Natural history collections: A call for national information infrastructure

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Natural history collections are essential to biodiversity research, as they are the fundamental underpinnings of all biological information. Converting these data sets in electronic format and digitizing the specimens would provide easy access to valuable baseline information. While collections and museums from the developed world have initiated such work for the last few years, those from the developing and under-developed parts of our globe are lagging behind. This article, while emphasizing the need for such initiatives, describes SAMPADA, a software developed for automating a repository of collections and digitizing specimens. We further propose a model for developing a 'National Natural History Management Information Infrastructure' to ensure digitization, automation of Indian biological collections and their dissemination to the user community.

NATURAL history collection records the world's biota in space and time, and documents what we do and do not know about the biota[1]. Collections of organisms are the fundamental underpinnings of all biological information. They are time-capsules to analyse conditions from the past and compare them with our present-day state of affairs. This information provides baseline data against which biological variations and environmental changes can be measured[2,3]. Therefore, collections are absolutely essential to biodiversity research.

The power of collections lies in their data: anatomic, morphologic, genetic and geographic information that contributes to our overall understanding of how species evolved, how they are related, and how they operate in ecological systems[4]. The challenge is to make this information accessible to those who need it the most, so as to facilitate them to make informed and appropriate decisions. Curators of the natural history collections are aware that museum research can no longer remain an end in itself, and must be increasingly geared to answering questions of contemporary relevance – in particular about the management of the environment and biodiversity[5].

Creating a complete inventory of life on earth is incomplete without reference to museum specimens. This emphasizes a need for a unique method of addressing these biodiversity concepts, by providing an automated system through which our rich natural history collections are made more readily available to scientists and society. Since knowledge derived from biological collections will influence the decision-making process and aid in new discoveries, it will also affect the quality of life to be enjoyed in the future[6].

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Hence, having the data for collections in electronic format will help to provide a rapid tally of what is known and what is not known, and where and when biodiversity collections have been made[7]. Further, developing a well-constructed database will greatly increase the value of the collection[8]. This knowledge will help prevent duplication of research effort and will facilitate scientists' ability to focus their attention on broad areas that are either completely unknown or are likely to host significant diversity.

This is especially true for a mega-biodiversity and developing nation like India, which harbours rich and diversified natural history collections. This article reviews biological collection digitization efforts worldwide. It highlights the salient features of SAMPADA, a tool developed by the authors' group to aid curators and collection managers to automate and digitize their collection repository. Authors propose development of National Natural History Management Information Infrastructure to ensure digitization, automation of Indian biological collections and their dissemination to the user community.

Digitizing biological collections

Status

The collections held in the world's 6500 or so natural history museums – which total about 3 billion specimens, not counting microorganisms – represent the work of thousands of individuals carried out over centuries[9]. This does not include living collections, preserved and documented DNA samples, data from mapping and surveys and documented multimedia data through recent surveys. In recent years, an attempt has been made by major natural history collections/museums to use tools and techniques offered by Information Technology to better manage their repositories. Many of these museums and collections are making their presence felt on the World Wide Web (WWW), and thereby invite thousands of virtual visitors. However, this attempt is limited to the museums located in the developed part of our globe.

By 2001, Smithsonian Institution has completed digitizing over 3.7 million specimens, which is 9% of its total specimens housed[10]. Mexico houses about 10 million specimens of which 20% has been digitized. Mexico's National Commission of Knowledge and Use of Biodiversity, not only supported developing inventories of museums within the country, but sent scientists to museums worldwide to assemble data on Mexican specimens[11]. An exemplary database created by CONABIO, has helped to set national priorities for conservation in Mexico. Recently, French National History Museum received a grant of US $ 420 million for a period of ten years for its renovation and modernization, much of which would be spent on digitizing the collection that it harbours[12]. China holds 25 million specimens of which 1% is digitized. Japan has 10 million specimens to be digitized. Canada houses about 32 million specimens, while Indonesia houses about 5 million specimens. German collection facilities house nearly 74 million specimens, much of which is in the process of digitization.

This clearly means that museum curators from developed and a few developing countries feel that digitization of the world's collections, and their inclusion on the web-based databases is the way forward. Exploiting the opportunities offered by networked databases is essential to 'translating research-based information in a form that is accessible and useful'[13]. However, collections/museums from the developing nations do not have encouragement, expertise and infrastructure to automate information about their repositories. Recently, Global Biodiversity Information Facility (GBIF; http://www.gbif.org/), has identified digitization of biological collections as one of its major focus areas. GBIF plans to digitize the biological collections of the entire world within next ten years, with a rate of 0.5 billon every year. GBIF is the largest of several initiatives to make collection-based research and information available to a wider audience by digitizing it and putting it on networked databases. We hope that with such an ambitious plan GBIF would be able to mobilize support in terms of technology, knowhow and also funding to collections/museums from developing nations, to help them automate their repository and digitize their specimens.

Technology at hand

Attempts have also been made to develop software tools which could be used in collection management. These packages aim at helping to manage specimens or observations of biological objects. These packages can be categorized as (a) multiple collections software, (b) botanical garden software, (c) herbarium collection software, (d) entomological software, (e) survey/observation software, (f) palaeontological collection software, and (g) other software. Table 1 lists the major packages.

However, many of the packages only collate index information and do not digitize the repository itself. Many packages do not incorporate detailed systematics of each specimen, as taxonomic relationships are complex and dynamic. Due to different database structures, data gathered by these packages vary in precision and accuracy, and thus lose out on the interoperability front. Many of the packages lack use of controlled vocabulary and standardized terminology. None of these packages encodes biological data collected from disparate sources (geographic, environmental, bibliographic). Most of these packages fall short in collating region or ecosystem-specific information[13]. This calls for development of a unique, easy-to-use, cost-effective tool that could be used by the collections from developing and under-developed nations for collating specimen repository information and also to digitize the specimen itself.

Several information management systems have emerged during the past decade. Notable among them are World Data Center for Microorganisms, BioCISE (for European Union), National Electronic Natural History Museum Reinvention Laboratory (for USA) and HISCOM (Herbarium Information Systems Committee, Australia). Many of these museums and collections are making their presence felt on the WWW and thereby invite thousands of virtual visitors. Species Analyst, with the use of XML, can currently search approximately 10 million specimen records from 13 national history collections located worldwide.

Natural History Collections in India: Status

India is one of the 12 mega-biodiversity countries bestowed with rich floral and faunal diversity. Through modern biological studies and surveys started during late 18th century, India has a long history and tradition of eco-friendly and sustainable nature conservation practices deeply rooted in its lifestyle and culture. Botanical Survey of India (BSI) was constituted in 1890 and Zoological Survey of India (ZSI) came into existence in 1916. Recently, Forest Survey of India (FSI) was constituted in 1981. By 2000, BSI and ZSI have covered little over 60 and 35% of the geographical region for floristic and faunal surveys respectively[14].

These agencies are involved in maintaining biological collections in addition to those maintained by numerous university departments and colleges and other research institutions. To date there are about 200 + herbariums, 100 + zoological museums and more than 40 + micro-organism collections spread across the length and breadth

Table 1. Software tools for management of biological collections

Software	URL	Taxon specificity
ATTA	http://atta.inbio.ac.cr/atta03.html	Taxon-independent
AviSys	http://www.avisys.net/	Birds
BibMaster	http://www.rjb.csic.es/bibmaste/bibcaract.htm	Botany
BioLink	http://www.biolink.csiro.au	Taxon-independent
Biota	http://viceroy.eeb.uconn.edu/biota	Taxon-independent
Biotica	http://www.conabio.gob.mx (Look under 'Sistema de Información BIÓTICA')	Taxon-independent
Bird Recorder	http://www.wildlife.co.uk/	Birds
BG-BASE	http://rbge-sun1.rbge.org.uk/BG-BASE/	Botany
Brahms	http://www.brahms.co.uk	Botany
Cassia	http://www.nybg.org/bsci/cass/	Botany
DEMUS	http://www.mzm.cz/engmzm/demus.htm	Taxon-independent
FieldNote	http://www.cs.ukc.ac.uk/projects/mobicomp/Fieldwork/Software/index.html	Taxon-independent
FLORIN	http://www.florin.ru/florin/	Botany
HERBAR	http://www.rjb.csic.es/herbario/herbar.htm	Botany
KE EMu	http://www.ke.com.au/ke/products/emu/emu.html	Taxon-independent
Mandala	http://pherocera.inhs.uiuc.edu/index.htm	Entomology (esp. Diptera)
Mantis	http://viceroy.eeb.uconn.edu/interkey/database.html	Entomology (esp. Orthoptera)
Multi MIMSY 2000	http://www.willo.com/cgi/content.cgi?main.html,mm2000.html,intro_left,mm2000.html,intro_right	Taxon-independent
MUSE	http://usobi.org/specify/musesup.html	Taxon-independent (but with strong fish focus)
PaleoTax	www.paleotax.de	Palaeontology
PANDORA	http://www.rbge.org.uk/pandora.home	Botany
PRECIS	http://www.sabonet.org/countries/precis.html	Botany
SAMPADA	http://www.ncbi.org.in/sampada/index.html	Taxon-independent
SMASCH	http://www.mip.berkeley.edu/www_apps/smasch/	Botany
Specify	http://usobi.org/specify/default.htm	Taxon-independent
SysTax	http://www.biologie.uni-ulm.de/systax/index.html	Botany
TAXIS	http://bio-tools.tcn.ru/products/taxis/index.htm	Taxon-independent
TRACY	http://www.csdl.tamu.edu/FLORA/input/inputsys.html	Botany
UCD HMS	http://herbarium.ucdavis.edu/herbaccess/databaseinfo.htm	Botany

of this nation. It is estimated that these collections together house more than 10–15 million specimens. Also, information on availability and occurrence of these specimens has been documented through hundreds of mapping and survey projects during the last 50 years.

However, many of these collections are in a bad condition, for want of appropriate funding and better management. The biological collections community in India, like its counterparts in other regions of the globe, is fragmented because of taxonomic boundaries, project scope (survey vs collection, etc.). Until recently, there have not been any significant efforts made towards computerization of biological collections in India. One of the major issues is unavailability of required funds and lack of interest of R&D managers in better maintaining our rich natural heritage through collection holdings. This is further aggravated by the fact that there is no pressure/ demand for the same from the user community.

Given these facts, there lies great potential for undertaking activities in this area. Such efforts would prove as a bridge between holders of biological collections and the users, and greater and efficient access to information about specimens or observations. This would provide access to ready-to-use baseline data for a variety of studies. Hence, initiating consorted efforts towards digitization of biological collections would be the first step towards building a 'National Natural History Management Information InfraStructure (NHMIS)'.

SAMPADA: An Indian initiative

In order to accelerate efforts to computerize the biological collections in India, National Chemical Laboratory (NCL), Pune, as part of its initiative in the field of biodiversity informatics, developed SAMPADA. One of main aims of this activity was to develop cost-efficient, easy-to-use, and interoperable tools for biological collections located in the developing world.

SAMPADA is a Sanskrit word, which means 'natural wealth' or 'heritage'. It is an attempt to assist individual biological collections to develop their own repository database. SAMPADA was developed keeping in view that it should facilitate data acquisition and storage, moderate query support, unique specimen and collection-specific barcode, digitization of specimen, restrictive data access to prevent mishandling of data/information, easy-to-use with bare minimum infrastructure.

Considering that many collections/museums from developing and under-developed nations do not have state-of-the-art computing infrastructure, the current version of SAMPADA is intended to be used as a stand-alone package by individual museums/collections. Though used in a distributed manner because of its uniform database structure, SAMPADA would achieve its goal of data/information in easily exchangeable format, thus achieving interoperability with other databases of similar nature.

Closer interaction with subject experts and museum curators revealed that information on parameters such as museum details, collector/identifier details, repository information, field data, systematics, synonym, common name, images of specimen, additional notes and references for the species, must be collected through this package. Data structure of SAMPADA consists of ten interrelated sections (referred to as tables), encompassing information on the above-referred parameters. Both between and within the tables, relationships have been created to facilitate the organization of information. Figure 1 shows the overall structure of the database, including shared relationships. MySQL (http://www.mysql.org/), a public domain RDBMS is used for database creation and information handling. Netbeans 3.3 is used for interface development. A combination of these two provides scalability and platform independence to the package. Public domain package InstallAnyWhere (http://www.installanywhere.com/) is used for creating install-ready version of the application. Beta-users tested the system on their own PCs. Current version of SAMPADA would run on any Pentium II PC (350 MHz or more) with minimum of 64 MB of RAM. Operating systems required for SAMPADA can be Microsoft Windows 98/ME/NT/2000. It also requires Java Development kit and Java Media Framework. Sufficient care has been taken in the current version of SAMPADA to provide enough security and restrictive access to data entered.

Generation of barcode

Generation of a unique barcode for each individual specimen is one of the major features of SAMPADA. This

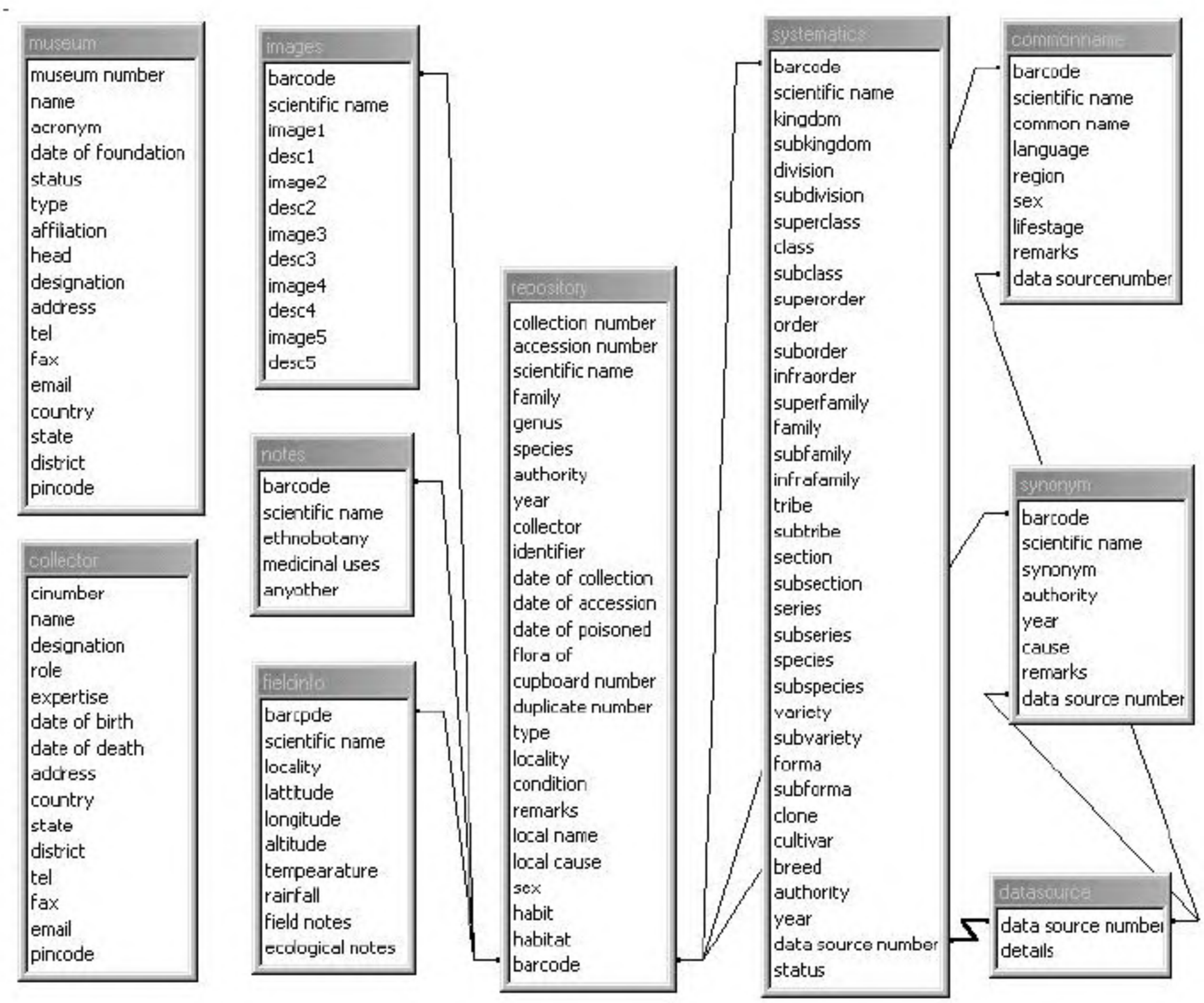

Figure 1. SAMPADA database structure and interrelationships between tables.

would help locate the specimen with ease by curators and researchers. This shall prevent potential trafficking of the specimens. For the current exercise Code 128, which is capable of encoding the full ASCII 128 character set, the 128 extended ASCII character set and four non-data function characters is implemented. It allows numeric data to be represented in a computer double-density mode, two data digits for every symbol character. Barcode for each specimen is generated as a combination of geographic location of the museum/collection and accession number of the specimen in the respective collection (Figure 2). It was felt that with such a schematic, creation of the same barcode for two different specimens could be prevented. Figure 3 shows the barcode generated for sample specimen. Currently, fields relevant to location of the specimen are encoded to generate a unique identifier for the collection sample. However, it is proposed to encode the entire scientific content in a compact format, which will be available with global standard. As advanced bar coding systems are available, today encoded data can be portable in this format, hence overcoming the space issue in the digitized world itself.

Taxonomic knowledge management

The systematics section offers fields for a complete taxonomic tree of the species from kingdom to species level and, where applicable, sub-specific designations (Figure 4). Publication details from which classification has been validated/referred can be entered in the data source table. A synonym and common name of the species would be collated through synonym and common name tables respectively. For multiple specimens of the same species, classification details need not be entered repetitively

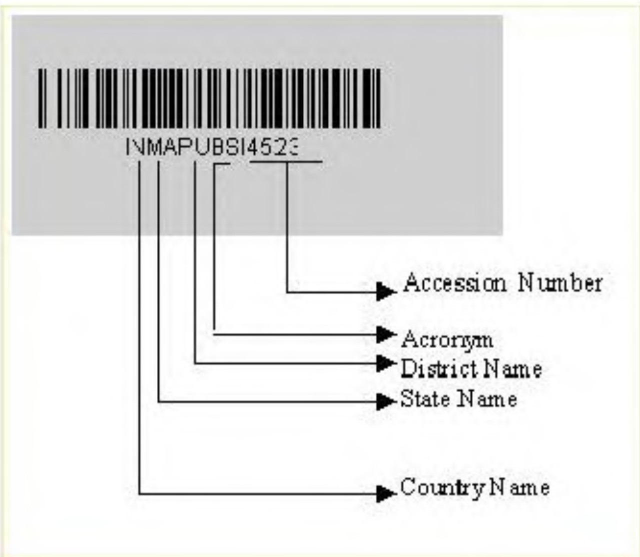

Figure 2. Scheme used for barcode generation for each specimen.

every time. Data gathered from specimens and bibliographic sources, names, authors, synonyms, common names, types, ecological details, etc. are formatted into different categories, saving vast amount of time with fussy and complex data sorting and formatting. Hence, collections/museums can use SAMPADA to index their collections and scientifically credible taxonomic information. Enriched with information, SAMPADA would become a tool for accessing knowledge about accepted scientific names, synonyms, common names and authenticate systematics of specimens within the museum/collection.

Digitizing specimen

One of the major objectives of developing SAMPADA was to facilitate digitization of specimens themselves. The program facilitates archiving five images for each specimen (Figure 5). These images can be line diagrams, scanned photographs, video and/or audio clippings of the specimen, which would prove helpful in visual identification of the specimen based on characteristics as captured in the graphics.

Easy to use

Based on the various tests conducted with beta-users, it could now be concluded that the overall performance of the system was satisfactory. Beta-users consist of potential experts, scientists, academicians, software professional, etc. Positive responses received from them indicate the high level of user-friendliness of the system. The benefit of SAMPADA is efficient data entry and data framework that help in editing data in a logical and step-by-step manner. Currently, around 20 collections/ museums are using SAMPADA, which is available free of cost to R&D, academic and non-profit collection facilities. It can be downloaded or requested at http://www. ncbi.org.in/sampada. Feasibility of extending the use of SAMPADA on a global scale is being explored, and necessary modifications are being incorporated in the current version.

A call for national information infrastructure

The current version of SAMPADA (ver. 2.0) is part of a broader vision and strategy to develop national NHMIS (Figure 6) for developing and under-developed nations. Use of this stand-alone version of SAMPADA by various collections would allow exchange/sharing of data amongst collection facilities, as collected information would be in a uniform and standardized format. It is envisaged that once individual collections would automate their repository information using SAMPADA, integrating these individual information bases at a national level could generate a collective mega database. This would aid scientists, researchers, ecologists, biologists and environmentalists as well as common public in retrieving information about the specimen of their interest.

Possible architecture for NHMIS includes (a) single client/server database by all collections, (b) central summary systems, (c) central gateway to distributed databases (common access system), (d) peer-to-peer databases (multiple Z39.50 servers and clients), and (e) web directory pointing to data sources. In order to achieve this goal, we are planning to develop a central repository package, which would work at the server end (Figure 6). This would facilitate museums/collections with Internet connectivity to directly utilize resources available at the central repository. Currently, the system is working at the institute level; as the number of users increases, the encoded data can be made available at the country level or even at the global level. In one way this system will be instrumental to map the distribution of species in our subcontinent.

However, developing such a national information infrastructure facility calls for concerted efforts on the part of all concerned, viz. curators, taxonomists, managers of collection/museum facilities and users. The following section explores possible blocks and barriers to bring the dream of 'virtually connected collections/museums' into reality.

Blocks and barriers

One of the major blocks that curators often talk about is unavailability of required funds to undertake digitization activities. In order to overcome the financial crunch, big collections are becoming independent institutions[15,16]. However, smaller collections as well as even big ones from developing and under-developed nations cannot afford to become independent to overcome the financial problem. Museum funding continues to decline and many institutions survive on starvation budgets; thus computerization is of lower priority compared to other urgent infrastructure needs. The option of minimal management

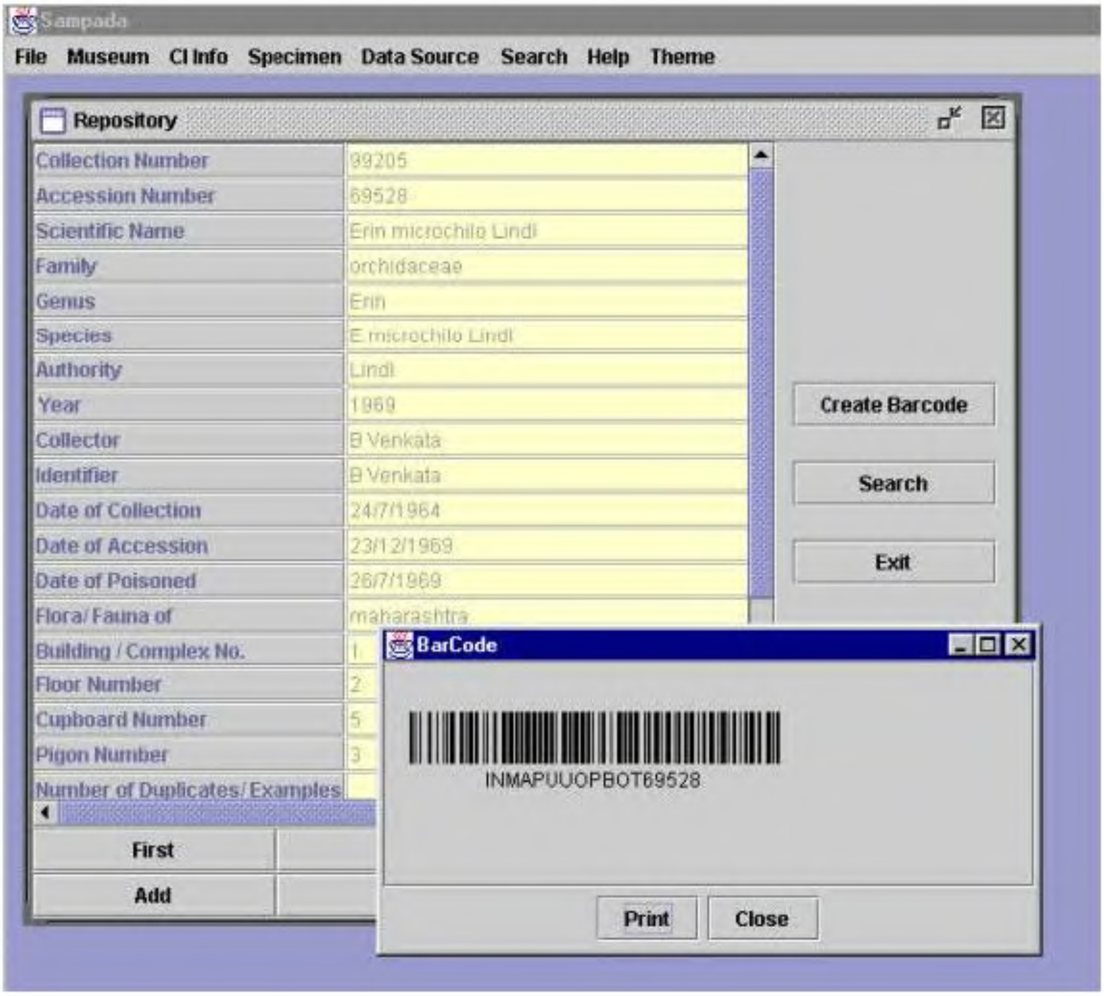

Figure 3. Unique barcode generated for each specimen.

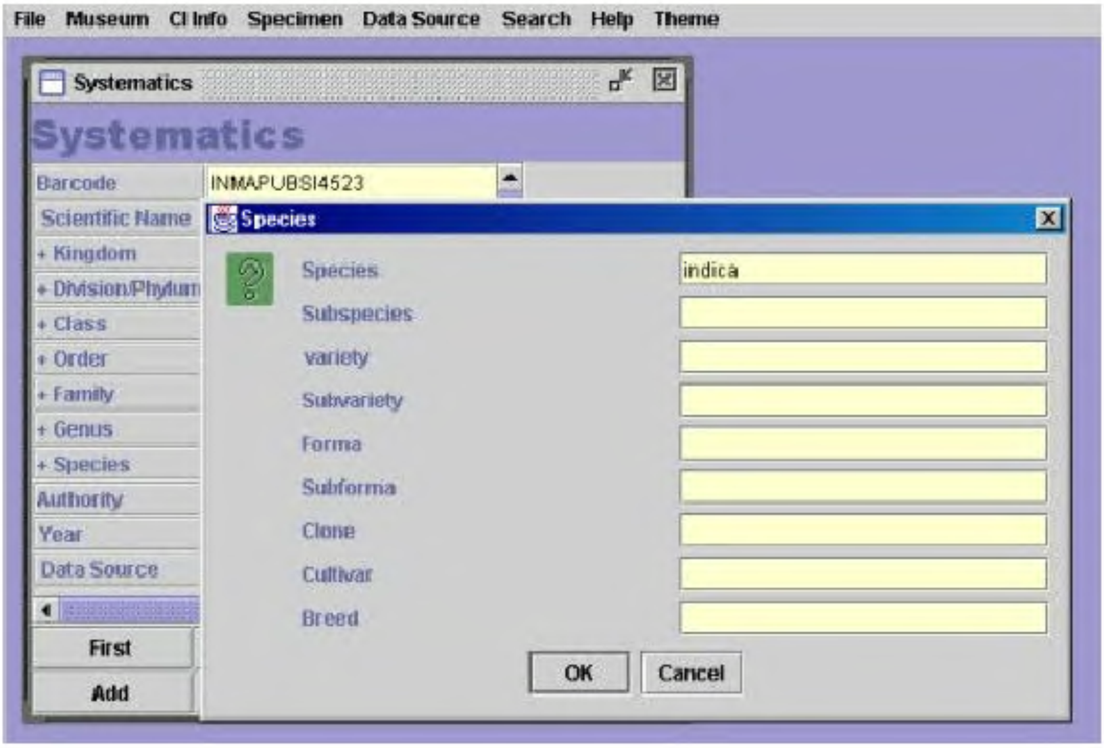

Figure 4. SAMPADA facilitates collation of detailed systematics knowledge.

of collections is often adopted, leading to a collection/museum often becoming orphaned. The result is a tragic, irreplaceable loss of biodiversity data. Financing the creation of such information systems is beyond the resources of the institutions that possess the knowledge base of specimens and expertise. Further, funding agencies consider the task insufficiently innovative. However, the irony is that a country stands to benefit immensely from such information system. Government and international development agencies should realize that investing now in computerizing systematic biology collections would pay dividends now and in the future.

However, we strongly believe that an equally important problem is that of culture and attitude amongst many of our collection facilities. Majority of the museum facilities strongly resist becoming multidisciplinary in their approach and opening their gates to wider user-community. Reasons for such a state are rooted in insufficient infrastructure facilities, as well as lack of capacity (training) and career-building opportunities for those working in these facilities. This is further aggravated by lack of required encouragement and support from managements and potential funding agencies, which is forcing this community to shrink within its own cocoon.

In today's world of competitive globalization, success depends on how well one teams up together. Contrary to this fact, the museum/collection community in our part of the globe is fragmented. Due to lack of collaborative efforts amongst the community, the significant role of natural history collections in biodiversity conservation remains unnoticed. We see potential in receiving more funding from national governments, by leveraging on access to museum data. However, there seems to be misled conviction amongst curators about issues related to intellectual property rights, and wider and free dissemination of data/information. Emergence of more European and US collections/museums on the web, demonstrates that enough safeguard mechanisms, policies and legislations are in place with respect to intellectual property rights, appropriate acknowledgements, credits and minimal misuse of data/information. These could further be worked out considering the mega diverse nature of our biotic resources. However, what is required is proactive action and teaming together without any preconceived excuses to start planning and implementing digitization activities.

Potentials and recommendations

For NHMIS to achieve its objective of making data on biological collections available to its user community across the globe, proper planning, phased implementation and collaborative efforts are the keys to success. A National Workshop on Information Technology in Biological Collections Management held at NCL, Pune during 10–11 January 2002 discussed the strategies and action plan for digitizing biological collections in the

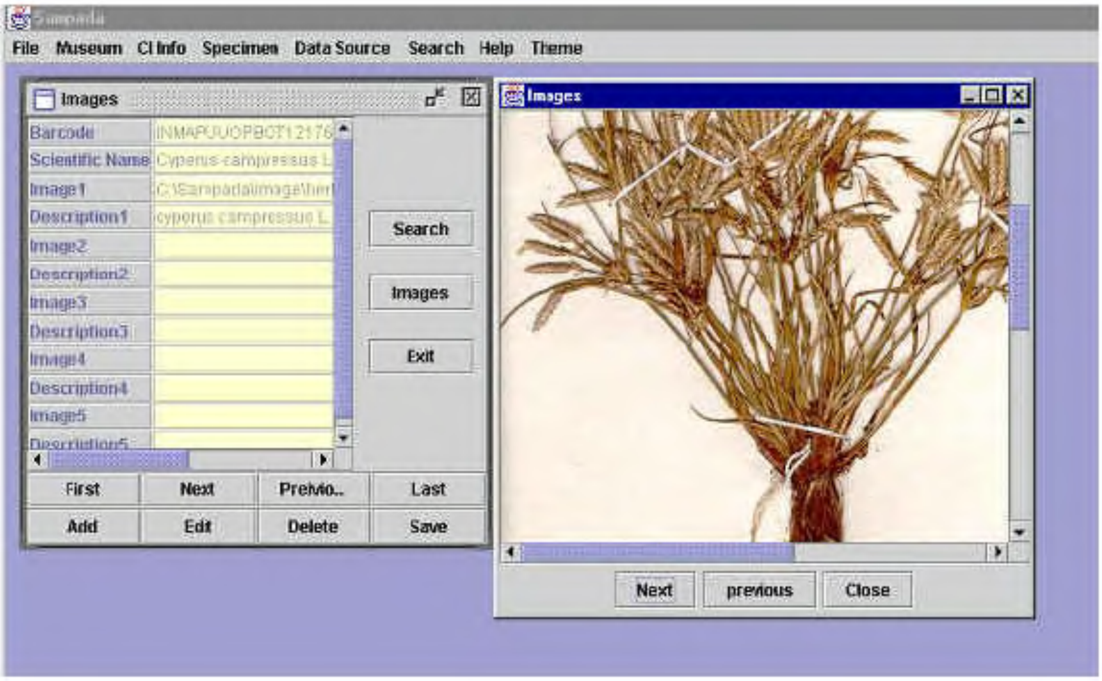

Figure 5. Archiving of digitized images of specimen.

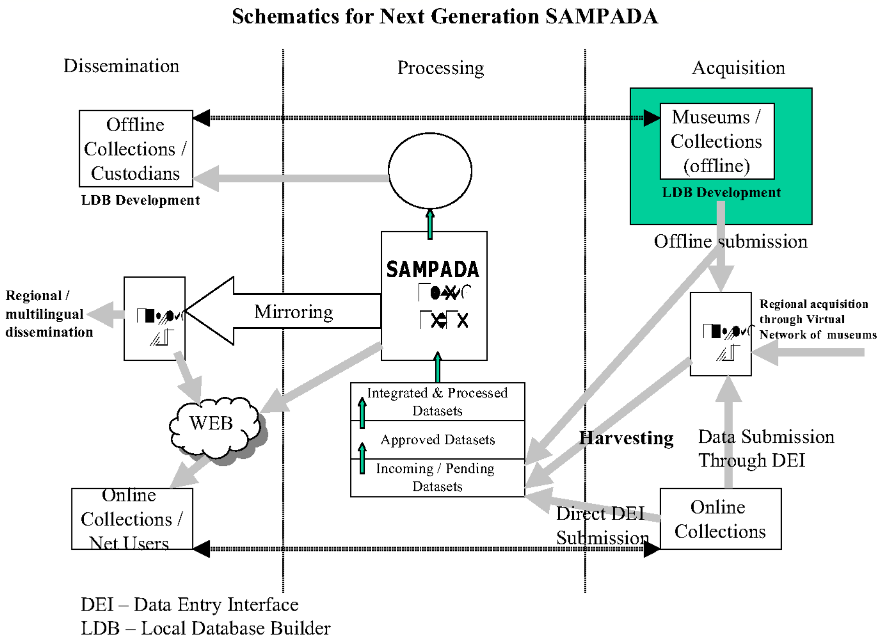

Figure 6. Schematics of Next Generation of SAMPADA.

country and made recommendations specific to development of a national information infrastructure for natural history collections[17].

It is important that collections become multidisciplinary in research, and show greater willingness to collaborate with external researchers. Museum staff should be encouraged to seek research collaborations, both within and in the wider community. National and international collaborative initiatives for digitalizing the collection are imperative as costs of digitalization are beyond the budget of individual institutions. Concerted efforts are needed to seek technical and financial support from national, multinational, international agencies as well as corporate houses for achieving the task of NHMIS. This would ensure wider participation of various agencies (academic, research agencies and universities) into this programme.

Initially, NHMIS may concentrate to collate knowledge about biological collections (dead plant and animal specimens). However, at later stages its scope should be expanded to collate information about living collections (botanical gardens, zoological parks, etc.). Interactive identification keys, which consist of digital images and associated text, also allow museums to increase accessibility to their collections. Biological collections data along with remote sensing, geographic information systems, and geo-referencing tools would help to develop predictive models for the distribution of rare and threatened species, management plans, models for restoration, and monitoring protocols for protected areas when repository information from various collection holders is integrated into a single collated database.

Along with web-based dissemination, CD-ROM dissemination of digitized information is essential. It was suggested that facility for building customized reports should be provided while disseminating information. In order to be able to exchange/share information collated through Indian NHMIS, with those of other initiatives of similar nature, the issue of compatibility and interoperability may be given serious consideration, especially those for taxonomic, ecological and geographical knowledge management.

In order to pursue the goal of NHMIS, brainstorming discussion among experts, technocrats and users may be held at regular intervals (atleast once a year). Review of the progress made in this direction can also be undertaken at such meetings. It is important that a Memorandum of Understanding (MOU) be developed and signed among parties participating in NHMIS. Such MOU may cover issues related to information exchange/sharing, ownership, intellectual property rights, commitments, financial sharing, etc. To achieve the goal of NHMIS, capacity-building training programmes are needed for collection managers, curators and staff. Such training programmes/workshops may be conducted at regular intervals. Funding for such activities can be sought from national/regional/global agencies interested and working on biodiversity-related issues.

For taxonomic knowledge management, five-kingdom classification system must be used in SAMPADA. For this, feasibility of integrating the already developed systems such as Integrated Taxonomic Information System (ITIS) or similar systems into SAMPADA may be explored. Discussions may be initiated with such international initiatives for potential collaborations.

Due credits and acknowledgements should be given to data collectors, holders and curators as well as agencies. Before museums permit sensitive data fields (e.g. collector, date, locality and distribution and reproductive information) for entire collections to be posted on the web, legally binding safeguards and provisions are needed. Some of these include (a) intellectual property rights, (b) commercial use and licensing, (c) acknowledgement in the publication, (d) endangered species data and (e) privacy rights of collectors and researchers. Until flaws in the network safeguards are fixed, data requests can be handled on a case-by-case basis.

Conclusion

Rapid biological inventories would provide powerful means to bridge information gaps leading to fool-proof policy making. The advent of new information technologies allows natural history museums to digitize collections and to make associated scientific data accessible to a wide audience. These technologies enable the sharing of data with parties that have provided collection material, thereby closing the digital divide. Database and imaging technologies can also transform enormous collections into innovative tools for identification in the field.

Natural history museums should collect and disseminate information faster. The economic forces that drive unsustainable natural-resource depletion are strong and are gaining speed. Rapid biological inventories provide time-sensitive, accurate data for areas of high conservation concern. By actively forging relationships with government officials, scientists and community leaders, natural history museums can increase the number and impact of concurrent rapid biological inventories.

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