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Conservation and Modern Information Technologies: The Global Register of Migratory Species (GROMS)

Klaus Riede[1]

Abstract:

The present paper reviews the state of knowledge of migratory species protected under the Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animals) and presents first results from the "Global Register of Migratory Species" (GROMS). GROMS summarises our knowledge on migratory species within one relational database in combination with a geographical information system (GIS). GROMS will reveal information deficiencies, support the Convention on the Conservation of Migratory Species of Wild Animals, and contribute to the Clearinghouse Mechanism under the Convention on Biological Diversity. At present, GROMS contains 412 species distribution maps in GIS format. As an initial example of the potential of GIS-analysis, GIS-maps of birds and mammals were intersected with administrative borders, and the number of species was calculated for each province. The resulting map shows a high diversity in temperate regions, which is in contrast to maps that usually show most "biodiversity hotspots" to be in the tropics. Consequences for conservation policies are discussed and future prospects for GIS analysis are outlined.

Keywords:

Biodiversity informatics, migratory species, Geographical Information Systems, databases, Bonn Convention; Convention on the Conservation of Migratory Species of Wild Animals.

1. Introduction:

A careful scientific assessment of baseline data is the prerequisite for species conservation. Reliable population assessments for species, and knowledge of its geographic distribution, are necessary for diagnosing its status[2] and the health of its habitat. Such baseline data is critical for the development of programs to pre1vent unsustainable exploitation, formulation of recovery plans[3] and the designation of protected areas. Additionally, this information is important for determination of whether a species should be included in the threatened or endangered categories under international and regional wildlife treaty regimes.[4]

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[1]Center for Development Research, Walter-Flex-Straße 3, D - 53113 Bonn, Germany; phone: int+228-731872; fax: +228-731869; k.riede.zfmk@uni-bonn.de.

[2] Commonly assessed by IUCN Red List categories, <http://www.iucn.org/themes/ssc/redlists/ssc-rl-c.htm>. Note that there are both international and national Red Lists. For an interesting discussion of Red List criteria *see* J.P. Rodríguez, et al., *Local data are vital to worldwide conservation*, 403 NATURE 241 (2000).

[3] For example, *see* R.C. BEUDELS, P. DEVILLERS & R.M. LAFONTAINE, ACTION PLAN FOR THE CONSERVATION AND RESTORATION OF SAHELO-SAHARAN ANTELOPES, DJERBA, TUNISIA (1998).

[4] See Fig. 1 at the conclusion of this article for a list of major agreements for the protection of migratory species.

To be accepted by the respective conference of parties, proposals have to be thorough and carefully reviewed by experts.[5]

Modern information technologies can facilitate and systematise these time-consuming and expensive assessments, which, unfortunately, are often initiated only after the diagnosis of a most severe, and sometimes irreversible, decline of species.[6] In addition, new technologies such as Geographical Information Systems (GIS)[7] provide the methodology to predict the effect of larger development projects, intensified land use or climatic change on certain species, instead of documenting population declines with hindsight. This paper reviews the state of knowledge on migratory species derived from the "Global Register of Migratory Species" (GROMS). GROMS combines a relational database (Microsoft Access) with a geographical information system (GIS) based on ARCVIEW desktop GIS (ESRI).[8] GROMS will allow GIS-intersections of animal distribution maps with GIS-layers from different sources. GROMS will ultimately help reveal information deficiencies, support the Convention on Migratory Species and contribute to the Clearinghouse Mechanism under the Convention on Biological Diversity.

2. Knowledge about Migratory Species

Any discussion about migratory species requires a clear definition of this term. "Migratory species," as defined by the Bonn Convention,[9] include "the entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries**.**"[10] This definition is based on political units. In addition, it emphasises the return component of migrations, and therefore is close to the biological definition of "true migration," used under GROMS.[11] However, this biological concept is independent of national boundaries, and therefore includes species migrating within large range states.[12]

The scientific literature,[13] bibliographic databases[14] and the Worldwide Web were searched to assess the present state of knowledge of migratory species. Online information for most endangered species is provided by databases maintained by the World Conservation Monitoring Centre (WCMC),[15] the US Fish and Wildlife Service,[16] and several other

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[5] For example, Proposal of the Federal Republic of Germany for the inclusion of sturgeon species in Appendix II of CMS, BMU 1999. These documents contain valuable information, but are often unavailable or out of print.

[6] E.g., Siberian crane: CMS 1993; slender-billed curlew: CMS 1996

[7] A Geographical Information System (GIS) consists of a data bank and a system permitting processing and analysing spatial (geographical) data. *See* GEOGRAPHICAL INFORMATION SYSTEMS: PRINCIPLES, TECHNIQUES, APPLICATIONS AND MANAGEMENT (P.A. Longley, et al., eds. 1999).

[8] Further details, data model and present status of the database, available at <http://www.groms.de>. GROMS will be available on the Internet and on CD-ROM by the end of this year.

[9] 19 I.L.M. 15 (1980).

[10] *Id.* at art. 1. Note that the Bonn Convention includes some species nomadising between different countries (art. XX), such as the monk seal, river dolphin or the mountain gorilla. For complete text of the agreement text and species lists *see* <http://www.wcmc.org.uk/cms/>.

[11] "True migration" has been defined as a seasonal movement that implies some element of a return to some initial starting point – see McKeown 1984, p. 3, for a discussion of different definitions. For GROMS, a minimal migration distance of 100 km was chosen. Small-scale migrants such as amphibians are not included, though the GROMS data model would be appropriate.

[12] E.g,., Amazon catfish such as the piramutaba (*Brachyplatystoma vaillantii*) migrate 4000 km upstream for spawning (Barthem and Goulding 1997).

[13] R.R. BAKER , THE EVOLUTIONARY ECOLOGY OF ANIMAL MIGRATION (1978) is still the most comprehensive review of animal migration, summarizing the scattered literature for most migratory species.

[14] BIOSIS (BIOSIS Inc., <http://www.biosis.org>

[15] WCMC: <http://www.wcmc.org.uk/>

[16] <http://www.fws.gov/>

organisations. In addition, specialist groups of the International Union for the Conservation of Nature and consultants for CMS compile extensive species reports.

Table 1 lists the estimated number of species classified as "true migrants," with a minimal migration distance of 100 kilometers, and confirming to the biological definition set forth above. Among these approximately 4000 species, our knowledge is incomplete for several major groups, including small whales,[17] bats, and tropical and non-commercial fish (*See* Table 2). Information sources on conservation focus on “endangered species,” which fall into well-defined Red List categories, while the “data deficient” category seems to discourage any further research or conservation efforts.[18] Assessment of Redlist status is usually a time-consuming and arduous process. Unfortunately, for migratory species in particular, there have been unanticipated population crashes within a few years. For example, the Passenger Pigeon (*Ectopistes migratorius*) was once the most abundant species in North America, but rapidly hurtled toward extinction in 19th century.

The selection of a widely accepted taxonomic reference source is crucial for an effective linkage of a database to other information sources. Scientific bird names in particular are characterised by major inconsistencies. GROMS adopts Sibley-Monroe (1991) as its taxonomic reference source. Sibley-Monroe is widely accepted by conservationists, but differs in its taxonomic classification from many other lists, including even standard reference sources such as *Handbook of the Birds of the World* (del Hoyo et al. 1992). This necessitates management of parallel taxonomies and complicates data entry and exchange between different database projects. GROMS consults with major biodiversity and taxonomic initiatives, to ensure future compatibility.[19]

[17] G. Rose, *International Law and the Status of Cetaceans*, THE CONSERVATION OF WHALES AND DOLPHINS: SCIENCE AND PRACTICE 23-53 (M.P. Simmonds & J.D. Hutchinson, eds. 1996)
[18] Note that Red Lists are based on notifications from experts. This means that unlisted species have not necessarily been checked. A complete coverage has only been intended for mammals and birds.
[19] *See* Species2000 initiative : <http://www.species2000.org>.

GROUP	Digitised Information Sources	Taxonomy	Approximate Number of True Migrants
Mammals Bats Terrestrial mammals Marine mammals	Local ringing databases (Australia, Europe)[20] African Elephant database (AED)[21] African Mammal database (AMD)[22]	Wilson & Reeder 1993	All mammals: max. 600
Birds	Regional ringing databases Arctic bird database[23]	Sibley & Monroe 1991	Max. 2000
Turtles	WCMC turtle database[24]	King and Burke 1989	7
Fish	FishBase (CD)[25]	FishBase (based on Eschmeyer)	800
Invertebrates			500
S			**~ 4000**

Table 1: Compilation of estimated numbers of "true migrants" and some major digital and taxonomic information sources. For birds and bats, several regional ringing databases contain a wealth of information, but provide limited access.

An extensive database exists for fish (FishBase).[26] The migratory status of better-known fish species has been assessed, drawing upon major reviews and handbooks, and integrated into both GROMS and FishBase. The results are summarised in table 2.

[20] G.B. Baker et al., *Report on the Australian Bird and Bat Banding Scheme, 1995-1996* (1997) ; H. Roer, *60 Years of Bat-Banding in Europe – Results and Tasks for Future Research,* 32-33 MYOTIS 251-261 (1995).
[21] R.F.W. Barnes, et al., *African Elephan Database* (1998).
[22] Institute of Applied Ecology, *AMD African Mammals Databank. A Databank for the Conservation and Management of the African Mammals* (1998).
[23] C. Zöckler, Arctic Bird Library, <http://www.wcmc.org.uk/arctic/data/birds/index2.html>
[24] World Conservation Monitoring Centre, *Marine Turtle Nesting Database* (1999).
[25] R. Froese & D. Pauly, *FishBase 98. Concepts, Design and Data Sources* (1998)
[26] Fishbase, <http:www.fishbase.org>

		ana-	cata-	limno-	potamo-	oceanodromous
Migratory	741	109	35	10	88	499
Non-migratory	1087					
Unknown	16561					

Table 2: Migratory status of fish according to major reviews of fish migration.[27] Note the high number of fish species with unknown migratory status. More detailed evaluation of the literature is necessary to improve our knowledge about this category.[28] Anadromous: Return from ocean to fresh water for breeding (e.g. salmon); catadromous: migration into the sea for reproduction (eel), limnodromous: migration within major freshwater lakes, potamodromous: well-defined migration within lakes, streams and rivers, oceanodromous: migration within sea water (e.g. cod, herring, plaice and tuna).

3. Present State of the GROMS Database

Given the current state of knowledge and the diversity of digitised formats, GROMS required the design of a database from scratch.[29] The database provides fully referenced information on species, populations, a bibliography, and addresses of monitoring organisations and experts. Distribution maps, migratory routes and point data have been geo-referenced in ARCVIEW and can be exported to other GIS projects.

The species table contains scientific names with authorities, synonyms, vernacular names (English, French, German, Spanish), protection status, habitat and threats. Eighteen hundred species have been entered to this point, including 873 migratory fish species imported directly from FishBase. The basic unit within the GROMS data model is the "population," which is either defined taxonomically (subspecies), geographically or by sex and age. This differentiation is necessary because of considerable differences in migration behaviour among populations or sexes (e.g., male/female/juvenile seals). In addition, geographically or genetically defined populations are delineated as management units for conservation purposes.

GROMS includes geo-referenced maps in GIS-Format, which can be exported into any other GIS. These maps include other relevant factors relevant to species conservation (e.g., land use). It is possible to differentiate between three types of Geo-objects:

- areas ("distribution maps", at present: 412)
- lines (migratory routes or flyways)
- points (Observation points and aggregation areas: 2000 sites)

"Observation points" are simply defined by latitude and longitude, and could be aggregation sites for breeding, staging or moulting, monitoring sites such as bird observatories, or even catastrophic events that may severely affect species such as oil spills, affecting certain species. By linking observation points with species tables, GROMS encompasses all these factors in one common underlying data model. Eight hundred and fifty aggregation areas for Eurasian ducks and geese have been entered,[30] to assess database

[27] In cooperation with FishBase, based on B.A. McKeown, *Fish Migration* (1984); R.M. McDowall, DIADROMY IN FISHES (1998).
[28] In particular, migrants within tropical river systems will increase the number of potamodromous fish. For Amazonia, *see* R. Barthem & M. Goulding, THE CATFISH CONNECTION: ECOLOGY, MIGRATION, AND CONSERVATION OF AMAZON PREDATORS (1997).
[29] Data entry started in June 1998, after an initial phase of database design. For background information, *see* <http://www.groms.de>.
[30] D.A. Scott & P.M. Rose, *Atlas of Anatidae Populations in Africa and Western Eurasia* (1996).

structure, functionality and retrieval tools (see below). A compilation of bat caves has also been started.

4. Connecting Biodiversity Maps to a Geographical Information System

Maps are clearly among the most important tools to represent the complex geographical distribution of migratory species. Migratory species occupy distant geographical areas during feeding or breeding, using specific migratory routes and "stepping stones" for resting and fuelling. Certain areas are often visited only briefly (days), but might harbour most or even all members of a population. Most of this information is published as text or simple map line drawings, often without exact geographic data such as latitude/longitude, scale or projection. This poses a severe impediment for transfer into GIS-formats. However, appropriate, well-defined map projections are important for a comparison of maps from different sources or the analysis of flyways.

Especially for birds, distribution maps of varying quality form an integral part of most field guides and handbooks. The general problem with such distribution maps is concisely summarised by K. Kaufmann:

> Most bird cartography takes what might be called a 'broad brush' approach . . . such a map is comforting because it looks so absolute. But it is also invariably misleading . . . compiling perfect range maps is not just difficult, it's literally impossible[31]

The only way to ameliorate this problem is a raster approach, i.e. covering whole regions with a definite counting protocol within a well-defined geographical grid. Impressive data sets exist for certain groups and regions, providing population numbers with high spatial resolution.[32] However, the generation and maintenance of such data sets is expensive, and up to now it has only been successfully applied to some regions. Moreover, it requires the assistance of many volunteers.

Another set of high-quality data is based on point observations, either from field observations at certain monitoring sites,[33] ringing recoveries, satellite data of migration routes[34] or museum specimens. The latter provide a largely untapped source of high-quality information, including historic data extending back one century. Several major natural history museums house about one million bird specimens each. The collection sites could be digitised into a huge database for distribution maps. Ambitious bioinformatics projects are planning to make such museum data available via the Internet.[35] However, point data sets over-represent accessible sites such as roads or biological stations, and important areas might remain undetected. To obtain a complete picture, extrapolations are necessary, which up to now are mostly "informed guesses" of experienced biologists. GIS-based techniques can help to make such extrapolations transparent. Further point data are provided by ringing recoveries, and counts at certain key sites.

Once entered into a GIS, digitised distribution maps or point data can be used for a number of analyses by intersection with other maps. For example, the intersection of all merged distribution maps with borders of administrative units such as states or provinces produces species lists and numbers for each administrative unit (Fig. 1). The resulting map

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[31] Introduction by K. Kaufmann , in J. PRICE, S. DROEGE & A. PRICE, THE SUMMER ATLAS OF NORTH AMERICAN BIRDS (1995).

[32] *See*, the EBCC bird breeding atlas with a resolution of 50x50 kilometers, E.J.M. HAGEMEIJER & M.J. BLAIR, THE EBCC ATLAS OF EUROPEAN BREEDING BIRDS: THEIR DISTRIBUTION AND ABUNDANCE (1997).

[33] Wetlands International maintains an impressive database of waterbird counts at important staging posts and wetlands, < http://www.wetlands.agro.nl/>.

[34] *See* the Argos-website for satellite tracking of endangered species, <http://www.argosinc.com/docs/biouser.htm>.

[35] *See*, for example, the Global Biological Information Facility (GBIF): <http://www.gbif.org/>.

shows a high diversity of migrants within temperate regions, which may call into question the current focus of conservation efforts on "biodiversity hotspots" in the tropics.[36]

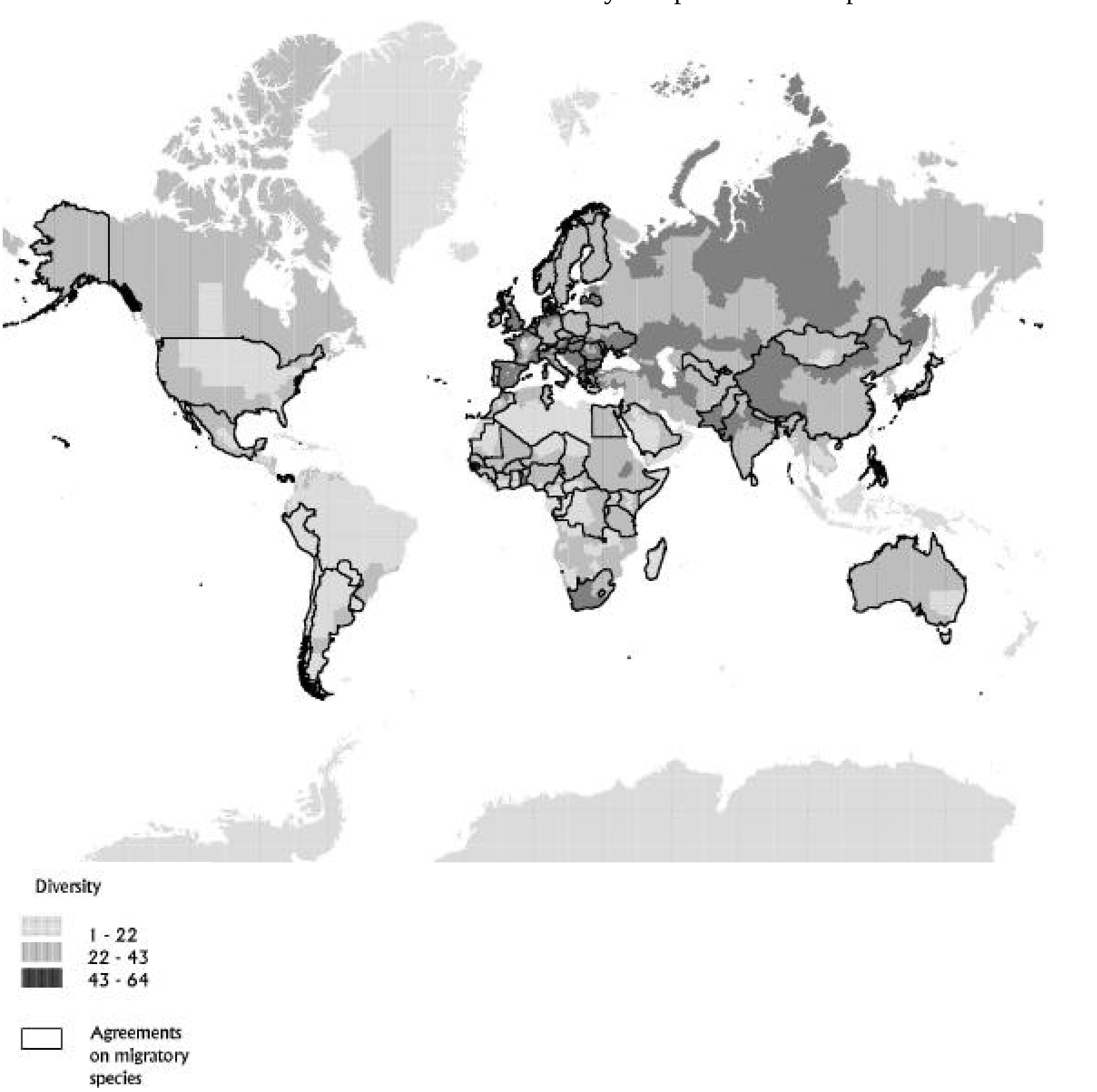

Fig. 1:

Number of migratory species per administrative unit, based on an intersection of 247 mammal and bird distribution maps in GIS-format with administrative borders. Note that diversity is high in temperate regions, e.g. in the northern Siberian provinces of Krasnoyarsk or Tiumen, and the lack of a latitudinal gradient. Member states of international agreements for the protection of migratory species are delineated, including Bonn convention members and signatories as well as bilateral agreements (North America - Mexico, Japan - Australia , China – Australia; Australia is also a member of the Bonn Convention).
Sources for distribution maps:
Birds (150 species): Curry-Lindahl 1981; Cramp 1977; raptors: del Hoyo et al. 1994 (all migratory raptors), del Hoyo et al. 1992,1996; Johnsgard 1983 (all cranes), Madsen 1998, Scott 1996.[37]
Mammals (97 species): 9 terrestrial African mammals: Institute of Applied Ecology (African Mammal Database) 1998; Mongolian gazelle (Procapra gutturosa): Lhagvasuren 1997, Lushchekina 1999, Wang 1999; 13 bats: Baker 1978; Straw-coloured fruit bat (*Eidolon helvum*): Smithers 1983; 74 marine mammals: Ridgway 1981, 1985, 1989, 1994, 1999.

[36] N. Myers, et al., *Biodiversity Hotspots for Conservation Priorities*, 403 NATURE 853-858 (2000).
[37] For a complete list of species, *see* <www.groms.de>.

The maintenance of range state lists is an important and time-consuming task for conservationists. Our example shows that range states or even provinces for each species can be calculated by using GIS maps based on a well-defined data source (in this case, the reference for the distribution map). Thereby, range state information can be provided more quickly, and can be made more transparent. Different sources can be compared, and in the case of contradictory results, states can be queried. The advantage of "calculated administrative units" becomes even more evident in the case of provinces. In fact, the half-life of administrative units is often longer than that of states. In addition, provinces are responsible for nature protection or hunting laws in many federal states. Thus, it sometimes makes sense to analyse long-term political aspects of nature conservation at a provincial level.For example, the monk seal was protected in Croatia since 1935.

There are numerous additional applications for biodiversity maps in GIS-format, among them:

- Comparison of maps from different sources and different projections
- Calculation of diversity hotspots
- Intersection with other GIS-layers such as ecoregions, land use, population pressure or climate change predictions, to name just a few.

In spite of the advantages of this technology, biologists are still reluctant to use GIS tools. In the field of zoology, GIS use is growing rapidly, but is still in its infancy.[38] Most of the papers in the discipline that employ GIS analysis focus on one species. The analysis of diversity patterns using GIS has great potential, but there are only a few cases where this technique has been applied to whole species assemblies.[39] The analysis of local raster data has yielded some impressive results.[40] This analysis revealed a clear decline of many species, especially farmland birds, attributable to intensification of agriculture. The recommendations of researchers for changes in European Union agricultural policies to address these trends[41] will be difficult to implement, highlighting the fact that solid data sets are a necessary, but not sufficient condition to conserve species.

One of the reasons that zoologists have not embraced this technology more enthusiastically is because GIS-World does not provide a standardised query language. The introduction of desktop GIS has helped, but there are still many problems. Even simple questions, such as how many species occur within a certain area, require execution of a number of complex GIS operations. Therefore, we have designed a completely new Graphical User Interface (GUI) to publish and visualise interactive maps on the Internet.[42] This interface allows geographic filtering of information, visualisation of maps, and generation of simple species reports. Dropdown-menus for information retrieval are specially adapted to users working for and in collaboration with the Bonn Convention.[43]

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[38] The number of publications mentioning GIS in title or abstract rose from about a dozen (1988) to around 200 in 1997 (source: BIOSIS)

[39] e.g. the interesting results on range restriction of endangered flagship species by M. Channel & M.V. Lomolino, *Dynamic Biogeography and Conservation of Endangered Species*, 403 NATURE 84-86 (2000). Some more examples of GIS databases are mentioned in Table 1.

[40] Such as censuses from the British Trust of Ornithology, *see* J.R. Krebs, et al., *The Second Silent Spring?*, 400 NATURE 611-612 (1999).

[41] *Id.*

[42] In cooperation with the Geographic Institute, Bonn University, <http://www.giub.uni-bonn.de/exse/>.

[43] *See* J. Fitzke & T. Friebe, *Kartengestützte und internetbasierte Auskunft über die geographische Verbreitung von Pflanzen und Tieren,* in Umweltdatenbanken im Web 18–27 (1999). Users are encouraged to test this pilot version at <http:www.groms.de>. Their feedback will be incorporated into the final version, scheduled for release by the end of 2000.

5. Conclusions and Caveats

Finally let me proffer some caveats: GROMS is collating information on a global scale. This means that zooming into maps and displaying them on a country scale reveals considerable lack of acuity.[44] Data sets that are more accurate do exist, and these might be incorporated into GROMS in the future. In addition, the underlying database has a rigid structure, which is not always compatible with the information gathered by biologists. Certain methodological constraints or subtle additional information might get lost by simply entering numbers or standardised key words into a database. Facts might be generated from hypotheses and conjectures, important hints might get lost. Consequently, there will always be an "expert-user dilemma." An expert on a certain species or region is still a better information source than any database or GIS could ever be. However, a waterbird expert might not know about some endangered fish or turtle species occurring within the same wetland as "his" bird, and a natural park manager might be interested to learn about the importance of “her” park for a certain species on a global scale. Therefore, modern information technologies should prove to be of great assistance for conservationists in the third millennium.

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[44] Note that scale is a general, often overlooked problem in conservation planning. For an enlightening discussion, *see* B.F.N. Erasmus et al., *Scale and Conservation Planning in the Real World*, 266 PROC. ROYAL SOC’Y LONDON B 315-319 (1999)

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