AN INTERNATIONAL VIEW OF NATIONAL BIOLOGICAL SURVEYS[1]

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ABSTRACT

Museums and herbaria in industrialized countries hold a huge amount of data in the form of labels associated with specimens collected in developing countries. These data represent a significant part of the existing information on biodiversity available for most developing countries. In this paper we first discuss the usefulness of the label information, providing some examples from Mexico. Acquiring and updating the information requires international cooperation, including the agreement of common policies for ownership and use of the data. Beneficiaries of such efforts will be not only the countries that assemble the databases from foreign museums, but the international scientific community as well, due to the increased scientific value that large databases coupled with modern computer technologies provide.

Surveying the biological diversity of a nation involves the inventorying, cataloging, and mapping of ecosystems, species, populations, and genes. It may also include research on the dynamic aspects of population biology, community and ecosystems ecology, and human uses of the different components of biodiversity. The task of biological surveying is among the oldest that biologists have faced (Badiano, 1552; Hernández, 1790). However, the increasing rate of ecosystem destruction with its associated species extinction and genetic erosion (McNeely et al., 1990; Wilson, 1992; Ehrlich, 1995; Whitmore & Sayer, 1992), and the realization that perhaps 90% of the species on the planet remain to be named, not to mention mapped or understood (May, 1990; Groombridge, 1992; Stork, 1988), have added urgency to the problem. To address this urgency, new methods of documenting biodiversity are currently being developed—such as Rapid Assessment Programs (RAPs) (Conservation International, 1991, 1992, 1993a–c), the division of labor and information management methods of Costa Rica's Instituto Nacional de Biodiversidad (INBio) (Janzen et al., 1993), All Taxa Biotic Inventories (Janzen, 1993), new sampling methods including the so-called BioRaps (Margules & Austin, 1995), where extrapolations of distributions are obtained prior to the sampling (Margules & Redhead, 1995), and advanced methods using sensors and pattern recognition software.

The reasons different societies and cultures may have for cataloging biodiversity run the spectrum from the strictly utilitarian to the philosophical and religious (Norton, 1987; Wilson, 1992). In countries like Mexico, which has a large, diverse rural population (Sarukhán et al., 1996), utilitarian reasons are very important. Indeed, in Mexico more than 3000 species are used as medicinal plants (Argueta et al., 1994), many other species have industrial applications (Sarukhán & Dirzo, 1992), such as jojoba for high-grade oil, and there are hundreds of varieties of corn, beans, chile, and other species that are used for food. Still, non-utilitarian reasons for preserving biological diversity are expressed very forcefully by different segments of the public, such as outcries for protecting the monarch butterfly [Secretaría de Desarrollo Social (SEDESOL), 1993], waterfowl [Commission for Environmental Cooperation (CEC), 1995], marine mammals (Salinas & Ladrón de Guevara, 1993), and other conspicuous species. A good example in plants is the recently discovered *Lacandonia schismatica* (Martínez & Ramos, 1989), which despite being apparently useless and inconspicuous has been protected by the Chole Indian community of San Javier, Chiapas, at the cost of not clearing the remaining patch-
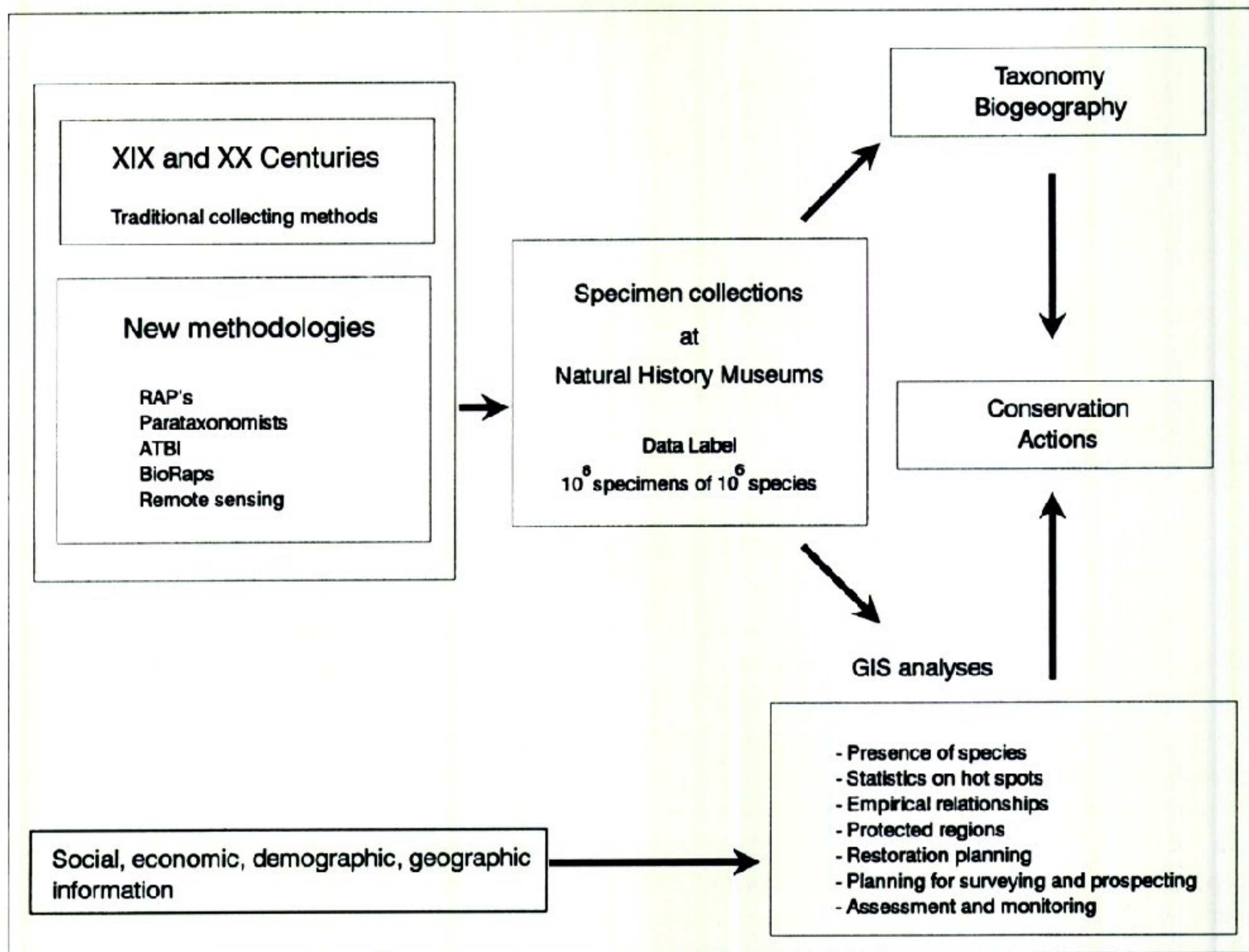
Figure 1. Traditional and new methods of collecting provide information about presence of species, mostly as labels on specimens. This information may ultimately have practical applications for conservation, alone or coupled with other types of data.

es of rainforest where the first population was discovered (Coello et al., 1993).

There is no doubt, then, that both in developed and underdeveloped countries different segments of the public, for different reasons, desire to preserve or sustainably use biodiversity. Consequently, governments have begun to design national programs for surveying biological diversity [National Research Council (NRC), 1993; Maddox & Gee, 1994; Gámez et al., 1993; Environmental Resources Information Network (ERIN), http://www.erin.gov.au/general/], and to create multinational agencies or agreements that support or encourage such efforts (e.g., Global Environment Facility, Convention of Biological Diversity).

In this paper we will concentrate on surveying species from the point of view of the Mexican biodiversity agency, the Comisión Nacional de Biodiversidad (CONABIO). First, we will present arguments for inventorying existing collections and exploring the possible uses of the specimen label data. Second, we will describe our experiences and points of view on the role that foreign institutions

play in such efforts. Third and finally, we will illustrate these two points using specific examples from CONABIO databases.

THE USEFULNESS OF LABEL DATA

During the last two centuries major efforts were made to explore, collect, and inventory the natural world. Museums and collections are the depositories of the results, and it is because of the existence of the specimens located in those depositories that organized biological studies are possible (Janzen, 1993; Wheeler, 1995).

The museums and herbaria of the world hold in the order of 10^8 specimens of an order of magnitude of about 10^6 species (Chalmers, 1996), collected in localities that, to a certain gross spatial scale, cover most of the surface of the planet and an important part of its waters. Therefore, the information these specimens provide should represent the base for national inventories. However, for most of these specimens, we know little more than the date, location, collector, and name, and much of this in-
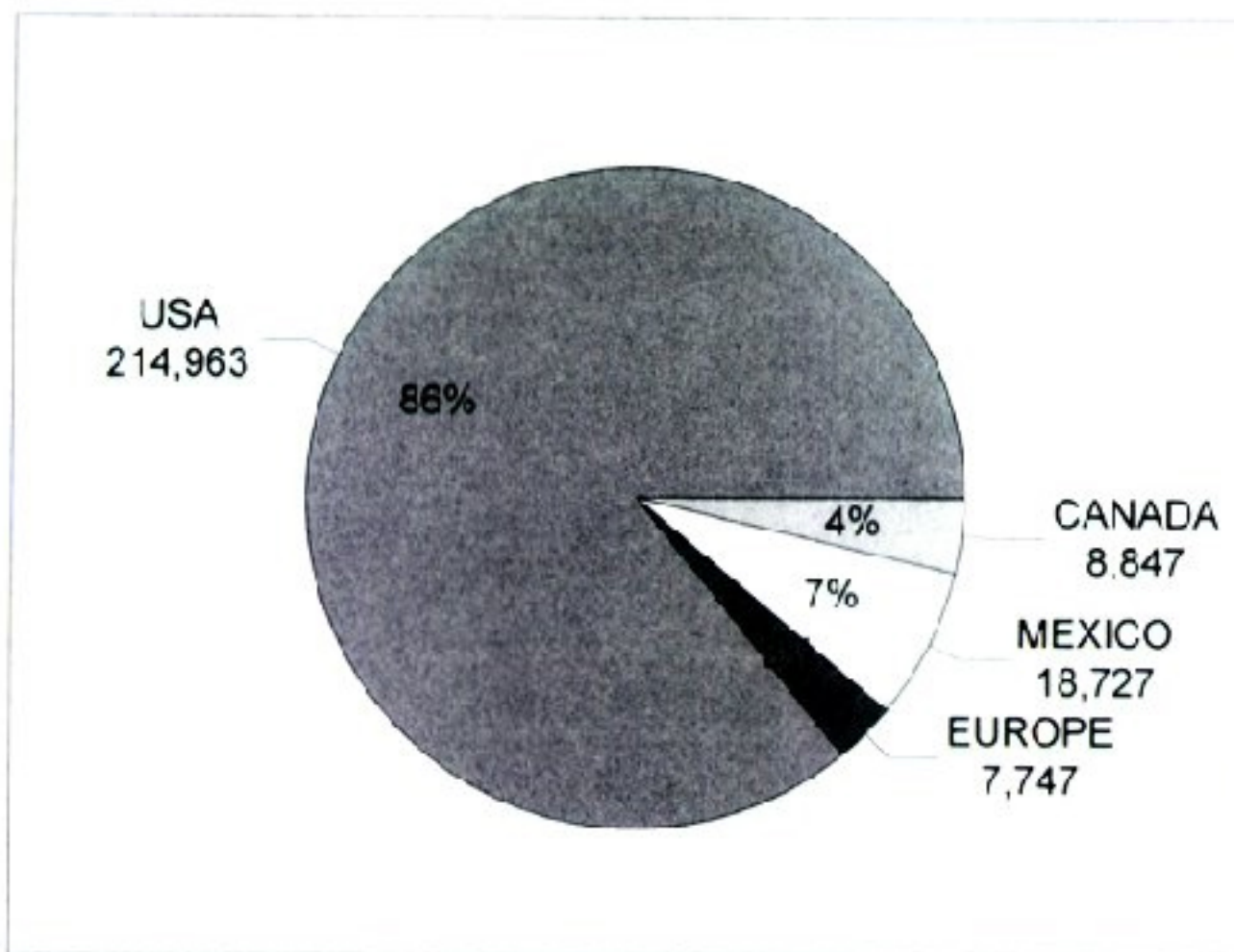
Figure 2. Graphic representation of the Bird Atlas of Mexico database showing the proportions of Mexican specimens that are housed in collections in different countries.
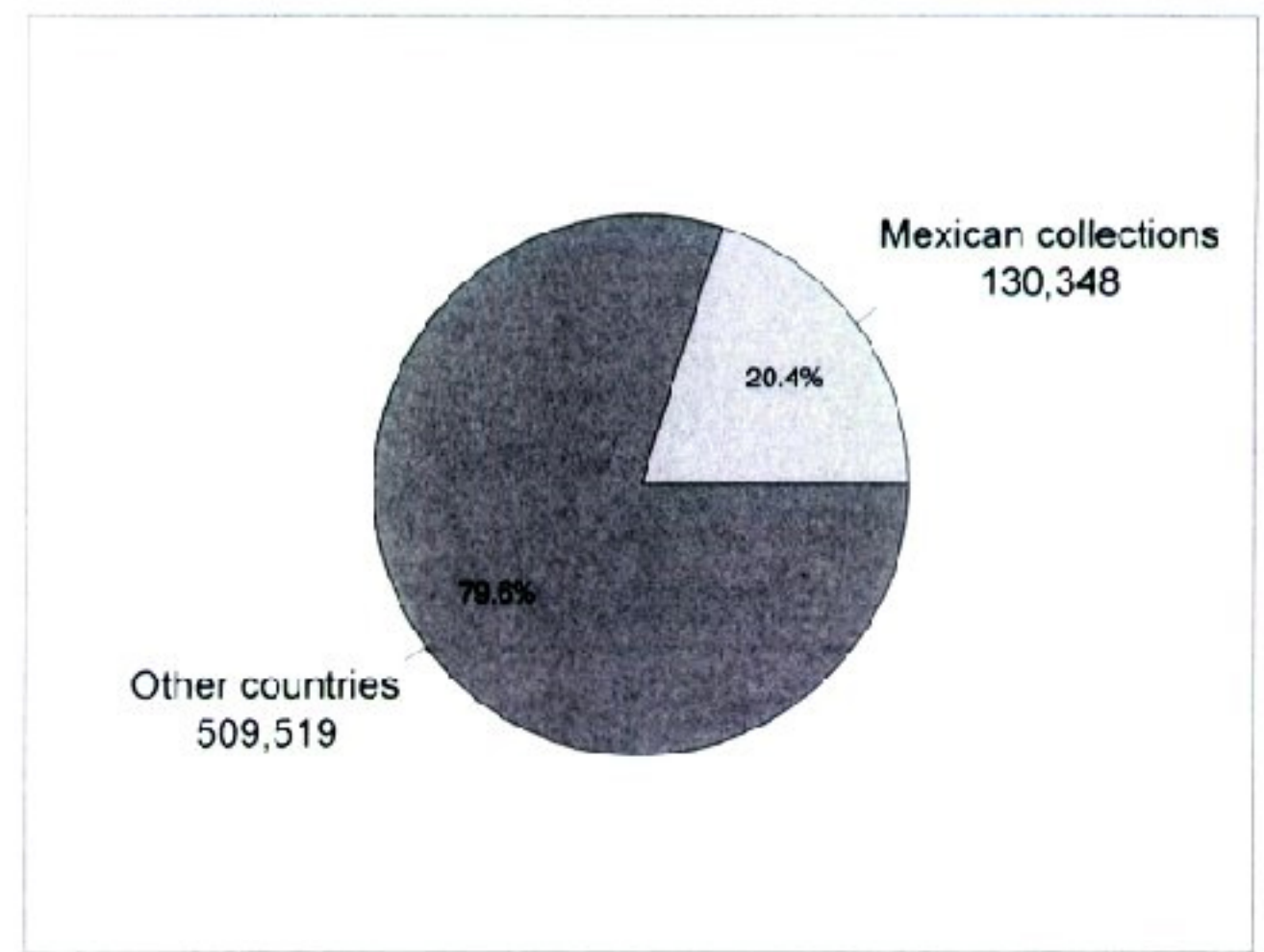

Figure 3. Graphic representation of CONABIO's all-species databases showing the proportions of Mexican specimens housed in collections in different countries.

formation has some degree of uncertainty, both taxonomic and geographic. One obvious question is what use such apparently meager data has for conservation biology. Despite the serious limitations, such data have constituted the basis for much of classical biogeography, and it is the common ground where systematics, biogeography, and ecology come together to contribute to conservation biology (Fig. 1).

From the viewpoint of conservation biology, the basic results that label data from museums produce are lists of taxa and the distribution areas of taxa. Both types of biogeographical information are essential to the practical applications of conservation policies. In many countries, choosing areas to be preserved or finding locations of certain important species are the most common "scientific" tasks for conservationists (not to mention the economic, social, and political actions that in the end are the *sine qua non* of conservation).

In countries with high alpha and beta diversities but with a lack of knowledge about that diversity, having reliable lists and ways of extrapolating data from a collection locality to a larger area allow, among other things, the following:

(1) For a given site, determination of the likely presence of endemic, protected, scientifically interesting or economically important species (Bojórquez et al., 1995).

(2) Obtaining important statistics such as number of species and percentage of endemics. This also allows the location and mapping of hot and cold spots for better ecological planning (Prendergast et al., 1993; International Council for Bird Preservation, 1992; Nelson et al., 1990).

(3) Development of empirical relations between

the above and easily measured climatic, geologic, and biological parameters to allow extrapolation (Margules & Austin, 1995; Margules & Redhead, 1995; Butterfield et al., 1994).

(4) Restoration planning using historical records or empirical rules for hypothetical distribution areas (Allen & Wilson, 1991).

(5) Efficient planning of surveying and prospecting, both for areas lacking previous fieldwork using "hypothetical species lists" and for species of scientific or economic interest (Margules & Redhead, 1995; Sittenfeld & Gámez, 1993).

(6) Assessment and monitoring of global climate effects on the areas of species distributions (Chapman & Busby, 1994).

Despite their usefulness, floristic and faunistic studies, and the development of procedures for the production of reliable distributional areas, have been the subject of far less theoretical and methodological development than other approaches such as, e.g., the population biological methods that underlie Minimum Viable Population Analysis (Soulé, 1987), and which are, at least in many underdeveloped countries, often far removed from the actual practice of conservation. There is no doubt, however, that the proper use of the huge amount of existing label information, in conjunction with modern computer systems, introduces many methodological and even theoretical issues, some of which we will discuss below, and therefore this should be an area of active research.

Of course, any information coming from museums, even assuming it is taxonomically adequate, may require field corroboration and is not a substitute for detailed ecological studies. But label information, because of the sheer abundance of it, its
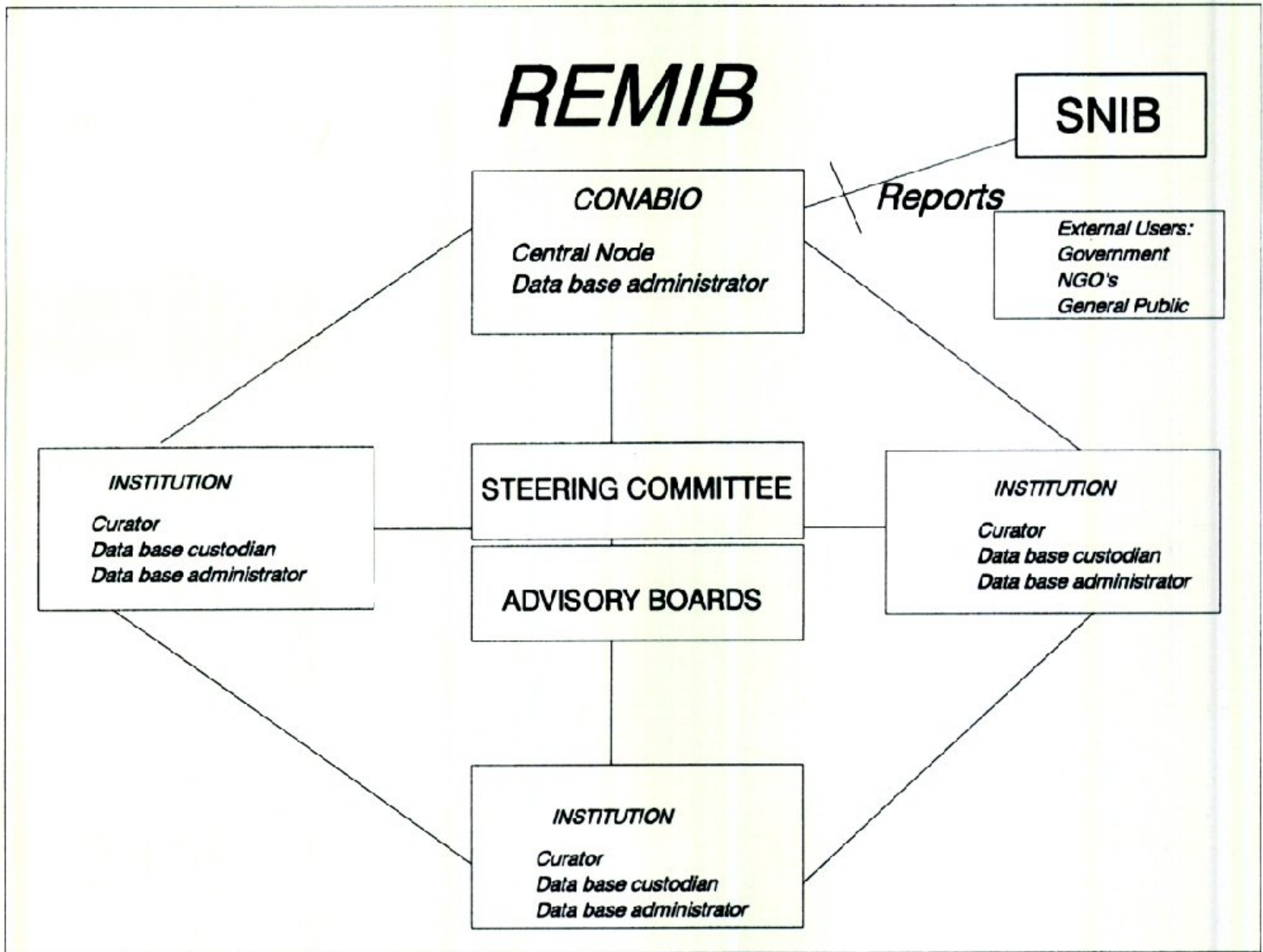
Figure 4.   Structure of the Mexican network of biodiversity information (REMIB). The steering committee and advisory boards are academic bodies in charge of overseeing standards and membership to the network. SNIB is the national system of biodiversity information. The function of REMIB is to provide a mechanism for updating information maintained in the different institutions.

historical importance, and its direct relevance to important conservation questions, should have high priority in any national biological survey.

SURVEYING THE MUSEUMS OF THE WORLD

In this section we will rely heavily on the experiences of CONABIO that we believe are most amenable to generalization. Although CONABIO has supported a certain number of field studies, mainly on protected areas, and a pilot parataxonomist program, modeled on the experience of INBio, has been started, most of the efforts have been directed toward computerization of national collections and sharing information with foreign collections.

When CONABIO was created, its main objective was to promote the inventorying of Mexican biodiversity in computer data banks that could be updated regularly. There are several problems in fulfilling this task: (1) Clearly, to inventory all species inhabiting the Mexican territory is a task for generations. Priorities must be set. (2) Most of the

specimens that have been collected in Mexico, with the exception of plants, are not held in Mexican collections. Sharing of data is necessary. (3) Gathering and updating the data are tasks for professional (or, in some cases, advanced amateur) taxonomists working in museums and herbaria. Policies and methods for determining the quality of data, acceptance and rejection criteria, accessing and updating the information, ownership, copyrights, economic compensation, etc., should be agreed upon between taxonomists and their institutions. (4) The size and distribution of the data make its capture in electronic formats expensive and time-consuming, requiring long-term commitments. (5) Given the dynamic and complex nature of taxonomic information and the lack of accepted standards for a taxonomic "data model," the creation of a suitable computer system was not trivial. (6) In order to be useful to a heterogeneous public—including government officers, scientists, members of non-governmental organizations (NGOs), and perhaps the general public—statistical, analyti-
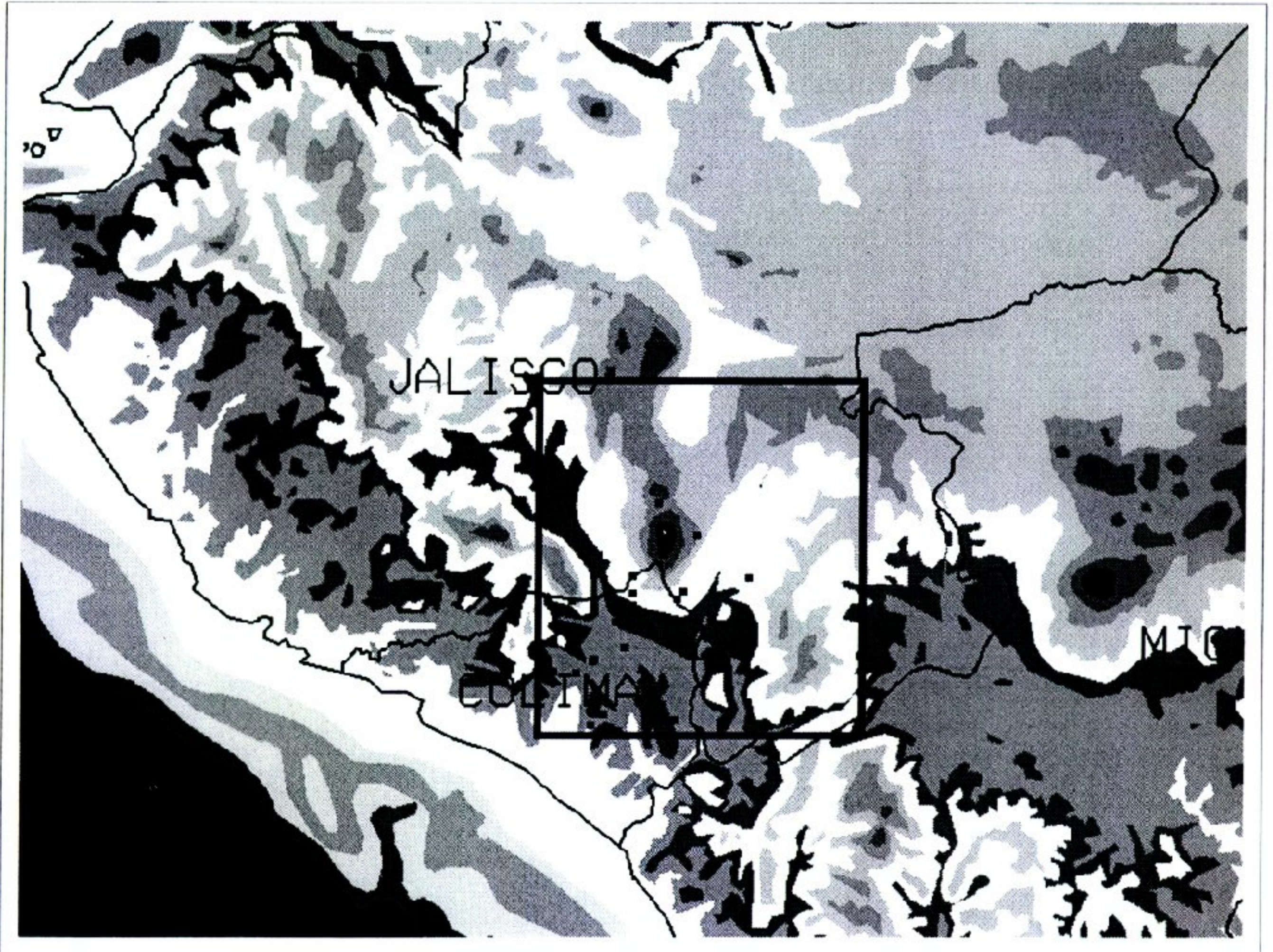
Figure 5.   Distribution of collecting localities of two families of butterflies (Papilionidae and Pieridae) in a one degree per side square of the Pacific Coast of Mexico. The dots represent collection sites, and the shadings categories of altitude over sea level. Most collecting has been restricted to a limited range of altitude, suggesting that the sampling of ecological conditions is insufficient. The database used is the Butterflies Database of the Zoology Museum, School of Sciences, National University of Mexico.

cal, and display tools that help to organize the data in user-friendly and interesting ways should be devised and implemented.

SETTING PRIORITIES

Setting taxonomic and geographic priorities for the biological inventories was intensely discussed by CONABIO and its advisors. The final, pragmatic option we chose was to support work on groups in which Mexican experts were willing to work, or where there were ample and easily available data. In a second stage, results of these discussions will be used to pinpoint areas of both taxonomic and geographic ignorance. This leads many of the grants from CONABIO to be oriented toward vertebrates (terrestrial and aquatic), butterflies, some beetle families, and other important invertebrate groups, like certain families of parasitoid wasps and mollusks and annelids. The first results of those projects are now being used to plan field trips to fill in gaps, as will be described below.

SHARING INFORMATION WITH FOREIGN INSTITUTIONS

It is well known that many countries with great biological diversity do not house the best collections of their own flora and fauna. For example, about 90% of the bird specimens collected in Mexico are housed in foreign museums, mostly in the United States, Canada, and the United Kingdom (see Fig. 2). This is the case for almost any group considered at higher taxonomic categories, with the exception of vascular plants, for which there are two very large Mexican collections and several medium-sized ones. CONABIO is supporting the work of Mexican taxonomists to obtain information from the labels of specimens housed in foreign collections. In fact, by September 1995 almost 80% of CONABIO's data bank came from specimens housed in foreign collections (Fig. 3). To obtain the information a variety of procedures are used, from requesting computerized catalogs from curators to manually recording the information attached to each specimen. In this way, in the last two years
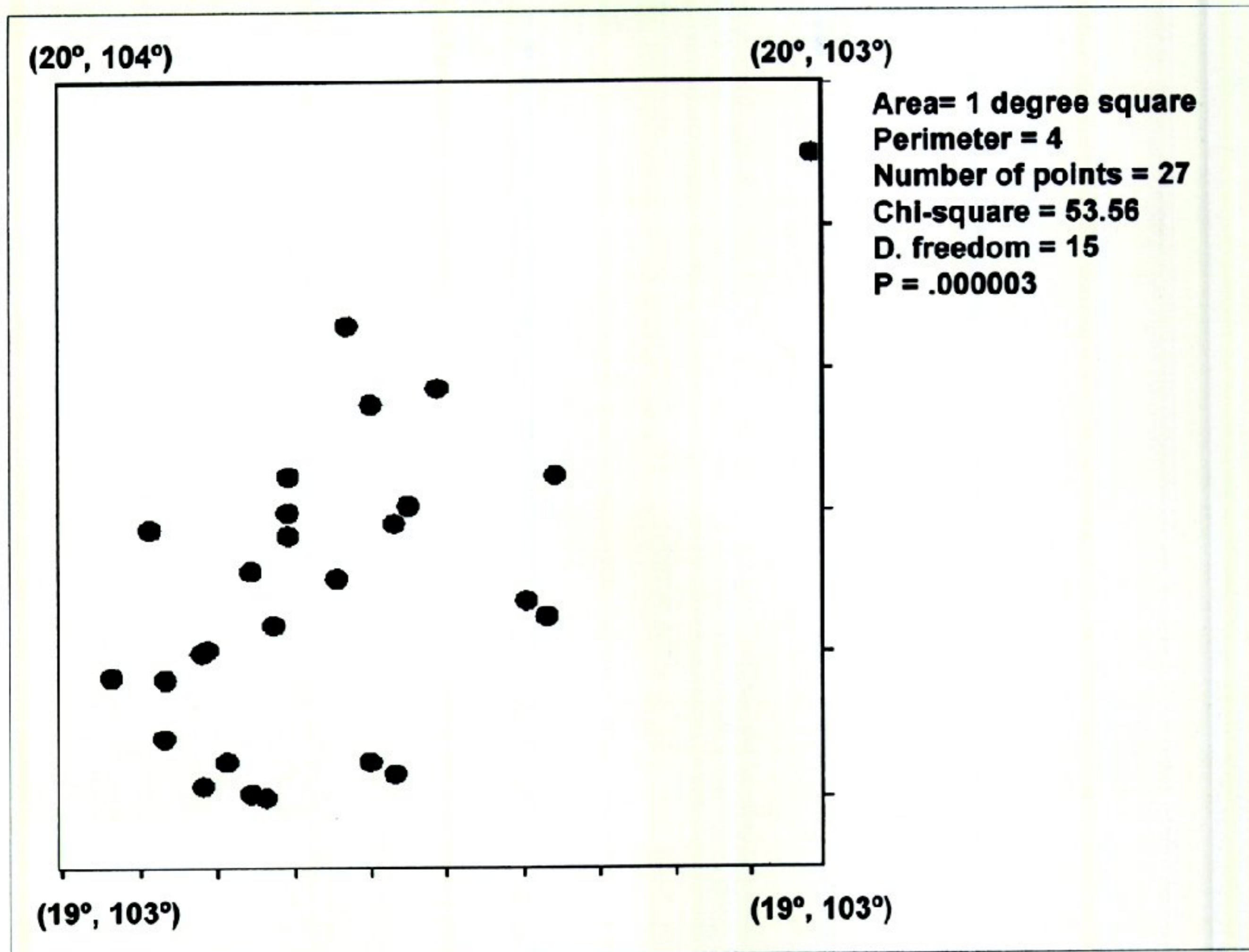
Figure 6. Spatial analyses of the data from Figure 5. Spatial distribution was analyzed for randomness of pattern, using standard techniques (see text). The null hypothesis of a random distribution of localities within the square was rejected.

information on hundreds of thousands of specimens, mostly of vertebrates and butterflies, have been assembled in databases now kept in some Mexican institutions, and eventually most of the information will be available through the Internet, via CONABIO's home-page.

Several interesting points can be learned from CONABIO's experience. When the work is done by taxonomists acquainted with the proper handling of collections, almost all foreign museums have been open to and helpful with the effort of computerizing labels. Among other things, this sometimes benefits the museums that lack computerized catalogs or the resources to computerize large collections. However, there were a number of concerns related to the idea as a whole. Most concerns of providers are associated with the precise conditions for releasing information to the public domain. In many cases this issue has been resolved by carefully stating the rights of the providers following ideas already used by the Australian Environmental Resources Information Network (ERIN), or contained in the published Association for Scientific Collections' (ASC,

1993) "Guidelines for Institutional Database Policies." These points can be formalized by signing letters of agreement or Memoranda of Understanding between the national biodiversity agency and the foreign museum. In our case, CONABIO has already signed a Memorandum of Understanding with the British Museum of Natural History, and is working on other such agreements.

POLICIES ABOUT OWNERSHIP AND UPDATING

Ownership of information is a subject closely related to the above. Although who is the "owner" of information in a public museum is open to discussion, there is no doubt that the museums, the curators of the collections, and the taxonomic experts are the actors directly involved in creating and updating the information, and they should be the authorities on the use of it. CONABIO is following the experience of ERIN regarding the concept of custodianship of the information. This means that we agree that only the providers of the databases and the curators of the collections have the authority to
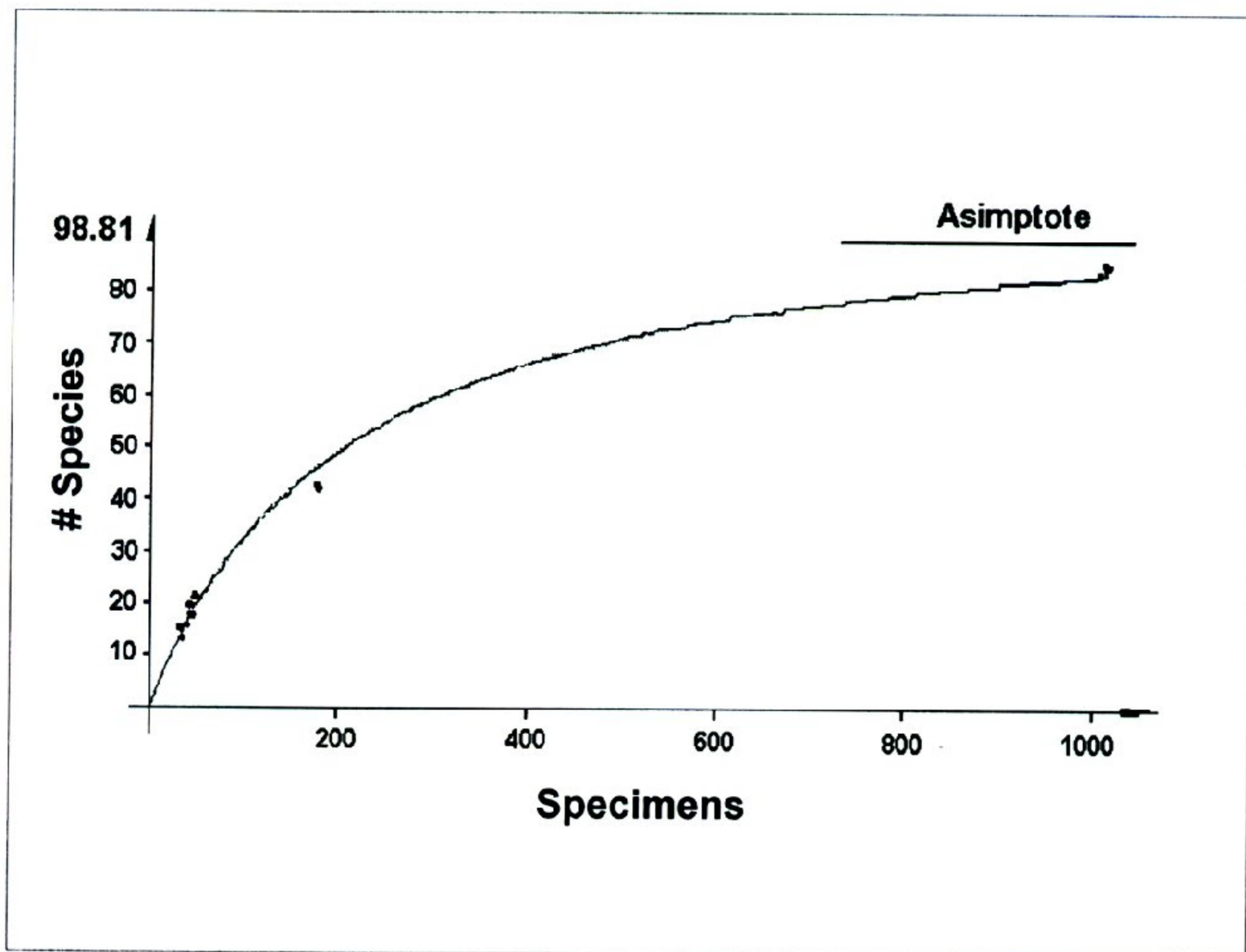
Figure 7.   Species-effort analyses of the data from Figure 6. Using CONABIO's database, an accumulation of number of new species plotted as a function of collecting effort (number of specimens in five-year intervals) was done. The curve shows that for the area sampled there is a decreasing rate of new registers, and the asymptote of the curve (about 99 species) is near the last value of different species (86) collected in the area. See text for further explanation.

modify the databases. It also means that if part of the information is regarded as sensitive (for example, precise georeferencing of populations of commercially valuable endangered species) or not yet ready to use by non-experts (for example, if it is not stable taxonomically), the providers or curators have the authority to mark the fields or records as access-restricted.

CONABIO, as well as some other national biodiversity agencies (INBio, ERIN), supports a policy of open access to most of the basic information on biodiversity, that is, the label data. However, this is not universally agreed upon, and therefore before releasing any information to the public domain the formal agreements and permits should state at least what parts of the information are considered open, the disclaimers and pointers in the databases that identify the original sources and dates of the information, the responsibility (or lack thereof) of the sources, the procedures to report to the sources the amount of use of their information, and any updating mechanisms for the database.

The periodic updating of databases containing label data from many tens of thousands of specimens located in dozens of institutions in many countries is not a simple task. However, the existence of the Internet makes the task feasible. Pioneering efforts are already under way by many institutions that are making their catalogs available on-line through the World Wide Web. Among the many entry points, Cornell University Biodiversity and Biological Collections is a useful one. (Its URL is: http://muse.bio.cornell.edu.) Nevertheless, a truly distributed database of museum information is still lacking. A major international effort will be required to reach this goal (Systematics Agenda 2000, 1994).

In Mexico, CONABIO is coordinating a network of institutions in an effort called Red Mexicana de Información sobre Biodiversidad (REMIB), in which the partner institutions will have access to the information held in each collection using widely available Internet navigators. Although short of full interoperability of the databases, this will allow the
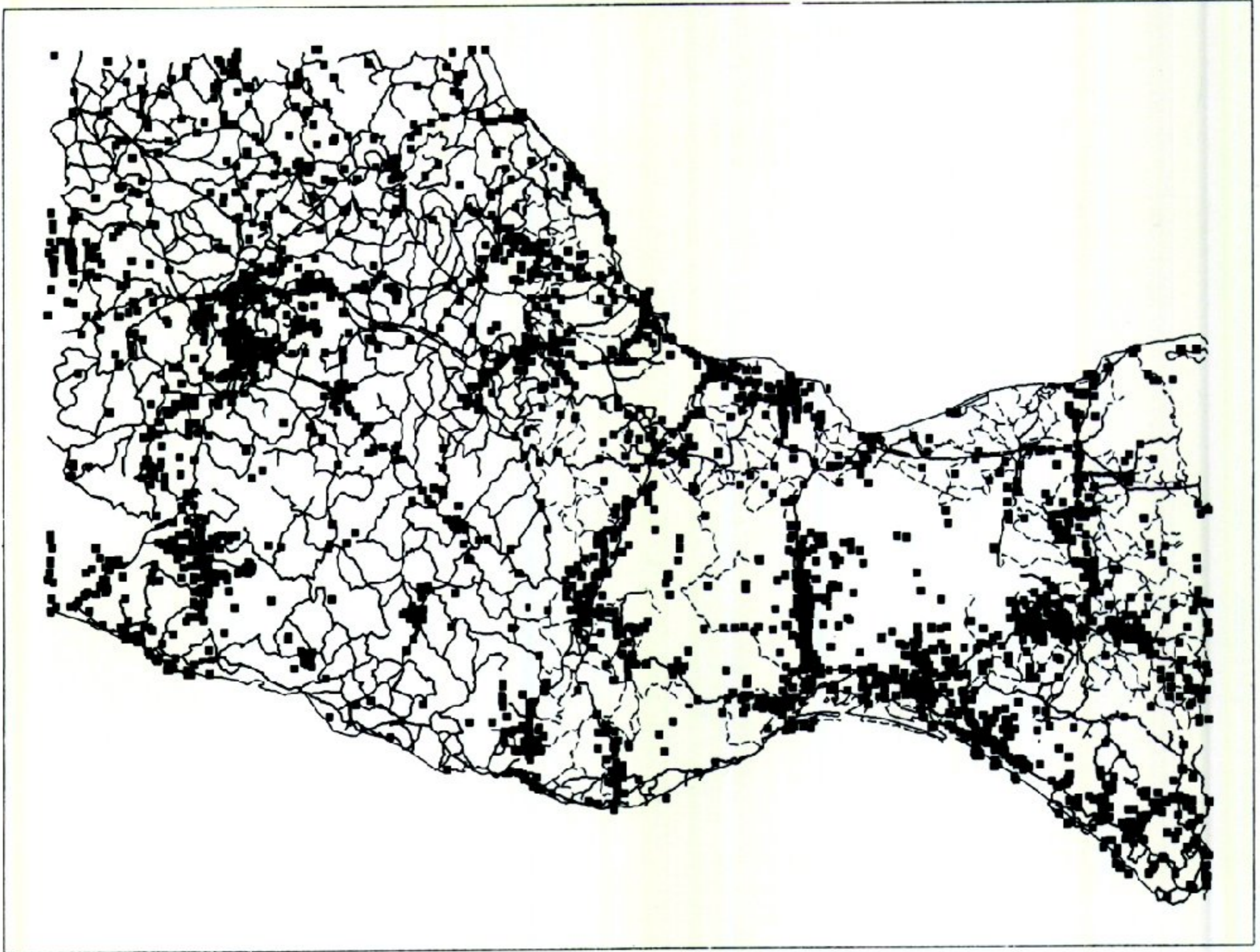
Figure 8. Dots represent collecting points in the Bird Atlas of Mexico database, near the Isthmus of Tehuantepec, in southern Mexico. Lines are roads. The figure displays the "Collector's Syndrome," in which dots tend to accumulate along roads or around biological stations.

partners to retrieve information on-line and to gain experience with the problems of creating a distributed database (Fig. 4).

LONG-TERM COMMITMENTS

Any country that attempts to create national inventories must be prepared to make a long-term commitment. Not only are lists incomplete even for vertebrates, but the detailed georeferencing required for modern studies (Margules & Redhead, 1995) is available only for certain groups or in a few countries. In the developing world, this will require the creation and strengthening of national capacities in terms of physical and human infrastructure (at the technical, professional, and research levels) to do conventional exploring and taxonomic work, but since most of the already existing data are based in museums in the developed countries, some new commitments are required. As an example, we can take the Birds of Mexico database that was compiled by A. Navarro and H. Benítez of the Museo Alfonso L. Herrera, at the School of Sci-

ences of the National University of Mexico, and Townsend Peterson, of Kansas University. This database took more than five years and visits to 40 museums in seven countries to be assembled. The georeferencing of the locations has been going on for three years, and the debugging of the geographical fields alone has involved some 30,000 of the total 280,000 records. Maintaining and updating this database will be a permanent task that may require a budget to allow for trained personnel, traveling, computer resources, etc. Because scientific grants are difficult to obtain for these efforts, governments may have to allocate money specifically for the compilation and maintenance of these databases. All the other databases of a national scope that CONABIO is supporting (mammals, fishes, reptiles and amphibians, butterflies, and scarabeid beetles) have taken many years to be compiled and georeferenced and will require continuous efforts by their custodians at universities to maintain, debug, and update. This effort will cost resources and institutional commitments at national and international levels.
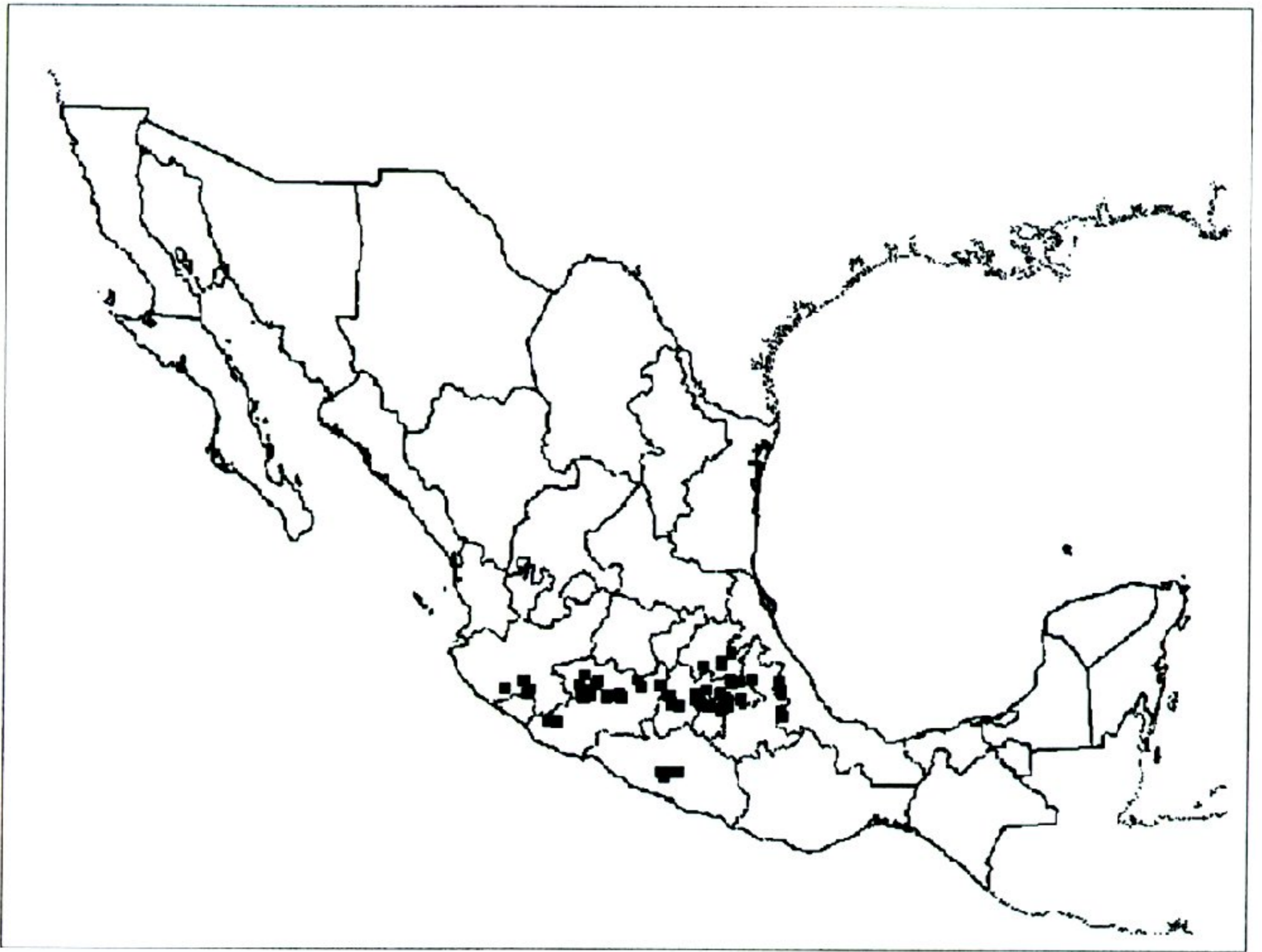
Figure 9. Collecting localities for *Abies religiosa*. Data are from herbarium specimens deposited at the Instituto Nacional de Investigaciones Agropecuarias y Forestales (INIFAP).

The commitment also means participating in the many international forums that deal with this subject. Since the issue of sharing and updating collections information on a global scale has presented a great many questions, it is important that many opinions and points of view be taken into account when agreeing on policies, standards, methods, etc. Currently, there are several more or less international efforts addressing these problems, groups like the International Organization for Plant Information (IOPI), the Working Group on Taxonomic Databases (TDWG), the International Union for Biological Sciences' group DIVERSITAS, and initiatives like Systematics Agenda 2000, Species 2000, and the Clearing House of the Biological Diversity Convention. Regular participation from member countries is needed in order to maintain an institutional memory.

DESIGN OF A DATA MODEL

To date, there is no single agreed-upon data model that can be used for an effective exchange of information among data holders around the world. This is an important subject to confront if we are to exchange and update information from different sources efficiently and consistently.

Several data models are in use in institutions around the world, for example, the databases MUSE (http://muse.bio.cornell.edu/), SMASCH (http://ucjeps.berkeley.edu/smasch.html), and TROPICOS (http://www.mobot.org/MOBOT/research/datamodel.html) and others accessible through the Biodiversity and Biological Collections Home page (http://muse.bio.cornell.edu/). However, this effort is not complete, and becomes even more complicated when other themes are added to the purely taxonomic information. CONABIO has dedicated significant time, money, and human resources to define a data model that can adequately address the diverse needs of government institutions dealing with the manifold aspects associated with biological information.

In many cases incompatible data formats among museums highlight the additional standardization effort that is required to be able to use information

Figure 10.   Data on altitude, precipitation, and average yearly temperature were obtained for the collecting localities in the previous figure. The geographical information system was then used to plot other localities with similar conditions (see text).

from different sources. Taxonomists and scientific societies throughout the world must participate more actively in order to propose and enforce more effective "standards" for taxonomic information, since curatorial information represents the "core" of any biodiversity information system.

ANALYTICAL TOOLS

Amassing large databases of label information requires the development of many tools for its analysis. This includes, first, display and exploratory tools. Since the information and its interpretation are basically geographical, Geographical Information Systems (GIS) are an essential tool for displaying and organizing the data. However, due to large gaps of knowledge, inferential and predictive tools are also needed. Given the non-randomness of these samples (in space, time, and taxa), and the fact that most label information is just *presence* data, this presents some interesting statistical problems.

As an example of display tools, in Figure 5 we present the distribution of collecting localities of Papilionid and Pierid butterflies (the database comes from 15 museums in Mexico, the United States, Canada, and Europe) in a one degree per side square on the Pacific Coast of Mexico. At a glance one can tell that most of the highlands are not well sampled. An analysis of the randomness of the spatial distribution (Pielou, 1969) confirms that the points are far from being randomly distributed (Fig. 6). In Figure 7 an accumulation curve (Soberón & Llorente, 1993) is displayed. This curve shows that the effort concentrated on the area covered by the points has resulted in a significant drop in the discovery of new species. The two exploratory tools show that although the lowlands in the square may be adequately sampled, more effort is required in sampling other areas.

In another example, in Figure 8 we show the collecting localities for birds in Mexico. The map clearly displays the artifactual pattern created by overcollecting along roads or near biological stations and points out gaps where few or no collecting efforts have been made. This type of information is already being used by CONABIO to evaluate the

information about location of species provided in some environmental impact assessments.

On the matter of predictive methods, empirical modeling of the presence data as a function of easily measured, climatic or physiographic variables holds great promise (Butterfield et al., 1994). In Figure 9 we display the points where the fir *Abies religiosa* has been collected, according to the data of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) herbarium in Mexico. In Figure 10 the shaded areas show regions where similar conditions of average temperature, precipitation, and elevation occur. Similar regions were defined using a boxcar method (Carpenter et al., 1993). It is quite possible that the large shaded areas may include non-reported localities for *Abies religiosa*, and perhaps for other species of *Abies* as well. Inclusion of the information of other national and foreign herbaria would lead to a much better analysis. Leaving aside the work of Soto and Gómez-Pompa (1990), empirical modeling is just beginning in Mexico, and although the Australian experience shows that the tool has predictive power, more work is needed in the mountainous regions of Mexico. The possibilities that empirical modeling opens for bioprospecting, planning, and restoration are significant. The National Reforestation Program in Mexico will be using this tool for planning their actions in the immediate future.

Conclusions

The use of label information that is currently housed in the many museums around the world will be extremely useful for ecological planning and monitoring. The ability to assemble large label databases, together with the computing tools required to analyze them, is increasing the value of collections, museums, and the work of taxonomists around the world. Besides the practical implications for prospecting for important species, restoration and reforestation, ecological planning, locating priority areas, and monitoring and evaluating environmental impact statements, the scientific applications of the databases are quite interesting. Biogeographical and ecogeographical analyses previously done on the scales of thousands of square kilometers may be refined a thousandfold. Empirical modeling should conduce to forming hypotheses and suggesting mechanisms for explaining the correlations found.

For most countries all the above requires more than just national efforts. The collaboration of museums all over the world, together with scientific societies and many multilateral agencies and programs, will be needed to computerize and distribute the information, agree on policies and standards, develop methods and techniques for analyses, and provide funds.

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