arrangements:
Anne Bedos
Louis Deharveng
Jacques Durand
Alain Mangin
Frédéric Casteras, maire de Moulis

Rapporteurs:
Mary C. Christman
Daniel W. Fong
Horton H. Hobbs
William K. Jones

Technical Assistance:
William K. Jones
Megan Curry

KARST WATERS INSTITUTE OFFICERS

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INTRODUCTION

David C. Culver

Department of Biology
American University
4400 Massachusetts Ave., NW
Washington, DC 20016
U.S.A.

Louis Deharveng

U.M.R. 5552 du C.N.R.S.
Laboratoire d'Ecologie Terrestre
UPS 118 route de Narbonne
31062 Toulouse cedex 4
France

Janine Gibert

Laboratoire d'Ecologie des Hydrosystèmes Fluviaux
Equipe d'Hydrobiologie et Ecologie Souterraines
Université Claude Bernard Lyon1
43 Bd du 11/11/1918
69622 Villeurbanne cedex
France

The impetus for this workshop grew out of discussions held at the meeting of the Societe Internationale de Biospeologie in Makarska, Croatia. Culver had sent out an email beforehand expressing an interest in meeting informally with participants in the meeting that were interested in mapping subterranean biodiversity. He had in mind finding three or four European colleagues interested in mapping. Deharveng told Culver of some of the large-scale European mapping efforts that involved mapping subterranean elements of the fauna and Gibert informed him about the multi-national proposal to the European Union on mapping aquatic subterranean biodiversity she was putting together. So it was really no surprise when more than 30 people showed up at the end of a long day of meetings to talk about mapping subterranean biodiversity. It then became clear to all three of us that there was an extraordinary amount of interest in the topic, and we decided to hold a workshop with the focus on mapping efforts in Europe and North America.

Of course, in order to make a map of subterranean biodiversity, one needs data, whether it is in the form of a spreadsheet or database. One of the recurring themes of the workshop was that these data structures and the derived maps have three overarching functions — education, research, and conservation planning. For each of these three areas there is both a sense of urgency and a sense of timeliness that explains the high level of interest in the topic.

The rapid development of digital mapping technology (Geographic Information Systems), the availability of high capacity spreadsheets and databases, and the ability to pinpoint locations with Global Positioning Systems have made it possible to present highly accurate information and construct spectacular maps. Web sites designed to educate the public about the patterns of biodiversity are growing rapidly. Two of the most prominent examples are the British Museum's World Map web site (www.nhm.ac.uk/science/projects/worldmap) for Europe and the Association for Biodiversity Information's NatureServe web site (www.NatureServe.org) for North America. The Association for Biodiversity Information has also produced a book on United States biodiversity for the general public, entitled *"Precious Heritage. The Status of Biodiversity in the United States"*. While there has been some attempt to incorporate data on subterranean organisms into the web sites and even a few educational web sites devoted to particular aspects of subterranean biodiversity (see www.CaveBiology.com and Iliffe's paper in these proceedings), subterranean organisms certainly deserve more prominence.

There are also research web sites with searchable databases with enormous amounts of information on the distribution of plants and animals. Prominent examples include the database on the Italian flora and fauna, Ckmap, adopted by the Italian Ministry of the Environment, the database on western Europe, ENDEMICA, and the databases for the individual states of the United States developed by state Natural Heritage programs. To varying degrees, data on subterranean species has been incorporated into these databases.

Finally, there have been conservation planning documents on both sides of the Atlantic that set the agenda for conservation priorities. Most prominent of these are the European Union's Habitat Directive and the identification of threatened habitats and communities in the United States by both the World Wildlife Fund and The Nature Conservancy. In these cases, subterranean communities and habitats are scarcely mentioned.

The question that many of us have asked is why subterranean species are not featured more prominently? The answer is of course is that there has not been a coordinated effort to map subterranean biodiversity. It was the purpose of this workshop to begin to coordinate efforts and to share information about mapping subterranean biodiversity. The specific charge to the participants was

> *to agree upon a standard minimum format for data on subterranean biodiversity, including geographic scale and a coordinating structure for data collection, entry, and mapping.*

More than 50 people from 14 countries attended the three day workshop and in the end we did agree upon a standard minimum format for data on subterranean bioidiversity as well as establishing a working group to continue development of the data.

The proceedings that follow differ from the format of previous conference proceedings that have been published by the Karst Waters Institute in several important ways. Since this was a workshop rather than a conference, the organizers felt it would be more appropriate not to publish the proceedings in advance of the conference, but rather to have the bulk of the proceedings develop from the workshop itself. To this end, we present a narrative of the workshop, based on the notes of the rapporteurs and a tape of the workshop. This is not intended to be a transcript, but rather a report of the workshop. Following the summary of each session, we have included both abstracts and brief papers that workshop participants supplied at our request. We hope that both workshop participants and others interested in mapping subterranean biodiversity will find this combination of narrative and short papers a useful guide to this rapidly changing field. In order to provide a timely publication, we have not cross-checked all statements, and any errors of rapporteurs are the responsibility of the editors. For any and all of these, we apologize. The editors also wish to thank all participants for a lively and informative workshop.

PROGRAM

Sunday, March 18

16:00 - 17:30 **REGISTRATION AND WELCOMING RECEPTION**

17:30 **OPENING OF THE WORKSHOP:**
Alain Mangin (Director of the Subterranean Laboratory of Moulis, CNRS)

18:00 - 19:30 **PLENARY LECTURES: LARGE SCALE NON-CAVE DATABASES AND LESSONS TO BE LEARNED**

Mapping endemic biota in Western Europe
Louis Deharveng (France)
Mapping Western Hemisphere Fauna, Flora, and Ecological Communities - Natural Heritage Programs and the Conservation Data Network
Larry Master (Massachusetts)

Monday, March 19

08:45 – 09:00 **WELCOME ADDRESS**
Francois Blasco (Director of the Laboratoire d'Ecologie Terrestre de Toulouse, CNRS)

09:00 - 12:30 **SESSION 1 : CREATING A DATABASE**
Chair: David Culver (Washington)
Rapporteur: Daniel Fong (Washington)

Topic Outline:

I. Ongoing efforts for database construction for subterranean species
- A. **European groundwater project** Janine Gibert (France)
- B. **Center for Subterranean Biodiversity databases** Sarah Krow (Washington)
- C. **A database and website on Anchialine Fauna** Thomas Iliffe (Texas)
- D. **Discussion and summary**

II. Problems with creating databases - Round table
- A. **What is included? Just obligate species? Just cave records?**
- B. **Who has access to database? How can it be controlled?**
- C. **How can participation be encouraged as well as credit for work given?**
- D. **Can all cave and other site locations be obtained?**
- E. **Discussion and summary**

14:00 - 18:00 **SESSION 2: USES OF DATABASES**
Chair: Janine Gibert (France)
Rapporteur: William Jones (West Virginia)

Topic Outline:

I. Making maps
- A. **Presentation on hexagon grids** David Culver (Washington)
- B. **Demo of the database and mapping program Ckmap, adopted by the Italian Ministry of Environment, including most of Italian cave fauna** Fabio Stoch (Italy)
- C. **Discussion and summary**

II. Spatial statistics
- A. **Predictions** Mary Christman (Maryland)
- B. **Extrapolating biodiversity values from landscape features** Guillem Chust (Spain)

C. **Analysis of gaps in data collection** Sarah Krow (Washington)
D. **Worldmap software presentation** Miguel Araujo (Portugal/UK)
E. **Discussion and summary**

18:00 - 19:30 VISIT TO THE MOULIS LABORATORY CAVE
More on Worldmap Miguel Araujo (Portugal/UK)

Tuesday, March 20

09:00 - 10:00 SESSION 2: USES OF DATABASES (Continued)

III. **Conservation planning-what scale is needed?**
A. **Geo-referenced computer recordings as an instrument for protecting cave-dwelling species of Tenerife (Canary Islands)**
Isaac Izquierdo, Jose L. Martin, Nieves Zurita & Ana L. Medina (Islas Canarias)
B. **Creating and development of a Biospeleological database in Croatia**
Sanja Gottstein Matocec (Croatia)

10:00 - 12:30 SESSION 3: STATUS REPORTS
Chair: Louis Deharveng (France)
Rapporteur: Horton Hobbs (Ohio)

I. **General presentation: lessons from the Encyclopaedia Biospeologica** Christian Juberthie (France)
II. **Subterranean biodiversity in the United Kingdom** Graham S. Proudlove (UK)
III. **Database of invertebrate species from Tasmanian caves** Arthur Clarke (Tasmania)
IV. **Report of status for Italy** Fabio Stoch (Italy)

14:00 - 16:00 SESSION 3: STATUS REPORTS (continued: mapping)
V. **Mapping the diversity of subterranean fishes** Graham S. Proudlove (UK)
VI. **Mapping *Niphargus* distribution in France** Stephane Blondeau (France)
VII. **Mapping subterranean biodiversity in Brazilian karst areas** Eleonora Trajano (Brazil)

16:30 - 17:30 SESSION 4 : FRAMEWORK FOR FUTURE WORK
Chair: Giuseppe Messana (Italy)
Rapporteur: Mary Christman (Maryland)

Topic Outline:
I. **A minimum standard for data entry**
II. **Possible grant proposals**
III. **A coordinating structure**
A. Role of Societe Internationale de Biospeologie Giuseppe Messana (Italy)
B. Role of Karst Waters Institute David Culver (Washington)

19:30 FINAL DINNER

WORKSHOP PARTICIPANTS

ARAUJO Miguel
Biogeography and Conservation Laboratory
The Natural History Museum
Cromwell Road
London
United Kingdom
miga@nhm.ac.uk

BAUBY Annie
Laboratoire Souterrain du CNRS
09200 Moulis
France

BEDEK Jana
Menceticeva 16
10 000 Zagreb
Croatia
jana@marvin.cc.fer.hr

BEDOS Anne
Laboratoire d'Ecologie Terrestre
UMR 5552 du CNRS
UPS, 118 route de Narbonne
31062 Toulouse Cedex 4
France

BESSON Jean-Pierre
Parc National des Pyrénées
59 route de Pau
65000 Tarbes
France
pnp.scientifique@wanadoo.fr

BLASCO François
Laboratoire d'Ecologie Terrestre
UMR 5552 - BP 4072
31029 Toulouse Cedex 4
France
francois.blasco@cict.fr

BLONDEAU Stéphane
Université Lyon 1
Hydrobiologie et Ecologie Souterraines
UMR CNRS 5023
43 Bd du 11 nov. 1918
69622 Villeurbanne cedex
France
Stephane.Blondeau@univ-lyon1.fr

BOUTIN Claude
Laboratoire d'Ecologie Terrestre
UMR 5552 du CNRS
UPS, 118 route de Narbonne
31062 Toulouse cedex 4
France
boutin@cict.fr

CAMACHO Ana
Museo Nacional de Ciencas Naturales
C/Jose Gutierrez Abascal 2
28006 Madrid
Spain
mcnac22@mncn.csic.es

CHRISTMAN Mary
Dept of Animal and Avian Sciences
University of Maryland
College Park MD 20742
USA
mc276@umail.umd.edu

CHUST Guillem
Dpt Ecologia
Universitat de Barcelona
Diagonal 645
08028 Barcelona
Spain
chust@porthos.bio.ub.es

CLARKE Arthur
P.O. Box 245
North Hobart Tasmania 7002
Australia
arthurc@southcom.com.au

COINEAU Nicole
Laboratoire Arago
66650 Banyuls-sur-Mer
France
n.coineau@obs-banyuls.fr

CULVER David
Department of Biology
American University
4400 Massachusetts Ave. NW
Washington DC 20016
USA
dculver@american.edu

DE BROYER Claude
Dpt Invertébrés
Labo. Carcinologie
Institut Royal des Sciences Naturelles de Belgique
rue Vautier 29
1000 Bruxelles
Belgium
debroyer@kbinirsnb.be

DEHARVENG Louis
Laboratoire d'Ecologie Terrestre
UMR 5552 du CNRS
UPS, 118 route de Narbonne
31062 Toulouse cedex 4
France deharven@cict.fr

DELIOT Philippe
Laboratoire Souterrain du CNRS
09200 Moulis
France

DUMAS Pascal
Laboratoire Souterrain du CNRS
09200 Moulis
France
pascal.dumas@libertysurf.fr

FONG Daniel
Department of Biology
American University
4400 Massachusetts Ave. NW
Washington DC 20016-8007
USA
dfong@american.edu

GENEST Lucien-Charles
Chemin de Villaz Coupeau
74310 Les Houches
France
lgenest@club-internet.fr

GENTILE Gabriele
Dip. Biologia
Università "Tor Vergata"
via dellaRicerca Scientifica
00133 Roma
Italy
gentile@uniroma2.it

GERS Charles
Laboratoire d'Ecologie Terrestre
UMR 5552 du CNRS
UPS, 118 route de Narbonne
31062 Toulouse cedex 4
France
gers@cict.fr

GIANI Narcisse
CESAC UPS
118 route de Narbonne
31062 Toulouse cedex 4
France
giani@cict.fr

GIBERT Janine
Université Lyon 1
Hydrobiologie et Ecologie Souterraines
UMR CNRS 5023
43 Bd du 11 nov. 1918
69622 Villeurbanne cedex
France
janine.gibert@univ-lyon1.fr

GOTTSTEIN MATOCEC Sanja
Dpt Zoology
Fac. Sciences
University of Zagreb
Rooseveltov Trg. 6
10 000 Zagreb
Croatia
sgottst@biol.pmf.hr

GRIFFITHS Paul
544 Springbok Road
Campbell River
B.C. V9W 8A2
Canada
pgriff@island.net

HOBBS Horton
Dept Biology
Wittenberg University
PO Box 720
Springfield OH 45501-0720
USA
hhobbs@wittenberg.edu

ILIFFE Thomas
Dept Marine Biology
Texas A&M University
Galveston TX 77553-1675
USA
iliffet@tamug.tamu.edu

IZQUIERDO Isaac
Centro de Planificacion Ambiental
Ctra. de la Esperanza
Km 0.8 38071 La Laguna
Santa Cruz de Tenerife
Islas Canarias
Spain
isaac.izquierdozamora@
gobiernodecanarias.org

JALZIC Branko
Croatian Natural History Museum
Demotrova 1
10 000 Zagreb
Croatia
branko.jalzik@hpm.hr

JONES William K.
Karst Waters Institute
P.O. Box 537
Charles Town WV 25414
USA
wjones@intrepid.net

JUBERTHIE Christian
Laboratoire Souterrain du CNRS
09200 Moulis
France
cjuberthie@aol.com

KROW Sarah
Environmental Studies Program
American University
4400 Massachusetts Ave. NW
Washington DC 20016
USA
skrow@loyola.edu

MAGNIEZ Guy
Université de Dijon
12 rue des Planchettes
21000 Dijon
France
guy.magniez@u-bourgogne.fr

MANGIN Alain
Laboratoire Souterrain du CNRS
09200 Moulis
France
mangin@lsm.cnrs.fr

MARTIN Patrick
Dpt Invertébrés
Institut Royal des Sciences Naturelles de Belgique
rue Vautier 29
1000 Bruxelles
Belgium
martin@kbinirsnb.be

MASTER Larry
Conservation Data Network
201 Devonshire St. 5th floor
Boston MA 02110
USA
larry_master@abi.org

MESSANA Giuseppe
CNR - CSFET
via Romana 17
50125 Firenze
Italy
messana@fi.cnr.it

MESSOULI Mohamed
Lab. Hydrobiologie
Fac. Sciences Semlalia BP
2390 Marrakesh
Morocco
messouli@ucam.ac.ma

MICHEL Georges
Comm. Wall. d'Etude et de Protection des Sites Souterrains
av. Rodin 21
1050 Bruxelles
Belgium
cwepss@swing.be

NOTENBOOM Jos
De Engh 16-3
3972 JM Driebergen
The Netherlands
jos.notenboom@wanadoo.nl

OZIMEC Roman
Croatian Biospeleological Society
Demotrova 1
10 000 Zagreb
Croatia
roman.ozimec@zg.tel.hr

PEREZ GONZALEZ Abel
Sociedad Espeleologica de Cuba
A.P. 2778
C.P. 11300
La Habana 13
Cuba
biokarst@unepnet.inf.cu

PETRICIOLI Donat
Trnsko 12
10 000 Zagreb
Croatia
TatjanaBakran.Petricioli@rg.tel.hr

PROUDLOVE Graham
Dept Zoology
Manchester University
Manchester M13 9PL
Great Britain
g.proudlove@umist.ac.uk

PUCH Carlos
c/o A. CAMACHO
Museo Nacional de Ciencas Naturales
C/Jose Gutierrez Abascal 2
28006 Madrid
Spain
mcnac22@mncn.csic.es

RIBERA Carles
Dpt Biologia Animal
Universitat de Barcelona
av. Diagonal 645
08028 Barcelona
Spain
carles@porthos.bio.ub.es

RUI Jorge Cegonho Raimundo
Lab. Biol. Cartography
University of Evora
Largo dos Colegiais 2
7000-544 Evora
Portugal
rjcr@uevora.pt

SASIC Martina
Croatian Natural History Museum
Demotrova 1
10 000 Zagreb
Croatia
martina.sasik@hpm.hr

STOCH Fabio
Museum di Storia Naturale
Lungadige Porta Vittoria 9
37129 Verona
Italy
fabiocop@tin.it

TRAJANO Eleonora
Dpt Zoologia
Inst. Biociencias da USP
C.P. 11461
CEP 05422-970
Sao Paulo
Brazil
etrajano@usp.br

TRONTELJ Peter
Dpt Biology
University of Ljubljana
PO Box 2995
1001 Ljubljana Slovenia
peter.trontelj@uni-lj.si

TURQUIN Marie-José
Université de Lyon 1
300 av. Elie Vignal
69300 Caluire
France
marie-jose.turquin@univ-lyon1.fr

ZURITA Nieves
Centro de Planificacion Ambiental
Ctra. de la Esperanza
Km 0.8 38071 La Laguna
Santa Cruz de Tenerife
Islas Canarias
Spain
marianieves.zuritaperez@gobiernodecanarias.org

PLENARY LECTURES

LARGE SCALE NON-CAVE DATABASES AND LESSONS TO BE LEARNED

Synopsis

The workshop opened with welcoming speeches from **Alain Mangin**, Director of the Laboratoire Souterrain and from the mayor of Moulis, **Frédéric Casteras**.

Larry Master of the Association for Biodiversity Information in the United States spoke on "Mapping Western Hemisphere Fauna, Flora, and Ecological Communities – Natural Heritage Programs and the Conservation Data Network". The mission of the Association for Biodiversity Information is to develop, manage, and distribute information critical to the conservation of biodiversity. The questions we wish answered are:

- What is to be conserved--species, communities?
- What are their exact locations?
- How are they doing?
- What do they need to survive?
- What are the critical sites to conserve?
- What are the threats?

The object of study can include species and communities. The Nature Conservancy created an organization and a network--The Association for Biodiversity Information and the Natural Heritage Networks. The members are 85 different programs in all U.S. states, all Canadian provinces, and 10 Latin American countries. Most are state agencies. They list species and com-munities, give a status assessment, prioritize, and map and computerize the data. They both do field work and manage the information. They all use the same methodology so that they can share information.

A ranking system developed by The Nature Conservancy and similar to the IUCN red list is used. According to this system, the subterranean fauna of North America is 95% imperiled or vulnerable. In general, aquatic groups are the most imperiled. The data are organized around elements occurrences (EO's). Everything is related to the EO. The data for each EO includes what it is (species, etc.), where it is, accuracy of the location, its status, who found it and when. Other information is also collected when available, such as population size. It is important to locate data as points rather than grid cells. We need to know the exact location in order to preserve it; and grids aren't accurate enough. From point data it is easy to aggregate sites into grids of any size and shape. For example, we mapped by drainage basin, by 640 km^2 hexagons, and by 15 minute quadrats.

We can also use point data to predict species ranges by overlaying environmental data. Primary use of the data is for preserve identification and design, managing threatened species, land use planning, natural resource management plans, and environmental impact assessment. For example, one can look for hotspots and overlay threats to identify possible preserve sites. By using collection dates we can also see how ranges and occurrences are changing through time. There is a public web site with information about state biotas that is for the general public — www.NatureServe.org.

A question was raised about how range prediction was actually used, with some skepticism expressed about the predictive power of such models. Masters answered that most of the uses were for local users to assess questions such as the impact of zoning or lack of zoning on the future range of a species. Another question was raised as to why a different status ranking from that of the IUCN was used. Masters answered that The Nature Conservancy started theirs earlier and that until 1993 or 94 the IUCN rankings were qualitative. They are now looking to coordinate and reconcile TNC rankings and IUCN red lists.

Louis Deharveng spoke on "Mapping Endemic Biota in Western Europe". A separate summary of his talk is appended. Endemica is a database for Western Europe. Data on endemics are needed to protect species. It is actually a federation of databases maintained by different specialists. Each specialist controls his or her list and there is no centralization. The structure of the database is shown in Figure 1 in the accompanying paper. There are four basic tables—coordinates; sample information (including location, accuracy of location, collector, and date), taxonomic information, and ecological and biogeographic information. One of the outcomes of the mapping was that protected areas are generally not areas of endemism. Most of the gridding was done using UTM grids although there was a problem with the border between UTM zones, which in this case was of particular zoogeographic interest. Among the problems encountered were

- Collections were better in some areas than in others.
- The scale of the grid was important because there were different patterns at different scales. It is not clear which scale or scales is appropriate.

- Size of the site may vary.
- Border zones between UTM zones made it difficult to have regular sized grids.
- Locations plotted from the literature were often inexact.

In spite of the difficulties there is much to be learned. A particularly intresting example was provided by distribution of species in relation to glaciation in the Pyrenees.

A question was raised about the definition of endemics. Deharveng said that for this study it was defined as limited to the Pyrenees, but he pointed out that endemism was a relative term. A comment was made that the issues facing mapping efforts in North America and Europe were generally the same.

Mapping European Endemism: The project "Endemism"

Louis Deharveng

U.M.R. 5552 du C.N.R.S.
Laboratoire d'Ecologie Terrestre
UPS 118 route de Narbonne
31062 Toulouse cedex 4
France

By virtue of their diversity and their restricted range, endemic taxa globally constitute the most valuable part of biological heritage. Yet, even in Europe, the origin, maintenance and geography of endemism remains poorly explored. These issues were addressed in a European project "High Endemism Area, Endemic biota and the Conservation of Biodiversity in Western Europe" which ran from 1994 to 1998 and involved researchers from Spain, Portugal, France, Belgium and Sweden.

A prime task of the project was to develop databases and mapping protocols in order to spatially characterize endemism patterns at scales operational for biogeography and conservation. The experience gained in this domain throughout the "Endemism" project is summarized here.

1 - Building the databases

Lack of staff, limited funding and a critical overview of existing biodiversity mapping projects led us to operate as a federation of databases rather than setting up a large central database. Each specialist had a direct control on the organization of his or her own dataset. This was more rewarding to him or her, and allowed the databases to continue to grow beyond the end of the funded project. Major drawbacks of such an approach were data heterogeneity and problems of data exchanges. We minimized these problems by adopting a common minimal structure on which databases for storing personal data (Ecobase, Table 1) and bibliographical /collection data (Endemica were implemented by each specialist using his own software.

Datasets from different specialists were pooled together for annual reports and for certain publications. This was made in high-end databases with built-in procedures written to prepare the data for mapping (management of detailed information on taxa, locations and habitats, assistance for coordinate homo-genisation, calculation of biodiversity values in cell grids, flexible export capabilities).

2 - Managing the data

Most distribution data related to endemic taxa were sparse in the literature. Compiling this information and making it readily available for mapping was a major task of the project. Data heterogeneity appeared as a recurrent problem along this process, and led us to set up a few very basic rules for catching and storing information with minimal return to data source. These guidelines are listed below.

Entering data in the database

1. Storing the source of the information (literature reference, collection, personal collecting).
2. Storing location records exactly as given in the source.
3. Storing taxon name exactly as given in the source for literature/collection data; the current name used for mapping was given in a second step.
4. Storing the source of the coordinates (literature, map, GPS...)
5. Storing information about the entry and last modi-fication of each record of each file (automatically done at each work session in Endemica)

Checking data quality

Data quality is the weakest aspect of most existing biological database which encompass many taxa and large regions. We checked data quality at two levels:

- Geographical coherence: one name for one geographical object (G.O.). Frequently encountered problems included misspelling, inconsistencies, homonymies (an identical name for two G.O.) and synonymies (different names for a same G.O.). Direct examination of outlier

points in distribution maps, cross-checking of information and use of gazetteer for the region under study helped minimizing these problems.

- Taxonomical coherence: one name for one taxon. A real management of synonyms appeared far beyond the capabilities of a mapping-oriented database, and was left under the responsibility of each specialist, as was the identification validity. Misspelling was corrected by direct examination of the data lists.

3 - The mapping process

Mapping biodiversity is putting on a base map a spatial representation of a subset of the data stored in the database. The main tasks of the mapping process were progressively refined during the project "endemism" and included the following steps:

1. Acquisition or construction of the georeferenced base map(s), tailored and organized in different layers if necessary, to support the biodiversity data (region boundaries, grid, hydrology, etc.
2. Selection of a projection system for the map
3. Selection of the kind of information to be displayed, *i.e.*, either map of taxon distribution, or biodiversity pattern map (biodiversity values attached to geographic objects)
4. Selection of biodiversity value(s) to be mapped: presence/absence, abundance, relative abundance, historical changes; for taxon distribution maps; biodiversity measures (species richness, number of endemics, endemicity ratios, taxonomic ratios, indices ...) for biodiversity pattern maps
5. Selection of the kind of geographical objects to which biodiversity values would be associated: points, natural regions, administrative regions or socioeconomic regions, cell grids, etc.
6. Elaboration of the table of biodiversity value(s) per geographic objects, with metadata like species lists or geographical features
7. Elaboration of the cosmetic appearance of the map.

These different tasks were carried out in the databases and under the GIS Mapinfo software.

4 - Making endemism maps operational

A biodiversity map combine complex information in a simple display, and may be strongly misleading for end-users. A variety of biases and distortions, rarely explicit on the map display, are attached to both the dataset and the mapping design.

Data-related biases include data quality and sampling heterogeneity. Data quality is for a part an ethic problem of the mapper: data messiness is not reflected in the map display. Some ways to improve taxonomical and geographical coherence of the data have been listed above. Sampling heterogeneity is the second concern of all biological datasets. Sampling gaps and taxa absence are identically displayed, and hot-spots may be simply intensively sampled areas. This underpins the need to associate information on sampling evenness to biodiversity maps. Sampling heterogeneity may be roughly evaluated by displaying sample points on a biodiversity pattern map, or by evaluating sampling exhaustively for each geographical object using cumulative curves of species richness.

Mapping-related biases are distortions of the basic biodiversity pattern introduced by the mapping design: scale, uneven size of geographical objects, transfer of biodiversity values from one object to another.

Biodiversity patterns displayed at different scales proved to be strongly misleading for end-users specially around hot-spots; adapting the scale to the goal of the map helped smooth the problem.

Size heterogeneity of geographical objects to which biodiversity values are attached (natural regions, administrative entities or cell grids) strongly limits the validity of mapped biodiversity patterns. Natural regions, the geographical objects of choice for biogeographical studies, and administrative entities, the obligate approach in conservation issues, may show a large range of surface areas, especially in mountainous regions. None of the grids used so far in Europe for standardized comparisons of biodiversity have cells of equal surface areas (compensations areas of UTM fuses and progressive surface changes with latitude in degree-based grids are such "grid impediments"). In addition, there is always a depleting edge effect at the land/ocean boundary for grid-based patterns of terrestrial biodiversity. This is especially worrying for archipelago landscape configurations. This may be corrected using species-area relationships, assuming that sampling was even enough and that underlying models are stable enough across the studied areas. Fabio Stoch is presently exploring these considerations in mapping Italian biodiversity.

Transfer of biodiversity values between geographical objects had to be done when original biodiversity data were not point data. For example, we frequently transferred to cell grids the biodiversity data recorded

for administrative entities in the literature, using arbitrarily the centroid position of administrative entities to determine to which cell the biodiversity values were to be transferred. This obviously led to errors and distortions which are inherent to all published biodiversity maps and which cannot be corrected directly.

The ultimate question is therefore: are these wonderful but distorted biodiversity maps operational tools for biogeographical studies or conservation purpose? This is essentially a question of scale and spatial data density. At "large" scale, biodiversity maps, more especially biodiversity pattern maps, tend to be easily misleading for end-users and there is a clear need to attach to them comments about the way they were built, data quality, sampling evenness, and the scale range at which they can be used.
At "small" scale, and in spite of the numerous limitations listed above, it seems that patterns may be accurately displayed by these imperfect datasets and maps. This is clearly supported by the congruence between patterns based on literature data and those based on more recent and accurate data.

However, the work to make these maps really operational for conservation at the European level seem often endless, and predictive spatial models appear increasingly necessary to back up the basic mapping work.

Table 1. The Ecobase (version 2000) low-end database structure. Note that the columns share fields. For example, the first two columns share the field "Coord_Ref", and the second and third share "Sample_code". These common fields make such a database structure "relational".

Coordinates	**Samples**	**SampTax**	**Taxa**
Coord_ref	Sample_code	Samp_Taxon	Tax_Taxon
Xorig	Collect_event	Group	Belongs_to
Yorig	Date	Sample_code	Biol._Categ
Proj_System	Country_Prov	Abundance	Ecol_Categ
XYorig_source	Natur_Region	Juveniles	Biogeogr_Categ
Xdd	Locality	First_instar	Perso_Key
Ydd	Site	Prepared_number	Tax_Remarks
Altitude	Coord_ref	Identification	Indate
Precision_Level	Geology	Perso_Key	Last_update
Perso_Key	Vegetation	Samtax_Remarks	
Coo_Remarks	Strata	Indate	
Indate	Biotope	Last_Update	
Last_Update	Technique		
	Collector		
	Perso_Key		
	Samp_Remarks		
	Indate		
	Last_update		

WORKSHOP SESSION 1

CREATING A DATABASE

Synopsis

The session began with a welcoming address by **Francois Blasco**, Director of the Laboratoire d'Ecologie Terrestre de Toulouse, CNRS. Dr. Blasco pointed out that databases can bring knowledge to everyone. Among the points to be considered for any mapping project are:

- What are the relevant data to be mapped?
- What is the appropriate scale?
- What is the cost effectiveness of different methods?
- What is the usefulness of maps—who are they for?
- All maps are simplifications.
-

In this workshop we should determine what we know, what the areas of controversy are, and what ideas have come out.

The first part of the session was devoted to ongoing efforts for database construction for subterranean species. **Janine Gibert** spoke about the European groundwater project: "**P**rotocols for the **AS**sessment and **C**onservation of **A**quatic **L**ife **I**n the **S**ubsurface (PASCALIS): a European project." A summary of this presentation appears elsewhere in these proceedings. This ambitious project involves seven groups of scientists from five countries. The project will have three phases:

- Establishment of a large database on existing knowledge of groundwater species in Europe
- Development of a stratified sampling scheme in order to obtain as complete as possible dataset on six regions
- Validation procedure to test assessment tools developed in the second phase.

The ultimate goal of the project is to develop an action plan for the conservation of groundwater biodiversity at a European level.

A question was asked about the likely number of stygobites included in this project. Gibert estimated this to be about 2500 in the database. In the presentation, Gibert spoke about using indicators for biodiversity. A question was asked about whether these were biological or geological, and Gibert replied that they could be both. A comment was made that the number or density of caves might be a good indicator of biodiversity as well. A question was raised about whether there would be sufficient time to incorporate species that were described as a result of these collections. She responded that since the project lasted only three years, there would not be sufficient time to incorporate them. For the project, establishment of a common protocol is the first priority, and completeness is a long term goal.

Sarah Krow spoke about the database of the Karst Waters Institute's Center for Subterranean Biodiversity. Relative to European database, this is a simpler dataset. It is limited to troglobites and stygobites and most of the work has been done on cave records. The original data were developed at the county level. There are over 3000 records of stygobite and troglobite occurrences by county of over 1000 species. This is available as a downloadable EXCEL™ file at the Karst Waters Institute website—www.karstwaters.org. A dataset of individual site occurrences is now being constructed. It will likely to have about 10,000 entries for the U.S. Data entered includes:

- Taxonomy including taxonomic authority
- Site name, including county, state, and FIPS (Federal Information Processing Standards), a five digity county code
- Location in latitude and longitude and UTM coordinates
- Conservation status—The Nature Conservancy status rankings (GX – G5)
- Habitat (aquatic vs. terrestrial; karst vs. non-karst)
- Taxonomic distinctness
- Source of information including collection date

Sources of information include data from state Natural Heritage programs, information from collectors, and information in the literature.

A question was raised as to how troglobite and stygobite were defined. Krow answered that they were defined by their distribution—95% of records had to be subterranean for the species to be called a stygobite or troglobite. Morphological criteria (*i.e.*, troglomorphy) were not used. A question was raised about taxonomic distinctness. Krow responded that this was a categorical variable reflecting the number of species per genus. A question was raised about defining habitat. She responded that the only subdivision was between aquatic and terrestrial, and cave vs. non-cave. A comment was made that more detail would be useful, including zone of the cave

(entrance, twilight, etc.). A question was also raised about whether any information was recorded about location within the cave system, and the problem of large cave systems as a single unit. Krow responded that information of this kind was not recorded. In addition, most records are from small caves, and that information on distribution within a system was almost never available. An exception to this is Mammoth Cave in Kentucky. A question was raised about the validity of specimen identification. Krow responded that validity of identifications in the literature and in lists of taxonomists was accepted.

Thomas Iliffe spoke about a database and website on anchialine fauna. A summary of this presentation appears elsewhere in these proceedings. He has developed an internet source (www.cavebiology.com) to present data on coastal caves with fresh or brackish water and direct connections to the sea (anchialine caves). This fauna is highly unusual. One in four new species was in a new genus and one in 25 was in a new family. Emphasis was on photographs, including satellite imagery. A series of anchialine caves are featured on the website together with a species list and a map. For the Yucatan, Spanish language pages have been developed that parallel the English language pages. The site has been up and running for about a year and a half, with 16,000 "hits" during that time. Many of these were from school children, cavers, and cave divers.

A question was raised about whether access to information about these sites had created any problems. Iliffe responded that no precise locations were given and that many of the sites were in any case well known. Another question was raised about how the web site was maintained. Iliffe responded that several students work on the web site aided by grant monies. A question was raised about intellectual property rights for the information. Iliffe responded that this was especially important for photographs and that credit was given and permission obtained for photos.

The rest of the session was devoted to a roundtable discussion about problems with creating databases. As a framework for discussion the following questions were considered:

- What is included? Just obligate species? Just cave records?
- Who has access to the database? How can it be controlled?
- How can participation be encouraged as well as credit for work given?
- Can all cave and other site locations be obtained?

There was considerable discussion about what to include in the database. Colleagues from troglobite-poor areas such as England argued for inclusion of troglophiles because they were often dominant in the caves. This was supported by colleagues from countries where the cave fauna is poorly known. In these situations the ecological status (*e.g.* troglobite vs. troglophile) of species is often not known. It was also pointed out that troglophiles should also be considered for conservation and protection because they are often endemic to small areas. For example, in Cuba many of the cave species are troglophiles and endemic. One difference to emerge was that in North America and Europe there exists an extensive historical record in the literature with many described species. In other regions, there are proportionately more undescribed species and unvisited sites. The question was raised about the completeness of the records for different groups. For example, troglophilic dipterans have been undercollected and underreported in the literature, even though they are important components of cave ecosystems. The comment was made that at least in North America, records of troglophiles and stygophiles were much less complete than the records for troglobites and stygobites. An additional comment was made by several participants that the cave fauna was better known than the surrounding surface fauna, both in the tropics and in temperate regions. Examples include most groups in Brazil and millipedes in the U.S. It was also pointed out that there is often considerable genetic variation among populations in troglophilic species. Fabio Stoch summed up much of this discussion by stating that troglophiles and even trogloxenes should be included in the data because there is a gradient from the surface to the cave habitat and a corresponding gradient of generalist species to specialist species. In addition, there may be a geographic gradient in specialization for a particular species. That is, for some species, some populations are essentially troglobites and other populations are troglophiles.

The next topic was access to the database and control of information. The most critical part of this was access to information about cave and other site locations. There is tremendous variation between established databases. For example, in Croatian and Slovenian databases, cave locations are given exactly and there is open access to the information to all citizens. This pattern is more or less general for European countries. There is some restriction on locality data for critical species in the French Pyrenees. In contrast, in Australia and United States, exact cave locations are not generally available. In the U.S., it is only generally available at the level of

county (approximately 1500 km^2). Larry Master stated that Association for Biodiversity Information records are decentralized to states, and that exact locality for these records is on a "need to know" basis, as determined by each Natural Heritage Program. Several participants raised the question about whether there was a need for secrecy. In part, this seems to depend on cultural differences. For example, individual property rights are often strongly defended in the United States. Paul Griffith pointed out that the situation is even more complex in western Canada because aboriginal property rights are important in many areas. Opinions were also expressed that increased access to information about the exact location of caves and other sensitive sites actually led to greater protection because more people were looking after the site. The question was who or what are we keeping locations secret from? Culver pointed out that even in the U.S., it is the locations of only a few caves that are jealously guarded and kept secret, and that their absence from a database will make little difference. Even though the large majority of workshop participants felt that secrecy was rarely if ever warranted, cooperation with proponents of secrecy is often needed and that accommodations must be made.

The discussion then moved toward a consideration of protection and conservation issues. The point was raised that karst areas are what need protection, not individual species. It was also pointed out that in the U.S. the primary law for protection is the Endangered Species Act, which focuses on individual species.

We also came back to the theme that there were three overarching purposes of the database: conservation and protection, education, and research. How do we want the information to be used and what should be included? The different objectives may require different information.

We next addressed the question of intellectual property rights. One of the parameters of this issue is how to give credit to people in the context of a large database. In general we recognized that this was a serious issue, but we had little to offer in the way of solutions. One suggestion was that a data structure always include a entry for the source of the information and that this could serve as an acknowledgement of the contribution. Gibert noted that the web site of Iliffe (www.cavebiology.com) did a very good job of acknowledging authorship of information provided. However, Iliffe pointed that his site serves an educational function rather than a research function, and that there may be other intellectual property issues involved in research.

At the end of the session, we began to consider what should be included in the database, keeping in mind the different purposes for which it may be used. There was more discussion about what species to include and what habitats to include. Gibert made the point that non-cave subterranean habitats should be included, and there was consensus on this point. Messana argued that the data structure should be a "living system", one that was inclusive, both of habitats and species. We can always exclude information for project-specific analysis. Culver pointed out that this was indeed desirable, but that the reason that the North American cave database for county distributions was completed was because it was not inclusive, and considered only the obligate cave fauna. The question was also raised as to who would be involved and responsible for this undertaking. Gibert returned us to the issue of the purpose of the database. Others pointed out that while there is more support for education and protection than for research, as a workshop we tend to focus on the research issues. We came to the following tentative list of information to be included, a topic that we returned to in the final session:

Recommendations for biotic coverage:

- Include troglophiles and all subterranean organisms, including microorganisms

General recommendations for information to be included:

- Identify how the species is using the subterranean habitat, what is it doing in this habitat? (e.g., trogloxene, etc.)
- Assemble existing information, particularly in the literature, in a database
- Make a flexible database structure for future data types
- Allow for the possibility of unnamed taxa
- Locational information, especially point locations, should be available whenever possible. Standard rules for point locations (e.g., northernmost entrance) should be established.
- Reliability and precision of coordinates should be indicated. Include a place name.
- Whenever possible, include synonymies for species and locations
- There should be both required fields and optional fields.
- For national and personal collections—four fields are coordinates, samples, taxa sampled, and taxonomic category.

Protocols for the ASsessment and Conservation of Aquatic Life In the Subsurface (PASCALIS) : a European project

Coordinator : Janine Gibert

Laboratoire d'Ecologie des Hydrosystèmes Fluvial
Equipe d'Hydrobiologie et Ecologie Souterraines
Université Claude Bernard Lyon1
43 Bd du 11/11/1918, 69622 Villeurbanne cedex
France

Many surface habitats have received considerable attention and are currently managed for conservation through a number of relevant regulations. In contrast, groundwater ecosystems appears as a "forgotten realm", despite their high contribution to global biodiversity. The only European directive for preserving groundwater biodiversity (European recommendations n°36, 1992, on the conservation of subterranean habitats) is nothing but an eloquent plea for the inventory and designation of subterranean habitats of special interest. We identified two major constraints for the successful implementation of a protection policy of groundwater biodiversity: i) the current incomplete state of knowledge on groundwater biodiversity; ii) the lack of a rational conservation strategy.

The project concerns 7 partners in Europe from 5 countries as follows:

Short name	***Explicit name (laboratory)***	***Country***	**Responsible**
UCBL/CNRS	*University of Lyon1/CNRS, France*	*FR*	J. Gibert (gibert@univ-lyon1.fr)
ECOTOUL	*University/CNRS of Toulouse, France*	*FR*	L. Deharveng (deharven@cict.fr)
UNIVACQ	*University of l'Aquila, Italy*	I	D. Galassi (galassi@aquila.infn.it)
UNI-LJ-BF	*University of Ljubliana, Slovenia*	S	B. Sket (b.sket@Uni-Lj.si)
BIB	*National Institute of Biology of Ljubliana, Slovenia*	S	A. Brancelj (anton. brancelj@Uni-Lj.si)
MNCN	*Museo Natcional de Ciencas Naturales de Madrid, Spain*	S	A. Camacho (mcnac22 @mncn.csic.es)
IRScNB/KBIN	Institut Royal des Sciences *Naturelles de Belgique*	B	P. Martin (martin@ kbinirsnb.be)

The project is an integrated approach to groundwater biodiversity that considers a large range of groundwater habitats (Fig. 1), encompasses the majority of taxonomic groups living in groundwater, and applies different approaches (morphologic and molecular) for the estimation of biodiversity. The ultimate goal of this project is to establish a rigorous and detailed protocol for assessing groundwater biodiversity and to develop operational tools for its conservation. The project duration will be of 36 months. Its objectives are:

1) to set up a robust evaluation procedure for estimating biodiversity across a wide range of groundwater ecosystems throughout European countries;
2) to identify biodiversity indicators based on a large data set arising from a stratified sampling of ground water in 6 selected

regions across Europe;

3) to predict overall biodiversity in non selected regions based on biodiversity indicators;

4) to foster public and regional manager awareness of the necessity to conserve groundwater biodiversity by emphasising its economic, social, and scientific value;

5) to designate regions of major biological interest and to set up a specific action plan for the conservation of their groundwater biodiversity.

The project is organised in three complementary phases.

In the first phase a large database will be established to store data on subterranean taxa distribution at the European scale. Based on this dataset, a series of maps illustrating the **present-day knowledge of distribution patterns** of groundwater biodiversity across a European gradient will be established. This first phase will be achieved in three steps: 1) the definition of a common data base structure and mapping tools; 2) storing of data available from each partner; 3) complementation of the data base using information from the literature.

In the second phase of the project, we develop **a stratified sampling** scheme based on a **hierarchical approach to groundwater ecosystems** in order to obtain a dataset as complete as possible on groundwater species diversity in 6 selected regions distributed along a representative gradient for southern Europe: the Walloon karst (Belgium), the Septentrional French Jura (Eastern France), the Têt valley (France: Pyrénées), the Picos de Europa (Spain), the Lessinian mountains (Italy), the Krim massif (Slovenia). Although biodiversity assessment will essentially rely upon morphological criteria, DNA-analysis will be used as an explorative method for estimating the "hidden" biodiversity within selected cryptic taxa. A region is defined as a large area (100 to 500 km^2) that has been subjected to a succession of similar historical events (e.g. sequence of marine transgression / regression, glacial covering, orogenesis). Each region includes several groundwater systems that contains karst and alluvial aquifers. At the lowest level of resolution, we distinguish between the vadose and saturated zones of karst aquifers and the phreatic and hyporheic zone of alluvial aquifers (Fig.1). These nested habitats will be sampled following standardised design, protocols and techniques in the 6 selected regions. All collected species will be identified thanks to the involvement in the project of most groundwater taxonomists of Europe. The data set arising from this intensive sampling survey and species identification effort will be analysed in order to: 1) establish an **optimum field sampling strategy** for obtaining an unbiased estimate of biodiversity in regions where data are lacking; 2) define **a method for qualifying the reliability of biodiversity assessment in a particular region**; 3) identify potential **biodiversity indicators** for the selected regions; 4) **examine the partitioning of the species pool** among the different units of a region; cross-comparison between the selected regions will reveal whether the partitioning of regional biodiversity is relatively constant over space.

The third phase is essentially **a validation procedure** in which the assessment tools developed in the second phase of the project will either be tested against data from the European data base (phase 1) or used to improve the quality of this data base. First, non-selected regions for which sufficient data are available from the data base will be used to test the relevance of biodiversity indicators identified from the extensive sampling surveys carried out in the 6 selected regions. If reliable, these indicators will be used to predict the overall species richness in non-selected regions with incomplete data sets. Second, the classification method will be applied to specify the reliability of regional biodiversity patterns revealed by the large-scale mapping of existing data. Third, sensitive regional hotspots of biodiversity will be designated.

Because there are continuously evolving economic, social and cultural pressures on groundwater resources, it is now urgent to provide an updated picture of groundwater biodiversity and to propose a global strategy as well as specific measures for its conservation. This project will provide authorities with updated and validated information on the present status of groundwater biodiversity. The ultimate goal of the project **is to propose a specific Action Plan for the conservation of groundwater biodiversity at a European level.** This Action Plan is intended to support the implementation of the various EU policies related to the sustainable management of water resources and to adapt the national or regional legislation. We will also identify some regions of special biological interest, identify the spatial scale of relevance for conserving biodiversity within these regions, and formulate a series of appropriate measures for maintaining their biodiversity.

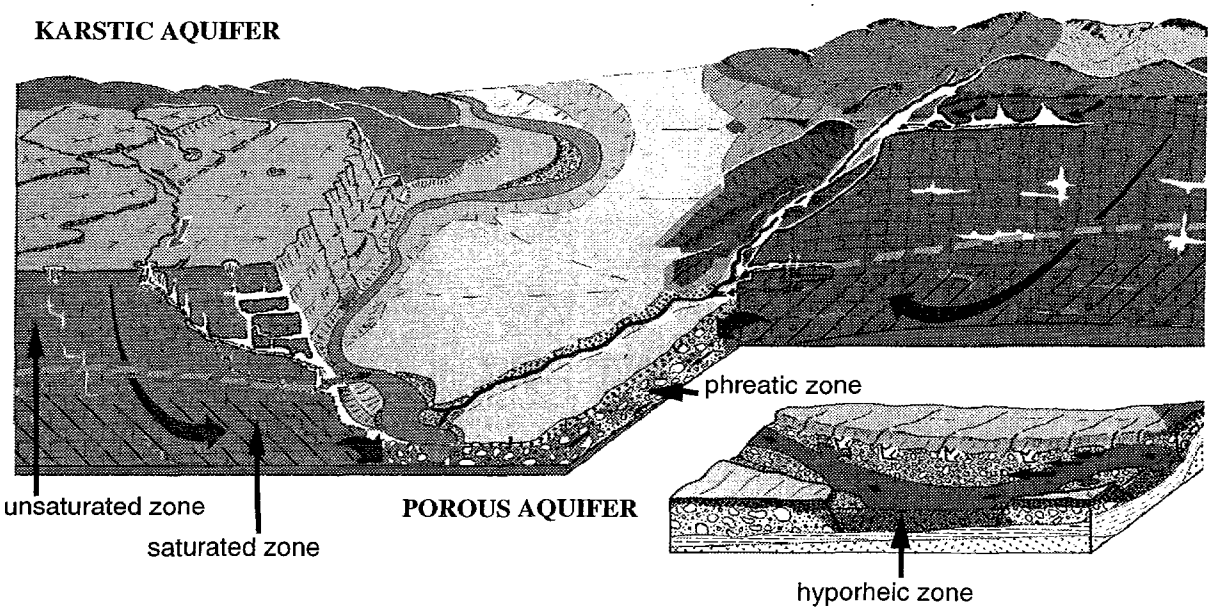


Fig. 1. Groundwater ecosystems represented by karstic and porous aquifers.

CaveBiology.com – The Anchialine Cave Biodiversity Website

Thomas M. Iliffe

Department of Marine Biology
Texas A&M University at Galveston
Galveston, TX 77553-1675
USA

Publication and presentation of scientific data through the Internet has a number of significant advantages. It provides a rapid and inexpensive means of providing global access to high quality information including color photographs, diagrams or even audio and video clips. Recently, various funding agencies have instituted requirements for electronic publication. For example, the Biotic Surveys and Inventories Program of the US National Science Foundation requires projects to produce "electronic and electronically accessible (*e.g.*, available via the World Wide Web to the scientific community and to the public) specimen-based databases, and other electronic information products such as keys, expert identification systems, checklists, and authority files" (Biotic Surveys and Inventories NSF 98-158).

To this end, we have developed a website with the registered domain names of cavebiology.com, cavebiology.org and cavebiology.net to document the diversity, significance and distribution of anchialine caves and cave animals of the world. This website actually resides on the University server at Texas A&M University at Galveston, but through domain forwarding and URL keeper services (*e.g.*, see domaindirect.com), it retains the cavebiology URL.

The cavebiology website includes data on anchialine caves and cave animals from the Bahamas, Yucatan Peninsula of Mexico and Bermuda. For each geographic region, a checklist of all described stygobitic and stygophillic fauna contains embedded internal links to individual species pages. These species pages in turn contain illustrations, color photographs, distributional maps, taxonomic description, ecological classification, size, genus range, species range, ecology, life history, evolutionary origins, conservation status, references and external links. Contributing taxonomists provide and check this information. Representative caves are described from each region. Cave web pages include maps, photographs, cave descriptions, exploration history, faunal lists and references. Internal links between these cave and species lists, along with introductory pages on each geographic region, provide a logical hierarchy for data retrieval. Maps, as well as a selection of Earth photographs taken by shuttle astronauts, provide a frame for geographic reference.

A research projects page provides an opportunity for speleologists worldwide to submit descriptions, photographs, charts and other data from ongoing cave research projects. It is intended that such information should foster collaboration and cooperation to further the speleological investigations of all types. The website also contains an interactive message board, "Cave Talk", to seek answers to questions, promote exchange of ideas and disseminate information.

Acknowledgements are presented in a Contributors page containing names, postal and e-mail addresses, research interests and web page links for collaborating taxonomists and speleologists. A Sponsors page provides information and links to organizations and companies that have assisted with our anchialine cave investigations.

A Links page provides cross reference to caving and cave diving organizations; cave diving links pages; Bahamas and Yucatan caves; cave biology; ecology, biodiversity and evolution; and marine biology. A Link to CaveBiology.com page provides banners, logos and animated images that allow other websites to link to ours. An About Us page contains biographic information, publication lists and descriptions of our research expeditions from newspaper reports or other websites.

CaveBiology.com is the official website for the Exploration and Conservation of Anchialine Faunas Project of International Biodiversity Observation Year 2001-2002 (IBOY). IBOY is a program of DIVERSITAS that aims to focus global attention on the critical issue of biological diversity and its contribution to Earth system functioning, through promoting biodiversity science.

Ease of internal navigation was a key concern during preparation of the website. Navigation buttons and a drop-down menu are present in top frames, while links to related pages are found at the top and bottom of each web page. A Sitemap page provides overall organization, as well as links to all pages within the website.

Future goals include the addition of other geographic areas; streaming video and audio clips of caves and cave animals; and a new frames interface. Plans are also underway to add non-technical descriptive information on representative higher taxa, regional geology, speleogenesis, cave diving, biospeleological methodology, ecology, biodiversity, evolution and conservation that would be understandable by a general audience that includes school children.

The CaveBiology.com website has been well visited since it was first established in August 1999. More than 16,000 people have logged on to the site for an average or 38 hits per day. These visitors have come from 86 top-domains (countries).

WORKSHOP SESSION 2

USES OF DATABASES

Synopsis

David Culver discussed the Karst Waters Institute's annual list of the ten most endangered ecosystems. Started in 1998 to publicize threatened karst subterranean ecosystems, the criteria for inclusion on the list are:

- a significant ecosystem, either surface or subsurface, is present
- a threat to the ecosystem
- the likelihood that publicity will improve the situation
- nomination by a knowledgeable individual or group

The lists for 1998 and 1999 were originally published in the *National Speleological Society News* and are now available on the KWI website (www.karstwaters.org). The 2000 list will be on the website by early May, 2001. It will soon be possible to nominate sites directly from the website.

Louis Deharveng asked whether listing helped the situation. Culver replied that it is still too soon to tell in most cases and that KWI needs to do an evaluation. It is clear that at least in a few cases the situation markedly improved in part due to the publicity generated by the list. A question was asked about how much information was available about each site. Culver responded that it varied from site to site, but that the available information was on the web.

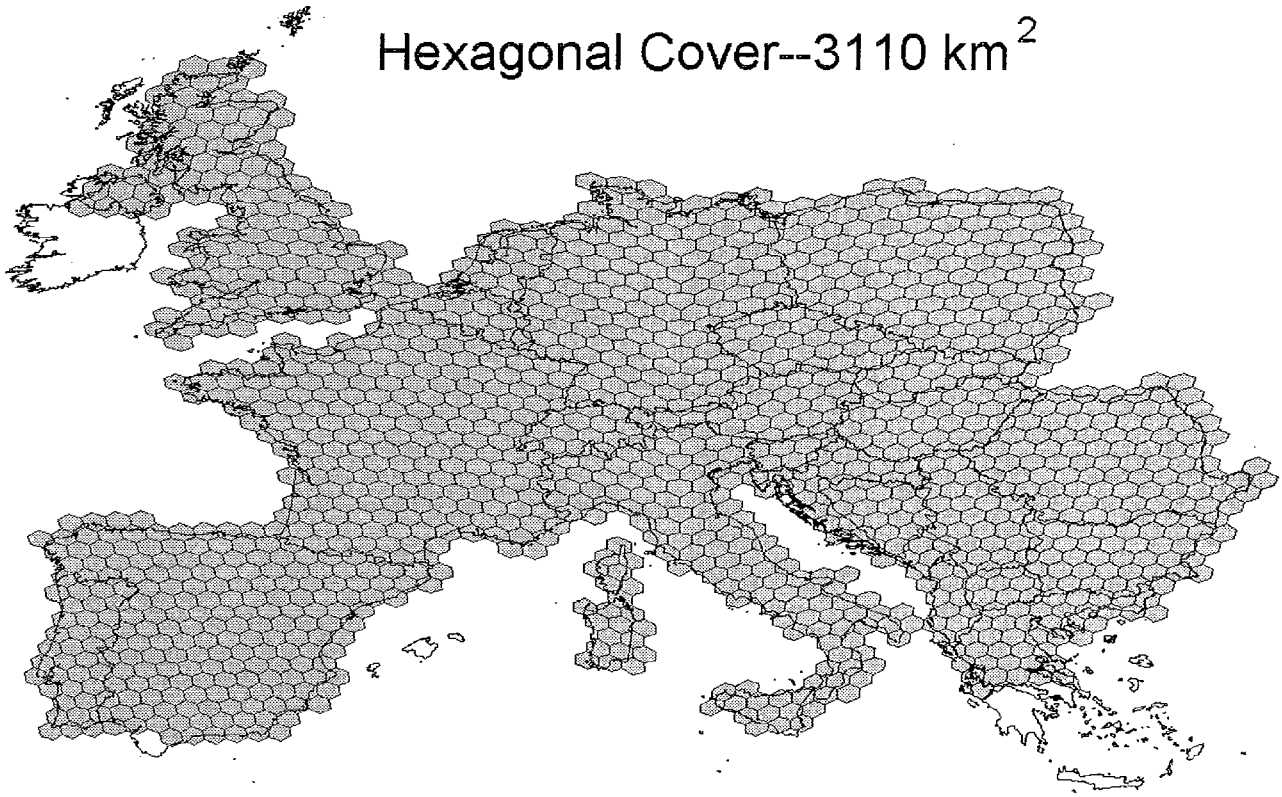
David Culver then spoke on using hexagons for a grid in mapping biodiversity. Existing systems using either grids or administrative units such as counties or districts. For example, in the U.S. counties are irregularly shaped and tend be larger as one moves west. Other grid systems have other drawbacks. Latitude and longitude grids change in shape and area from north to south, and UTM grids suffer from problems at boundaries between zones. Denis White and his colleagues at the Environmental Protection Agency's Environmental Research Laboratory in Corvallis, Oregon have developed a hexagonal grid system based on the tessellation of truncated icosahedrons and pentagons to produce a grid with equal shape, equal area, and one that allows statistically meaningful comparisons of global data. Conceptually it is like a soccer ball with the pentagons in the oceans, and the hexagons partitioned in the appropriate size. We have used hexagons at three sizes:

Level	Size	Global Number
7	3110 km^2	163,830
9	195 km^2	2,621,430
11	12 km^2	42,943,030

The main references for this work are D. White *et al.* 1992. Cartographic and geometric components of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems* 19:5-22 and A.J. Kimerling *et al.* 1999. Comparing geometrical properties of global grids. *Cartography and Geographic Information Science* 26:271-288. Grid coverings are available from EMAP Design, 200 SW 35th Street, Corvallis, OR 97333-4902 USA (olsen.tony@epa.gov). An example of a hexagonal grid for Europe is shown following:

A question was asked about whether the hexagonal grid was predetermined globally. Culver replied that it was. A question was asked about how biodiversity records were attached. Culver replied that there were several ways to do this, but that they had joined the records to the hexagon, then created an EXCEL™ file to look for unique records within each hexagon. This is to avoid multiple counting of the same species. The number of records was found for each hexagon (using the subtotal feature in EXCEL™) and brought back into ArcView™. A question was raised about how species abundance was handled. Culver replied that only presence/absence data were used. A question was raised about how widely hexagonal maps were being used. Larry Master replied that it was used in the EPA Gap Analysis program and by The Nature Conservancy in the U.S. Culver replied that many hexagon maps were used in the recent publication by B. Stein *et al., Precious Heritage. The Status of Biodiversity in the United States*

Fabio Stoch spoke about the database and mapping program, Ckmap. A paper by Stoch, which includes a synopsis of the Italian subterranean fauna (see Workshop Session 3) is appended. This project was funded by the Italian government in order to obtain a database on Italian species, and to identify natural areas needing protection. A checklist of 56,000 species, 10 per cent of them endemic to Italy was developed. A relational database was developed with all species included. There are some 300,000 records in the database. The program allows for automatic mapping of distributions and species richness at the scale of 10 km by 10km UTM grids. Tables include information about taxonomy,



distribution, feeding habits, etc. Locational data includes place name and its coordinates, UTM square, elevation, location of collection and year of collection.

A question was raised about how information was added to the database and whether anyone could add data. Stoch replied that information was added in steps and that there was a central database with control. A question was asked about whether marine submerged karst was included. Stoch answered no. A question was raised about the detection of hotspots and Stoch answered that they could be detected. A final question was raised about applying corrections to grids to take into account the greater area of those with greater elevational differences. Stoch answered that this was a problem, especially since mountain areas tend to be biodiversity hotspots.

Mary Christman spoke about using spatial models for prediction. A paper by Christman and Culver is appended. Christman spoke about developing a statistical model to describe biodiversity. The model allows for variation at different scales:

- micro-scale (between caves)
- meso-scale (between grid cells)
- macro-scale (between regions)

Macro-scales may vary due to large scale trends in habitat and in paleo- events. There may be small scale trends due to spatial connectedness. A spatial variable Z_{xy} is thus composed of a trend plus an autocorrelation plus an error. She used this model to predict the number of stygobite and troglobite species, based on number of caves in a county, number of caves in adjoining counties, and region (*e.g.*, Ozarks).

A question was asked about whether the same conclusion would be reached in different regions. Christman responded that different regions had different equations. Number of caves alone is not a

sufficient variable to predict species number. A question was asked about the spatial threshold for autocorrelation. Christman responded that this question was not explored. A question was raised about whether the effects of different types of caves was explored and Christman responded that this had not yet been investigated. The question was raised as to whether goodness of fit was affected by counties with zero species. Christman responded that it wasn't. The question was raised as to why hexagonal grids weren't used. Christman responded that exact locational data weren't available to put the data in regular grids. A comment was made that the analysis allows description of the pattern but not why it was there. Christman responded that this was true and that sampling pressure and missing data could be important. A question was raised that the relationship to number of caves was an artifact if more caves were sampled in counties with more caves. Christman responded that this problem had not been studied and that a statistical resampling of a subset of caves would be of interest in this regard.

Guillem Chust spoke about extrapolating biodiversity values from landscape features. A paper by Chust and his colleagues is appended. He focused his remarks on the question of the appropriate scale of analysis, which is dependent on the animal group being studied. Remote sensing was used to assess spatial features and this was related to a variety of measures of the diversity of Collembola. The linear relation between spatial indices and Collembola diversity was analyzed using stepwise multiple regression for different window sizes. From this it was possible to derive the optimal landscape scale to predict species number.

A question was raised about how this could be used with subterranean species. Ghust replied that it might be important to look at areas of limestone at different scales.

Sarah Krow spoke on determining gaps in sampling. A paper by Krow and Culver is appended. Krow described a procedure for determining gaps in sampling. She associated both cave location data and species location data with hexagons in a grid over the state of West Virginia. She used a grid size of 12 km^2. About 15% of the known caves have been investigated biologically. About 25% of the hexagons with caves have been investigated biologically. Only ten hexagons had ten or more caves but with no biological collections. Since number of troglobites and stygobites increases with the number of caves, these cave rich hexagons should be the focus of future sampling efforts.

Miguel Araujo gave a presentation on Worldmap software developed by the Natural History Museum of London (see www.nhm.uk/science/projects/worldmap/worldmap/demo2.htm). He pointed out that there is too little knowledge about where biodiversity is. This software also provides an important tool for the analysis of biodiversity patterns. For example, one can do ordination studies based on physical conditions in the grid cells, such as rainfall and temperature. The case study for this is the European data base for plants, birds, mammals, and herptiles (reptiles and amphibians). Based on ordination studies to represent environmental diversity, it appears that rare species are out of sync with the present climate. If sites are chosen on the basis of environmental diversity, this will fail to represent the most vulnerable species.

A question was raised about whether the best environmental variables were chosen. Araujo answered that standard variables such as rainfall, temperature, and elevation were used but that others may be better. A question was asked about whether reptiles and amphibians were rare or just spatially rare. Araujo answered that tolerance not habitat was being modeled. A question was asked about why reptiles and amphibians were geographically distributed the way they are and Araujo answered that glacial maxima were important. The question was raised about how an environmental analysis could be applied to the cave fauna with little dispersal and high endemism. Araujo replied that non-equilibrium historical events were likely important. Several questions were raised about the biodiversity patterns themselves, especially the lack of high values in the Balkans. Araujo replied that in some cases the map was old and that more field work was needed. In some cases regional and national lists had not been fully integrated into the Eruopean lists.

Sanja Gottstein Matočec discussed the creation and development of biospeleological databases in Croatia. A paper by Matočec and her colleagues is appended. Croatia has a rich cave fauna and a long history of biospeleological research. As an integral part of the database, there will be a list of endemic taxa, a red list of endangered taxa, and a corresponding bibliography. Treatment of endemic taxa is based on two criteria: the boundaries of Croatia and physiographic features such as the Dinaric region. Human alterations of the habitat are considered to be a major reason for species being endangered. These include disruptions due to hydroelectric power plants, organic pollution, and increased pesticide concentrations in water. Several

interstitial species from the Zagreb area and a cave species from Ogulin are greatly reduced or extinct. It is expected that future research will reveal even more endemic species. Information on anthropogenic impact and environmental change should be given directly to the appropriate the Ministry of Environmental Protection and Physical Planning in Croatia and the information should also be made public on the national television channel. The database should serve not just as a checklist, but a standard for research in related fields. Among the information included in the database are taxonomic information including synonymies, region, endangerment status, slope, location of specimens, distance from entrance, sample data, size of collection, associated organisms, physico-chemical data, and publications.

A question was asked about whether this was a single table. She answered that at present it was, but that at a later time several tables would be created. A question was asked about whether graphical data and photos were included and Gottstein Matočec replied that they were.

Isaac Izquierdo spoke about geo-referenced computer recordings as an instrument for protecting cave-dwelling species of Tenerife (Canary Islands). A paper by Izquierdo and his colleagues is appended. The object of this study was to protect caves, choose the ones to protect, and to present a priority area analysis. The Canary Islands have about 17,000 total species, 4000 of which are endemic. The software used was *Atlantis*. Data were collected in 500m by 500m cells and in 5000m by 5000m cells. For troglobites in lava tubes, species were restricted to small areas of the cave. There are 106 troglobites on Tenerife, 56 of them endemic. When an overlay of protected area and the distribution of troglobites was done, 20 species were outside the protected areas. Just 13 cells contained 78% of the species. Several procedures to determine the minimum number of cells needed to protect the maximum number of troglobites were elaborated.

Culver made the comment that in the U.S. a small fraction of counties contained a large fraction of the troglobite and stygobite biodiversity and that this pattern was similar to what was observed in Tenerife. The question was raised as to how keen the government is to buy the areas need to protect the cave species. Izquierdo said that government was trying to buy the areas needed for protection. Deharveng asked what the major environmental threats to the cave fauna were. Izquierdo replied that it was domestic sewage and wastewater treatment.

Mapping subterranean biodiversity: structure of the database and mapping software CKMAP and report of status for Italy

Fabio Stoch

Museum of Natural History
Verona, Italy

Address for correspondence:
viale XXV Aprile 24,
I-34015 Muggia (Trieste)
Italy

Italy has some of the best species-based distribution data of any country in the world (Stoch 2000) and a complete checklist of its fauna is available (Minelli *et al.*1993-95). Based on the checklist and the amendments introduced by taxonomists contributing to the database, the Italian fauna includes nearly 57,500 species and 3750 subspecies, approximately 10% of them being endemics. This fauna is probably one of the richest in Europe (Minelli 1996). The distributional database of Italian fauna includes nearly 5000 species (mainly invertebrates) and over 250,000 distribution records. Considering that 27% of the Italian territory is karstic, and more than 33,000 caves are included in the Italian survey (Stoch 2001), it is reasonable to suppose that the number of obligate cave-dwelling species is high as well. This assumption is reinforced by the results given by Culver *et al.* (1999), who demostrated a close relationship between number of species and number of caves per county in the United States where nearly 45,000 caves are known. Recent papers and books (Cobolli-Sbordoni *et al.*1994, Stoch 2001) confirm the high diversity and the antiquity of troglobitic and stygobitic fauna of Italy, where some of the richest hotspots of subterranean biodiversity are located (Culver and Sket 2000).

Unfortunately, knowledge of the distribution of subterranean biodiversity in Italy remains poor in comparison to epigean taxa. Considering that most of obligate cave-dwelling species in Italy are narrow endemics (Cobolli-Sbordoni et al., 1994; Stoch, 1995, 2001), a complete inventory of subterranean species distribution is needed for at least two reasons: a) endemic species have been a popular focus for studies of biodiversity and conservation (Williams et al., 2000) and a significant aid in the identification of priority areas for conservation (Deharveng, 2000 and contributors in the same volume); b) endemism is one of the criteria adopted by the Habitat Directive of European Community for selecting key-species for "Nature 2000" network (European Commission, 1992). The purpose of this short communication is to illustrate the methods adopted in Italy for implementing the database, the structure of the mapping program CKMAP (Stoch, 2000a) and the first results on the distribution of Italian obligate cave-fauna extracted from the database.

The digital database project of Italian fauna is financially supported by the Ministry of Environment and is being assembled by the Museum of Natural History in Verona and the Unione Zoologica Italiana. The data were compiled by well-experienced taxonomists (over 130 contributors) from published atlases and literature; additional records were obtained from museum and private collections, as well as from unpublished data sets given by the specialists (Stoch 2000). The ongoing project will include at the end of 2001 over 10,000 species of the Italian fauna; up to now (spring 2001) it includes 5337 invertebrate taxa (species and subspecies) and nearly 250,000 georeferenced distributional records. Within this data set, 899 species and their subspecies (903 total taxa) are subterranean, comprising 16.9% of the total taxa.. It is divided among subterranean habitats as follows: 317 (35.1% of the total number of subterranean species and subspecies) are exclusive of soil litter or MSS (Milieu Souterrain Superficiel); 265 (29.3%) are stybobionts; and 321 (35.6%) are terrestrial troglobionts and eutroglophiles up to now known only from cave habitats. A list of the taxa for which distributional data are available is given in Table 1. They include gastropods, oligochaeta, crustaceans, pseudoscorpions, centipedes, and insects (mainly coleopterans and orthopterans). The number of endemic species is incredibly high (685 subterranean species and subspecies - 75.85% - are narrow endemics, and 637 - 70.5% - are endemic to Italy).

The selection of the taxa to be included in the database followed precise guidelines (Pearson 1995, Stoch 2000). Criteria meeting the requirements of a conservation-oriented database include the degree of taxonomic knowledge, habitat specialization, and

potential bioindicator value. The basic requirement was the inclusion of all the species and subspecies present in selected families (or higher taxa) to avoid any subjective choice.

The database was implemented on PC computers using the Windows®-based software MS Access®. This is a relational database-package useful for files not larger than 2 Gb; for larger data sets (*e.g.* millions of data entries) more sophisticated software is required. This is probably not the case even for a complex country like Italy, and it is not needed for subterranean biodiversity databases where data are usually scarce even in larger countries. For example, Culver *et al.* (1999) used less than 3000 locations in their survey of USA cave fauna. In any case, with millions of data entries, the user has two choices: to change database software package, or to divide the large database into smaller units (e.g. on a regional or taxonomic basis).

Specialists contributed their files in MS Access® tables, MS Excel® sheets, or even ASCII text delimited files; with modern database the data formats can be easily interchanged; these formats were adopted by Mac users as well.

The database structure is very simple. This is essential when exploring and querying thousands of data. Furthermore, a simple structure allows an easy link with other databases (at a regional level or at an European level) and metadata structures. For this reason, the number of "core" tables is limited to three (four in the new version): 1) taxon table (divided into a taxon table and a species table in the new version); b) distributional data table; c) references table (the last one, very simple, does not need to be considered further). The relational data structure is illustrated in fig. 1. Species and distributional data are joined using the species code; species names are repeated in the distribution table as well, were synonyms may be reported for literature records.

The taxon table includes taxon (subspecies, species, and genus) code, name and authorship, and several explanatory fields (dealing with standardized chorological groups, habitat types, feeding habits, sizes, etc.); higher taxa codes and names are added to this table (older version) or included in a relational taxon table (joined using a family-code in CKMAP 2000 version). The separation of the taxon table into two joined tables allows an easier programming of data exploration and more facilities to link other databases based on a common "higher taxon" structure (considering the high number of Italian endemics at the species level). The most important part of the table is the code, because it has a hierarchical structure (three digits for phylum code, subsequent 3 digits for class code, and so on for order, family, and - in the species table - genus, species and subspecies codes; every triplet is separated by a point; sometimes additional digits are added to avoid changes in the whole coding structure while adding new taxa). For example, the stygiobiont isopod family Sphaeromatidae has the code 029.010.008.051, derived from: phylum Arthropoda (029); class Malacostraca (029.010); order Isopoda (029.010.008). The sphaeromatid isopod *Monolistra racovitzai racovitzai* Strouhal, 1928 is joined to its family using the previous code and has a further code (030.197.0.005.0.001): Italian checklist reference (030 – this part is the number of the volume where the species is listed, and may be omitted) followed by genus *Monolistra* (197.0), species *M. racovitzai* (197.0.005.0), subspecies *M. r. racovitzai* (197.0.005.0.001). This code was appended to the checklist (full explanation of the usage of one digit extensions in Minelli *et al.* 2000). Intermediate taxa (as subclasses, subfamilies, etc.) are not included for the moment in the database. Hierarchy allows to select all the species or subspecies belonging to higher taxonomic units, as well as to reproduce the correct taxonomic sequence using a tree-like structure, currently available in Windows® programming languages.

The distributional data table includes: species code, species name (or synonym), locality entries (region, province, generic locality, detailed locality), data source (literature citation, linked with the references table; museum or private collection; original data), coordinates, and a field dealing with the accuracy of the coordinates. Localities are reported in two fields: the first one (generic locality) includes only data obtained from the index of a common road atlas of Italy (edited by the Touring Club Italiano – TCI – scale 1:250000), *e.g.*, a well known place name close to (or identical with) the locality reported in the original citation (literature, collection label); the second one (detailed locality) reports fine-scale data and habitat data (e.g. cave name), when available. The TCI place name is used for two purposes: a) easy location of the spot on a widely distributed commercial atlas; b) the possibility of assigning coordinates based on this place name (the full list is reported in a separate database table) in the case we have no more detailed geographical coordinates. For a cave-oriented database, we can join this table to a cave registry, generally available in most European countries.

Georeferencing of data is a complex problem; the database uses a UTM grid (10x 0 or 1x1 km grid cells, names following MGRS convention, datum European 1950), which is used also for mapping species distribution using the program CKMAP or commercial GIS software. Routines to convert between geographical coordinates and metric coordinates in different datums (ED 50, WGS 84 and the national datum Rome 40) were implemented in the database. Grid size (10 km or 1 km) gives the precision of the coordinates reported in the database. Precision is not synonymous with accuracy: the accuracy of georeferencing (included in a separate field) may be defined as good, poor, etc. depending on the quality of the data reported in the literature or in the labels accompanying the specimens.

The software programmed for exploring and mapping the data set is called CKMAP (Stoch, 2000a). It is not a new GIS package, but a simple mapping program for the exploratory analysis of data, with powerful statistical functions as in WORLDMAP (Williams, 1996). It has the following advantages over other software packages (see Fig. 2): a) hierarchical structure of the species tree, which allows an easy exploration of the species and taxon tables using a Windows Explorer ® – like structure; b) immediate mapping of the distribution of every subspecies, species, or higher rank taxon selected on the tree, using UTM 10 x 10 grid cells; c) the possibility of overlaying layers representing regions, provinces, DTM, reserve networks and hydrography (geological and climatic maps will be implemented); d) facilities to export distributional maps to commercial GIS software packages like ArcView® and MapInfo®; e) interactive maps, easily zoomed, which allows the listing of all records included in the selected UTM grid cell; and f) database tables easily accessible and editable in spreadsheet format; g) biodiversity, rarity and endemism statistics and other calculations easily performed using simple button clicks or menus. CKMAP is intended as a user-friendly interactive software package which allows the exploration and mapping of hundred thousands data and complex base maps in fractions of second on the new Pentium® based-machines.

Two outputs from the database and CKMAP software are presented as examples of the importance of mapping subterranean biodiversity and a synthesis of the distributional data of subterranean species and subspecies in Italy updated to spring 2001.

In the first example, Figure 3 displays the geographical variation of the number of obligate subterranean endemic species and subspecies among UTM 10 x 10 km grid cells in Italy. All of the taxa endemic to Italy (637 species and subspecies) were included in the analysis. Considering that several important taxa (like carabid beetles) will be added in a near future, the figure is given as a provisional report of status of subterranean fauna mapping in Italy, and no effort is made to explain the observed patterns. However, the map reported in Fig. 3 deserves some comments: a) regional trends of endemics richness are evident, and mark the extent of karstic areas; b) a higher number of endemics is displayed in the Prealps of northern Italy and, to a lesser extent, in Liguria, northern Appennines and Sardinia island, while richness decreases moving southwards. This pattern follows the overall trend of species richness in Italy delineated by Stoch (2000), and clearly shows a "peninsular effect" (Massa 1982) reflecting several historical and ecological factors (Stoch 1995), mainly size and age of karstic massifs. Unfortunately, heterogeneous sampling effort may influence the general trend, and careful statistical data analysis is needed to confirm this pattern.
The second example shows the overlay of the plots of subterranean endemics richness and European nature reserves network "Nature 2000" in an area located in the most important karstic massif of Italy, the Prealps. Figure 4 shows that the natural reserves network fails to represent subterranean endemic species. This failure is due to two main factors: a) the criteria for choices of natural reserves are usually oriented towards protection of "charismatic" surface species assemblages (mainly vertebrates – especially birds – and plants [Araújo 1999]); b) although caves are included in the list of habitats of communitary interest (appendix 1 of the Habitat Directive), and endemism is a key concept for nature protection in Europe (article 1), no troglobiont or stygobiont species are included in the list of appendix 2 (species of communitary interest: European Commission, 1992). For this reason, apart from the presence of bats or troglobitic amphibians, no "key species" are available to protect subterranean ecosystems in western Europe. Mapping the distribution of cave-dwelling species is thus an essential approach to propose an integration of the species lists of Habitat Directive (hence of the current reserve network) taking in account the protection of subterranean biodiversity.

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References

Araújo, M.B. 1999. Distribution patterns of biodiversity and the design of a representative reserve network in Portugal. *Diversity Distribution* 5:151-163.

Cobolli-Sbordoni, M., M. Paoletti, V. Sbordoni, A. Vigna Taglianti. 1994. Italie, pp. 737-751. In C. Juberthie and V. Decu [eds.], *Encyclopaedia Biospeologica, Vol. 1.* Moulis, France.

Culver D.C., H.H. Hobbs III, M.C. Christman, and L.L. Master. 1999. Distribution map of caves and cave animals in the United States. *J. Cave Karst Studies* 61:139-140.

Culver, D.C., and B. Sket. 2000. Hotspots of subterranean biodiversity in caves and wells. *J. Cave Karst Studies* 62:11-17.

Deharveng, L. 2000. The Workshop Endemism: introduction. *Belg. J. Entomol.* 2:5-8.

European Commission. 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. O.J. L206, 22.07.1992.

Massa, B. 1982. Il gradiente faunistico nella penisola italiana e nelle isole. *Atti Società Italiana Scienze Naturali, Museo Civico di Storia naturale di Milano* 123: 353-374.

Minelli, A. 1996. La checklist delle specie della fauna italiana. Un bilancio del progetto. *Bollettino Museo Civico Storia naturale Verona* 20:249-261.

Minelli, A., Ruffo S. & La Posta S. [eds.], 1993-1995. – *Checklist delle specie della fauna italiana.* Fascicoli 1-110. Edizioni Calderini, Bologna.

Minelli, A., F. Stoch and S. Zoia. 1999. Aggiornamenti all checklist delle specie dell fauna Italia. *I. Contributo. Boll. Soc. Entomol. Ital.* 131-269-278.

Pearson, D.L. 1995. Selecting indicator taxa for the quantitative assessment of biodiversity, pp. 75-79. In D.L. Hawksworth [ed.], *Biodiversity measurement and estimation.* The Royal Society, Cambridge University Press, Cambridge.

Stoch, F. 1995. The ecological and historical determinants of crustacean diversity in groundwaters, or: why are there so many species? *Mémoires Biospéologie* 22: 139-160.

Stoch, F. 2000. How many endemic species? Species richness assessment and conservation priorities in Italy. *Belg. J. Entomol.* 2:125-133.

Stoch, F. 2000. *CKMAP 2000: software e help on-line, versione 3.0.* Ministero dell'Ambiente, Roma & Museo Civico di Storia Naturale, Verona.

Stoch F. [ed.]. 2001. *Grotte e fenomeno carsico.* Quaderni Habitat, Ministero dell'Ambiente, Roma & Museo Friulano Storia Naturale, Udine: 158 pp.

Williams P.H. 1996. *WORLDMAP 4 WINDOWS: software and help document 4.1.* Distributed privately, London. Available at http://www.nhm.ac.uk/science/projects/worldmap.

Williams P., C. Humphries, M. Araújo, R. Lampinen, W. Hagemeijer, J. P. Gasc, and T. Mitchell-Jones. 2000. Endemism and important areas for representing European biodiversity: a preliminary exploration of atlas data for plants and terrestrial vertebrates. *Belg. J. Entomol.* 2:21-46.

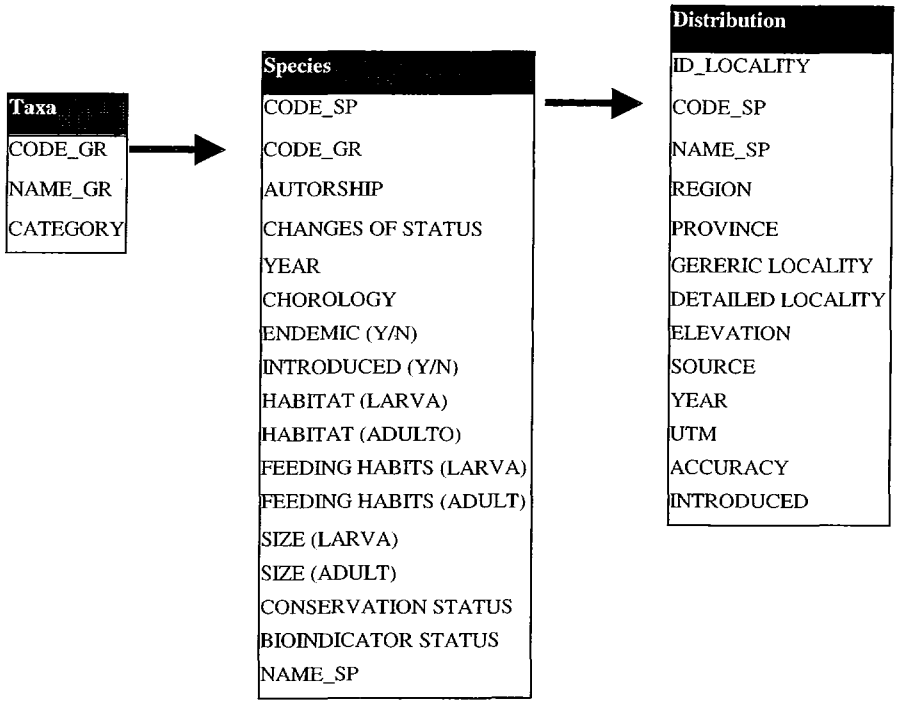


Fig. 1. Structure of the main tables of the database and their relationships.

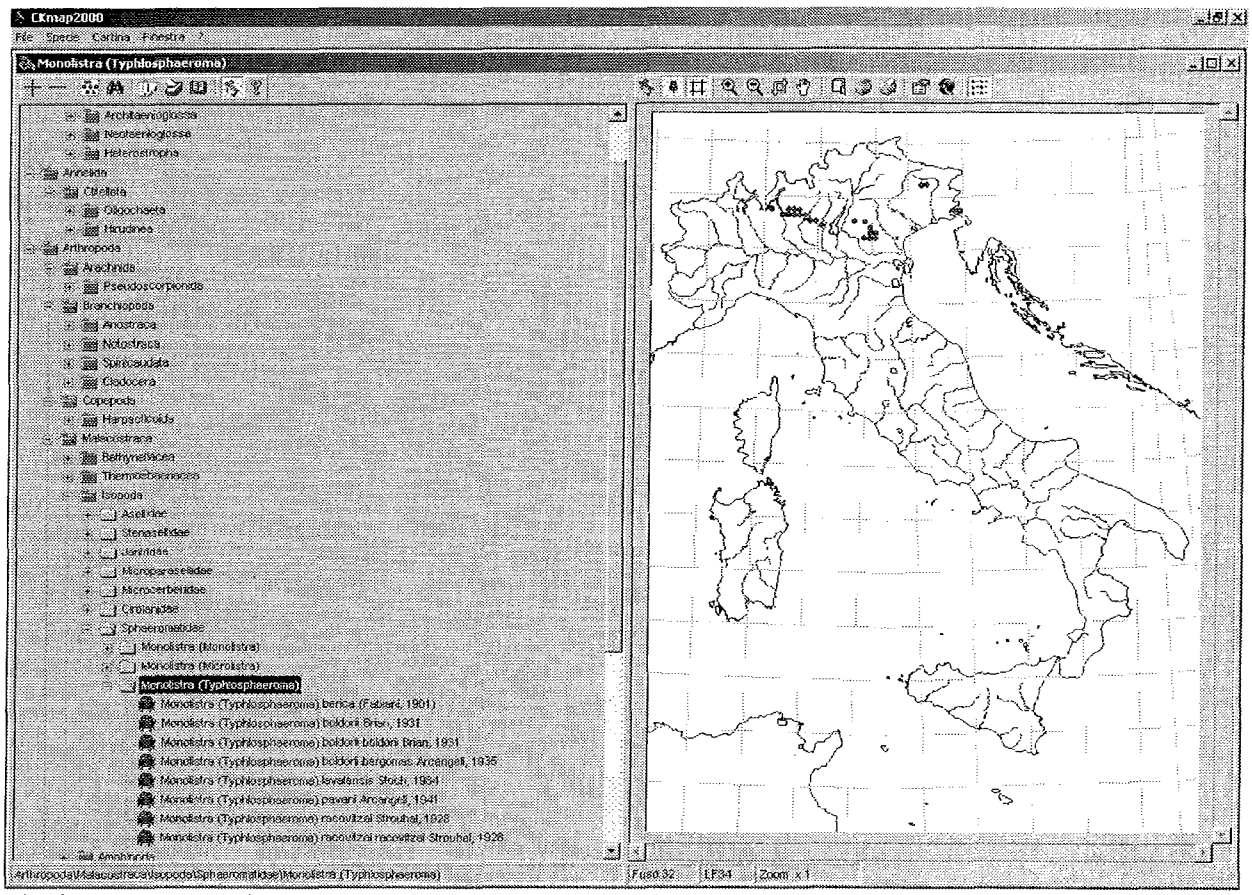


Fig. 2. Main screen of the CKMAP software

Table 1. List of the taxa including the subterranean species and subspecies entered in the Italian database up to spring 2001; numbers in brackets are comprehensive of endogeans and species of MSS.

		N sp+ssp	N records	Total sp.
Gastropoda	Hydrobiidae	49	1709	**49**
Oligochaeta	Lumbriculidae	5	15	
	Tubificidae	8	20	**13**
Pseudoscorpionida	Chthoniidae	30 (39)	202	
	Neobisiidae	41 (43)	425	
	Syarinidae	4	18	
	Larcidae	1	1	
	Chernetidae	3	21	**90**
Harpacticoida	Ectinosomatidae	3	3	
	Ameiridae	23	86	
	Tetragonicipitidae	1	1	
	Canthocamptidae	40	206	
	Cylindropsyllidae	11	32	
	Parastenocarididae	32	100	
	Latiremidae	1	3	**111**
Bathynellacea	Bathynellidae	7	7	**7**
Thermosbaenacea	Halosbaenidae	1	1	
	Monodellidae	3	7	**4**
Isopoda	Asellidae	24	105	
	Stenasellidae	3	15	
	Janiridae	1	1	
	Microparasellidae	7	18	
	Microcerberidae	1	1	
	Cirolanidae	2	2	
	Sphaeromatidae	12	102	**50**
Amphipoda	Bogidiellidae	8	15	
	Gammaridae	6	28	
	Hadziidae	4	9	
	Salentinellidae	2	48	
	Ingolfiellidae	1	1	
	Metaingolfiellidae	1	1	
	Pseudoniphargidae	5	8	
	Metacrangonyctidae	1	1	
	Atyidae	2	30	
	Palaemonidae	1	7	**31**
Chilopoda	Lithobiidae	14	122	
	Cryptopidae	1	2	
	Himantariidae	1	2	
	Geophilidae	1	1	**17**
Orthoptera	Rhaphidophoridae	18	423	
	Gryllidae	1 (6)	1 (205)	
	Gryllotalpidae	(8)	(189)	
	Acrididae	(3)	(445)	**35**
Coleoptera	Histeridae	8	35	
	Cholevidae	113 (268)	679 (4585)	
	Pselaphidae	81 (160)	2626 (3092)	
	Staphylinidae	3	5	
	Curculionidae	1 (57)	2 (207)	**496**

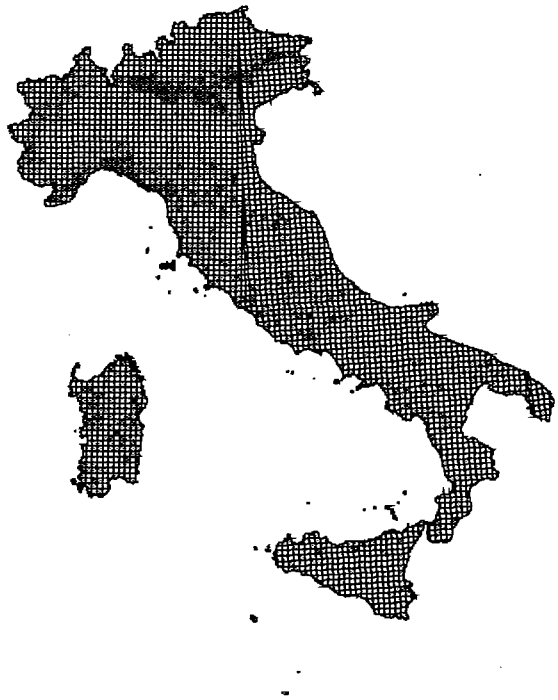


Fig. 3. Geographical variation of the number of obligate subterranean endemic species and subspecies (637 taxa) among UTM 10 x 10 km grid cells in Italy

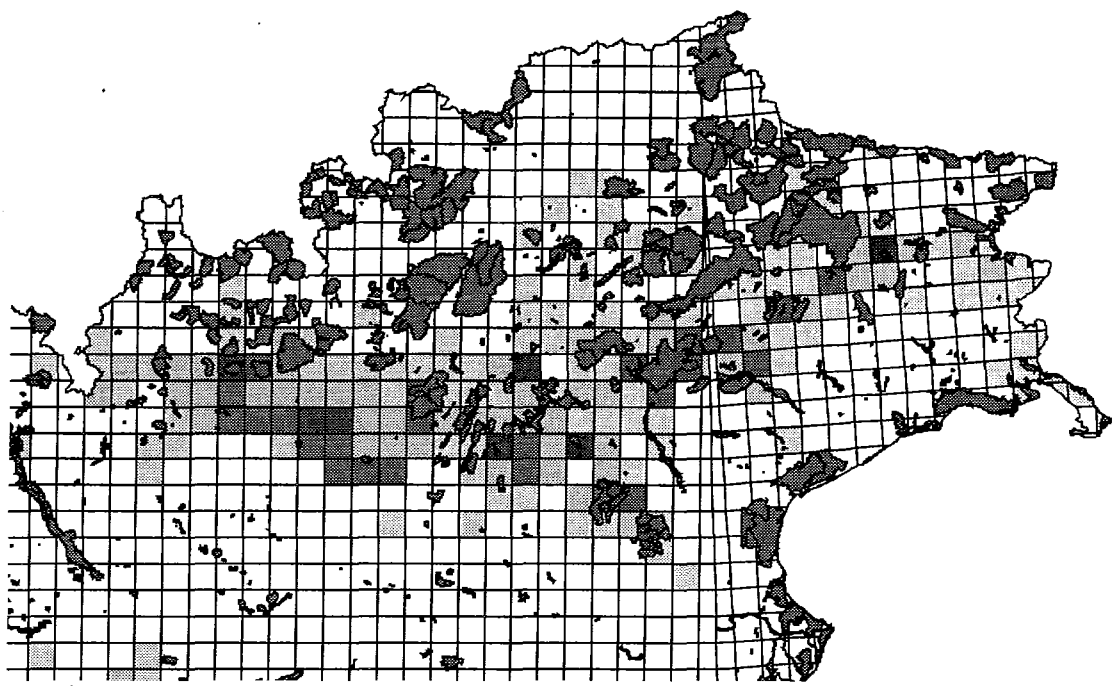


Fig. 4. Overlay of the plots of subterranean endemics richness and European nature reserves network "Nature 2000" on a UTM 10 x 10 km grid in Italy

Spatial Models For Predicting Cave Biodiversity: An Example From The Southeastern United States

Mary C. Christman

Department of Animal and Avian Sciences
University of Maryland
College Park MD 20742
USA

David C. Culver

Department of Biology
American University
4400 Massachusetts Ave. NW
Washington DC 20016
USA

In conservation biology one of the most important aspects of current research is the identification of geographic areas for future conservation in order to protect species diversity and richness. All of the methods to identify hotspots now in use require an understanding of the relationship of species richness to environmental factors influencing it. For example, GAP analysis relies on identifying unstudied regions for potential preservation that have environmental parameters similar to regions in which high endemism or species richness is well documented.

We consider a relatively new method, statistical spatial modeling, that provides a means for studying the spatial process that generates the observed geographic distribution of species. Hence it is useful for both research into the generating process as well as for identifying areas in which high species richness might be expected although not yet reported.

The spatial process that leads to the observed spatial distribution can be decomposed into several components. First, there is the large-scale trend over the region which is describable as a function of environmental conditions. For cave fauna, the explanatory variables might include cave number, cave quality, surface climate features, latitude, and others. Next is the meso-scale or small scale variation that is not explainable by the large-scale trend. Such variation might arise because of unknown factors that operate at smaller scales such as prevailing winds or rain. It might also be due to features such as connectivity of caves or water sources such as springs or underground rivers in common among different caves. The variations at this level are often observed to have covariability, *i.e.* adjacent areas or neighbors within certain distances often have similar numbers of species. As a result, this variation is often modeled as a spatial correlation of neighboring areas. The final component is random error or the unexplained variability that is unaccounted for after the fitting of the other components.

Hence, we can write that $Y(s)$, the number of species at location s, is a linear combination of the components:

$$Y(s) = \mu(s) + \delta(s) + \varepsilon(s)$$

where $\mu(s)$ is the large-scale trend at location s, $\delta(s)$ is the spatial correlation component describing the meso-scale variability, and $\varepsilon(s)$ is the random noise or unexplained variability. It is further assumed that the components are independent of each other.

In this paper we show an example of using such a model to describe the geographic distribution of stygobites and troglobites as a function of the number of caves in the southeastern United States below the furthest extent of the Pleistocene glaciation. We describe the dataset and then the statistical methods used to model the data. The results and an example of using the model for predictive purposes are also given.

A data set containing the numbers of species per county and the number of caves per county for the southeastern region of the United States was compiled. This region, south of the southern border of Pennsylvania (40^{th} parallel) and east of the western side of Texas (100^{th} meridian), roughly corresponds to the non-glaciated United States southeast of the Great Plains, and encompasses most of the known obligate subterranean species. The centroid (latitude and longitude of the geographic center) of every county in this region was added to the data set. Operationally, species and subspecies for which over 95% of occurrence records were in subterranean habitats are included. We refer the reader to Culver *et al.* (2000) for more detail and for discussion of sampling completeness and data quality and to Christman and Culver (2001) for a more complete analysis than is given here. A total of 1655 counties were included of which 621 have reported caves, 262 have reported troglobites, and 304 have reported stygobites.

A very small number of counties (32, 1.9% of the dataset) were so small and with no species or caves that they were not included in the analysis. Hence the number of counties was reduced to 1622. Before the analysis was performed, we determined that county size (km^2) was uncorrelated with either number of caves (counties with at least one cave, Spearman's r = –0.0507, p>0.20) or number of species (counties with at least one species, Spearman's r = –0.0105, p>0.20). These results lend support to the argument that county size does not influence the results and interpretations.

Initial analyses (Christman and Culver 2001) indicated that there is an increasing relationship between the log-transformed species richness and log-transformed number of caves for both the aquatic and terrestrial species. As a result all of the spatial analyses were performed on the log-transformed data.

We use a statistical model often called the conditional autoregressive model (Cressie 1993) in which the response variable (number of species) at location s depends on large-scale covariates (explanatory variables) and on the values of the response variable at other sampling locations. We modify the model so that counties with no species are *a priori* assumed to have zero subterranean species and otherwise counties with at least one species are modeled as an autoregression. In this way, the extremely large number of zero values in the dataset do not overwhelm and obscure the actual geographic pattern observed. Math-ematically this is given as:

$$Y(s) = \begin{cases} 0, & Y(s) = 0 \\ \mu(s) + \sum_t \eta(s,t)[Z(t) - \mu(t)] + \varepsilon(s), & Y(s) > 0 \end{cases}$$

where $Y(s)$ is the number of troglobites (or stygobites, both log-transformed) in the county with centroid s, $C(s)$ is the log-transformed number of caves in county s, $\mu(s) = \beta_0 + \beta_1 C(s)$ is the mean number of species given as a linear function of the number of caves, $\eta(s,t)$ is a spatial parameter that relates the number of species in county s with the number of species in county t, $\varepsilon(s)$ is the random error term which is assumed to have a zero-mean and constant variance σ^2.

For our study we modeled the spatial parameter as a function of a constant θ and a weight, $w(s,t)$, relating the distance between centroids of neighboring counties as follows:

$$\eta(s,t) = \begin{cases} 0, & \text{if } ||s-t|| > 56 \text{ km} \\ \theta \dfrac{\max_{i,j}(||s_i - s_j||)}{||s-t||}, & \text{if } ||s-t|| \le 56 \text{ km} \end{cases}$$

where $||s-t||$ is the Euclidean distance between centroids s and t, $\max_{i,j}(||s_i - s_j||)$ is the maximum Euclidean distance between any pair of centroids in the sample, and θ is the spatial autocorrelation which falls between –1 and 1. Only county centers which were within 56 km of each other were assumed to be correlated; those further apart are not.

The model is fit using maximum likelihood techniques assuming that the data are normally distributed with mean $\mu(s)$ and a variance-covariance matrix described by σ^2 and θ. Testing of the parameter θ is done using a likelihood ratio test.

For stygobites the fitted model is

$$\hat{Y}(s) = \begin{cases} 0, & Y(s) = 0 \\ -0.09 + 0.29C(s) + 0.8\sum_t w(s,t)[Z(t) + 0.09 - 0.29C(t)], & Y(s) > 0 \end{cases}$$

The spatial autocorrelation of 0.8 is significantly greater than zero (χ^2 test, p-value<0.001). Figure 1 shows graphically the contribution of the three model components to the observed distribution of stygobites in the southeastern United States.

A similar result holds for the troglobites. The fitted model differs slightly from the one obtained for stygobites:

$$\hat{Y}(s) = \begin{cases} 0, & Y(s) = 0 \\ -0.26 + 0.36C(s) + 0.6\sum_t w(s,t)[Z(t) + 0.26 - 0.36C(t)], & Y(s) > 0 \end{cases}$$

but the spatial autocorrelation is also significant(χ^2 test, p-value<0.001).

Although the models assume that a county with zero species does in fact have no species this is done solely for purposes of fitting an accurate model to the counties with reported species. We now reverse that and assume that the counties with caves but no reported species might in fact have species and use the model to predict the likely number to be found there. For example, the county of Gulf, Florida, has 3 caves but no reported aquatic species. Now, the Florida Lime Sinks area is relatively rich in aquatic species and the model reflects that by predicting that there are 1.52 species in that county. On the other hand, the county of Bollinger, Missouri has 4 caves but is in an area relatively depauperate of aquatic species. For this county the model predicts 1.14 species. Hence, the spatial autocorrelation model

provides a better prediction tool than is available from simple regressions which ignore the geographic differences and relationships between neighboring regions.

References

Christman, M. C. and D.C. Culver. 2001. The relationship between cave biodiversity and available habitat. *J. Biogeography.*

Cressie, N. A. C. 1993. *Statistics For Spatial Data*, Wiley and Sons, New York.

Culver, D. C., L.L. Master, M.C. Christman, and H.H. Hobbs III. 2000. Obligate cave fauna of the 48 contiguous United States. *Cons. Biol.* 14:386-401.

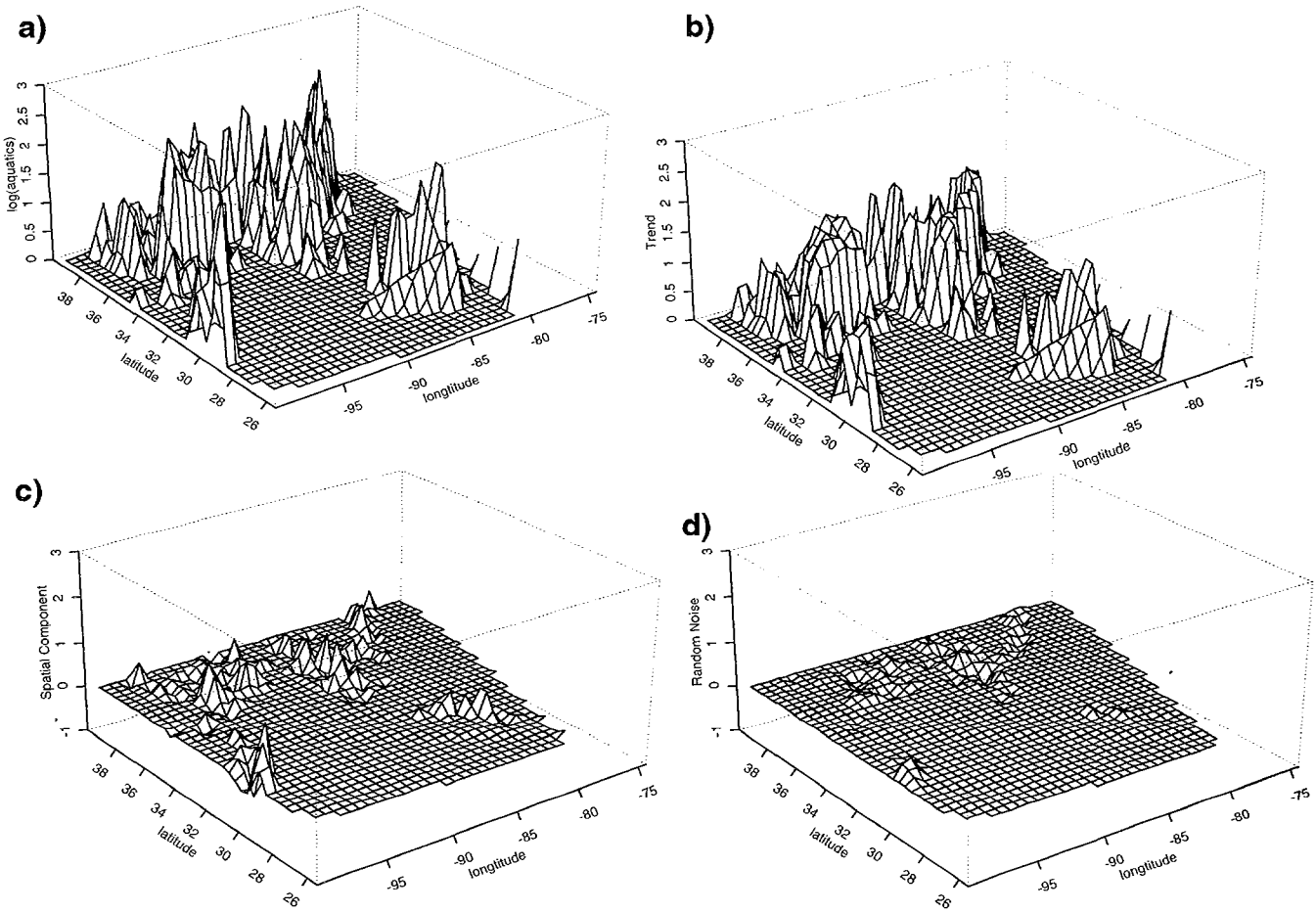


Fig. 1. Perspective plots showing a) the geographic distribution of the observed counts of stygobites (log-transformed) in counties in the southeastern part of the United States, b) the fitted regression plane for the large-scale component of the model in which the number of stygobites is related to the number of caves (log-transformed), c) the predicted values from the meso-scale component in which the number of stygobites is predicted conditionally using the counts in surrounding counties, and d) the residuals or unaccounted for variation in the data.

Extrapolating Biodiversity Values from Landscape Features

G. Chust [1,2,3], J. Pretus [2], D. Ducrot [3], L. Deharveng [4]

[1]*Institut d'Estudis Espacials de Catalunya*
Edif. Nexus
Gran Capità 2-4
08034 Barcelona
Spain

[2]*Departament d'Ecologia*
Facultat de Biologia (Universitat de Barcelona)
Diagonal 645
08028 Barcelona
Spain

[3]*Centre d'Etudes Spatiales de la Biosphère (CNES-CNRS-UPS)*
18, Avenue Edouard Belin
31055 Toulouse Cedex
France

[4]*Laboratoire d'Ecologie Terrestre (UMR 5552 du CNRS)*
118 route de Narbonne
F-31062 Toulouse cedex 4
France

There is an increasing interest in testing the reliability of biodiversity assessment by satellite images (Stoms and Estes 1993, Innes and Koch 1998, Cardillo *et al.* 1999, Nagendra and Gadgil 1999). Spectral information, for instance, can predict the occurrence of plant, butterfly and bird species (Debinski *et al.* 1999). A landscape diversity index derived from satellite imagery explained 50 % of bird species richness (Jørgensen and Nøhr 1996). Species habitat characterisation by spectral classification and posterior landscape spatial analysis constitutes the link between the information acquired from space and community structure. However, such a potential use of remote sensing is considered as very limited by Gulinck *et al.* (2000). The objective of this paper is to demonstrate remote sensing capabilities for mapping species richness and endemism of Pyrenean soil fauna.

The Massif of Arize comprises mountains of moderate elevation (maximum 1715 m above sea level) located in the Northern part of the French Pyrenees. Natural vegetation comprises beech forests (*Fagus sylvatica*), above 1000 m, and mixed woods of several other deciduous species dominated by oaks, below 1000 m. Pastures, agricultural land and small villages surround natural forests and stands of exotic coniferous introduced in the Massif.

Collembola were sampled in 27 stations during 1998, with sites ranging from 400 m to 1400 m in elevation. The stations were located in two forest habitats: beech and oak forests. The oak wood comprises also other deciduous species (*e.g.*, chestnut, birch, *Robinia pseudoacacia*). The soil fauna was obtained within7 to 10 days, using Berlese-Tullgren devices. Taxonomic identification of Collembola was at the species level. Two ecological variables were selected: species richness and the number of endemic species (*i.e.*, those species endemic to the Pyrenees or to a part of the Pyrenees).

A high-resolution optical image covering the area of the test site was used, based on that acquired on 13th of July in 1990 by Landsat Thematic Mapper (TM) satellite. The resolution of TM images is of 30 m by 30 m. Two types of thematic information were derived from satellite images: vegetation indices and a land cover classification. Infrared and red bands were used to derive the Normalised Difference Vegetation Index (NDVI) and the Leaf Water Content Index (LWCI). NDVI and LWCI give a measure of the photosynthetic active biomass and leaf water content, respectively. The advantage of those vegetation indices is that they mitigate the effect of shadows in radiometric response. Land cover data was previously derived by means of a supervised classification into 12 categories with a global accuracy of 90.1 %. The classification was performed with the maximum likelihood procedure, using spectral bands and ancillary data (digital elevation model and shaded relief model).

Spatial indices were performed over the thematic maps for a square window centred in the sample station. We calculated 5 spatial indices on the NDVI and LWCI maps: *Mean; Standard Deviation* (SD), as a measure of heterogeneity; *Angular Second Moment* (ASM), as a measure of spatial homogeneity; *Mean Distance* (MD), it is a measure of the difference between the mean of vegetation indices values, corresponding to the land cover of the sample station, and the vegetation indices values of the window; and *Mean Distance of Central Pixel.* We calculated 3 other spatial indices over the land cover classification: *Forest Land Cover Proportion*; *Land Cover Proportion of Central Pixel*; and *Number of forest patches.*

We tested the relationship between entomological data and landscape descriptors by stepwise multiple linear regression for each window size. The optimal scales, i.e. those with maximal multiple correlation of coefficient (R^2), were selected to map the soil fauna diversity by determining the collinearity of scales. Topographic variables and spatial trends (coordinates of x,y,xy,x^2,y^2) were introduced to improve the final model.

The species richness is correlated with spatial indices at the lowest scales, up to 900 m side (Fig. 1a), the curve is slightly erratic presenting a maximum value at 750 m side. This maximum corresponds to the unique optimal scale explaining a 64.7 % of total variance (Fig. 2a). The model involves a positive dependence on SD(NDVI) and a negative on SD(LWCI), ASM(LWCI) and MD(LWCI).

The number of endemic species is highly correlated with spatial indices at any scale, except in 90 m side (Fig. 1b). The collinearity analysis reveals that scales of 330 m X 330 m and 1590 m X 1590 m are optimal. When topographical and space variables are introduced, the final model involves only the first scale and elevation, together explaining 78.3 % of variance (Fig. 2b). Endemicity depends positively on elevation and patch number, and negatively on SD(LWCI).

Satellite data did provide information on the landscape pattern that partially explained important biotic parameters of Collembola assemblages, such as species richness and the degree of endemism. Remote sensing and digital elevation models are able to produce a reliable map of endemic Collembola by means of a scalar analysis. The method described above may be seen as a 3-step approach: first, setting spatial patterns from satellite images; second, linking spatial patterns to biodiversity measured at a limited number of points; third, extrapolating biodiversity values to the whole area under study. Implicit assumptions of the model are (i) that it may only apply in an homogeneous faunistic unit where the same habitat can be potentially colonized by the same species pool; (ii) that species do not spread freely into an ecological unit (the model is thus not operational or less operational for aquatic habitats).

It is possible that satellite data may provide insight into the subterranean fauna as well. For example, some of the characteristics of Landsat images may reflect underlying geological features that in turn may have a major impact on both the cave and interstitial fauna. It is even possible that measures of vegetation *per se* may directly influence the subterranean fauna. In nearly all subterranean communities, food is the result of infiltration from the surface rather than chemoautotrophy. Measures of vegetative cover and quality are measures of productivity of the surface environment, which may be a relative measure of the amount of food ultimately entering the subsurface environment. In fact, the most serious limitation of the method is the low and pre-defined number of access to subterranean habitats, especially in karstic areas. Where sampling can be done at a reasonable density, predicting patterns of biodiversity using this kind of model certainly deserves consideration.

The analysis of scale presented here may also be directly applicable to subterranean biodiversity. The question of the area of influence the surface has in determining subterranean biodiversity is also an interesting question, as it is for the soil fauna. Christman and Culver (2001) touch on this very question of the effect of scale when they investigated whether the number of caves in adjoining counties had an impact on the number of species in the county. Unlike the soil case where optimal scales were on the order of hundreds of meters, in the case of caves the optimal scale may be on the order of tens of kilometres. Both cases could be analysed using identical techniques.

Such spatial models could be used for designating areas with high biological diversity and not yet protected, namely *hotspots.* The *gap analysis*, or hotspot identification process, is a critical step to design environmental protection strategies with scientific criteria. In less populous or under developed regions, for instance, there is a case for predictive modelling in an attempt to identify sites which might be important for soil and subterranean fauna. In those cases, biodiversity mapping by sampling over the entire area at reasonable resolution, e.g. 1 km, is not feasible.

References

Cardillo, M. Macdonald, D. W., and S. Rushton. 1999. Predicting mammal species richness and distributions: testing the effectiveness of satellite-derived land cover data. *Landscape Ecology* 14: 423-435.

Christman, M.C., and D.C. Culver. 2001 The relationship between cave biodiversity and available habitat. *Journal of Biogeography* 28.

Debinski, D. M., Kindscher, K., and M.E. Jakubauskas, M. E. 1999. A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem. *International Journal of Remote Sensing* 20:3281-3291.

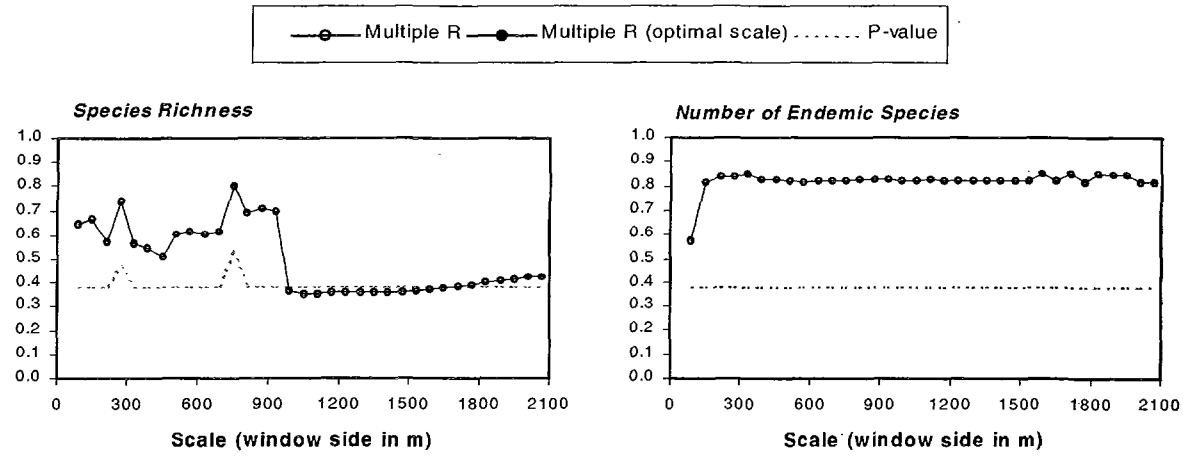
Gulinck, H., Dufourmont, H., Coppin, P., and M. Hermy. 2000. Landscape research, landscape policy and Earth observation. *International Journal of remote Sensing* 21:2541-2554.

Innes, J.L. and B. Koch. 1998. Forest biodiversity and its assessment by remote sensing. *Global Ecology and Biogeography Letters* 7 : 397-419.

Jørgensen, A.F. and H. Nøhr, H. 1996. The use of satellite images for mapping of landscape and biological diversity in the Sahel. *International Journal of Remote Sensing* 17:91-109.

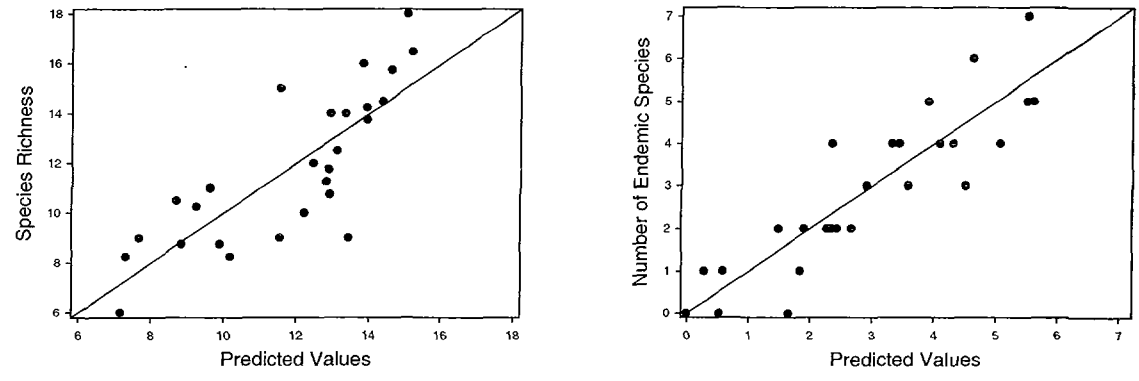
Nagendra, H., and M. Gadgil. 1999. Satellite imagery as a tool for monitoring species diversity: an assessment. *Journal of Applied Ecology* 36:388-397.

Stoms, D. M. and J.E. Estes. 1993. A remote sensing research agenda for mapping and monitoring biodiversity. *International Journal of Remote Sensing* 14:1839-1860.



(a) *(b)*

Figure 1. Species Richness and Number of Endemic Species response on landscape descriptors at different spatial scales.



(a) *(b)*

Figure 2. Predicted values of final multiple regression models against Species Richness *(a)* and the Number of Endemic Species *(b)*.

Determining Sampling Gaps for Cave Species

Sarah Krow

Environmental Studies Program
American University
4400 Massachusetts Ave. NW
Washington DC 20016
U.S.A.

David C. Culver

Department of Biology
American University
4400 Massachusetts Ave., NW
Washington, DC 20016
U.S.A.

The obligate cave fauna of West Virginia is rich and relatively well studied. A total of 46 troglobites and 34 stygobites have been collected from over 200 caves. However, over 1500 caves have been reported in the state. We were interested in the question of whether there were any significant gaps in geographic coverage of the existing collections.

Species records were obtained from Holsinger *et al.* (1976), the West Virgnia Natural Heritage Program, and from the database being developed by the Center for Subterranean Biodiversity of the Karst Waters Institute. Cave locations were obtained from the West Virginia Speleological Survey. Species records and cave locations were mapped unto a hexagonal grid of 12 km^2 area. Hexagons were used for grids because a hexagonal covering (tessellation) of the sphere produced the least distortion in shape and area (Kimerling *et al.* 1999). The grid was supplied by EMAP design of Corvallis, Oregon. Each species record and its latitude and longitude were associated with the appropriate hexagon using ArcView™. The number of caves and the number of obligate cave species was then determined, using EXCEL™.

Caves were found in total of 412 hexagons (Fig. 1) and troglobites and/or stygobites were found in 102 hexagons (Fig. 2). Thus, about 15% of the caves have been biologically investigated, and about 20% of the hexagons with caves have been biologically investigated. If hexagon size were increased, the per cent coverage would increase. At a hexagon size of 195 km^2, coverage was complete (Krow and Culver in prep.).

We next asked the question of whether hexagons with relatively large numbers of caves had been biologically sampled. The rationale for doing this is that number of caves is a fairly good predictor of the number of stygobites and troglobites. For example, Christman and Culver (2001) found that number of caves in a county accounted for 39% of the variance in number of troglobites and 35% of the variance in number of stygobites, in both cases a highly significant result ($p<0.001$). In this study, we combined numbers of stygobites and troglobites in a hexagon, and found that a log-log model accounted for 7.9% of the variance in species number ($p<0.001$):

$$\ln(S) = 0.198[\ln(N)] + 1.00$$

where S is the number of species, N is the number of caves, and 0.198 and 1.00 are fitted constants. The lowered percent of variation explained is the result of the small size of hexagons. Larger hexagons would like result in a better fit of the regression equation. This is the subject of continuing study (Krow and Culver in prep.).

The final step in the analysis was the identification of 12 km^2 hexagons with ten or more caves but no biological collections (Fig. 3). There were ten such hexagons, all of them were immediately adjacent to sampled hexagons. It remains to be seen what will actually be found in these caves, but this technique is a useful way to focus future sampling efforts.

References:

Christman, M.C., and D.C. Culver. 2001. The relationship between cave biodiversity and available habitat. *Journal of Biogeography* 28.

Holsinger, J.R., R.A. Baroody, and D.C. Culver. 1976. *The Invertebrate Cave Fauna of West Virginia.* West Virginia Speleological Survey Bulletin 7.

Kimerling, A.J., K. Sahr, D. White, and L. Song. 1999. Comparing geometrical properties of global grids. *Cartography and Geographic Information Science* 26:271-288.

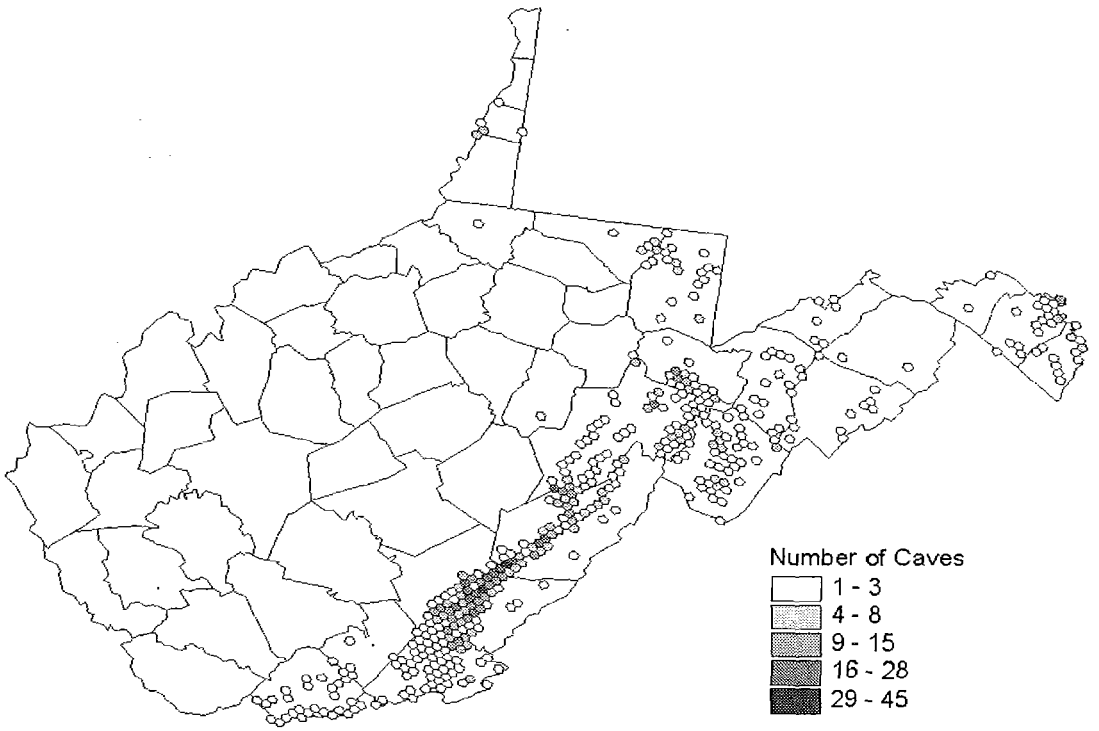


Fig. 1. *Distribution of caves in 12 km^2 hexagons*

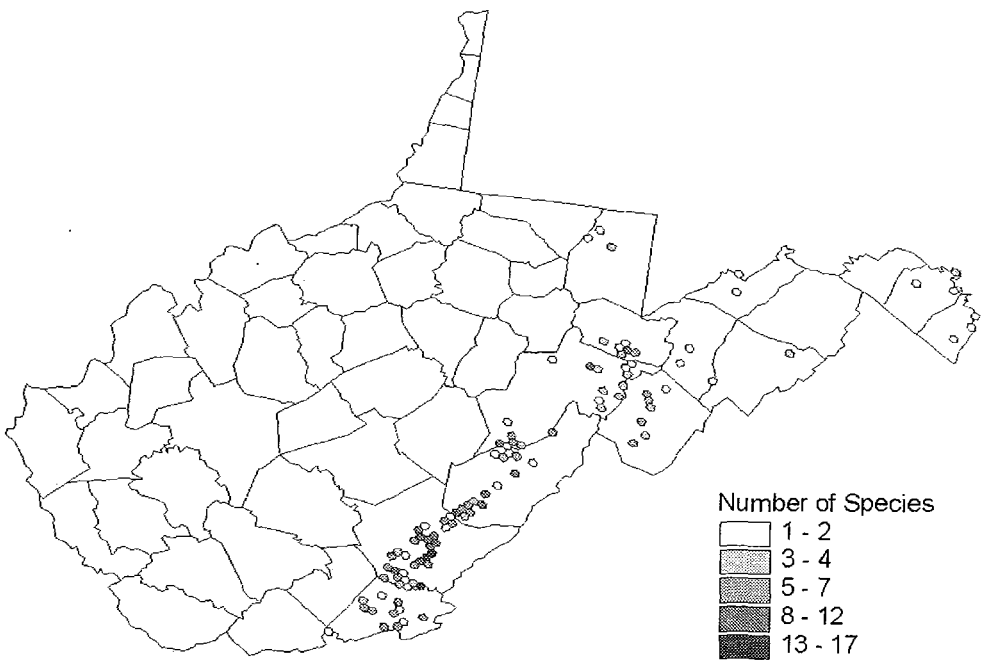


Fig. 2. Number of obligate subterranean species in 12 km^2 hexagons

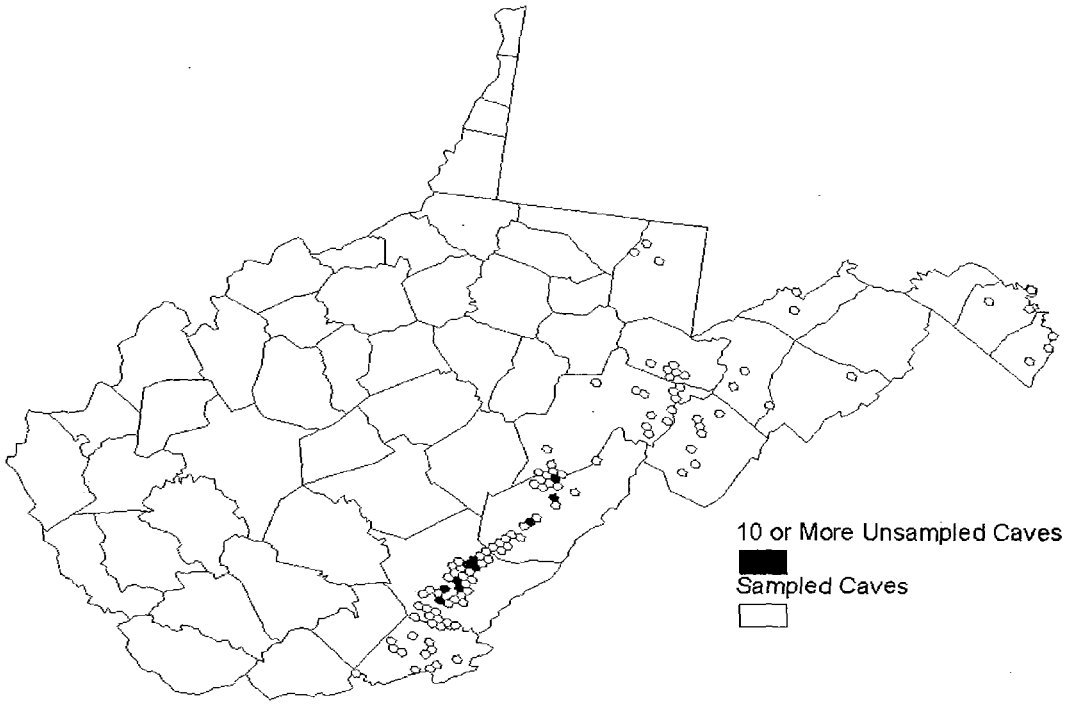


Fig. 3. Number of obligate subterranean species and unsampled hexagons with ten or more caves.

Geo-referenced computer recordings as an instrument for protecting cave-dwelling species of Tenerife (Canary Islands)

Isaac Izquierdo, José L. Martín

Centro de Planificación Ambiental
Consejería de Política Territorial y Medio Ambiente del Gobierno de Canarias
Ctra. de La Esperanza Km. 0.8
38071 La Laguna, Santa Cruz de Tenerife
Islas Canarias

Nieves Zurita

GESPLAN-La Laguna
Centro de Planificación Ambiental
Ctra. de La Esperanza Km. 0.8
38071 La Laguna, Santa Cruz de Tenerife
Islas Canarias

Ana L. Medina

Departamento de Biología Animal (Zoología)
Facultad de Biológicas, Universidad de La Laguna
38071 La Laguna, Santa Cruz de Tenerife
Islas Canarias

When conservation decisions have to be taken on which caves to protect, and we do not have sufficient resources for all of them, then we need criteria that will help us to establish priorities, in order to be able to protect the largest number of species in the least number of sites. The first candidate for protection is the site with the most species, but the second choice would not be the next richest in species, but the one with the largest number of different species from those found at the first site. It is important to have geo-referenced computer records to help in this decision-making process, such as those included in the ***Atlantis software***. This software has made it possible to simulate the conservation priorities of Tenerife's volcanic cavities, as is explained in this paper.

The geographical information on 14,000 species and subspecies of Canary islands is now computerised in a data base thanks to the setting up of the 'Biota–Canarias' project initiated by the Government of the Canary Islands in 1998. To carry out the project *Atlantis* software is used to organize the alphanumeric and geographic data on the species in the Canaries, at a minimum scale of 500 x 500 metres. The data are stored according to different levels of precision and confidence, depending on the source information. This *Atlantis* software includes an analysis module that enables calculations to be made on different ways of measuring biodiversity. Thanks to this module we have been able to carry out a simulation of conservation priorities for the underground environment of the island of Tenerife.

A total of 59 exclusively hypogean species have been described in Tenerife, of which 56 are endemic to the islands (Medina 1991, Martín 1992, Oromí *et al.* 2000). They are basically distributed along the entire southern strip of Tenerife and have been found both in volcanic compartments and in underground habitats near the surface. According to information taken from the Biodiversity Data Base of the Canary Islands, of the 8.500 cells of 500 x 500 metres spread over the surface of the island of Tenerife, troglobites are present in 335.

When we consider establishing the protection or conservation of the volcanic cavities or the underground environment in general, we should bear in mind how the species living in it are distributed. One of the most common estimates to calculate biodiversity is the "richness of species". When an analysis is made of the richness of troglobites on the island of Tenerife at a scale of 500 x 500 m, the result is a series of relatively high scores, coinciding with the location of the underground complex of Viento,

Sobrado and Felipe Reventón caves (Fig. 1).

Nine cells each contain 20 or more species. Another four, more dispersed, show up scores of between 10 and 20 species. The remaining cells hold fewer than 10 species. An initial conservation proposal would involve making a priority selection of the 9 'richest' cells, followed by the four that have intermediate scores for richness of species. Together, the 13 cells account for 46 species, *i.e.*, 78% of the total number of troglobites in Tenerife.

Another way of measuring biodiversity is based on the "rarity of species" by Rapoport *et al.* (1986). This consists of establishing which cells hold the largest number of species that have low representation in the total of cells studied. With the exception of one cell, the coincidence with the cells from the richness analysis is total. Together, the 10 cells account for 48 species, *i.e.*, 81% of the total number of troglobites in Tenerife.

The rarity of species can also be expressed to the full extent when those cells that contain exclusive species are selected. In this way "extreme rarity" can be calculated, through which irreplaceable cells can be obtained (Pressey *et al.* 1994), in such a way that the destruction of one of them involves the disappearance of some species of their unique localities. In Tenerife there are 6 irreplaceable cells in the analysis of troglobites, two of them containing 2 species and the others one. In this case, the coincidence in cell distribution in relation to the richness analysis is slight; 3 new cells appear and none of the 9 cells with a higher number of species is represented. Together, the 6 cells account for 38 species, *i.e*,. 64 % of the total number of troglobites in Tenerife.
As mentioned in the previous point, the choice of the most important areas in which to establish conservation should be based on high biodiversity values. Once the richest cell has been located, we should consider the next cell where conservation efforts are to be made, then the third most important, and so on until the largest number of species in the smallest number of locations or cells is obtained. Therefore, if the aim is to achieve the best possible use of the resources allocated to the conservation of biodiversity, we should focus priorities on the protection of the group of cells that contain the greatest representation of all the species. This objective can be achieved by applying the "principle of complementarity", whereby the process of cell selection should favour those with the largest number of species that have not been previously selected (Vane-Wright *et al.* 1994).

Through the automatic analysis of conservation priorities provided by the *Atlantis* software, a set of 13 cells of high distribution on Tenerife appears. This set has two major characteristics: 1) within the 13 cells, which account for 0.15% of the territory of the island, all the underground biodiversity of the island is represented, and 2) the analysis includes the order of priority whereby conservation efforts on the underground environment of the island should be established. A comparison of the result of the complementarity analysis with that obtained in the calculation of richness shows that the first one selects 8 cells not included in the richness scale. Moreover, of the 9 priority cells (given priority as a result of their richness of species) only 2 are selected in the complementarity analysis .
The cell selected in first place is the 500 x 500 m square with the largest number of species (33), located in the Cueva del Viento area. The next one has far fewer species (13) but contributes 5 new ones to the set. The next cell, despite containing more species than the previous one (16), only contributes four new species. The process continues until a cell is reached that does not contribute any new species. By this point the totality of the cave fauna species on the island of Tenerife have been covered. Within this selection process, at the same time as new species are incorporated, a process of repetition or "redundancy" of species is introduced. This process is important when it comes to selecting between two or more cells containing the same number of new species (Fig. 2). The option in this case would be making the selection in favour of the higher redundancy value, because we would thus give priority to the conservation of a larger number of populations of already protected species.

However, even in the selection process for complementarity the number of new species could be the same, and exactly the same could occur with the number of redundant species, so it would be necessary to support decisions on priority by applying other analyses to this limited group of cells. In this specific case we have used the calculation of the rarity and the calculation of "taxic diversity" by Vane-Wright *et al.*, 1994. The results of the calculation or rarity are as follows: cell 6 (0.053), 8 (2.342), 12 (1.025) and 13 (1.076) (see presentation). For the calculation of taxic diversity, the values of the number of families and genus in cells are: in cell 6 (3,4 respectively), incell 8 (4,4), 12 (2,3) and 13 (3,3). In this manner, through the calculation of both rarity and taxic diversity, an order of priority is obtained, *i.e.*, 8-6 and 13-12.

Therefore, taking into account the principle of complementarity, progressive mean redundancy, local rarity and taxic diversity, a set of 13 priority cells is obtained for the conservation of the underground environment on the island of Tenerife, with an order of priority as follows (Fig. 3).

References

Medina, A. L. 1991. *El estudio subterráneo superficial en las Islas Canarias: caracterización y consideraciones sobre su fauna.* Tesis doctoral (sin publicar). Universidad de La Laguna, Tenerife.

Martín, J.L. 1992. *Caracterización ecológica y evolución de las comunidades subterráneas en las islas de Tenerife, El Hierro y La Palma.* Tesis Doctoral (sin publicar) . Universidad de La Laguna. 342 pp.

Oromí, P., E. Muñoz, N. Zurita & S. de la Cruz. 2000. *Conservación de la fauna invertebrada cavernícola de las islas de Tenerife, La Palma y El Hierro.* 3er informe. Dto. De Biología Animal-Universidad de La Laguna. 248 pp.

Pressey, R. L., I.R. Johnson & P.D. Wilson. 1994. Shades of irreplaceability: measuring the potential contribution of sites to a reservation goal. *Biodiversity and Conservation* 3:242-262.

Vane-Wright, R.I., C.J. Humphries & P.H. Williams. 1994. What to protect?-Systematics and the agony of choice. *Biological Conservation* 55:235-254.

Rapoport, E.H., G. Borioli, J.A. Monjeau, J.E. Puntieri & R.D. Oviedo. 1986. The design of nature reserves: a simulation trial for assesing specific conservation value. *Biological Conservation* 37:269-290.

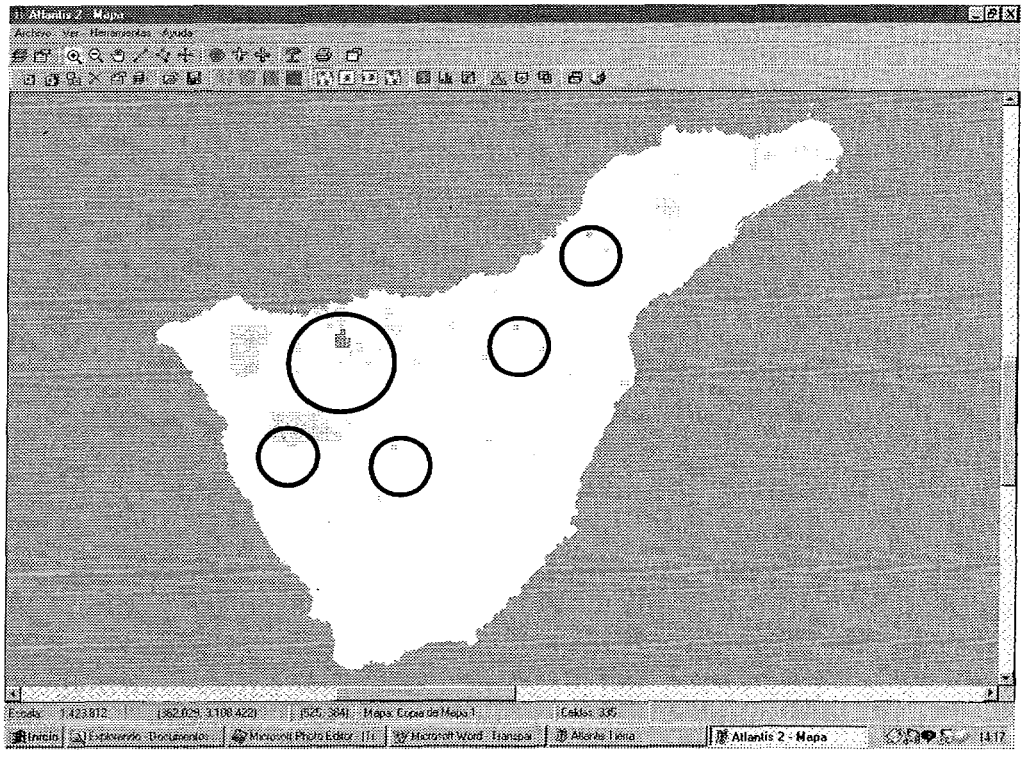


Fig. 1. Map of Tenerife with the most important sites of species richness.

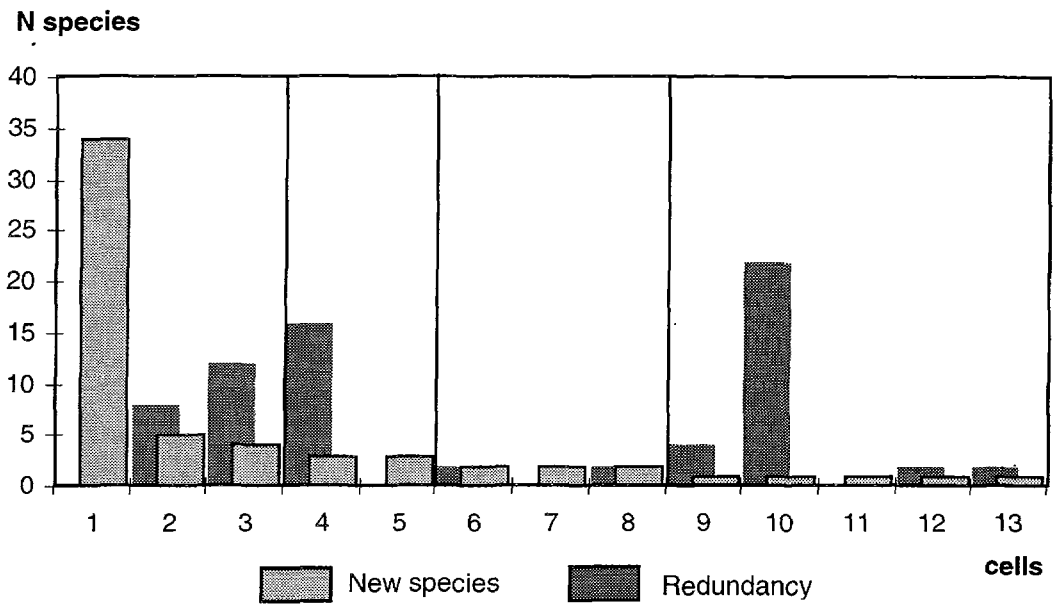


Fig. 2. Selected cells by the complementary priority-cells analysis. The light bars show the number of different species (new species) respect to last selected cell or group of cells. Dark bars show the number of redundant species.

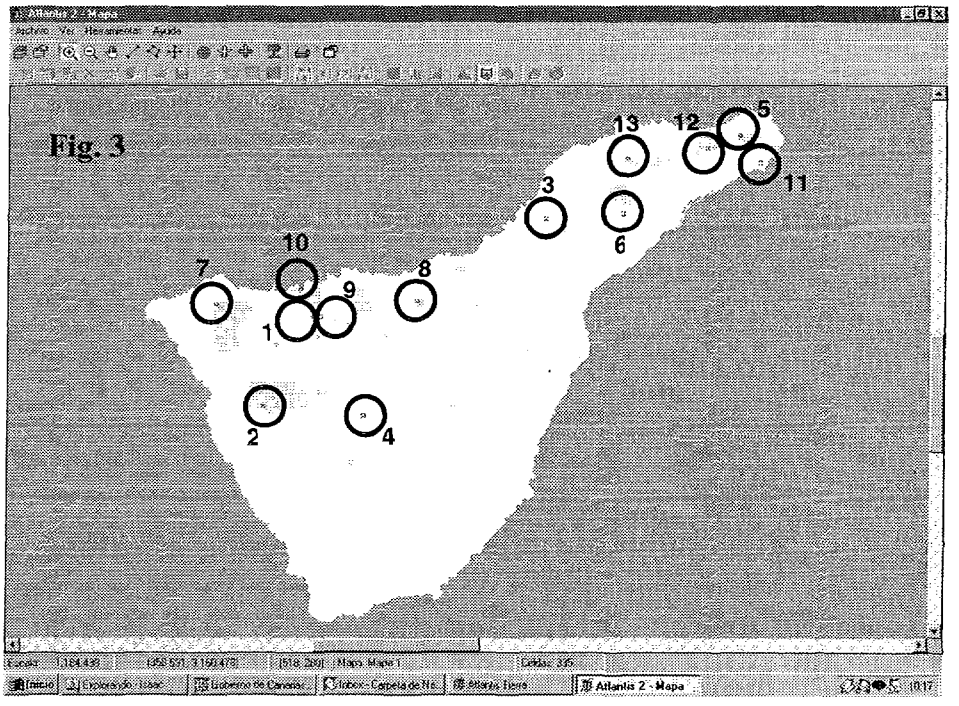


Fig. 3. Map of Tenerife with the conservation priority cells. The numbers show the priority order.

Creation and development of the biospeleological database in Croatia

Sanja Gottstein Matočec, T. Bakran-Petricioli

Department of Zoology
Faculty of Science
University of Zagreb
Rooseveltov trg 6
10000 Zagreb
Croatia

Branko Jalžić

Croatian Biospeleological Society
Demetrova 1
10000 Zagreb
Croatia

N. Matočec

Ruđer Bošković Institute
Bijenička 54
10001 Zagreb
Croatia

Roman Ozimec, Donat Petricioli

Croatian Biospeleological Society
Demetrova 1
10000 Zagreb
Croatia

The hypogean fauna of Dinarides is one of the richest faunas in terms of the world subterranean biodiversity. When in natural state, caves in Croatia have high aesthetic and scientific value, but unfortunately they all can be too easily damaged. Necessity for protection of the caves and cave life in Croatia against destruction is great and at the present time we can recognise a high number of present destructive anthropogenic factors. These facts are compelling arguments for designating important caves as sites of special scientific and public interest. Only through well-developed Biospeleological database we could properly analyse and evaluate the biodiversity of Croatian undeground and propose suitable conservation measures for the richest and/or most important caves. Mapping subterranean biodiversity in Croatia will bring new data concerning the geographical distribution of habitats and species as well as their vulnerability and ecological affinities. Also, it will point towards human activities harmful to the underground, which should be modified. It will also serve as the base for design of protection measures concerning the Croatian hypogean fauna.

The results of our preliminary researches on Croatian Biospeleological Database (CBSD) are widely applicable to zoogeography as well as to ecology. During the last decades of our systematic research, different kinds of pollution, physical habitat alterations and non-scientific collecting have reduced and deteriorated many populations of hypogean fauna and consequently some taxa have became extinct and some populations have decreased. On the other hand, most of the sea areas in Croatia were poorly explored for cave species, and consequently we lack data on their vulnerability.

Croatia has long history of biospeleological research. Numerous papers and authors gave abundant contributions on Croatian underground fauna (Gottstein & Lebreton, 1999, Gottstein et al. 2001). Input data were accumulated from a variety of literature sources and from our own sampling in

Croatia and from neighbourhood countries (Slovenia, Italy, Bosnia & Herzegovina, etc.). As integral parts, database contains a list of endemic taxa, Red list and corresponding biospeleological bibliography. Treatment of endemic status in CBSD is based on two criteria. The first one is geographical and it assigns the endemic status to the frame of political boundary (Republic of Croatia), while the second one considers the range of each taxon (e.g. Dinaric region). Check list of Croatian hypogean fauna for the first time will summarize the national hypogean fauna.

Habitat alterations are considered to be a major cause of threats to the underground fauna. Some of the habitats were destroyed by water regulations for hydroelectric power plants, causing water level fluctuations in some cave systems (e.g. Đula-Medvedica cave system, Kordun region). High levels of organic pollution and increased pesticide concentration from agricultural areas (Istria and Dalmatia) also cause changes in habitats and may change the composition of the hypogean fauna (Sket, 1997, 1999). Inferior water quality caused by different sources of pollution is another major problem (Radović, 2000). The hypogean drainage directions are often reticulate and this might be the reason for cave water pollution coming from unpredicted water bodies (Sket, 1997). Pollution from domestic sources, pollution from diffuse sources and industrial pollution cause reduction of some underground species populations and/or their extinction [e.g. *Protelsonia hungarica thermalis* and *Balkanostenasellus skopljensis croaticus* (Isopoda, Stenasellidae) from interstitial habitats in Zagreb; *Dendrocoelum subterraneum* Komarek, 1919 (Turbellaria) from Đula – Medvedica cave in Ogulin surrounding] (Tvrtković, 2001). Small caves regulated for tourism and situated in urbanized area are the most endangered caves in Croatia (Šipun, Pišurka, Biserujka). Anhialine caves, marine coastal caves and coastal springs are particularly subjected to deteriorating local human impact.

We expect that future research on the subterranean life will reveal even more endemic species in Croatia. On the other hand, if the adverse trends observed on the population level will be continued it could reflect even to the species level, and therefore a substantial portion of underground species may become extinct before being described by science.

Relevant information about anthropogenic impact and environmental change in Croatian hypogean habitats should be given directly to the Ministry of Environmental Protection and Physical Planning in Croatia, and information should be also made public on the national TV-channel. The most important issue is to understand the subterranean life as a valuable and vulnerable world biodiversity resource, and improve the public knowledge and awareness of this specific problem. In light of all previously mentioned facts we will initiate the continuation of the present project aimed to protect the most endangered hypogean species and most important karstic and alluvial areas in Croatia.

Modification of the structure of water courses, water extraction, irrigation or other hydrological changes, storage of waste material in potholes, caves or their entrances and building of the man-made structures or engineering works in vicinity of the cave area have been the major causes of endangering. Therefore all remaining natural hypogean habitats should be strictly protected by the Ministry of Environmental Protection and Physical Planning in Croatia to prevent their further destruction.

In the future work the CBSD will not serve only as a checklist of underground organisms and for taxonomical and nomenclatural research but also as a standard for practical and theoretical application in different zoological fields and other areas. It will promote a more productive relationship among the previous knowledge of underground biodiversity, current population status of each species, environmental changes, type of eventual anthropogenic impact, and suitable conservation.

In light of our protective efforts, this presentation brought further recommendations towards planned goals:

1. Educatiional leaflets and a poster would be produced and distributed in large numbers.
2. Local citizens must be encouraged to help make decisions about the future of underground habitats.
3. Relevant information should be constantly given on the national TV-channel.
4. Reduction of chemical fertiliser and pesticide use must be one of the main priorities.
5. Traditional farming and agricultural activities must be promoted by various stimulating measures.
6. Regime of use, visiting and exploration of caves must be strictly regulated by means of regular inspections and other measures.
7. Establishment of the status of Biospeleological Reserve and Biospelelological Natural Monument for

most important caves in view of their biodiversity and endemism.

References

Gottstein, S., & Lebreton, B., 1999, Croatian biospeleology bibliography. *Bibliographie biospéologique de la Croatie*. World Wide Web URL: [http://members.aol.com/blpays/croatie.htm]. 23.XII.1999.

Gottstein, S. (ed.), Bakran-Petricioli, T., Bedek, J., Bukovec, D., Buzjak, S., Franičević, M., Jalžić, J., Kerovec, M., Kletečki, E., Kovačić, M., Kralj, J., Kružić, P., Kučinić, M., Kuhta, M., Matočec, N., Ozimec, R., Rađa, T., Štamol, V., Ternjej, I. & Tvrtković, N., 2001, Croatia. In: Juberthie, C. & Decu, V. (eds.) *Encyclopaedia Biospeologica. III.* Société de Biospéologie, Moulis (in press).

Radović, J. [ed.]. 2000. *An Overview of the State of Biological and Landscape Diversity of Croatia with the Protection Strategy and Action Plans.* Ministry of Environmental Protection and Physical Planning, Zagreb, 158 pp.

Sket, B., 1997, Biotic diversity of the Dinaric karst, particularly in Slovenia: history of its richness, destruction, and protection. In: Sasowsky, I. D., Fong, D. W. & E. L. White (eds) *Conservation and Protection of the Biota of Karst.* Karst Waters Institute, Washington D. C. Special Publication 3: 84-98.

Sket, B., 1999, The nature of biodiversity in hypogean waters and how it is endangered. *Biodiversity and Conservation* 8: 1319-1338.

Tvrtković, N., 2001. Threatened fauna of Croatia, pp. 45-75. In J. Balabanić, I. Grbac, D. Holcer, M. Šašić, and N. Tvrtković [eds.], *Survival or extinction? Exhibition catalogue* (in Croatian with English summary). Croatian Natural History Museum, Zagreb.

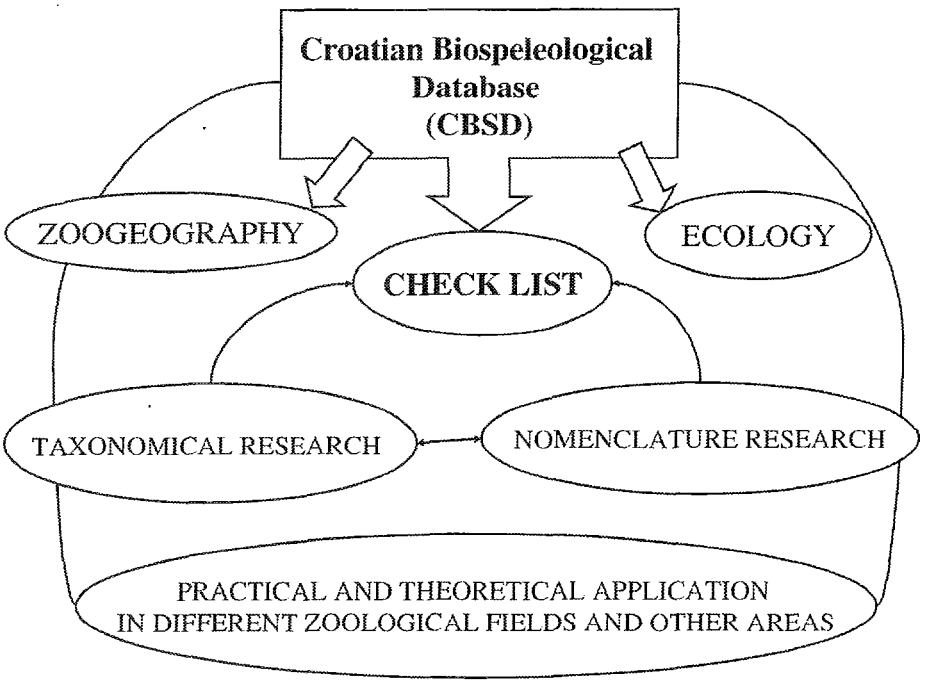


Fig. 1. Potential products of Croatian Biospeleological Database (CBSD).

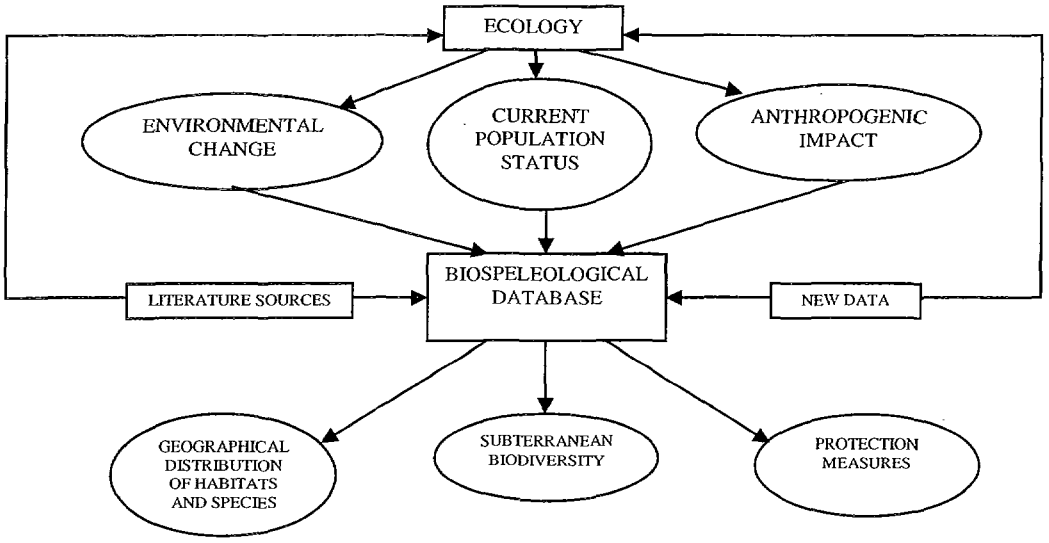


Fig. 2. Output and input data relations in data processing.

WORKSHOP SESSION 3

STATUS REPORTS

Synopsis

The purpose of this session was to report on the status of data, data collection, mapping progress, by country and by taxonomic group.

Christian Juberthie provided a overview of taxonomic knowledge by habitat and by geographic region. Among the patterns are the absence of the MSS (milieu souterrain superficial) from the tropics and possibly from the southern hemisphere. It is also rare and/or poorly known in North America. There are approximately the following numbers of stygobites and troglobites from various regions:

- North America—1000
- Europe—5000
- Africa—500
- Asia—1200

About 8000 obligate subterranean species have been described world-wide. In terms of conservation, at least in Europe bats have received the most attention and invertebrates have been generally ignored. In Ariege, France, 23 sites, including caves, MSS, and the interstitial are being protected.

A question was asked about where the greatest future biospeleological discoveries will be made. Juberthie answered that it will be in areas where the political situation has prevented cave access. Generally there is great potential in Oceania, Asia, and possibly Mars! The question about the effectiveness of gating caves was raised. Juberthie replied that gates were often ineffective because they were frequently breached.

Arthur Clarke spoke about the database for the Tasmanian subterranean fauna. There are about 4000 known caves in Tasmania, and karst covers about 3500 mi^2, about 5 % of the land area.

Three relational databases were used:

- taxonomic
- geographic information
- occurrence and collection information

Among the fields were species id number, cave number, collector, date of collection, reference, habitat, etc. The database includes 460 caves with 630 invertebrate species, including obligate, facultative, and accidental species. The database is tied to the IUS. Problems with the database include taxonomic fields are not detailed enough for higher order taxonomy, ecological status is not given, and much of the data are old. He proposed the following minimum fields for cave records:

1. taxonomic description
2. collection detail
3. ecological status
4. significance (type, etc.)
5. identifier and lodgement
6. map reference
7. datum, UTM zone
8. location (suppressed for general access)
9. recorder and date
10. data source

A comment was made that taxonomists should not be relied on for ecological status. A question was raised as to the number of obligate cave species in Tasmania. Clarke replied that it was about 300.

Graham Proudlove spoke about subterranean biodiversity in the United Kingdom, a report of which is appended. In general, the UK is a subterranean biodiversity cold spot, in large part due to the Pleistocene glaciations which covered the country. Food supply may also play a role. Of subterranean habitats, caves are the best known. Data are housed nationally with the British Cave Research Association records. While there are only a handful of stygobites and troglobites, the fauna is interesting because it affords an opportunity to study colonization and evolution in action. There is a rich fauna of troglophiles, stygophiles, and accidentals. Future work should target particular habitats such as the phreatic and particular taxa, especially Collembola, mites, and Diptera. The extensive groundwater has not been thoroughly or recently sampled. Because the fauna is recent, it may prove particularly interesting to look for sibling species based on DNA analysis.

Fabio Stoch gave a status report of the mapping of subterranean biodiversity in Italy. A report, combined with a description of the database, is appended to Workshop Session 2. The Italian fauna database is very large, including 57,408 species, 3742 subspecies, and 250,000 records. There are approximately 900 exclusively subterranean species and subspecies, approximately evenly divided between cave troglobites, MSS (milieu souterrain superficial) troglobites, and stygobites. There were approximately 12,000 records of subterranean species.

Preliminary mapping of 5000 species showed island effects, hot spots, and biases around population centers that have been better collected. The basic mapping unit used was 10 km by 10 km UTM squares. Most subterranean species were found in less than 10% of the squares. Areas of high subterranean biodiversity included northern Italy, the western most part of the Balkans, Sardinia, among others. History rather than ecology seems to be more important in determining hotspots.

A series of conservation issues are important. The Natura 2000 Habitat Directive lists no subterranean forms except for bats and *Proteus anguinus.* Given the high levels of endemism, protection at the generic level might be a first priority.

Some questions were raised about the completeness of the geographic patterns presented given that it was just a sample of the species. Others pointed out that it was such a large sample that it was unlikely to change substantially.

Mohamed Messouli gave a status report on subterranean biodiversity in Morocco. A summary is appended. There is about 100,000 km^2 of limestone in the country. It is rich in troglobites but there are few data. For stygobites, the situation is somewhat better. Copepods are widespread but poorly studied. Amphipods are better studied, with six genera whose distribution is well known. There are about 50 stygobites, 10 of which are described.

Graham Proudlove spoke about diversity of subterranean fishes, a summary which is appended. Cave fishes are concentrated in the tropics. There are no cave fish in Europe. Cave fishes are found in 30 countries with a total of 85 species. Twenty four genera are restricted to hypogean habitats. Countries with the most fish are China, Mexico, Brazil, USA, and Thailand. The southern hemisphere has only 22% of the species. Forty-six of 85 species are known from a single site. Seventeen sites have more than one species. Of the 85 species, 76 are threatened. He predicted, based on a curve-fitting model, that there might be 250 species described by 2050.

The question was asked why there were no cave fishes in Europe. Proudlove replied that it was likely in part due to glaciation and the short time available for colonization.

Stéphane Blondeau spoke about mapping *Niphargus* distribution. A summary of this work is appended. The distribution of the 25 species of the amphipod *Niphargus* that are found in France were studied. This was based on the extensive records of Professor Ginet. The database used was 4th Dimension 6.5.4 and the GIS software was ArcView™. The database included information on abundance, location, collector, altitude, taxonomy, and remarks. The distribution of *N. rhenorhodanensis* and *N. virei* were considered in detail. Even through they are found in the same general region, their distributions are quite different. The distribution of *N. virei* was split by glaciation and the distribution of *N. rhenorhodanensis* corresponds to the shoreline of Miocene seas.

Eleonora Trajano spoke about mapping subterranean biodiversity in Brazilian karst areas. Biospeleological research in Brazil began in the 1970's. There is a serious scarcity of taxonomic specialists. Thus, 40% of the taxa have only been identified to the family level. About 5 to 7% of the land area of Brazil is karst—about 500,000 km^2. About 10% of the known caves have been surveyed for fauna. About 350 species (troglobites, troglophiles, trogloxenes, stygobites, stygophiles, and stygoxenes) have been found. Terrestrials far exceed aquatic species in all karst areas. In general subterranean biodiversity is related to subterranean habitat diversity and available of organic matter. For stygobites and troglobites, historical factors seem to be important, not necessarily revealed by analysis of present conditions. Hotspots of general subterranean biodiversity do not correspond to hotspots of diversity of stygobites and troglobites.

A question was asked about whether the subterranean fauna of any non-cave area had been studied, and Trajano responded that none had been studied. Culver asked about a comparison of Brazilian and southeast Asian caves, a tropical area of high biodiversity. Deharveng replied that there were few trogloxenic and stygoxenic species except where large rivers sank. It was difficult to say anything about the troglophiles and stygophiles. Trajano was asked if there were any data on the interstitial and she replied that there wasn't.

Abel Perez Gonzalez spoke about the subterranean fauna of Cuba. A report by Gonzalez and Yager is appended. A total of 111 troglobites are known from Cuba—57 aquatic and 54 terrestrial. Of the aquatic species, 52 are Crustacea, 4 are fishes, and one is a mite. Of the terrestrial species, 30 are arachnids, 21 are insects, and 3 are myriapods. During the last 10 years, 15 new species have been described. A total of 328 caves have been sampled and there were 850 reports of fauna from these caves.

Subterranean biodiversity in the British Isles

Graham S. Proudlove

British Cave Research Association Biological Recorder
Department of Zoology
The Manchester Museum
Manchester University,
Manchester M13 9PL
United Kingdom

The collection of fauna from British hypogean habitats began in the mid-19th century, although the main period of interest was from the 1930s to the 1970s. Since the 1970s there has been little systematic collection undertaken. Nearly all of the fauna were collected by amateurs and little cave biology was undertaken by professional biologists. In most instances animals were collected sporadically and without any clearly defined plan. Specimens were sent to the Biological Recorder of the Cave Research Group of Great Britain (Mary Hazelton) who assured that they were accurately and authoritatively identified by experts in the relevant group. Thus there is some degree of confidence that most identifications are correct. The records were published, with collectors name and site details (National Grid Reference), in 16 parts (Hazelton 1955 and following), covering the collection of fauna from caves, other accessible passages (mines and tunnels), and some groundwaters between 1938-1976. Some analysis and historic reviews have been undertaken for subterranean community data (Hazelton and Glennie 1962, Jefferson 1976 and Chapman 1993), and for specific regions e.g., Yorkshire (Dixon 1974), Mendip (Hazelton 1975), Derbyshire (Hazelton 1977) and Wales (Jefferson 1989). The fauna from the threshold zone of British caves have been reviewed by Jefferson (1983) and the accidental and possible troglophilic fishes have been summarised by Proudlove (1982). All of the published studies above concentrate on caves to the exclusion of groundwaters. Recently a new phase of hypothesis driven collection and analysis has been initiated (*e.g.* Gunn et al. 2000).

The only easily accessible data are those published (on paper) as the "Biological Records" and these have two major drawbacks. First, the data are recorded under the name of the collector and it is not possible to do either site searches or taxon searches without looking through the whole data set. A partial index to sites is available (Howes 1994) but this only covers parts 1-9 (of 16) issues of the Records. A list of sites within vice-counties also exists. Second, there are a number of errors and duplications in the published data so that it is not possible to rely on any analyses undertaken. Clearly a computer database of these records, suitably corrected for errors, is the prime requirement of cave biologists in the UK. Table 1 indicates the number of caves and mines sampled in each geographical area together with the total number of hypogean sites. About 400 caves have been sampled, from in excess of 3000 (Hardwick and Gunn unpublished database). There are many more publications regarding British hypogean biology, but relatively few systematic studies; Edington (1977) and Chapman (1979) being notable exceptions for caves, and Gledhill (1977) for *Niphargus* species in groundwaters. Most attention has been devoted to faunal groups and little is known about cave flora (summarised and reviewed by Cubbon 1970, 1976). The number of groundwater sites sampled historically is low.

The most diverse group recorded in caves are the troglophilic/stygophilic taxa and there are relatively very few troglobites/stygobites. This is most frequently attributed to the effects of the Pleistocene glaciations. While most of east and south of the country remained clear of ice during the Devensian glaciation, the Anglian covered the land northward of a line roughly between the R. Severn and R. Thames. The accidentals are obvious: Ephemeroptera and Plecoptera nymphs and Trichoptera larvae are good examples. Troglophile status is accorded to many species because morphologically similar forms are known from surface and hypogean habitats. It seems likely that most of these are true cases of troglophilly, but it is possible that some populations are actually reproductively isolated from surface members and are *de facto* troglobites but unrecognisable as such. The picture that emerges from the existing records indicates a community dominated by trogloxenes and troglophiles. However, as Chapman (1993:115)

states: "Our cave fauna is in a dynamic phase of colonisation and adaptation ... There is thus enormous scope in our caves for research into the process of cavernicolous evolution." The most important members of terrestrial cave communities are Collembola, mites and Diptera. Aquatic communities are dominated by the stygobitic crustacea in the south but in the north the most common animal is the troglophilic amphipod *Gammarus pulex*.

The following list indicates the fauna restricted to hypogean habitats in the British Isles:
Crustacea (Syncarida: *Antrobathynella stammeri*, Isopoda: *Proasellus cavaticus*, Amphipoda: *Niphargus fontanus, N. glennei, N. aquilex, N. kochianus, N. wexfordensis, Crangonyx subterraneus,* Ostracoda: possibly a few species), Insecta (Collembola: *Archaphorura schoetti, Pseudosinella dobati, Disparrhopalites patrizii*, Coleoptera: *Hydroporus ferrugineus, H. obsoletus,* Diptera: *Speolepta leptogaster, Limosina racovitzai*), Arachnida (Aranaea: *Porhomma rosenhaueri*, Acari: *Eugamasus tragardhi, E. anglocavernarum, Rhagidia longipes, R. vitzthuni* (?), *Troglocheles* sp., *Bonzia brownei*). The following interstitial acari have also been recorded: *Azugofeltria motasi, Vietsaxona lundbladi, Neoacarus hibernicus, Hungarohydracurus subterraneus, Wandesia racovitzai, Atractides latipalpis.*

There has recently been a resurgence of interest within the UK and some very interesting and important contributions are beginning to appear (*e.g.*, Gunn et al. 2000). This work is a multidisciplinary combination of hydrology, geomorphology, chemistry and biology. Future work on the distribution of stygobitic crustacea, within a framework of landscape history, is likely to lead to significant and surprising results. The outcome of the Moulis meeting will help to determine the way forward for a UK cave-biota database. Together with ongoing discussions with the Biological Records Centre this should lead to an improved knowledge of the British hypogean fauna. Very little is known regarding the flora of UK caves. Examples of bacteria, actinomycetes, fungi, algae, lichens and higher plants have all been recorded. The pioneering work of Mason-Williams and Benson-Evans (1958) should form the basis for further research. Investigations of groundwaters are necessary, both the large scale reservoirs of chalk aquifers, and the hyporheos of streams.

I thank Paul Harding, for letting me use his hypogean crustacea distribution data in Figure 1. Also Tony Waltham for permission to use his excellent map. Paul Wood made valuable comments on the text.

References

Chapman, P. 1979. The biology of Otter Hole, near Chepstow. *Transactions of the British Cave Research Association* 6:159-167.

Chapman, P. 1993. *Caves and cave life*. Harper Collins, London.

Cubbon, B.D. 1970. Flora records of the Cave Research Group of Great Britain from 1939 to June 1969. *Transactions of the Cave Research Group of Great Britain* 12:57-73.

Cubbon, B.D. 1976. Cave flora, chap. 11. In T.D. Ford and C.H.D. Cullingford [eds.], *The Science of Speleology*. Academic Press, London.

Dixon, J.M. 1974. Biospeleology in Northwest England. chap. 9. In A.C. Waltham [ed.], *Limestones and caves of Northwest England*. David and Charles, Newton Abbot.

Edington, A. 1977. Biospeleology in Dan-yr-Ogof. *Transactions of the British Cave Research Association* 4:331-341.

Gledhill, T. 1977. Numerical fluctuations of four species of subterranean amphipods during a five year period. *Crustaceana Supplement* 4:144-152.

Gunn, J., P. Hardwick, and P.J. Wood. 2000. The invertebrate community of the Peak-Speedwell cave system, Derbyshire, England - pressures and considerations for conservation management. Aquatic Conservation: *Marine and Freshwater Ecosystems* 10:353-369.

Hazelton, M. 1955 and following. *Biological Records of the Cave Research Group of Great Britain.* Biological Supplements 1-5 (years 1938-1953), Biological Records 6-9 (years 1954-1963), Hypogean fauna and Biological Records 10-16 (years 1964-1076).

Hazelton, M. 1975. The biology of Mendip caves, chap. 7. In D.T. Smith [ed.] *Limestones and caves of the Mendip Hills*. David and Charles, Newton Abbot.

Hazelton, M. 1977. Life underground – Biospeleology, chap. 13. In T.D. Ford [ed.], *Limestones and caves of the Peak District*. Geo Books, Norwich.

Hazelton, M. and Glennie, E.A. 1962. Cave fauna and flora, chap. 9. In C.H.D. Cullingford [ed.], *British caving: An introduction to speleology. 2nd edition*. Routledge and Kegan Paul, London.

Howes, C. 1994. Index to the Biological Supplements and Records of the Cave Research Group of Great Britain, 1-9, 1955-1965. *Proceedings of the University of Bristol Speleological Society* 20:15-41.

Jefferson, G.T. 1976. Cave fauna, chap. 10. In T.D. Ford and C.H.D. Cullingford [eds.], *The science of speleology*. Academic Press, London.

Jefferson, G.T. 1983. The threshold fauna. *Studies in Speleology* 4:53-58.

Jefferson, G.T. 1989. Cave biology in South Wales, chap. 5. In T.D. Ford [ed.], *Limestones and caves of Wales*. Cambridge University Press, Cambridge.

Mason-Willimas, A. and K. Benson-Evans, 1958. *A preliminary investigation into the bacterial and botanical flora of caves in South Wales*. Cave Research Group, Numbered Publication No. 8.

Proudlove, G.S. 1982. Cave life. Part 2 cave fishes. *Caves and Caving* 15:6-7.

Table 1. British caves and mines sampled for fauna.

Region	Total caves *	Sampled caves #	%	Sampled mines/other #
Yorkshire Dales	1420	81	6	22
N. Pennines	620	50	8	21
Derbyshire	210	56	27	+
S. Wales	270	35	13	3
Mendip	220	53	24	8
Forest of Dean	~60	7	12	7
Devon	124	39	31	13
N. Wales	~60	7	12	5
Scotland	176	19	11	7
Clare	246	11	4	0
Fermanagh	483	9	2	0
Other	c100	3	3	10
Totals	3989	370	9	96

* Data from Hardwick and Gunn (unpublished database), Self (1981) Clare. Jones et al. (1997) Fermanagh, Ebbs (2001) Wales

Data from Hazelton (1955 and following), using unpublished index (Proudlove unpublished)

+ Most mines intersect natural passage

The status of subterranean biodiversity in Morocco

Mohamed Messouli

Lab. Hydrobiologie
Fac. Sciences Semlalia BP
2390 Marrakesh
Morocco

Morocco, because of its geological traits is a country particularly rich in caves, with some 100,000 km^2 of limestone and calcareous sandstones, and about 1000 known caves. Caves habitats are potentially rich in species. Some unstudied groundwater and permanent caves have rich organic matter input from the surface and seem to have high productivity. In fact a relatively large number of terrestrial species have been recorded from caves, done on occasional visits from speleologists, often coming from Europe or other countries, to Moroccan caves. The efforts and methods used for these collections were very variable and different from one region to another. A first synthesis was given in the third volume of the "Encyclopaedia Biospeologica" (in press). Finally the mapping of terrestrial subterranean diversity has to be restricted to Coleoptera, which are widely distributed and represented by more than 50 species including 20 troglobites.

For the aquatic subterranean fauna the situation seems to be quite different. Only a few collections from caves are available, as the main aquatic subterranean environments studied are wells and springs, which remain largely used in many parts of the country to access to the underground water. Sampling springs (karstic or not) and the interstitial milieu (when it is not filled in) have provided good results. Some regions are relatively well known because they are near an University (Marrakech and more recently Fes) or because they were the field of local studies in subterranean ecology leading to doctorate thesis (Errachidia, Guelmim, Tiznit and Agadir). Other regions of the country have been occasionally in the context of more extensive research aiming at the knowledge of the biogeographic range of some stygobiontic species.

One of the main groups within stygobiontic communities are the Crustacea. Some groups such as copepods and ostracods are largely distributed in Moroccan groundwaters but remain still poorly known (because not studied by specialists) therefore they cannot be mapped to date. Conversely Malacostraca, especially stygobiontic peracarids and syncarids may be mapped, especially amphipods and isopods, but also syncarids and pancarids.

A provisional taxonomic list of terrestrial troglobites or troglophiles, stygobites or stygophiles found in different Moroccan subterranean environment, with the number of taxa in brackets:

Terrestrial:
- Isopoda Oniscidea (3)
- Pseudoscorpiones (4)
- Araneae (7)
- Acari (4)
- Diplopoda (4)
- Chilopoda (4)
- Collembola (8)
- Diplura (1)
- Psocoptera (1)
- Coleoptera (56 including 20 endemic troglobites)
- Chiroptera (27 troglophiles)

Aquatic:
- Foraminifera (1)
- Oligochaeta (15)
- Gastropoda (35 including 5 stygophiles)
- Copepoda (10)
- Ostracoda (6)
- Isopoda: Cirolanidae (15), Microcerberidae (2), Microparasellidae (4)
  Stenasellidae (1 or 2) Asellidae (2)
  Microcerberidae (2)
- Amphipoda: Salentinellidae (1),
  Bogidiellidae (3),
  Pseudoniphargidae (15)
  Metacrangonyctidae (35),
  Gammaridae (2 stygophiles)
  Syncarida (1 or 2)
- Thermosbaenacea (2)

The diversity of subterranean fishes

Graham S. Proudlove

British Cave Research Association Biological Recorder
Department of Zoology
The Manchester Museum
Manchester University
Manchester M13 9PL
United Kingdom

Although subterranean fishes had been seen on several occasions in the preceding centuries it was not until 1842 that the first true hypogean fish was formally identified, described and named. It was *Amblyopsis spelaea* from Mammoth Cave in Kentucky (and the specimen described was probably collected by Stephen Bishop). Since then fishes have been discovered in hypogean environments in many other areas and there are now 85 described species. There are a number of known, but undescribed hypogean fishes and the current total is around 100 species. It is possible that there will be 250 species described by 2050 (Fig. 1). This is about 0.4% of all fish diversity and 1% of freshwater fish diversity. Since most studied hypogean habitats are caves in continental karst areas it is not surprising that most hypogean fished are derived from freshwater ancestors. Only a few species are derived from marine invaders. Hypogean species are highly endemic: 46 species are known only from their type localities, 24 genera are hypogean restricted and 20 genera are monotypic hypogean restricted. No less than 73 species are classed as Vulnerable by The International Union for the Conservation of Nature and Natural Resources (IUCN), and 3 critically endangered. There are 14 instances where two species coexist in the same hydrological system, and three where three species coexist.

Tables 1, 2 and 3 show how cave fishes are distributed in the countries (political divisions) of the world, major land masses, and degree of latitude, respectively. Figure 2. shows this distribution. In these tables the species are referred to by two letter codes. There is insufficient space here to include full specific names but these can be obtained from the author. About 50% of all species are from just 5 countries, with the other 50% from 25 countries. The 5 main countries have enormous areas of karst and therefore opportunity for cave development and colonisation by fishes.

Summaries of the distribution and biology of hypogean fishes can be found in Thines (1969), Thines and Proudlove (1986), Weber et al. (1998) and Weber (2000). Their conservation status is covered by Proudlove (2001).

References

Proudlove, G.S. 2001. The conservation status of hypogean fishes. *Environmental Biology of Fishes* 62:1-13.

Thines, G. 1969. *L'evolution regressive des poissons cavernicoles et abyssaux.* Masson et Cie, Paris.

Thines, G. and Proudlove, G.S. 1986. Pisces. In: Botosaneanu, L. (ed.) *Stygofauna Mundi.* Brill, Leiden.

Weber, A., Proudlove, G.S. and Nalbant, T.T. 1998. Morphology, systematic diversity, distribution, and ecology of stygobitic fishes, pp. 1179-1190 and 1207-1213. In C. Juberthie and V. Decu [eds.], *Encyclopedia Biospeologica.* Societe de Biospeologie, Moulis and Bucarest.

Weber, A. 2000. Fish and Amphibia, pp. 109-132. In H.Wilkens, D. Culver, and W. Humphreys [eds.] *Subterranean Ecosystems.* Elsevier, Amsterdam.

Table 1. Distribution by country. Species are abbreviated by the first letter of genus and species.

Country	Species	%	Date of first described species
China	Tn/Sa/Sn/Sm/Sg/Sh Sc/Oa/Tg/Tx/Ty/Th Pb/Py/Pt	18	1979
Mexico	Aj/Aa/Pp/Pl/Rr/Rz Rm/Op/Pm/Oi	12	1936
Brazil	St/Pc/Pk/Ti/Ac/Af Ev	8	1907
USA	Tp/Se/As/Ar/Ts/Sp	7	1842
Thailand	Ps/Nt/Ct/So/Sj/Pm	7	1988
India	Ss/Ie/Hk/Me/Mr	6	1950
Cuba	Ls/Ld/Li/Lt	5	1858
Somalia	Pa/Bd/Uz	4	1923
Madagascar	Tm/Ta/Ga	4	1933
Iran	It/Ns	2	1944
Iraq	Tw/Cb	2	1955
Oman	Gb/Gd	2	1984
Australia	Mv/Oc	2	1945
Japan	Lp/La	2	1940
Zaire	Cg	1	1921
Trinidad	Rq	1	1926
Namibia	Cc	1	1936
Venezuela	Ag	1	1994
Ecuador	Ap	1	1962
Galapagos	Og	1	1965
Bolivia	Tc	1	1968
Bahamas	Ll	1	1970
Belize	Rl	1	1982
Turkmenia	Tt	1	1983
Malaysia	Si	1	1990
Philippines	Cr	1	1991
Peru	Ai	1	1994
Papua New Guinea	Oe	1	1996
Vietnam	Ph	1	1998
Laos	Tk	1	1999
30 countries	85 species	1842-1999 (157 years)	

Table 2. The distribution of hypogean fishes on the major land masses of the earth. [*1] Includes Trinidad and Galapagos, [*2] Includes Madagascar, [*3] Includes the Antilles and the Bahamas. Species are abbreviated by the first letter of genus and species

Land area	Species	Total	%
China	Tn/Sa/Sn/Sm/Sg/Sh/Sc/Oa/Tg Tx/Ty/Th/Pb/Py/Pt	15	18
S. America[*1]	St/Pc/Pk/Rq/Tc/Ti/Ac/Ag/Af Ap/Ai/Ev/Og	13	15
C. America	Aj/Aa/Pp/Pl/Rl/Rr/Rz/Rm/Op Pm/Oi	11	13
S.E. Asia	Ps/Tk/Nt/Ct/So/Sj/Si/Ph/Pu Cr/Oe	11	13
Africa[*2]	Cg/Pa/Bd/Cc/Uz/Tm/Ta/Ga	8	9
N. America	Tp/Se/As/Ar/Ts/Sp	6	7
Arabia	It/Tw/Cb/Gb/Gd/Ns	6	7
Caribbean[*3]	Ls/Ld/Ll/Li/Lt	5	6
India	Ss/Ie/Hk/Me/Mr	5	6
Australia	Oc/Mv	2	2
Japan	Lp/La	2	2
C. Asia	Tt	1	1
Total		85 species	

Table 3. The distribution of hypogean fishes by degrees of latitude. [*] and [+] indicates that *Typhlichthys subterraneus and Lucifuga spelaeotes* respectively span more than 5° of latitude and the former is the species with the largest known distribution. The location of one species (*Pterocryptis cucphuongensis*, Siluridae) is not known beyond 'North Vietnam'. It is included in the total for the northern hemisphere but not placed by latitude. Species are abbreviated by the first letter of genus and species.

Latitude	Species	Total	%
36°- 40°N	As/Lp/La/Ts[*]	4	5
31°- 35°N	It/Tw/Cb/Ns/Ar/Sp/Ts[*]	7	8
26°- 30°N	Sc/Tp/Sc/Pp/Ll[+]	5	6
21°- 25°N	Aj/Gb/Tn/Sa/Sn/Sm/Sg/Sh/Oa/Tg/Tx/Ty Th/Ss/Py/Pt/Pl/Ls/Ld/Li/Lt/Pb/Ll[+]	23	27
16°- 20°N	Gd/Ps/Ct/So/Sj/Ie/Rl/Rr/Rz/Op/Pm/Oi/ Aa/Tk/Rm	15	17
11°- 15°N	Tt/Cr/Nt/Pu	4	5
6°- 10°N	Bd/Hk/Rq/Me/Ag/Mr	6	7
0°- 5°N	Pa/Si/Uz	3	4
---------- Equator ----------			
0°- 5°S	Cg/Pc/Ap/Og	4	5
6°- 10°S	Ai/Oe	2	2
11°- 15°S	Ac/Ti/Ev/Ga	4	5
16°- 20°S	St/Cc/Tc	3	4
21°- 25°S	Pk/Oc/Tm/Ta/Mv/Af	6	7

Mapping *Niphargus* distribution in France

Stéphane Blondeau and Janine Gibert

Laboratoire d'Ecologie des Hydrosystèmes Fluviaux
Equipe d'Hydrobiologie et Ecologie Souterraines
Université Claude Bernard Lyon1
43 Bd du 11/11/1918
69622 Villeurbanne cedex
France

Niphargus (Crustacea, Amphipoda, Niphargidae) is a typical genus of the south-east of Europe (Karaman and Ruffo, 1986; Holsinger, 1994). It is by far the largest and most widespread one in its family. The distribution of the twenty-five species (Morand-Chevat, 1972 and Ginet, 1986) living in the French subterranean ecosystems (there are 200 or so species in Europe) has been mapped in order to increase the ecological knowledge on this genus. From these data the question on how and why a species is found in such a region and not in another one, could be answered.

Data, mostly collected by scientists working in the Groundwater Hydrobiology and Ecology Research Team, have been compiled by Professor Ginet. At present data are gathered in a database under 4th Dimension 6.5.4. in which the sampling conditions, the spatial and temporal locations, and the different species found are accurately described (see the structure of the database in Deharveng, this issue). 971 sites are nowadays described in the database. However it has to be enlarged, by obtaining data from other French and foreigner colleagues and from literature.

A G.I.S. software ArcView has been built. Each site, where *Niphargus* has been collected, has been mapped. Its attribute is a binary number, characterizing the presence or absence of each species in the site (Fig.1)

A problem encountered during the data compilation is due to the bias in the sampling effort: most of the samples were taken from the region of the laboratory. This can be compensated for by reducing the weight of the data from Lyon. However we must be aware of the double problem: the sites of the data collected by a laboratory are close to the laboratory so overweighed, but the laboratories are also settled near a hot-spot of interesting samples.

The first results show that in the region surrounding the Lyon laboratory, *Niphargus* was over-represented compared to the rest of the country (Ginet, 1983). The distribution is far from being homogeneous all over the country (Fig. 2A). Presence of *Niphargus*, is closely related with the karstic regions in France (Fig. 2B after Juberthie and Ginet, 1994).

Among all species collected in France (Morand-Chevat (1972) and Ginet (1986)), *N. rhenorhodanensis* and *N. virei* (Fig. 3A-B) are the most represented in the dataset (Table 1). In spite of the fact that the two species, *N. virei* and *N. rhenorhodanensis*, are found in the eastern part of the country, their distribution appears to be quite divergent. *N. rhenorhodanensis* has a distribution that coincides with the shore of the Miocene Sea in the south-east of France (Ginet and Juberthie, 1987). *N. virei* has populations on one side in Ardèche-Cévennes and on the other side in Jura. The distribution was likely to be originally continuous. The quaternary alpine glacier (Würm, Riss period), by having covered the intermediate zone, might have caused the deseapparence of the species. After the glaciation era, this zone might have been colonized only by the small individuals and especially by *N. rhenorhodanensis*, that could achieve the migration owning to the continuity of the interstitial waters (Ginet and Decou, 1977). *N. rhenorhodanensis* could also have survived under the glacier (Ginet and Juberthie, 1987). Other species seem to be endemic : 4 *Niphargus* have been found in a single station in France (Table 1). Among them, *N. corsicanus* has been collected only in Corse Island (Fig. 2A). The diversity of species in a site could also be highlighted by building thematic map. For example, it exists a noticeable specific diversity in Lyon area (Fig. 4), where half of the French species can be encountered (Ginet, 1983).

The database (in the software 4th Dimension 6.5.4.) and the G.I.S. (Arcview) offer a range of opportunities, that could greatly help in the visualization of the *Niphargus* sites and the understanding of the distribution pattern. Furthermore, by linking the data to ecological parameters (type of aquifers, hydrographic systems, human influences, land-uses...) or historical parameters (glaciations, marine regressions,

connections within the subterranean world...) with help of the G.I.S., we can expect a better understanding of the species colonisation. So there is an active interest in the creation of a database for a better knowledge of *Niphargus* at the European scale and so an appropriate design of conservation measures for the protection of the subterranean biodiversity.

Many thanks to Professor Ginet (Lyon, France) for having given us the entire data of his vast collection on the genus *Niphargus*.

References

Ginet R., 1983. Les *Niphargus* (Amphipodes souterrains) de la région de Lyon (France) : observations biogéographiques, systématiques et écologiques. *Mém. Biospéol.* 10:179-186.

Ginet R, 1996. *Bilan systématique du genre Niphargus en France, Crustacés Amphipodes Gammaridea Niphargidae.* Société linnéenne de Lyon. Hydrobiologie et Ecologie souterraines, Université Claude Bernard Lyon1.

Ginet R. and Decou V., 1977. *Initiation à la biologie et à l'écologie souterraines..* Delage, Paris.

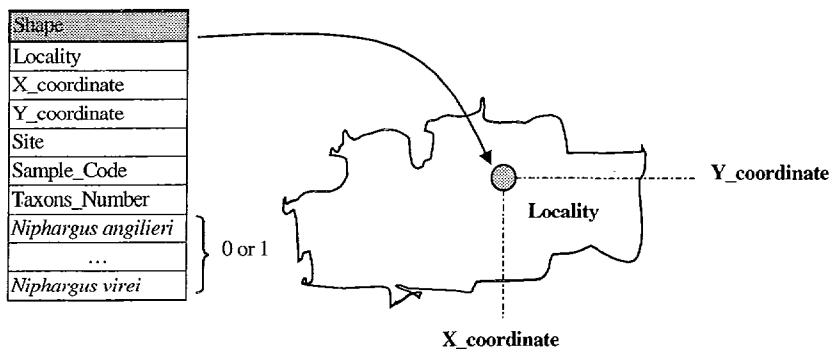
Ginet R. and Juberthie C., 1987. Le peuplement animal des karsts de France (élements de biogéographie souterraine pour les Invertébrés). Première partie : la faune aquatique. *Karstologia*, 10:43-51.

Holsinger J.R., 1994. Amphipoda, pp. 147-163. In V. Decu and C. Juberthie [eds.] *Encyclopaedia biospeologica.* Societe Biospeol., Moulis, France.

Juberthie C. and Ginet R., 1994. France, pp. 665-692. In V. Decu and C. Juberthie [eds] *Encyclopaedia biospeologica.* Societe Biospeol., Moulis, France.

Karaman G.S. and Ruffo S., 1986. Amphipoda: *Niphargus*-group (Niphargidae sensu Bousfield, 1982), pp. 514-534. In L. Botosaneanu [ed.], *Stygofauna mundi.* E.J. Brill, Leiden.

Morand-Chevat C., 1972. Bilan actuel du genre *Niphargus* en France et en Espagne. *Act. 1er Coll. Int. Genre Niphargus*, Verona 1969. Museo civico di storia naturale di Verona, Memorie fuori serie n°5.



Locality	X_coord	Y_coord	Site	Sample_Code	Taxons_Num	*N. rheno*	*N. virei*
Miribel	4.944885	45.841279	Bords du Rhône	01RL 0148	3	0	0
Miribel	4.944885	45.841279	Canal de Miribel	01RL 0066	0	0	0
Miribel	4.944885	45.841279	Station 11	01RL 0067	1	0	0
Miribel	4.944885	45.841279	Vieux Rhône, île de Mir.	01RL 0123	3	1	0
Montanges	5.793939	46.171391	Galerie artificielle : Pont	06JS 0120	1	1	0
Nurieux-Volognat	5.521837	46.183885	Tunnel SNCF de Mornay	06JS 0044	1	0	1
Murs et Géligneux	5.663125	45.641319	300 m Rhône pont	06JS 0068	0	0	0
Murs et Géligneux	5.663125	45.641319	Drift Rhône	06JS 0066	0	0	0
Murs et Géligneux	5.663125	45.641319	Ruisseau sans nom	06JS 0061. 0063.	3	1	0
Nattages	5.753570	45.723245	Puit de ferme n°2	06JS 0126	1	0	0
Neuville sur Ain	5.374186	46.092957	Puit de Rappe	06JS 0037. 0042.	2	0	1
Neuville sur Ain	5.374186	46.092957	Puit du Grand Pré	06JS 0041	1	0	1
Neyron	4.937367	45.818498	Canal de Miribel	01RL 0065	1	1	0

Fig. 1. Structure of the data in the G.I.S. software ArcView™

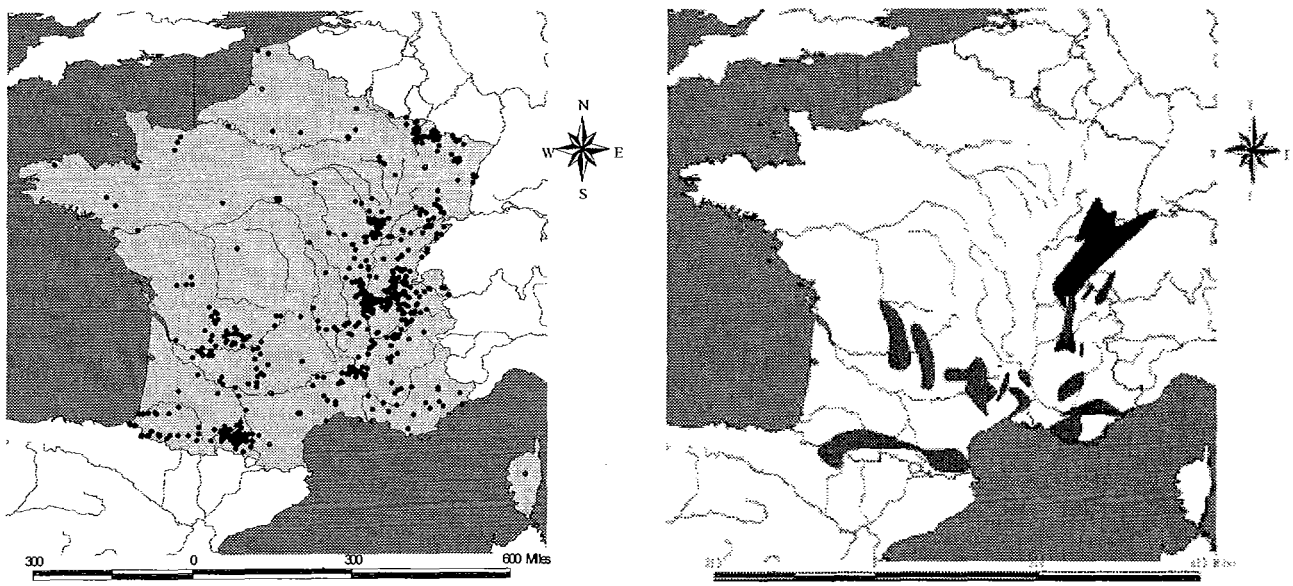


Fig 2. A, *Niphargus* distribution in France; B, main karstic regions in France.

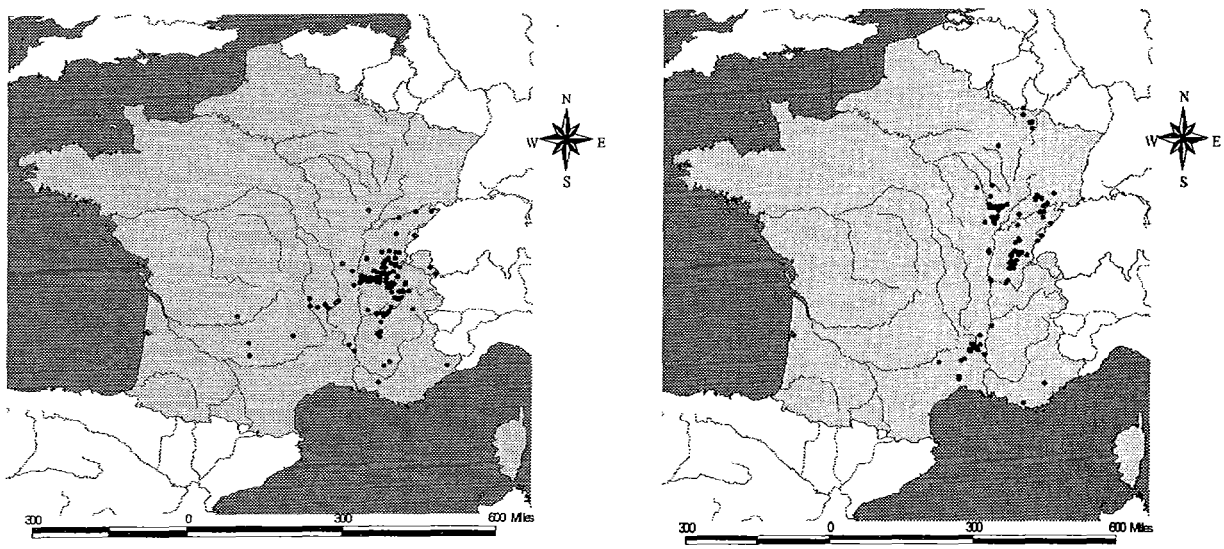


Fig. 3. Distribution of *N. rhenorhodanensis* (left panel) and *N. virei* (right panel)

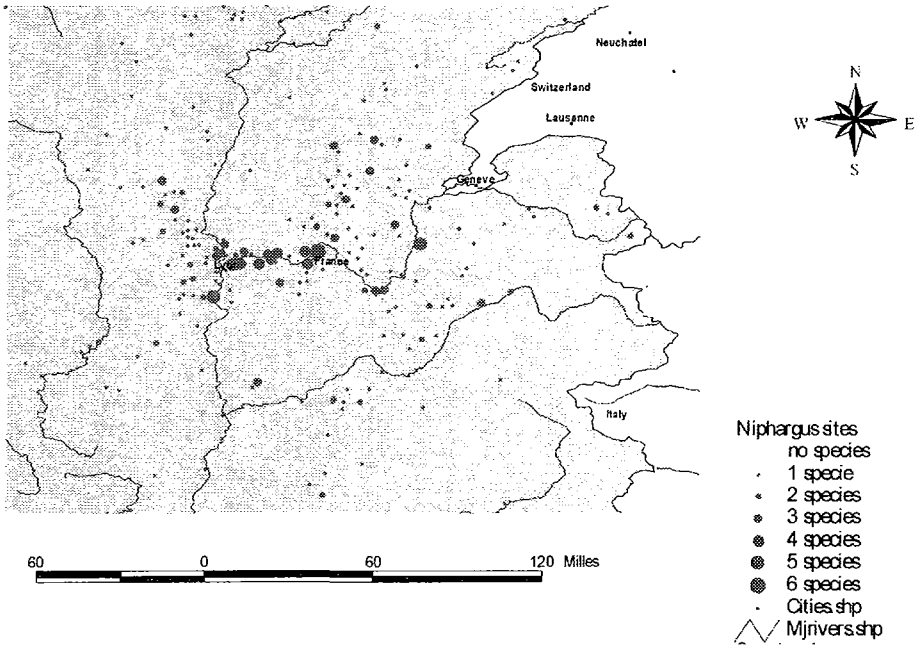


Fig. 4. Distribution of *Niphargus* in the vicinity of Lyon

Table 1. Summary of distribution of *Niphargus* in France.

	Number of sites	Number of departements
Niphargus aquilex	35	13
Niphargus balazuci	1	1
Niphargus ciliatus	9	5
Niphargus corsicanus	1	1
Niphargus delamarei	1	1
Niphargus dimorphopus	2	1
Niphargus fontanus	36	14
Niphargus forelli	54	21
Niphargus gallicus	11	4
Niphargus gineti	17	6
Niphargus jovanovici	2	2
Niphargus kochianus	63	18
Niphargus ladmiraulti	26	6
Niphargus laisi	5	3
Niphargus longicaudatus	10	9
Niphargus pachypus	29	11
Niphargus plateaui	40	20
Niphargus renei	12	3
Niphargus rhenorhodanensis	168	21
Niphargus robustus	34	11
Niphargus schellenbergi	77	11
Niphargus setiferus	5	2
Niphargus vandeli	1	1
Niphargus virei	138	16
Niphargus	914	63

Mapping Subterranean Biodiversity in Brazilian Karst Areas

Eleonora Trajano

Departamento de Zoologia
Instituto de Biociências da USP
C. P. 11461 - CEP 05422-970
Sao Paulo
Brazil

Mapping subterranean diversity implies assessing the number of species regularly found in subterranean habitats and distinguishing which ones are restricted to this environment (troglobites). Both are rendered difficult in tropical countries like Brazil, due to the insufficiency of epigean and hypogean faunistic surveys comparing to the huge tropical biodiversity, and to the relative scarcity of systematists able not only to determine the number of species in a given karst area, and to recognize troglobitic species through the detection of autapomorphic character states not present in epigean relatives. Therefore, delimitation of species is frequently difficult, a great number of taxa remain undescribed or undetermined and, in many instances, one cannot be sure if troglomorphic populations represent troglobitic species.

In spite of these limitations, any effort to map Brazilian subterranean diversity is worthy making for academic and conservation purposes. Comparisons between tropical and temperate faunas may provide important insights for models of hypogean evolution. Environmental disturbances, which have been threatening subterranean ecosystems throughout the World, also represent serious danger to the Brazilian hypogean fauna. Mapping subterranean biodiversity is the first step to understand processes involved in the origin of subterranean fauna, and to propose rational conservation actions to protect it. Nevertheless, this must be considered a first, preliminary approach to this issue.

A brief description of the current situation in the main Brazilian karst areas, with a comparative evaluation of subterranean diversity, is presented herein. Two components of biodiversity have been considered: general diversity (including trogloxenes, troglophiles and troglobites) and richness of troglobitic species, distinguishing those highly modified in relation to the epigean relatives ("ancient troglobites") from the little modified ones ("recent troglobites"), characterized by variability in troglomorphic characters.

The degree of biospeleological knowledge is variable among these areas due to differences in surveying efforts, and some areas, not included here (*e.g.*, Alto Paraguai), were not surveyed at all. As well, accuracy in identifications is also variable, and biodiversity may be understimated in several areas due to lumping of different species in more inclusive taxa or in single nominal species. In general, the invertebrate aquatic fauna was less surveyed than the terrestrial one, especially in cave streams. Due to taxonomic impediment and/or low collecting efforts, some groups are clearly underestimated, the most obvious case being that of acarians.

Vale do Ribeira speleological province (São Paulo and Paraná States, SE Brazil): this is the best known karst area, intensively surveyed since the 70's, with the largest number of cave taxa recorded. It presents a high concentration of small to medium-sized caves (up to 6 km), including vertical and horizontal caves, some dry, others crossed by streams. It presents the highest diversity of troglobites so far recorded in Brazil (tens of species), belonging to several terrestrial and aquatic taxa (gastropods, collembolans, beetles, diplopods, isopods, decapods, opilionids, heptapterine catfishes etc.). In general, degree of morphological differentiation of these troglobites is low, most showing reduced, but not totally lost, eyes and pigmentation. Recent vicariant events related to climatic flutuations probably explain at least part of such diversity.

Bodoquena speleological province (Mato Grosso do Sul, SW Brazil): the most remarkable characteristic of this region is the presence of several flooded, very deep caves. Progress of biological surveying was due to the recent development of cave diving in the area, with the discover of several populations of highly modified troglobitic crustaceans and fishes, some representing phylogenetic (spelaeogriphaceans) or geographic (bogidiellid amphipods, loricariid and trichomycterid catfishes) relicts. In general, dry caves are relatively small, and terrestrial diversity is moderate.

Bambuí speleological province (Central Brazil): Brasília karst area (Goiás State): this area was barely surveyed. It presents a concentration of small, dry caves harbouring large amounts of bat guano, with potential for high diversity of guano associated fauna, that frequently includes troglobitic mesoinvertebrates.

São Domingos karst area (Goiás State): this area was recently intensively studied. It is characterized by the presence of large caves (several km long) representing sinkholes of streams belonging to the Alto Tocantins river basin, Amazon basin. Probably due to the richness of Amazonian fauna associated with high food availability, the subterranean aquatic fauna is particularly rich in abundance and number of species, including several troglobitic fish populations. This is the Brazilian karst area with the largest cavefish diversity, and some populations present particularly high densities. However, the degree of morphological differention of these troglobites is low, eyes and pigmentation being slightly reduced in some populations and highly variable in others. Rare troglomorphic terrestrial invertebrates (a carabid beetle).

Médio São Francisco karst area (Minas Gerais State): in spite of its historical tradition of caving, there are few published data on subterranean diversity from this region, mainly characterized by small to medium-sized caves, which concentrate in some areas. Apparently, diversity is moderate and few troglobites were found to the south of Peru-Açu Valley (N Minas Gerais), where Olhos d'Água, by far the longest cave in Minas Gerais (more than 8 km) is located. There are several troglobitic species endemic to Olhos d'Água system, including a trichomycterid catfish, an oniscidean isopod, an opilionid etc.

South-central Bahia karst area (Bahia State): several large horizontal caves, many crossed by streams, with a rich subterranean fauna. High diversity of troglobites, including terrestrial (e.g., beetles, oniscidean isopods) and aquatic species (trichomycterid catfish, bogidiellid amphipods); the latter are related to troglobitic species from Bodoquena karst area.

Alto Paraguaçu karst area, Chapada Diamantina (Central Bahia State): medium to large caves, several with phreatic water bodies harbouring highly modified troglobites (heptapterine catfishes, bogidiellid amphipods). Terrestrial diversity moderate, also including very specialized troglobites (the most modified Brazilian cave beetle is found there) and geographic relicts (*e.g.*, rhyscotid isopods).

Una karst area, Campo Formoso (northen Bahia State): small to large caves (including Toca da Boa Vista, 87 km long, by far the largest in Brazil), mostly dry, some with phreatic water bodies in the lower conduits; temporary streams may cross some caves during the rainy season. General biodiversity relatively low due to the relative dryness. However, several highly modified troglobites, including geographic (heptapterine catfishes) and phylogenetic relicts (nicoletiid thysanurans; aquatic isopods representing the first record for Brazilian caves), were found in this area.

Rio Pardo karst area (southeast Bahia State, in the coastal region): small dry bat caves, with a moderately diversified, but abundant terrestrial fauna, including several unique cave taxa. No troglobite was found.

General subterranean biodiversity seems to be mainly related to ecological factors, such as habitat diversity and extension related to cave size and number in a given area, and availability of organic matter. In general, the highest diversity is observed in karst areas with large cave systems, especially those crossed by streams, and/or with high food input (sinkholes, bat caves). Forested areas, with a great diversity of potential colonizers, may also represent hotspots of subterranean biodiversity. On the other hand, richness of troglobitic species and their degree of differentiation is better explained by historical factors, mainly vicariance leading to speciation, not necessarily revealed by analysis of present conditions. For instance, the occurrence of several highly modified troglobites in the "agreste" (inlands) of Bahia State, presently a semi-arid region, may be explained by isolation opportunities offered by the local extinction of hygrophilic epigean ancestors a long time ago. Likewise, change from lotic (streams) to lentic conditions in caves from Bodoquena karst area, which have been flooded due to the subsidence of the region, accounts for the occurrence of several aquatic relictual troglobites in this area.

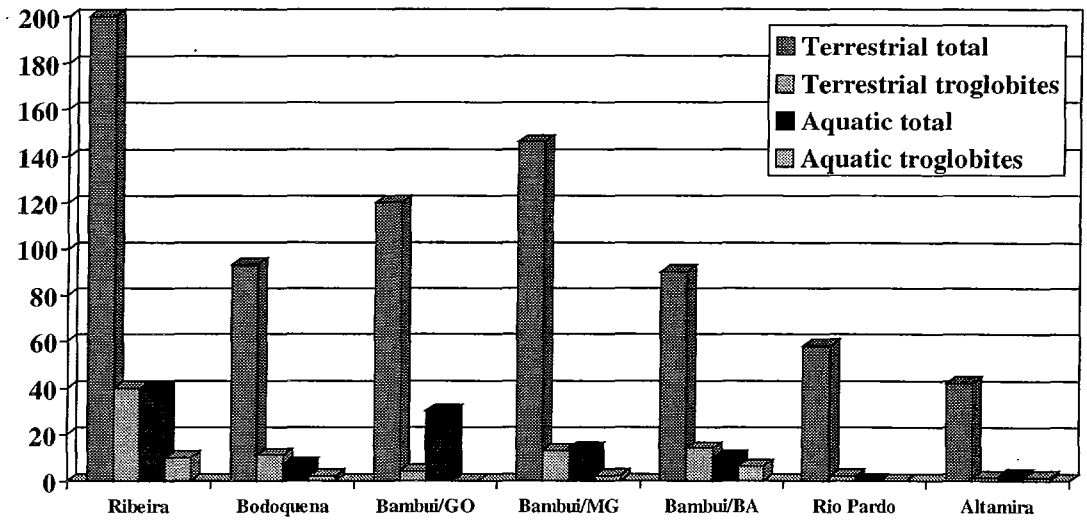
Therefore, hotspots of general diversity do not necessarily coincide with hotspots of diversity of troglobites (see São Domingos *versus* Campo Formoso karst areas), and both must be considered when mapping subterranean biodiversity for conservation and scientific purposes.

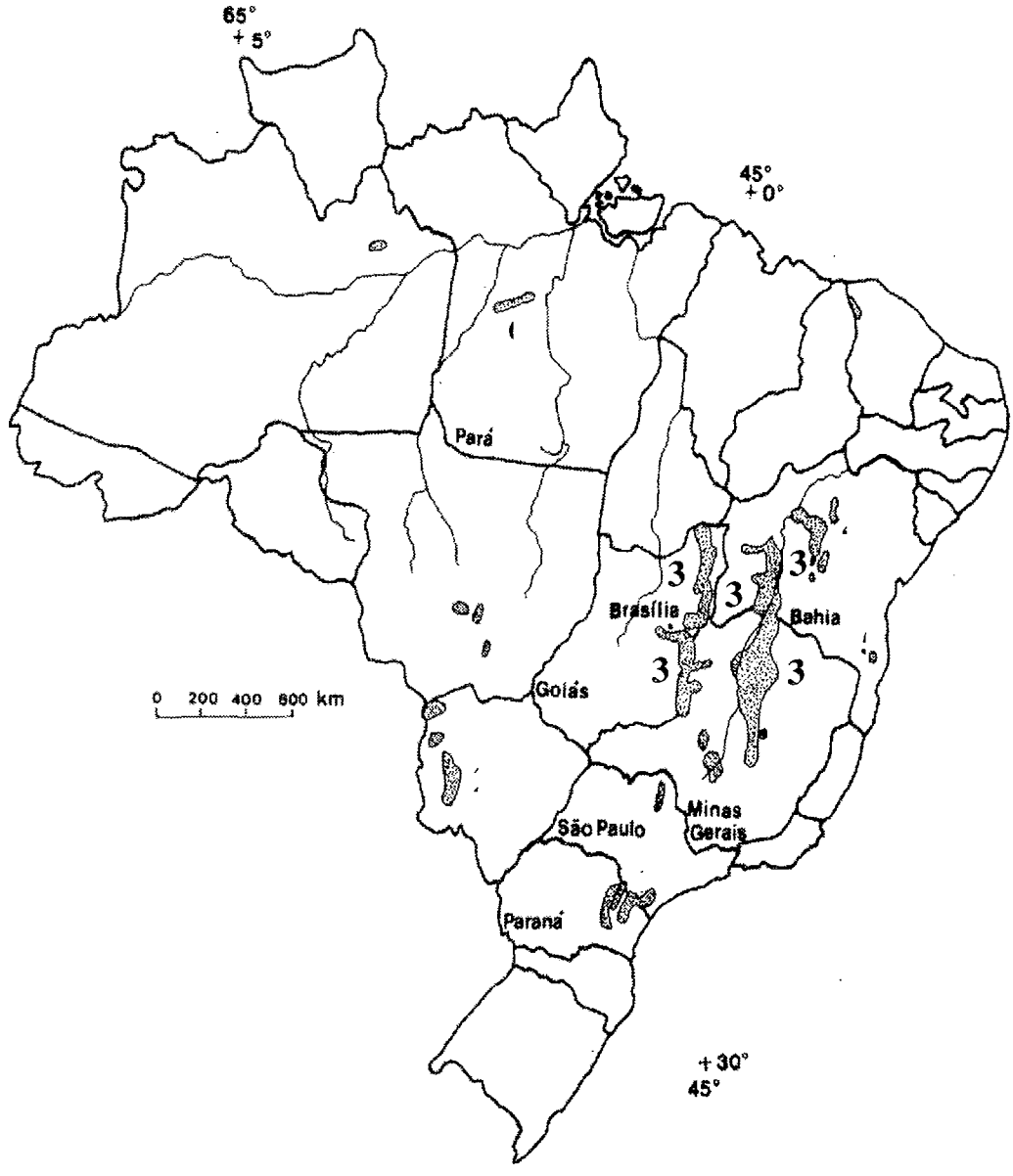
Invertebrate taxa recorded in Brazilian karst areas

Araneae, Pseudoscorpiones, Isopoda Oniscidea, Diplopoda
(including troglomorphic species)

	Ribeira SP-PR	Bodoquena MS	Bambui GO	Bambui MG	Bambui-Una/BA
Araneae	40(1)	14(2)	25(1)	40(2)	20(1)
Pseudoscorpiones	11(1)	4	2	9(1)	6
Isopoda	17(7)	7	5	9(5)	11(7)
Diplopoda	16(6)	11(1)	7	8	7

Numbers of subterranean invertebrate taxa recorded in Brazilian karst areas





Brazilian karst areas:

1. Vale do Ribeira speleological province.
2. Bodoquena speleological province.
3. Bambuí speleological province: 3a. Brasília karst area; 3b. São Domingos karst area; 3c. Médio São Francisco karst area; 3d. South-central Bahia karst area; 3e. Alto Paraguaçu karst area.
4. Una karst area.
5. Rio Pardo karst area.
6. Altamira-Itaituba sandstone karst area.

The Cuban Troglobites

Abel Pérez Gonzalez

BioKarst Group, Cuban Speleological Society,
A.P. 678, C.P. 11300,
Habana 13
Cuba

Jill Yager

Environmental and Biological Sciences Department,
Antioch College
795 Livermore Street,
Yellow Springs OH 45387
USA

Cuba possesses the richest and most diverse speleofauna of the West Indian/Caribbean islands. There are three publications which summarize Cuban speleofauna: Silva 1974, Silva 1988, and Decu *et al.* 1989. These include check lists, distributions, and bibliographies. Only two papers offer lists of the troglobitic fauna: the first Sinopsis de la Espeleofauna Cubana (Silva 1974) and the more recent chapter about Cuba by Decu and Juberthie 1994 in the *Encyclopaedia Biospeologica* (Juberthie and Decu, Eds.). Since the publication of the last list various biospeleological expeditions in Cuba have resulted in the discovery of many new troglobitic species, some of which have been described. For this reason we are offering an updated list of the troglobites from Cuba.

In our work we consider those organisms that have been considered as troglobites or neotroglobites and which are encountered exclusively in caves. There are certain troglobitic species mentioned by Decu and Juberthie (1994) but not included in our list because they are known from epigean habitats. Species whose some doubt about the classification, are indicated by a question mark.

For Cuba 109 troglobites have been recorded--57 are aquatic and 52 terrestrial. Crustaceans dominate the aquatic troglobites with 52 species. Among the crustaceans the copepods and decapods dominated with 18 and 13 species respectively. Two major groups dominate the terrestrial troglobites: the arachnids and insects, with 29 and 21 species respectively. Acari have the highest number of troglobites among the Arachnida, but the classification of "true troglobite" is in doubt because many of the mites are parasitic and because of the dependence of some adults on bat guano. The arachnids with high levels of troglomorphism (despigmentation, ocular regression or anophtalmia, etc) are inside of Araneae, Opiliones, Pseudoscorpiones and Schizomida. For the insects the Collembola and Coleoptera are the most diverse groups.

There are also several new troglobitic species whose taxonomic descriptions are in progress. For example, there is a new species of *Typhlatya* (Crustacea, Decapoda) (Jubarrero and García-Debrás pers. com.); a new species of Ostracoda (Crustacea) (Korniker com. pers.); a new species of amphipod of the genus *Bahadzia* (Crustacea) (Holsinger and Ortíz, pers. com.); two species of Thermosbaenacea (Crustacea) (pers. obs.), a new species (and probably a new genus) of Isopoda (Crustacea)(Ortíz pers. com.), three new species of the genus *Pseudocellus* (Arachnida, Ricinulei) (L. F. de Armas, pers. com), one new genus and new species of Pholcidae and a new species of Ochyroceratidae (Arachnida, Araneae) (pers. obs.), two new species of Stygnnomatidae (Opiliones) (pers. obs), a new genus and a new species of Ideoroncidae (Arachnida, Pseudoscorpiones) (Barba pers.com.) and a new species of the blind cave fish *Lucifuga* (García-Debrás, pers. com.).

Many thanks to Manolo Ortíz from the Centro de Investigaciones Marinas, La Habana; Augusto Juarrero de Varona; Luis F. de Armas and René Barba Díaz from the Instituto de Ecología y Sistemática, La Habana; Alfredo García Debrás from the Grupo BioKarst, La Habana; Louis S. Kornicker from the NMNH, Smithsonian, Washington; John Holsinger from Old Dominion University, Norfolk; for sending us his unpublished data.

References

Decu, V., M. Georgescu and N. Viña Bayés. 1989. Materiaux pour une biospéologie de la Cuba. Premiere parte. *Misc. Speol. Romanica* 1:201-272.

Decu, V. and C. Juberthie. 1994. Biospéologie de Cuba. In: C. Juberthie and V. Decu (eds.). *Encyclopedia Biospéologica*, Moulis, France - Bucarest, Romania, 1:459-575.

Silva T. G. 1974. Sinopsis de la Espeleofauna Cubana. *Ser. Espeleol. Carsol.*, 43:1-65

Silva, T.G. 1988. *Sinopsis de la Espeleofauna Cubana*. Editorial Científico Técnica, LaHabana, 144 pp.

LIST OF THE TERRESTRIAL AND AQUATIC TROGLOBITES FROM CUBA (included neotroglobites)

AQUATIC

CRUSTACEA

Remipedia

1. *Speleonectes gironensis* Yager

Ostracoda

2. *Caribecandona cubensis* Broodbaker
3. *Pseudocandona cubensis* Broodbaker
4. *Spelaeoecia cubensis* Kornicker and Yager
5. *Strandesia botosaneanui* Broodbaker
6. *Danielopolina orghidani* (Danielopol)

Copepoda

7. *Allocyclops cubensis* Plesa
8. *Canthosella antillica* Pandkovski
9. *Elaphoidella botosaneanui* Pandkovski
10. *Elaphoidella crenobia* Pandkovski
11. *Elaphoidella einslei* Pandkovski
12. *Elaphoidella karllangi* Pandkovski
13. *Elaphoidella neoarmata* Pandkovski
14. *Elaphoidella neotropica* Pandkovski
15. *Elaphoidella prohumboldti* Pandkovski
16. *Elaphoidella quemadoi* Pandkovski
17. *Elaphoidella subcrenobia* Pandkovski
18. *Elaphoidella turgisandosa* Pandkovski
19. *Mandacyclops paludicola dentatus* Plesa
20. *Mandacyclops rudis* Plesa
21. *Nitocrella negreai* Pandkovski
22. *Parapseudoleptomesocra botosaneanui* (Pandkovski)
23. *Stygonitocrella orghidani* (Pandkovski)
24. *Teratocyclops cubensis* Plesa

Mysidacea

25. *Antromysis cubanica* Bacescu *and* Orghidan
26. *Antromysis juberthie* Bacescu *and* Orghidan
27. *Gironomysis lalanai* Ortiz, Lalana and Perez
28. *Spelaeomysis ibarrae* Ortiz, Lalana and Perez
29. *Spelaeomysis nuniezi* Bacescu *and* Orghidan

Isopoda

30. *Anopsilana cubensis* (Hay)
31. *Anopsilana magna* Ortiz, Lalana and Perez
32. *Bahalana bowmani* Ortiz, Lalana and Perez
33. *Cyathura orghidani* Negoescu Vladescu
34. *Cyathura specus* Bowman
35. *Haptolana trichostoma* Bowman
36. *Neostenandroides schotterae* Ortiz, Lalana and Perez

Decapoda

37. *Barbouria cubensis* (Martens)
38. *Espeleonaushonia augudrea* Juarrero and Garcia
39. *Macrobrachium lucifugum* Holthuis (neotroglobite?)
40. *Procambarus niveus* Hobbs and Villalobos
41. *Somersiella sterrei* Hart and Manning (neotroglobite?)
42. *Troglocubanus calcis* Rathbun
43. *Troglocubanus eigenmanni* (Hay)
44. *Troglocubanus gibarensis* (Chace)
45. *Troglocubanus inermis* (Chace)
46. *Typhlatya consobrina* Botosaneanu and Houltis
47. *Typhlatya elenae* Juarrero
48. *Typhlatya garciai* Chace
49. *Typhlatya taina* Estrada and Gomez

Amphipoda

50. *Bahadzia yagerae* Ortiz and Perez
51. *Paraweckelia silvai* Shoemaker
52. *Weckelia caeca* Weckel

ARACHNIDA

Acari

Hydrachnellae

53. *Newmanikea coenotica* Orghidan and Gruia

PICES

Bythitiidae

54. *Lucifuga dentatus* Poey
55. *Lucifuga simile* Nalbant
56. *Lucifuga subterraneus* Poey
57. *Lucifuga teresinarum* Diaz

TERRESTRIAL

ARACHNIDA

Scorpiones

Bhutidae

58. *Alayotityus delacruzi* Armas

Pseudoescorpiones

Bochicidae

59. *Antillobisium mitcheli* Dumitresco and Orghidan
60. *Antillobisium vachoni* Dumitresco and Orghidan

Amblypygi

Phrynidae

61. *Phrynus noeli* Armas and Perez

Schizomida

Schizomidae

62. *Cubazomus orghidani* Dumitresco
63. *Cubazomus rowlandi* Dumitrescu

Ricinulei

Ricinuleidae

64. *Pseudocellus silvai* Armas

Opiliones

Biantidae

65. *Decuella cubaorientalis* Avram (troglobite?)

Minuidae

66. *Kimula botosaneanui* Avram

Phalangodidae

67. *Jimeneziella decui* Avram
68. *Jimeneziella negrai* Avram

Stygnommatidae

69. *Stygnomma spinifera bolivari* Goodnight and Goodnight (neotroglobite?)

Araneae

Barychelidae

70. *Troglothele coeca* Fage

Ctenidae

71. *Ctenus calzada* Alayon

Oonopidae

72. *Oonopoides cavernicolus* Dumitrescu and Georgescu

Pholcidae

73. *Anopsicus cubanus* Gertsh
74. *Anopsicus silvai* Gertsh
75. *Metagonia debrasi* Perez and Huber

Acari

Argasidae

76. *Antricola armasi* Cruz and Estrada-Peña (Troglobite?)
77. *Antricola centralis* Cruz and Estrada-Peña (Troglobite?)
78. *Antricola granasi* Cruz (Troglobite?)
79. *Antricola habanensis* Cruz (Troglobite?)
80. *Antricola martelorum* Cruz (Troglobite?)
81. *Antricola naomiae* Cruz (Troglobite?)
82. *Antricola occidentalis* Cruz (Troglobite?)
83. *Antricola siboneyi* Cruz and Estrada-Peña (Troglobite?)
84. *Antricola silvai* Cherny (Troglobite?)
85. *Parantricola marginatus* (Banks) (Troglobite?)

Hydrachnellae, Limnesiidae

86. *Syboneiacarus sordidus* Orghidan, Gruia, Georgescu and Viña Bayés

MIRIAPODA
- Scolopendromorpha
  - Cryptopidae
    87. *Cryptos troglobius* Matic, Negrea and Fundora Martinez
    88. *Newportia leptotarsis* Negra, Matic and Fundora Martinez

INSECTA
- Tysanura
  - Nicoletiidae
    89. *Cubacubana decui* Wygodzinsky an Hollinger
    90. *Cubacubana negreai* Wygodzinsky an Hollinger
    91. *Cubacubana ramosi* (Wygodzinsky)
- Collembolla
  - Entomobrydae
    92. *Metasinella acrobates* Denis
    93. *Metasinella nuniezi* Massoud and Gruia
    94. *Metasinella pseudofimetarius* Gruia
    95. *Metasinella rapoporti* Massoud and Gruia
    96. *Metasinella topotypica* Bonet
    97. *Troglopedetes delamarei* Massoud and Gruia
  - Neeliidae
    98. *Megalothorax bolivari* Bonet (troglobite?)
- Orthoptera
  - Phalangopsidae
    99. *Cophus thoracicus* Saussure
    100. *Cubacophus gibaraensis* Ruiz and Otte
    101. *Cubacophus glaber* (Bonfils)
    102. *Cubacophus velutinus* (Bonfils)
- Dictyoptera
  - Blattaria, Blattellidae
    103. *Paranocticola cubana* Bonfils
- Coleoptera
  - Catopidae
    104. *Proptomapharginus apodermus* Szymczakowski
  - Tenebrionidae
    105. *Trimytantron cubanum* Ardoin, 1977 (troglobite?)
    106. *Trimytantron decui* Ardoin, 1977 (troglobite?)
    107. *Trimytantron negreai* Ardoin, 1977 (troglobite?)
    108. *Trimytantron poeyi* Ardoin, 1977 (troglobite?)
    109. *Trimytantron vinai* Ardoin, 1977 (troglobite?)

WORKSHOP SESSION 4

FRAMEWORK FOR FUTURE WORK

Synopsis

Guiseppe Messana, President of the Societe Internationale de Biospeologie spoke about the potential role of the Societe in subterranean biodiversity. Research, education, and conservation are the goals of the society. As a society, what can we do to facilitate the development of a database? We can be a lobbying group and serve as an interface among researchers. We can serve an administrative function and we can organize the effort. The society should coordinate programs and disseminate information and act as a central group for standardizing the form of the data.

The discussion focused on (1) minimum data entry standard and (2) access, collection, and distribution. Louis Deharveng pointed out that while the society is international, the first database will focus on Europe and North America. Arthur Clarke added that he felt that Australia should included. David Culver pointed out that each country's database may be quite extensive with perhaps 40 to 50 entries for each record, but that we need to combine into a simpler common form. Thus, there will be two databases for each participating group—a common (minimum) part shared among countries and an individual part for each country.

The discussion started with a minimum list from Sarah Krow's description of the North American database:

- species name (including taxonomic authority)
- higher taxonomic information (family, order, class)
- ecological status (terrestrial or aquatic)
- site name (including state and county)
- site location (in latitude and longitude)
- source of information

Arthur Clarke argued that the ecological classification needed to be expanded to include, for example, aquatic, terrestrial, cave, non-cave, troglobite, troglophile, phreatobite, etc. Several people agreed that habitat type needed to be added to the list and that ecological status referred to troglobite versus troglophile, etc.

Fabio Stoch pointed out that with the European fauna, one started with a checklist, and the species table is the check list. There is another table for location. It may not always be possible to get location information. He also argued that a field indicating datum—such as WGS84. He also argued that a field for precision of the coordinates was needed. Finally he argued for using UTM coordinates rather than latitude and longitude. UTM coordinates present some advantages I mapping. Others countered that latitude and longitude is more universally available and more naturally spans the globe.

Abel Perez Gonzalez asked whether a minimum data entry meant that every field was required. Several others replied that it did. Eleonora Trajano pointed out that flexibility was needed since names change and even coordinates may be corrected. Arthur Clarke and Sanja Gottstein suggested that a entry for the location of the collection should be added, and Culver disagreed, arguing that this should be part of the local database. Stoch pointed out that the site name was also hierarchical, including state, region, county, etc. Deharveng suggested two more categories—contact person and notes/comments. Isaac Izquierdo pointed out the need to differentiate troglobite, troglophile, and trogloxene.

Miguel Araujo asked what do we want to do with the data? The data user may want to know how many species there are, where they are found, or when they were found. Both habitat and collection date should be included in the minimum data set. Graham Proudlove suggested that if time is included, use the most precise information available. Stoch argued that it must include the year of the collection. Larry Master suggested that year was sufficient in order to do temporal comparisons. Trajano argued that a separate entry for the source of the identification should be included. Other suggested adding common names and abundance. Others objected and the idea of including a common name was dropped. Messana asked whether the source of identification suggested by Trajano could also be the contact person. Araujo said that the issue of accuracy of identification was important but that local people should be the ones to assess the data before submitting the data to the database. Trajano disagreed and argued for the inclusion of the source of identification. The consensus was that information about the contact person was sufficient.

The discussion then focused on the categories of habitat and ecological classification. It was suggested that we use the classification in *Stygofauna Mundi* for aquatic habitats, but others felt that this was too elaborate. Someone else pointed out that we need to add guano as a habitat. For the ecological classification the troglobite, troglophile, trogloxene, stygobite, stygophile, stygoxene, and accidental. Others felt that this was to ambiguous, and that

different definitions were used by different people. Arthur Clarke suggested using a very simple classification of obligate, habitual, and accidental. Janine Gibert pointed out that we need to discuss habitat as well as an ecological classification. Messana recommended using obligate, habitual, accidental, uncertain, or combinations of the above. Araujo said that in his work on point locations of birds, he assigns ecological classification as he sees fit, and that such ecological classifications are user dependent. Hobbs suggested simplifying habitat to simply aquatic or terrestrial. Others suggested that cave vs. non-cave was an important distinction. Claude Boutin felt that the habitat classification was more important than the ecological classification. Culver pointed out that habitat may also be site dependent—it may vary within a species. Trajano suggested that the ecological classification be further simplified to be troglobite vs. non-troglobite. Boutin pointed out we need clarity on the definition of what a troglobite is. Guy Magniez suggested the following three habitat dichotomies:

- karst vs. non-karst
- interstitial vs. large cavity
- aquatic vs. terrestrial

The classification got widespread support from the workshop.

Location of sites and precision of location was also discussed. The following scale was proposed:

A—within 0.01 km
B—within 0.10 km
C—within 1.00 km
D—within 10 km
E—within 100 km

Deharveng raised the question about happens when the centroid is known, as for example a mountain. Larry Master replied that the centroid of the place should be found and then the precision should be indicated.

Izquierdo asked about adding a category for endemism, but several responded that endemism was a relative term.

Several suggested the following hierarchy for site name:

- country
- state (province, region)
- county (department, district)
- municipality
- site name

Messana returned to questions about the role of the Societe International de Biospeologie. The society should be one of the reference institutions. Culver suggested a small planning committee to test and foster its use. Messana, as president of the societe, appointed the following people to an American—European *working group* to do some further planning and testing:

- **David Culver—U.S.**
- **Louis Deharveng—France**
- **Sanja Gottstein Matocec—Croatia**
- **Isaac Izquierdo—Canary Islands**
- **Fabio Stoch—Italy**

Arthur Clarke volunteered to be the liaison for Australia.

Topics that were not discussed in this session were problems with sharing, credit and intellectual ownership of the data, and distribution of the database. These are among the issues the working group will need to consider. It will also test the data structure. Miguel Araujo indicate we could use World Map as part of the test.

The workshop came up with the following structure of the shared database. The minimum entry is as follows:

1. **Species name with authority**
2. **Family/Order/Class/Phylum**
3. **Ecological/habitat classification (coded)**
4. **Coordinates in latitude and longitude**
5. **Datum (coded)**
6. **Precision of reference location (coded)**
7. **Site name (hierarchical)**
8. **Collection year**
9. **Contact person/database**
10. **Notes and comments**
11. **ID number**

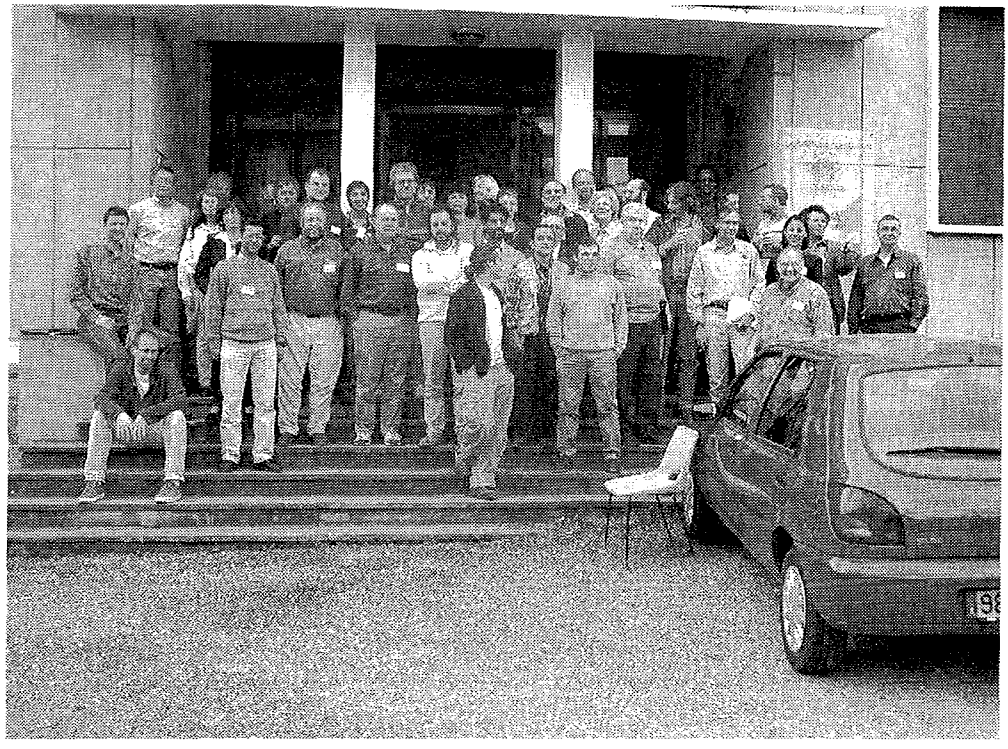
The ecological/habitat classification had four dichotomies:

1. **Obligate subterranean vs. others**
2. **Karst vs. non-karst**
3. **Interstitial (including the MSS {milieu superficial souterrain} vs. open space**
4. **Aquatic vs. terrestrial**

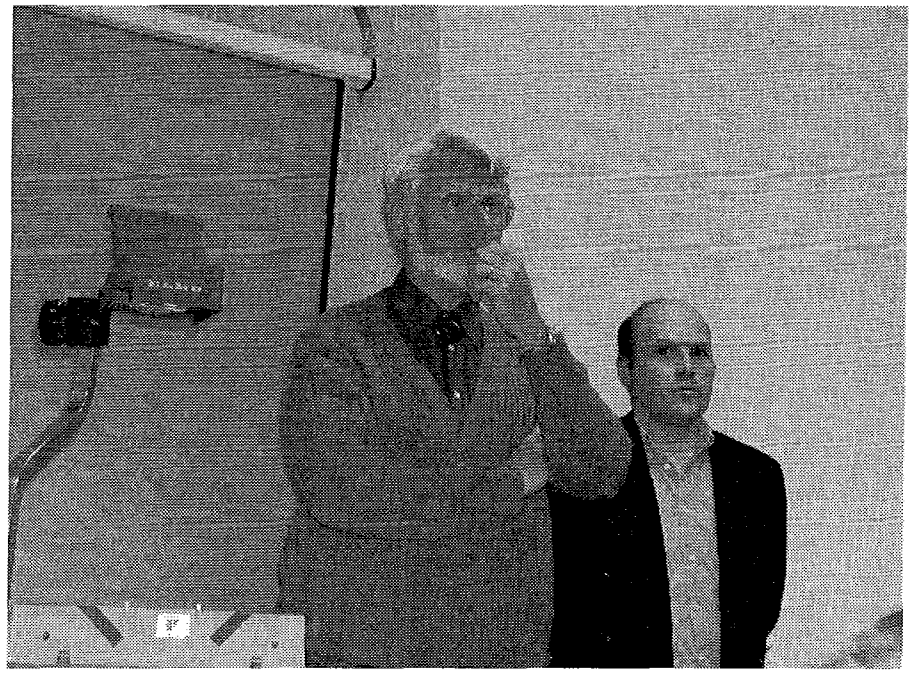
Precision of reference location will categorized as follows:

A—within .01km
B—within .1km
C—within 1km
D—within 10km
E—within 100km

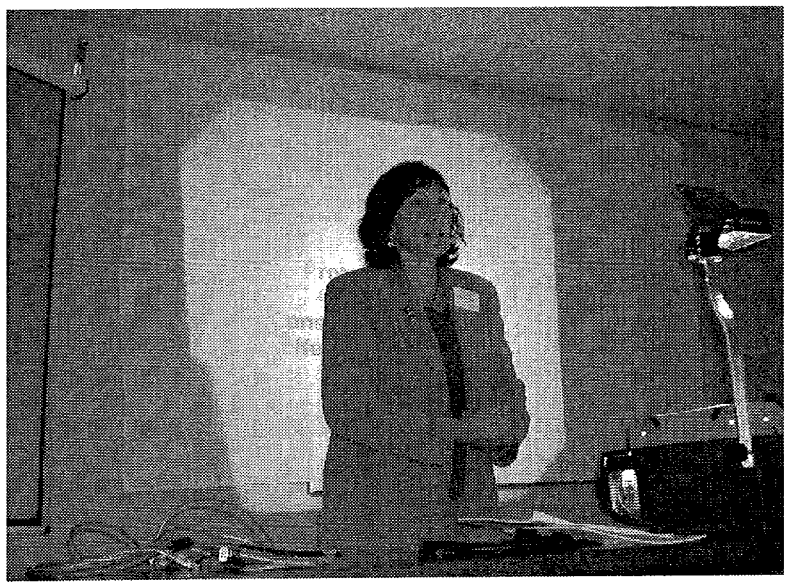
Datum refers to the coordinate system such as WGS 1984 or North American 1927. Site is hierarchial beginning with country and ending with site name. Intermediate categories include state, region, county, municipality, etc.



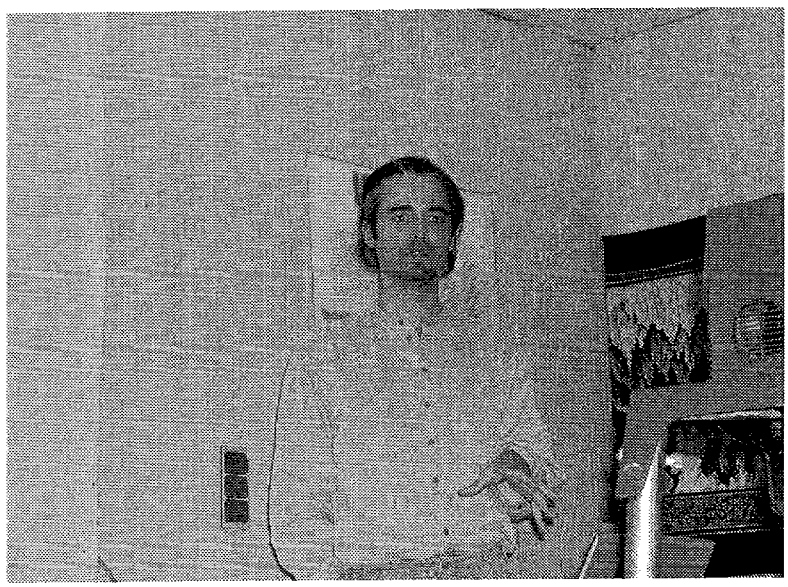
The assembled group in front of the Laboratoire Souterrain



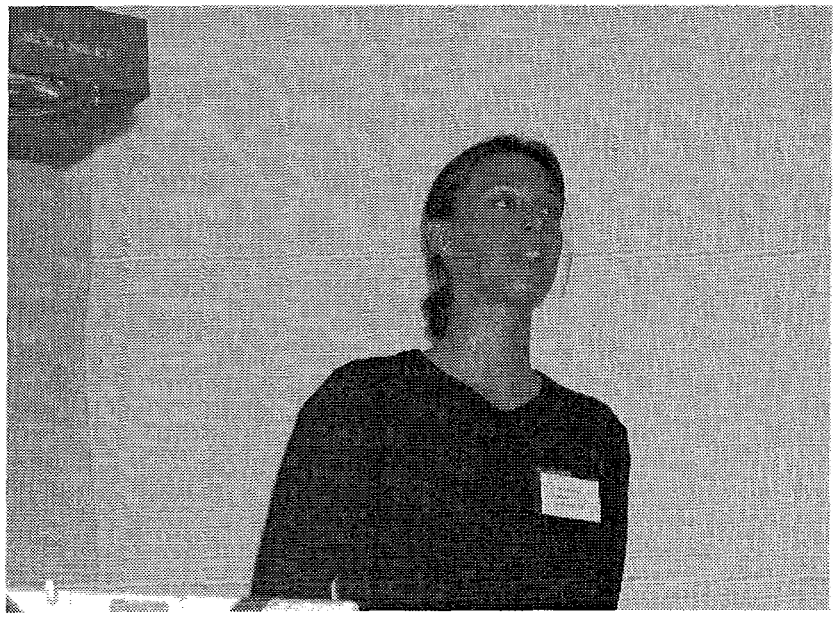
Welcome speeches from Dr. Alain Mangin (Laboratoire Souterrain) and Mr. Frédéric Casteras (Mayor of Moulis)



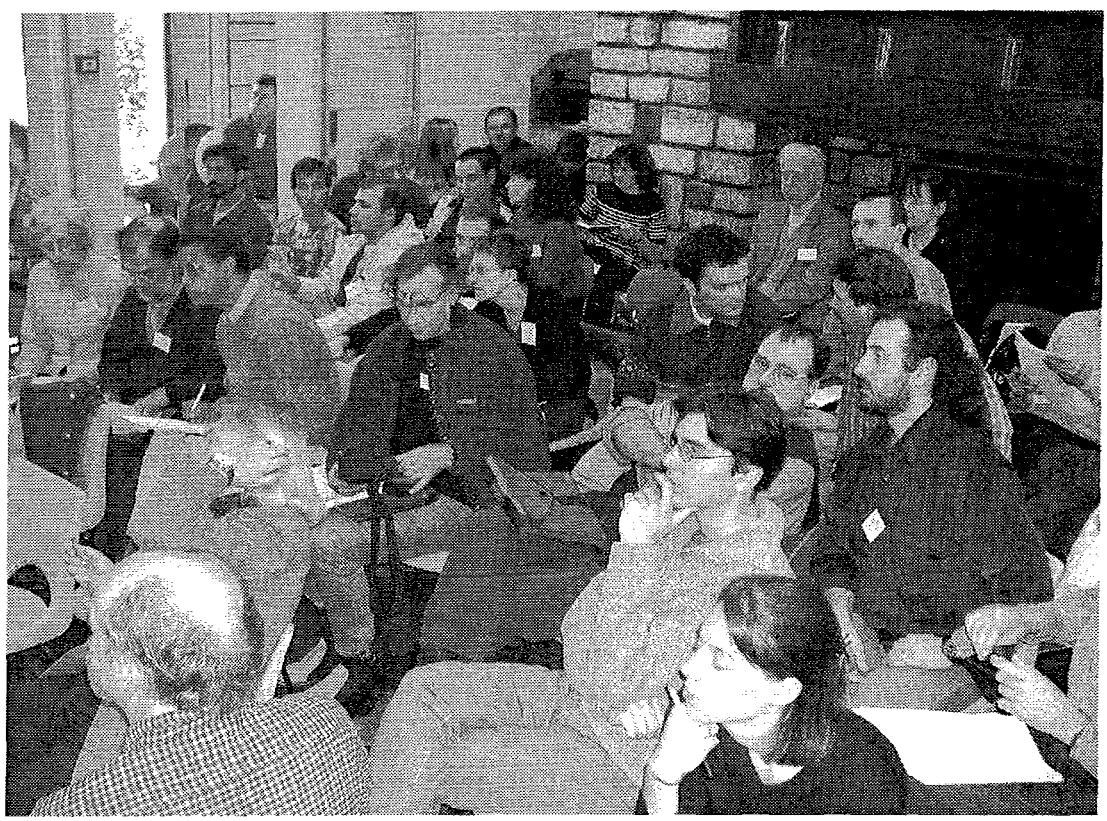
Prof. Janine Gibert, Université Lyon 1, Villeurbane, France



Dr. Miguel Araujo, The Natural History Museum, London, England



Ms. Sarah Krow, American University, Washington, DC.



A workshop session

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