

Cataloguing Indian biota: the electronic catalogue of known Indian fauna

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One of the major mega-biodiversity nations, India is known to harbour rich and diverse biotic resources within the length and breadth of its territory. Data and information regarding these resources remain distributed with several organizations and individuals, making it difficult to access adequate and accurate information about them, easily and efficiently. This calls for development of well-constructed electronic catalogues (ECAT) of known biotic resources of India. This article, while discussing the importance of development of electronic catalogues of known life, reviews the global and national scenario. We share our experience of developing web-interfaced ECAT of known Indian fauna (IndFauna). Accessible at <http://www.ncbi.org.in>, this catalogue raises several issues concerned with taxonomy or systematics and information technology in biodiversity information management. Baseline information on more than 93% of the 90,000 known faunal species in India has been documented in IndFauna, which demonstrates a model of collaboration between domain experts and IT managers. It is our belief that such ECATs would be effective in overcoming taxonomic impediments as well as better sustainable use and conservation of our biotic resources.

THE most striking feature of the earth is the existence of life, and the most striking feature of life is its diversity, popularly known as 'biodiversity'¹. The most practical and widely applicable measure of this biodiversity is 'species'. They are the common currency for biodiversity research and management, and the only measure of biodiversity with a well-established standardized code of nomenclature. The presence of a species can indicate the habitats present, environmental quality, and state of knowledge of biodiversity such as rates of discovery, and extinctions. The relative richness of species in comparable samples can be a good indicator of environmental health. The most important aspect of biodiversity is species composition. From checklists of species taken over time the rates of emigration, extinction and turnover of species in a community can be measured and modelled. The dynamics measure the stability of biodiversity in ecosystems. Species names or scientific names are thus at the foundation of quality control in biological studies². Further, scientific names are fundamental to biodiversity research as they are a means of communicating information across the globe.

About 1.8 million species are 'known' to the world so far, in the sense that they have been described and named by taxonomists³; however, it is estimated that anywhere from three million to more than 100 million species exist in the world today⁴. Spatial and temporal patterns in bio-

diversity distribution can be analysed by linking these names with information on nomenclature, taxonomy, ecology, distribution and abundance. Creating a single repository for such information is vital for future studies in biodiversity. Electronic cataloguing (ECAT) provides an effective tool for collation, analysis and dissemination of information about biological diversity. Such national, regional and global ECATs can be used for effective biodiversity management and policy making⁵.

Here we attempt to emphasize the importance and urgency of developing such ECATs of known Indian life. While we review the global and national scenario of development of ECATs, we share our experience of developing web-interfaced ECAT of known Indian fauna (IndFauna).

Cataloguing life: the state of the art

Global status

During the last decade or so, a number of ECAT development activities have been started in different parts of the globe⁶. As shown in Table 1, some of these are nation- or region-specific⁷⁻¹⁰, while others are dedicated to specific taxa¹¹⁻¹⁸. Most notable amongst them are Species2000 (ref. 19) and Integrated Taxonomic Information System (ITIS)²⁰.

The goal of ITIS (<http://www.itis.usda.gov/>) is to create an easily accessible database with reliable information on species names and their hierarchical classification. The

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GENERAL ARTICLES

Table 1. Major global, regional and national electronic catalogues of known organisms

Title	URL
All Biota	
Integrated Taxonomic Information System	http://www.itis.usda.gov/
Species 2000	http://www.sp2000.org/
ETI World Biodiversity Databases	http://www.eti.uva.nl/
Index to Organism Names (ION)	http://www.york.biosis.org/triton/nameind.htm
Australian Antarctic Division	http://www-old.aad.gov.au/
BIF – DEUTSCHLAAND	http://www.gbif.de/gbif-de/
KISTI	http://codata.kisti.re.kr/
The Taxonomic Name Server (TNS)	http://www.ubio.org/
BIOTA/FAPESP, The Virtual Institute of Biodiversity	http://www.biota.org.br/info/sac/composicao
Salticidae	http://tolweb.org/tree?group=Salticidae&contgroup=Dionycha
SinBiota/IABIN	http://wildlife.wisc.edu/sinbiota/
European Register of Marine Species (ERMS)	http://erms.biol.soton.ac.uk/
Census of Marine Life (CoML)	http://www.cuml.org/
Marine Species Index – Marine Biological Laboratory	http://database.mbl.edu/SPECIMENS/phylum.taf?function=form&page=2
UNESCO–IOC Register of Marine Organisms (URMO)	http://www2.eti.uva.nl/database/urmo/default.html
Animals	
Amphibian Species of the World	http://research.amnh.org/herpetology/amphibia/index.html
Amphibiaweb	http://www.amphibiaweb.org/
Coleoptera	http://www.coleoptera.org/
Cephbase	www.cephbase.utmb.edu/
FishBase	www.fishbase.org
OBIS	http://marine.rutgers.edu/obis/
Hemiptera Fulgoromorpha Lists on the Web (FLOW)	
Museum National d'Histoire Naturelle	http://flow.snv.jussieu.fr/
Fulgoromorpha	http://flow.snv.jussieu.fr/
Iberodorcadion: explorando y revisando	http://entomologia.rediris.es/
Maps of Michigan Reptiles and Amphibians	http://www.ummz.lsa.umich.edu/herps/miherps/index.html
Molluscs, OBIS	http://www.amonline.net.au/invertebrates/
Museum Victoria's Data on Butterflies, Snakes and Frogs	http://www.museum.vic.gov.au/bioinformatics/
The Parasite Database	http://brookswb.zoo.utoronto.ca/index.html
ScaleNet – Systematic Database of the scale Insects of the World	http://www.sel.barc.usda.gov/scalenet/scalenet.htm
Tiger Beetles of Connecticut: (Coleoptera: Carabidae: Cicindela)	http://www.eeb.uconn.edu/collections/insects/CTBnew/ctb.htm
USDA Nematode Collection Database	http://www.nem.barc.usda.gov/database/search.cfm
IndFauna – Electronic Catalogue of Known Indian Fauna	http://www.ncbi.org.in/biota/fauna/
Bacteria	
Bacteriology Insight Orienting System (BIOS)	http://www-sp2000ao.nies.go.jp/english/bios/index.html
The List of Bacterial Names with Standing in Nomenclature	http://www.bacterio.cict.fr/
The Economic Value of Microbial Diversity Information	http://www.wfcc.info/lois.html
Fungi	
Index Fungorum	http://www.indexfungorum.org/
Fungal Databases NZ	http://www.landcareresearch.co.nz/research/biodiversity/fungipro/
Plants	
International Plant Name Index (IPNI)	http://www.ipni.org/
Plant Fossil Database	http://www.ohiou.edu/~iop/index.html
AlgaeBase	http://www.algaebase.org/
Apiales Resource Centre	http://rbg-web2.rbge.org.uk/URC/arc.htm
Australian Plant Names Information	http://155.187.10.12/anbg/plant.names.html
BG-BASE	http://www.rbge.org.uk/collections/collections.htm
Dendrome Database (the Forest Tree Genome Database)	http://dendrome.ucdavis.edu/
Environment Australia Flora Biodiversity (ERIN)	http://www.erin.gov.au/life/species/species_flora.html
Flora of Europe	http://utopia.knoware.nl/users/aart/
ILDIS	http://www.ildis.org
Flora of China	http://flora.huh.harvard.edu/china/
Flora Base	http://www.calm.wa.gov.au/florabase/index.html
FLORIN	http://www.florin.ru/florin/
International Legume Database and Information Service (ILDIS)	http://www.ildis.com

(Continued)

Table 1. (Continued)

Title	URL
International Organization of Plant Information (IOPI)	http://www.bgbm.fu-berlin.de/iopi/gpc/default.asp
Moss TROPICOS	www.mobot.org/MOBOT/tropicos/most/welcome.shtml
Missouri Botanical Garden's VAST Nomenclatural Database and Associated Authority Files Via W3TROPICOS	http://mobot.mobot.org/W3T/Search/vast.html
http://www.nybg.org/bsci/online_pubs.html	
NZ Plant Names	http://www.hortnet.co.nz/publications/nzpps/publicat.htm
Plants db Taiwan, GBIF Rep.	http://taiwanflora.sinica.edu.tw/english/link_e.html
PLANTS	http://www.info.usda.gov
Rijksherbarium	http://nhnml.leidenuniv.nl/
University of California, Berkeley Searchable Botanical Datasets	http://elib.cs.berkeley.edu/calflora/botanical.html
Viruses	
ICTVdb	http://www.ncbi.nlm.nih.gov/ICTVdb/
The Universal Virus Database	http://life.anu.edu.au/viruses/univirdb.htm

database will be reviewed periodically to ensure high quality with valid classifications, revisions and additions of newly described species. ITIS includes documented taxonomic information of flora and fauna from both aquatic and terrestrial habitats. However, it places greater priority on North American species. Species2000 (<http://www.sp2000.org/>) is global in its coverage and initiated to compile a 'Catalogue of Life', using distributed networking on the Internet²¹. It aims at creating validated and uniform index of the world's known organisms (animal, plant, fungi, microbe and viruses). Species 2000–Catalogue of Life 2004 checklist integrates 19 distributed databases, including ITIS to collate baseline information on 308,000 species and 33,000 infraspecific taxa of animals and plants²². In early 1999, the world's leading marine scientists initiated Census of Marine Life (CoML) with the ultimate goal of developing detailed series of on-line atlases that will facilitate researchers visualize where marine organisms once lived, where they are now, and where they might be found in future. Ocean Biogeographic Information System (OBIS) has 2,929,761 records, 38,754 scientific names and 30,543 species which are accessible through the web²³. However, these as well as many national and regional databases are incompatible with each other in more than one way. Realizing this, Global Biodiversity Information Facility (GBIF) was formed with the major goal of providing a mechanism to promote and enhance the development of standards required for interoperability⁶. GBIF aims at indexing at least 90% of the 1.8 million known species names and its associated baseline data²⁴ by 2013. In its first phase, GBIF is interoperably linking species- and specimen-level databases, helping to complete the electronic catalogue of names of known organisms and devising a plan of outreach and capacity building, so that individuals in all countries will have access to scientific biodiversity data.

The preceding discussion reveals that a majority of these initiatives are from the agencies in the developed

regions. However, highest concentration of biodiversity is in the tropical region, especially in developing and under-developed nations. Similar to distribution of biological specimens in the museums of developed nations, biodiversity databases too are being developed by institutions from the developed world. It is therefore essential to encourage developing nations such as India, to undertake development of ECAT of its known biotic resources.

National status

The Indian scenario is in many ways representative of the difficulties faced by developing countries in biodiversity cataloguing. The rich diversity of Indian biota has posed considerable challenge to generations of taxonomists in India and across the world. In addition to the two hot spots of biodiversity, the Western Ghats and Eastern Himalaya, specialized ecosystems such as islands, oceans, deserts and mountains across India are rich in flora and fauna. The available information about flora and fauna is distributed in various sources and is not available from a single source. What makes India a more interesting nation are its multiple religions, ethnic communities with diverse lifestyles, habits, languages and cultures. This provides another dimension to documentation of biodiversity, as a single species is known in different regions and languages with a variety of local or vernacular names. There is an urgent need to develop widely accessible, up-to-date repository collating information on scientific names and common or local names in various regions and languages.

In the recent past, sporadic efforts have been made in the electronic documentation of known Indian biota. ATREE, Bangalore has released a CD-ROM titled *Sasya Sahyadri*²⁵, collating baseline information on flora of the Western Ghats. Legume database of South Asia²⁶, developed by the National Botanical Research Institute, Lucknow has been integrated in the Global Legumes

Database. National Institute of Oceanography, Goa has developed taxon-specific CD-ROM titles²⁷ on Marine Prawns of India, Marine Crabs of India, Mangroves of India, Lignicolous Fungi of India. Jawaharlal Nehru Centre for Advanced Research, Bangalore has developed a database on flora of Karnataka²⁸, indexing 4758 floral species that occur in Karnataka. Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore is developing a database of Birds of India²⁹. FRLHT, Bangalore is developing a medicinal plants database and Traditional Knowledge Digital Library (TKDL)³⁰. Know-Net-grin³¹, an information system on indigenous innovations and traditional knowledge, has been developed by SRISTI. Information about national parks and wildlife sanctuaries can be retrieved through National Wildlife Database³² being developed at the Wildlife Institute of India (WII), Dehradun. French Institute of Pondicherry has released a database on Endemic Plants of the Western Ghats³³. This indicates that electronic cataloguing of known life in India is happening in various distributed and isolated pockets. These datasets are restricted to some geographical regions or to certain taxonomic groups. Since most of these are off-line in nature, access to information requires special efforts. There is no interaction between individual developers and due to lack of uniform standards, most of them are incompatible with each other, raising serious interoperability issues.

To address these problems in the Indian context, NCL Centre for Biodiversity Informatics (<http://www.ncbi.org.in/>) has taken up the task of development of ECATs of Indian life. It is a coordinated and integrated approach to collect, maintain and provide baseline information on known Indian life (microbes, plants, animals, viruses and fungi) in a web-interfaced format. We intend to achieve this impossible-looking task in the next 4–5 years. This initiative is further justified because of the well-known fact that highest concentration of biodiversity is in the tropical regions, especially in developing countries and oceans⁶. For a mega-biodiversity nation such as ours, it is critical to have anytime, anywhere access to baseline information about our biotic resources for their efficient sustainable use and management. As a first step, we are currently developing ECAT of known Indian Fauna (IndFauna).

ECAT of known Indian fauna: why?

According to recent estimates there are about 89,451 known faunal species in India, which is about 7% of the total animal species in the world³⁴. However, only less than 50% of the geographic region of the country has been surveyed so far^{35,36}. The earliest studies on fauna date back to 1800s from which *Fauna of British India (FBI)* was put together by various researchers until 1940. However, since then, several new species have been described

and taxonomic status of the species has undergone many revisions³⁷. New species are discovered every year from various parts of India and there is no centralized system to disseminate secondary information regarding these descriptions. The exploratory phase in Indian taxonomy can continue for a long period as several areas such as Eastern Himalayas and Andaman and Nicobar Islands have not been surveyed so far. Several invertebrate phyla, viz. Nemertinea, Pogonophora, Priapulida and Pentastomatida are yet to be reported from India³⁴. The lower groups of organisms, especially insects are still to be documented in detail. A large number of invertebrate taxa are mainly known from collections in museums across the world to which Indian taxonomists have limited access. Although *FBI* is available as baseline literature, many invertebrate taxa were not covered in *FBI* and as a result such information is only available in monographs, collection records and catalogues published outside India. The information from various taxonomic studies carried out so far in India is distributed with several organizations and individuals, making it difficult to access adequate and accurate information on a variety of aspects of faunal diversity.

Zoological Survey of India (ZSI) is the central institution dealing with documentation of Indian faunal diversity. Established in 1916, ZSI has published monographs and taxonomic revisions of many taxa together with around 3929 new records³⁷ during 1916–91. In addition, several research groups in universities, colleges and research institutions across the country are also working on faunal taxonomy. Information related to the ecology, population biology, biogeography, phylogeny and traditional knowledge regarding fauna is available through various research projects and surveys by institutions such as Bombay Natural History Society, WII, Forest Research Institute (FRI), SACON, ZOO Outreach, etc. This information is mostly available in published text format as survey reports or papers and is not easily accessible to all.

Hence, at present there is no single repository to provide information such as scientific names, common names, occurrence of organisms, their spatial and temporal distribution and bibliography. Users such as conservationists, policy makers, environmental managers and para-taxonomists feel the need for this basic information about Indian fauna. Taxonomists themselves often feel the need for a single information source on Indian fauna and quick access to references. The diversity of languages and cultures across India should also be taken into consideration while disseminating information. It is therefore necessary at this stage to create an information system to collate existing information, create tools for receiving new information with facilities to integrate, exchange and disseminate it in multiple ways. ECATs provide the best approach to compile and integrate or exchange information, and hence the IndFauna.

IndFauna: features

IndFauna encompasses all taxa of animals and also the current political and geographic coverage of India, including 7000 km of coastline and an Exclusive Economic Zone (EEZ) of 2.1 million km². IndFauna is a web-based, dynamic data collation and dissemination information system providing collaborative environment to data contributors and 'taxon editors'. IndFauna adapts a species-centric approach, where scientific name is the nucleus of the database (Figure 1) to which taxonomic, synonym, common name, biogeographic and other information are linked. IndFauna collates the following baseline information for each species.

1. Valid scientific name with authority, year of publication according to accepted taxonomic opinion.
2. Systematics of the species from kingdom to form level.
3. Threat status and invasive status.
4. Synonyms with authority and publication year.
5. Common/local/vernacular names.
6. Details on references (DSN, Data Source Number).
7. Latest taxonomic scrutiny (Name of 'taxon editor' and date of latest taxonomic scrutiny).
8. Biogeography with occurrence within India, water bodies of India and reference.
9. Multimedia artwork such as images, sketches, photographs and audio–video clippings.

Data collation through IndFauna is live and transparent in the sense that there is no residency period for data acqui-

sition and its dissemination. Similar to Species2000 and ITIS²¹, IndFauna bring together taxonomic treatments from authors and institutions to provide a centrally collected system for Indian fauna.

IndFauna: architecture

The complex and interlinked biodiversity data and their dynamic nature posed many challenges for data management and networking. While there are tools available for creating off-line inventory and descriptive information systems such as Linneaus II of ETI³⁸, Platypus³⁹ and ITIS workbench⁴⁰, we could not come across tools or programs which can be used for developing web-interfaced ECATs. Further, we realize that many of them were not able to encode biodiversity data collected from disparate sources such as geographic, environmental and bibliographical data. It was therefore necessary to set up a unique cost-effective and easy-to-use information system for providing faunal database to assist searching of locations, taxonomy and other information of the fauna. In addition, precision and ease in data entry was required to deal with the rigorous task of entering data on about 90,000 species.

The taxonomy data explain the relation between the species based on certain characteristics. These characteristics on which the species are defined may vary in time due to discovery of a new class of characteristics, or corrections to previously recorded characteristics, etc. The system had to be flexible enough to accommodate frequent changes in taxonomic hierarchy, which is a com-

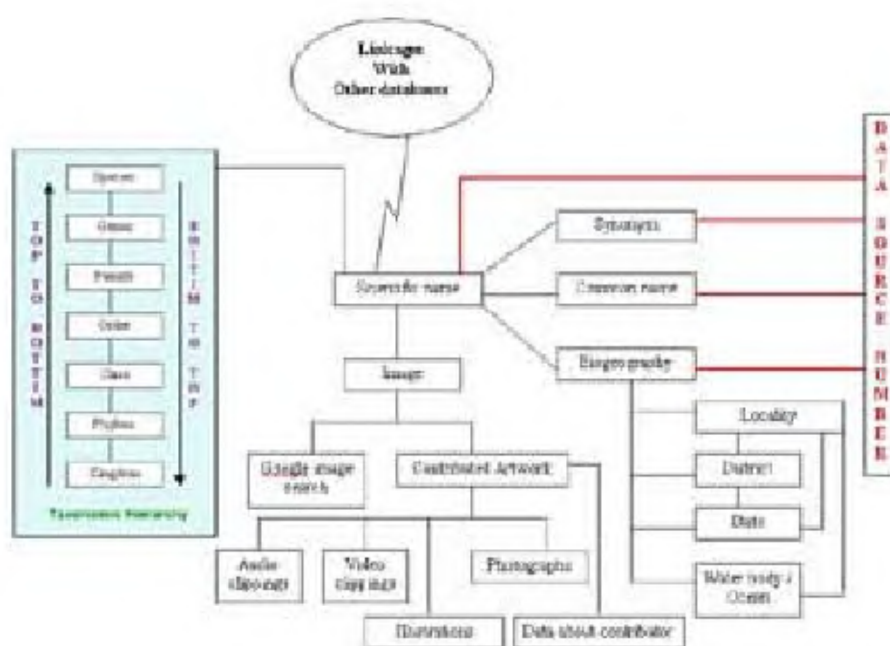


Figure 1. Information system architecture of IndFauna.

mon feature of all biodiversity data. Systematic data for a species is not uniform in different taxonomic systems and causes problems in building standard datasets. These faunal data types have deeply nested relationships within and among themselves. This difficulty was overcome by matching to the hierarchy with standards of ITIS and also referring with International Code of Zoological Nomenclature (ICZN).

Hence, our design goal was to create a database which can accommodate separate ownership of biodiversity data by different departments and deal with disparity in data-management standards, which is the main difficulty in biodiversity information exchange, sharing and comprehensive processing. Therefore, we created this database system keeping in view that it should facilitate data acquisition, storage, query support, unique species digitization, restrictive data access and be easy to use with bare minimum infrastructure. The overall working of the system is described here.

IndFauna consists of 19 tables, which include scientific names, taxonomic hierarchy, synonyms, common name, biogeography and bibliography (DSN), etc. Each record is linked to a DSN, which is the reference for review of the data in future. Database creation was one of the major tasks in implementing the system to store data. Oracle 9i is used as a database server to store data. JSP (Java Server Pages) technology is used to create user-friendly web-interfaces. Apache is used as a web server, and Tomcat 4.1 is used as a container for JSP applications.

Beta users were invited to test the application, and their suggestions were taken into consideration to improve the system. An advantageous feature of the module is its ability to provide directives to data contributors in following the data-entry sequence. Because data-entry is time-consuming, various graphical user interfaces are deployed by the system to alleviate this problem and ensure the consistency of data entry. Whenever required, the system displays pull-down lists and pop-up lists showing predefined attributes or attributes generated from the database at run-time.

Since we intended to develop dynamic web-interfaced information system, which would be interacting in real-time with data contributors as well as data users, several security measures were adapted. Secure login facility has been provided to data contributors and 'taxon editors'. The system generates history (date, time and details of data contributed) for each of the records contributed. Further, 'taxon editors' do not delete the records directly, but they simply mark them for deletion. The program coordinator in consultation with panel of experts takes the final decision on permanent removal of the record.

IndFauna: system modules

User interface is the main feature of the system, because it is the only way through which users will get connected

to the system. Hence, user interface should have good visualization interface for the results produced by the system. The establishment of user needs was an important aspect, because most of the end-users are biologists. Thus the result could be presented in a systematic, easy to understand and in a simple text format.

Taxonomic data management

This group of modules performs two distinct functions: (a) accepts scientific names, synonyms and common names, and their related references, and (b) accepts taxonomic hierarchy management of a given species. The scientific name table is at the core of the entire database. It collates information on valid/accepted scientific names, authority, year of publication, and DSN. It also gathers information on threat and invasive status of a species (Figure 2).

For the ease of taxonomic hierarchy management two data input approaches, viz. 'top-bottom' and 'bottom-top' have been provided (Figure 1). Using top-bottom approach, taxonomic hierarchy could be entered in a conventional manner from kingdom to species. However, using the bottom-top approach taxonomic hierarchy is entered in exactly the reverse way. Both approaches facilitate inclusion of sub-level details for each major taxon level. Our experience suggests that most of the time, data managers and 'taxon-editors' prefer using the bottom-top approach as it prevents repetitive data entry.

Biogeographical data management

The biogeography module collates data on the occurrence of each species in time and space. This module provides an add-on feature to link the place of occurrence (locality) with single or multiple districts or states in case of terrestrial organisms, and seas or oceans in case of marine organisms (Figure 3). It is possible to provide data up to point location using latitude and longitude position or range. Period of occurrence of species can be recorded as precise date of observation or period of observation. Associated with this are the data on altitude, which would prove important in analysis of spatial and temporal distribution of each species.

Multimedia artwork management

This module facilitates acquiring multimedia artwork for each species. These could be photographs, illustrations, as well as audio and video clippings (Figure 4). For each contributed artwork, data on the contributor and detailed description of the artwork can be collated. It facilitates the contributor or 'taxon editor' to upload artwork(s) of the species in the database. We believe that these artworks

Figure 2. Taxonomic data management module of IndFauna.

could later be used in visual identification of the species based on characteristics as captured in the graphics.

Cross-linkages with other databases

IndFauna being a web-based catalogue, it is possible to cross-link it with other datasets developed by outside agencies. Linkages with these and other databases such as sequence or molecular data, geospatial and climate data, and ecological and ecosystems data will enable 'data mining' never before possible⁶. This would facilitate the exploration of questions that, at present, cannot readily be answered. Currently, we have attempted to provide cross-linkages with public domain sequence databases such as nucleotide sequences (NCBI, and EMBL), protein sequences (NCBI, EMBL, SwissProt, PIR, and TrEMBL), and protein structures (PDBSum). Cross-link has also been provided with GoogleImages.

Query/search module

This module consists of two sections: (a) search module for web users, and (b) report module for 'taxon editors'. The search module facilitates web users to query on scientific names, common names, synonyms, biogeography,

and multimedia artworks (Figure 5). Wildcard searches can be made using options such as 'contains', 'is', 'begins with' and 'ends with' for each of these categories (Figure 6). Hyperlink feature of the web has been used to facilitate retrieval of data on other parameters, irrespective of search category. For instance, one can search for specific locality by selecting biogeography option from list box, and also retrieve data on taxonomic hierarchy, synonyms, common names and multi-media artworks of each species recorded from a given locality.

Report module is specifically designed for 'taxon editors' to retrieve the data on groups of organisms of their interest in typical checklist format (Figure 7). It is feasible to generate reports at various taxonomic hierarchy levels and sub-levels. Currently, the report consists of taxonomic hierarchy, accepted scientific names, synonyms, common names and biogeography, each being superscripted with DSN. All related DSNs are displayed at the end of the report. Secured logins have been provided to remote 'taxon editors'.

IndFauna: data collection and validation

The main goal of the project is to provide accurate, scientifically credible, and current taxonomic data that meet

Scientific name :

Enter Locality:

Please select: ☐ enter district(s) or state(s) for this locality

☐ Select District(s):
☐ Or:
☐ Select State(s):
☐ Or:

☐ Select Water body:

Observed date:

Observed Period: Year: (How to enter? [Help](#))

Latitude

From To

Deg	Min	Sec	Position	Deg	Min	Sec	Position
<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>

Longitude

From To

Deg	Min	Sec	Position	Deg	Min	Sec	Position
<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>	<input type="text" value=""/>

Dot position

Latitude Longitude

Deg	Min	Sec	Position	Deg	Min	Sec	Position
<input type="text" value="22"/>	<input type="text" value="00"/>	<input type="text" value="00"/>	<input type="text" value="North"/>	<input type="text" value="87"/>	<input type="text" value="00"/>	<input type="text" value="00"/>	<input type="text" value="East"/>

Min sea level: (in meters)

Duration:

Dis. pages:

Figure 3. Biogeographic data management module of IndFauna.

the needs of the user public. The data incorporated in the database are collected from multiple sources. Our main focus is on published literature, including research papers, faunas and monographs as sources of authentic and reviewed information. The collections of specimens in various museums are also important as they provide primary information regarding identity and occurrence of certain species. This is especially important in case of invertebrate taxa for which published literature is not available. Recently, many individuals and institutions have created web-based databases and checklists that are useful for getting information regarding Indian fauna. How-

ever, the information is carefully scrutinized for validity and accepted only if it is from reputed taxonomic institutions or experts. Non-taxonomic research papers on ecology, physiology, animal behaviour, distribution, etc. are a secondary source of information, especially for information supplementary to the scientific name. The data standard is then confirmed as per the International Code of Zoological Nomenclature (ICZN).

In case of invertebrate taxa such as Lucanidae, Embioptera, Anthicidae and Buprestidae, there is no published checklist for India. In this case, personal communication with taxonomists across the world was made to acquire

data on Indian taxonomy. Thus, for collecting information, highest importance is given to 'faunas' and 'monographs' followed by published research papers, then 'on-line and off-line databases' followed by 'region- and taxon-specific web sites' followed by 'personal communications with experts', and at the end to 'non-taxonomic publications'.

Validation of the data at various levels is the key factor for providing authentic information to users. In IndFauna, this process is carried out in four steps.

1. Orientation and hands-on training of data managers was carried out. Thus, some problems such as misprints, locality checks, etc. are effectively handled at the data entry level.
2. Checking of entered data is made by the data managers to detect any errors or conflicts in data entered from various sources.
3. The completed lists are sent to already identified 'taxon editors', who are active taxonomists. After receiving the revised data from them changes are made according to their suggestions and their name and date are entered in the group of species as 'scrutinized by'. So far 75 taxonomists, including foreign experts are contributing as 'taxon editors'.
4. The fourth major validation process will be carried out in a collaborative workshop of taxonomists from all parts of India.

Owing to multiple taxon reviewers, the ECAT on Indian fauna can function as a peer-reviewed publication which is easily accessible to all.

IndFauna: gap analysis

So far information regarding 84,000 organisms has been compiled, which forms more than 93% of the known taxa

of India (Figure 8). Along with this is information on 47,405 known synonyms, 14,347 common names, linked to 6191 localities distributed across India (as on August 10, 2004). About 6500 references have so far been accessed in collecting this information. Higher taxa such as vertebrates are almost complete. Some of the lower taxa such as insects, bryozoa, mesozoa, protozoa, etc. are yet to be completed, mainly due to the time required to gather information on them from dispersed sources or scarcity of information.

This exercise of developing IndFauna raised several issues pertaining to taxonomy and information technology in biodiversity data management. We discuss them in two of the following sections.

Information technology in biodiversity data management

Our experience indicates that the biodiversity data pose several unique challenges to the use of IT tools. For instance, during continuous data-entry, the Oracle was not able to store the huge data into memory. An error (number of cursors open exceeded) used to occur when multiple searches were done on Oracle data. It occurred when open connection exceeded the limit. Increasing the open cursor limit of the Oracle solved this problem. Previously, the web server was on Windows, but it was not able to give sufficient security from viruses. Thus the site was shifted to Linux. At times, multi-user data-entry was going on correctly, but data miss-linking happened because of the lack of higher level of transaction. The higher level of transaction was given to connections of Oracle and Java. Another serious problem was that Oracle did not accept a string containing an apostrophe (e.g. Common name: Marshall's Iora). Replacing the single apostrophe by double solved this problem.

Taxonomic and nomenclatural issues

The main issues that evolved during database development were more of taxonomic nature and need to be dealt with collaboratively by biodiversity scientists and IT managers. The first of these issues is the availability of authentic information on Indian fauna. A thorough search of zoological literature is in progress to collect information on species. It has revealed many deficiencies in the data. Even after 200 years of research work, information is available mainly on vertebrates, while invertebrates in general are grossly understudied. In this cataloguing work, we are dealing only with the known Indian fauna; even so it is extremely difficult to get information about known species of invertebrates. This is especially true in case of the class Insecta, order Coleoptera, which is the largest order in India. Even FBI, the primary source of information on Indian fauna, does not cover some families

Figure 4. Multimedia artwork management module of IndFauna.

Synonym for Scientific Name "Attacus atlas"

Scientific Name: *Attacus atlas*
 Synonym: *Phalaena bombyx atlas*
 Author: Linnaeus
 Year: 1733
 Cause: -
 Remark: -
 DSN No: 1733

Taxonomic hierarchy for Scientific Name "Attacus atlas"

Scientific Name: *Attacus atlas*
 Author: Linnaeus
 Status: Accepted
 Organism Type: -

Heredit Category
 Threat category: -

Invasive & Alien Status: Not known

Taxonomic Hierarchy

Kingdom: Animalia
 Phylum: Arthropoda
 Subphylum: Hexapoda
 Class: Insecta
 Subclass: Pterygota
 Infraclass: Neoptera
 Order: Lepidoptera
 Suborder: Macrolepidoptera
 Superfamily: Bombycoidea
 Family: Saturniidae
 Genus: *Attacus*
 Species: *atlas*
 DSN No: 81, 1733, 2904

Common Name for Scientific

Scientific Name: *Attacus atlas*
 Common Name: Atlas Moth
 Language: English
 Region: -
 Sex: -
 Lifestage: -
 Remark: -
 DSN no: -

11 locality records found for scientific name "Attacus atlas"

No.	Locality name
1	Tamil Nadu
2	Meghalaya
3	Andaman Island
4	Assam
5	Bihar
6	Chennai
7	Karnataka
8	Maharashtra
9	Uttar Pradesh
10	West Bengal
11	Sikkim

Taxonomic Scrutiny Status: No Scrutiny

[Synonym](#) [Common Name](#) [Genetics](#) [BSM](#) [Biology](#)



Figure 5. Query results through query/search module of IndFauna.

IndFauna
 (Search IndFauna)

Scientific name: contains:

☒ Single epithet ☐ Complete name

Please use 'epithet', complete 'scientific name', 'locality name', or 'common name' for searching

This is a work in progress.

[An Appeal](#) | [Comments](#) | [Credits](#) | [Statistics](#) | [Suggest a new Species](#) | [Taxon Editors](#) |
[Advanced Search](#) | [Reports](#) | [Resources for Taxon Editors](#) | [Administration](#) |

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<http://www.indfauna.org/indfauna.html>

Figure 6. Query/search module of IndFauna.

of Coleoptera. Recent faunas and monographs being published by ZSI are available only for certain groups such as Aphidoidea^{41,42}, scorpions⁴³, spiders⁴⁴, Dermaptera⁴⁵, etc. Thus, information on other taxa, not covered in these two major works, is dispersed in research papers in vari-

ous national and international journals, spread over a period of 100 years and accessing this is a major challenge. ZSI has made a major contribution by publishing a sourcebook of all taxa published so far by ZSI scientists³⁷. However, those published by other workers in other re-



Figure 7. Taxon editors report module of IndFauna.

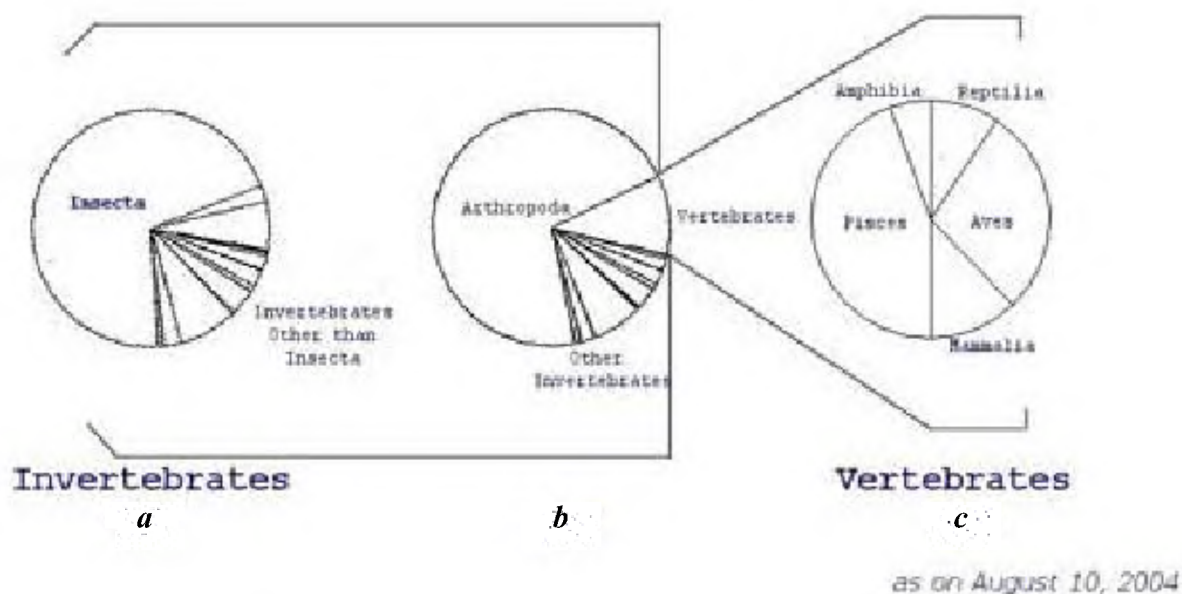


Figure 8. Taxon analysis of information collated in IndFauna (as on 10 August 2004). *a*, Out of 84,000 scientific names collated so far in IndFauna, class Insecta constitutes more than 60%. *b*, IndFauna coverage of vertebrate and invertebrate taxa, excluding class Insecta. *c*, IndFauna coverage of various vertebrate taxa.

search institutions cannot be sourced through a single repository. There exists no centralized system within the country for registering the new taxa, name changes or new combinations. Our effort in this case is to systematically go through the international zoological records to note the new taxa published so far from India. The question still remains about the names which have appeared in journals but not abstracted in zoological records. This leads to serious problems in estimating biodiversity richness, especially the number of species. No single source gives the entire list of 89,451 species according to recent estimates. Some of the old and also recent fauna volumes include species from adjacent areas such as Nepal, Burma (Myanmar), Bangladesh and Ceylon (Sri Lanka), and a mere addition of the numbers in faunas will lead to wrong estimates of species found within India. No reliable estimate can be provided for the number of subspecies and varieties present within India. An actual count of subspecies varieties can help in analysis of origin and zoogeographic studies of Indian fauna. The problem has been intensified due to inclusion in recent literature of species which are only identified to the genus level. It is not advisable to include these in ECAT; however, it is not clear whether they have been counted in the total species estimates for India.

ICZN⁴⁶ set up in 1895, is the international authority that rules on scientific names. It publishes the rules universally accepted as governing the application of scientific names to all organisms, which are treated as animals. It also gives rulings on individual nomenclatural problems brought to its attention, so as to achieve internationally acceptable solutions. Several million species of animals are recognized, and more than 2000 new generic names and 15,000 new specific names are added to the zoological literature every year. With such a multiplicity of names, problems are bound to occur. Hence it is necessary for individual researchers to adhere to and inform the ICZN regarding new species and nomenclatural changes. But in many cases in India, the new names or combinations published in journals are not brought to the attention of the Commission. ICZN also has a quarterly journal, the *Bulletin of Zoological Nomenclature*, in which problems that need a formal decision by the Commission are published for discussion by the zoological community. However, few taxonomic institutions have access to this journal. Hence zoologists hardly ever use the international system for registering names and keeping up with the multiple descriptions, nomenclatural changes, etc. is a burden for individual taxonomists. This is an extremely hard task considering the poorly equipped taxonomic research laboratories with meagre funding to libraries. It is not surprising that scientists do not get updated information about internationally accepted taxonomic changes.

This has given rise to a major problem, which is the great divide between taxonomic systems followed within

India and elsewhere in the world. We found several instances where taxonomic system and nomenclature followed in India do not match the ITIS. This is especially true in case of fish and nematodes. Even within India, there are many opinions about the correct taxonomic hierarchy and placement of taxa. The bifurcation in taxonomy is in fact bifurcation in taxonomic opinion and a consensus on the issue is most often impossible. In this case, the only alternative left for information managers is to display the placement of the taxon according to different alternative schemes. In spite of this option, it is necessary to confirm with the international taxonomic opinion to make the datasets interoperable with those developed in other parts of the world. This is an issue that needs to be discussed and resolved by taxonomists working in India. Although making changes in taxonomic hierarchy is technically possible in case of the electronic datasets, each change needs to be validated by taxonomic community as some taxa may or may not conform to that change. FBI describes order Rhynchota⁴⁷⁻⁵⁰. Now, several alternative classifications are available for the group, and recent trend is to avoid the term Hemiptera and to treat Heteroptera and Homoptera as orders⁵¹. However, ITIS shows all three as distinct, valid orders. In this case the challenge to our information management was to accordingly update the classification of species in the former order Rhynchota of FBI. Although ITIS was followed mainly for this purpose, confirmed decision could not be made about placement of some species.

Hence it is not merely a technical task, but essentially a taxonomic revision task, which is needed for conforming to recent taxonomic hierarchies. It is extremely difficult as it requires access to literature, type specimens, keys and protologues, but can be made possible by scientific collaborations across the world. ECAT in this case can form baseline dataset for revision work.

Another challenge faced while cataloguing is the change in the political boundary of India since the British period. This has led to many of the localities noted in early literature being now actually in the neighbouring countries. Even recently published faunas include organisms from Nepal and Sri Lanka. Although biodiversity transcends political boundaries, the distinction between species strictly in India and those in neighbouring countries is necessary for policy makers and managers, especially in case of endemic and rare species. Species which are only known from localities outside India, such as Tenasserim, Sylhet, Allahabad, which were in pre-independent India are excluded from IndFauna as they are now in Myanmar, Bangladesh and Pakistan respectively. The distributions provided by the literature often vary from point localities such as villages to regional distribution such as certain districts or states, or ecosystem coverage such as the Western Ghats, Himalayas, oceans, rivers, etc. ECAT provides alternatives to include all of these data and link them to the States within India. Old literature often refers

to regions such as United Provinces, Bombay Presidency, etc. which no longer exist. The post-independence India has also undergone major rearrangements, the most recent being formation of states like Uttaranchal, Chhattisgarh, etc. To compare the historical distribution data with today's geopolitical maps can be achieved by coupling multi-layered mapping facility with ECAT. In this we can overlay various maps with distribution at one historical place, and time and compare it with present reports.

The analysis of data so far indicates that some ecosystems like freshwater river systems, wetlands, and oceans are yet to be surveyed in detail. The data are also deficient in case of local names in multiple languages. It is possible that in case of invertebrates the local people have only broad category names for certain taxa, e.g. Koli for spider. For vertebrates, especially birds and mammals, names in only a few languages have been documented.

At present data about diversity are mainly textual. Images and artworks are available in case of some common taxa, especially of vertebrates. An illustration is most often provided for new species, however, it does not aid in visual identification. Audio and video data regarding animal behaviour can also help in identification and documentation of species. However, they are at present restricted to more 'popular' species such as mammals, snakes and birds.

Identifying and documenting synonymy is a major challenge in taxonomy, which created certain unique problems in cataloguing. In some cases, a single species had as many as 100 synonyms according to recent revision. In addition, the literature also quotes reports of names which are essentially not synonyms, but it is difficult to differentiate between a report and synonym in these faunas. Several of the names used in *FBI* and other old literature have now changed. But most of the recent works do not include a citation of *FBI* or old literature, making it difficult to check up synonymization. Indian floras as a rule include citation of *Flora of British India*, and this rule should be applied to faunal literature as well. In most cases, the published literature only included few of the more important synonyms owing to the limitation of printing space. Although electronic media has no such limitations, some rules are necessary to define the number of synonyms and reports essential to provide complete history of a particular scientific name. ECAT can provide a means to identify potential synonyms. For example, *Lucilia indica* Robineau-Desvoidy 1830 is reported as a synonym of two species, first of *Orthellia indica* (Robineau-Desvoidy)^{52,53} and second of *Orthellia lauta*⁵⁴. The documentation does not allow us to guess whether the two new names are of different organisms, or are in fact synonyms of each other. Several such instances of taxonomic ambiguity can be pointed out by the use of ECAT. The most common among these problems is of spellings. Documentation is available in cases such as change of name in tortoise-shell beetle, *Aspidomorpha* to

*Aspidomorpha*⁵⁵, but in many cases, research papers do not provide support to the specific spelling of the scientific name that is followed.

The role of ECAT in this case has been to raise these issues and put them forth in public domain for further discussion. It is hoped that the collaborative efforts in future can contribute positively in dealing with the above-mentioned ambiguities in biodiversity information.

IndFauna: significance

In case of biodiversity research, scientific names identify entities, determine the relationship among entities and facilitate location, function/role. Our effort in creating IndFauna has demonstrated that ECAT is a powerful tool to collect, analyse and disseminate biodiversity information, anywhere and anytime. The taxonomic issues identified here are significant for Indian taxonomy in the 21st century. This unique single source of information on Indian fauna would provide a sound base for resolving conflicts in taxonomy, planning future research and analysis.

As described earlier, the lack of central registry for names of organisms is a major impediment in tracking the number of species in India. In this case, ECAT offers an effective method of creating a unique register. Owing to the rules of acceptance of scientific names, the names cannot be registered as valid before the publication of description in a journal. To solve this a precedent can be set that in case of each new description, along with the type specimen a provisional registration number in the national ECAT should be quoted. This provisional number will be later changed to permanent registration number after furnishing the proof of valid publication of the species. Provisional registrations which fail to be converted to permanent registration will automatically be considered invalid after a certain period (five years). This method will lead to standardization of procedure for new name publication, will be useful for searching new descriptions and will electronically track the species publications in future.

ECAT can also be effectively used for linking information on species within diverse databases. At present, we have provided links to genomic and image data in other sources. In the same way links can be provided to ecological, ecosystem and climate databases. Links can also be made between host-parasites, prey-predator, and food plant databases. Cross-linking the data with databases of natural history collections will be of much help in taxonomic research.

ECATs such as IndFauna are only the starting point for biodiversity management and research. These lists provide a single nomenclature for species, which will generate further research to clarify anomalies². ECATs not only form a basis for more elaborate and specific databases on groups of organisms or species (speciesbank)⁵⁶,

but would benefit cooperation amongst scientists, leading to increased communication and interest in the management and use of taxonomic data. ECATs will provide a standard working list of names for non-specialists to use. Analysis of ECATs will identify where identification guides are most needed, in what taxa most species remain to be discovered, and where the expertise is weakest. It is anticipated that ECATs will become a standard reference and technological tool for biodiversity training, research and management. It can be used (a) to check the spelling or find the correct name of a species and the authority, (b) to find information on the distribution of species, (c) correct taxonomic information of species or group of taxa, and (d) indicate the level of knowledge of a group of species by analysing the rate of discovery of species.

For many organisms information is available only in the text form. Use of images, audio and video clippings along with scientific names will be beneficial for future identification. ECATs can serve as a basis for electronic field guides. Use of GIS and mapping tools to display and develop dynamic maps of species distribution would enhance the quality of end results, and create much required awareness among common people about the state of species distribution.

Since multiple cultures with diverse lifestyles, habitats, languages and dialects co-exist in India, it is essential that databases be made available in multiple languages so that they are more user-friendly⁵⁷. This will help in dissemination and acquisition of data from distributed sources. Further, it would help in overcoming the geographic and language barriers in biodiversity information.

Our experience on developing IndFauna, has left us wondering, as to why a similar exercise was not initiated before. Often the arguments made were lack of resources, man-power and standardized procedures. However, IndFauna, which is now 93% complete, required about 132 man months of human resources. Analysis of infrastructural investment, manpower and recurring costs indicates that expenditure incurred per species is Rs 100, approximately. However, in case of the European Register of Marine Species², the budget was 385,000 Euro for 29,000 species. This clearly demonstrates that we would be able to complete ECATs on our biotic resources with much less investment and also much earlier compared to other nations and regions of the world. All we require is to begin with determination to collaborate and coordinate between cross-disciplines and diverse expertise. Further, with process documentation for developing IndFauna, developing ECATs for other groups of organisms would be a much easier task.

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MEETINGS/SYMPOSIA/SEMINARS

National Symposium on Bioinformatics

Date: 7–8 October 2004
Place: Chennai

Topics to be discussed include Bioinformatics – an overview; Advances in Gene technology; Proteomics; Genomics and Drug designing.

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13th National Symposium on Ultrasonics

Date: 21–23 December 2004
Place: Jhansi

Topics include: Ultrasonic studies in solids and liquids; Ultrasonic characterization of liquids; Ultrasonic transducers, devices and instrumentation; Sensors, actuators, filters; Photo-acoustics; Physical ultrasonics, etc.

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