Floras: a model for biodiversity studies or a thing of the past?

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Floras (and Faunas) have a rich history that involves examining questions on evolution and biogeography. However, in recent publications Floras have been viewed as an end unto themselves, separate from clade-based monographs and evolutionary studies. Floras are not a separate entity but rather a part of a continuum that involves databases, checklists, floras, biodiversity studies, and conservation biology as well as monographs. As the importance of Floras and related studies has become more apparent, there have been comments about the lag time between when specimens are collected and when they are identified, the amount of time it takes to describe new taxa, and how long it takes to finish floras and other projects. Some have referred to this as the "Taxonomic Impediment", and it is sometimes laid at the feet of taxonomists. Taxonomists can become more efficient by using various on-line resources and this will continue to speed up as more literature, etc. become available but the impediments to taxonomy are many, not the least of which is a lack of funding and the dwindling number of taxonomists. Changes in how systematists work and interact with other branches of science must take place in order to speed up research and re-establish the importance of Floras but only a substantial infusion of funds and personnel will really accelerate our progress.

KEYWORDS: biodiversity, conservation, Faunas, Floras, systematics, taxonomy.

INTRODUCTION

Today taxonomists face "universal" questions as well as the more traditional taxon based ones. In addition to standard questions such as "How many species are there?", "Where do they grow?", and "How are they related?", we also contribute answers to questions such as "What are the global patterns of diversity?", "How important are certain taxa?", "Are endemicity levels real?", "What taxa should be conserved?", "Can taxa serve as surrogates for one another?", "What areas should be conserved?", "Can biodiversity be estimated in unexplored areas?", "How similar are different areas?", "Can we assess patterns of species richness?", and "How does species composition change over space and time?". Floras are a major source of information for helping answer such questions. Many of these questions come from what some think of as a new field of study "biodiversity" and the need for information for conservation, but in reality the tradition of using Floras to answer questions goes back to the 1700s. Floras, as well as Faunas, have a long, rich tradition of providing science with much insight and information. This discussion is about the future of Floras, the origin and development of Floras is covered by Frodin's monumental work, the "Guide to Standard Floras of the World" (2001). However, there are some aspects of older Floras and Faunas that may give us some guidance for the future.

Fig. 1. *Passiflora candida* (Poepp. & Endl.) Mast., from the Wassari Mountains, Guyana. Photo and collection by *H. D. Clarke* (*#8520*) in 2004; the first collection of this species in Guyana.

There are many flora projects either recently completed or underway. Some are moving briskly toward completion and others are moribund. Most are different from one another. Some cover natural areas, others political ones, and still others are of smaller areas such as parks or research sites; sometimes the smaller ones are called biodiversity plots or florulas. Some Floras involve extensive collecting expeditions to enrich our knowledge of an area (Fig. 1) and some depend on previously col-

Figs. 2–3. 2, Joseph Dalton Hooker (1817–1911), was the first to use Floras to study the past; the first historical biogeographer; photo taken by W. J. Hawker. 3, Carl Eigenmann (1863–1927), fish taxonomist who used Faunas to study relationships and faunal evolution.

lected material. Some Floras are being written mostly by one or two people, others have different taxonomists for each plant family. Some Floras have detailed descriptions and others have only illustrated keys. Some Floras are breaking new ground and others are following traditional methods. But they are all attempting to document the biodiversity of an area and such information can be used to answer many interesting questions.

Determining what constitutes a flora and how Floras relate to ecology, biodiversity studies, checklists, etc. shows that they fit in a complex network of studies from expeditions to monographs and most of these categories feed information back and forth among one another. The failure to see how Floras are connected with other types of studies has lead to the concept being considered outdated rather than central to modern science.

Many Floras take a long time to complete, especially if they cover a large area. The slowness of work has led some to refer to the "taxonomic impediment" which is often blamed on the taxonomists themselves. However, recognizing the causes of the impediments is just as important as seeking solutions.

Only by recognizing the underlying utility of Floras to provide answers to questions and with the knowledge that they are central to many important studies will Floras again take their place as important scientific research. This paper addresses Floras but the comments are equally applicable to Faunas.

BACK TO THE FUTURE

Floras (and Faunas) are a noble endeavor with a complex and interesting history. Early on they were used to ask questions about the history of plants on earth. At least since Buffon (1761) naturalists have known that different regions of the world are inhabited by distinct groups of plants and animals. By the early 1800s this concept was generally accepted for a variety of organisms. In 1820 Candolle recognized the identification of "botanical regions" as a problem of general interest. One individual stands out because, unlike his predecessors and colleagues, he saw the need for developing a general method for examining or explaining these regions. The

earliest suggested methods for classifying biogeographic regions are probably those of Sir Joseph Dalton Hooker [Fig. 2; Endersby, J. (n.d.); 1817–1911)], son of a prominent botanist, colleague of Charles Darwin, and Director of the Royal Botanic Gardens, Kew for 20 years. During his career Hooker described the Floras of Antarctica, New Zealand and Tasmania (Vols. 1–3, 1844–1860), Galapagos (1851), Arctic islands (1862), British Islands (1870), Himalayas (1993), and India (1855), among others, along with his monumental work with George Bentham on *Genera Plantarum* (1862–1883). Hooker sought to know and understand the origins of the Floras from around the world. In his treatments of the Floras of lands of the Southern Hemisphere he proposed a method to evaluate checklists and determine affinities of Floras, a method that is still being used today. Hooker's treatment of the *Botany of the Antarctic Voyage* (1853) provides an example of what is probably the first stated method in biogeography and an excellent evaluation is provided by Brundin (1966 pp. 46–55). Hooker's method was to place each species from every flora into different categories, each of which reflected the entire distribution of that species. He came to the conclusion that the "bands of affinity" (species shared among areas) demonstrated that there had been a single center of evolution in the south that had been broken up by geological and climatic causes. Further, he believed that species had arrived to each of the continents in question by dispersal across connections postulated to have formerly existed between continents. Of all the early workers in biogeography, Hooker's "...continuous extensive flora,...that once spread over a lager and more continuous tract of land..." (Hooker, 1867) came the closest to getting it right and he based all of his work on lists of taxa taken from his Floras. Unfortunately, Hooker and his supporters were overshadowed by the proponents of "dispersal over a permanent geography", who believed that the earth existed first and that the plants and animals dispersed around it. But it is clear that Hooker was asking questions about bigger issues. Brundin, a colleague of Willi Hennig, and a strong supporter of phylogenetic systematics, gave Hooker the ultimate complement when he wrote (1966, p. 49) that "...Hooker's suggestion of the former existence of continuous land connections between the other southern continents by way of Antarctica has had a powerful effect on the imagination of scientists". So Hooker's ideas from the 1850s were still exciting scientists in the 1960s.

Another insightful taxonomist was Carl Eigenmann (Fig. 3; 1863–1927) who began studying the fish fauna of South America in 1887. In one publication, (1912, p. 1) he states as his purpose: "First to observe, photograph, and incidentally collect as many species as possible for my monograph of the characins; second, in connection with my general faunal study of the fishes of South America to determine, if possible, the relationship of the fish fauna of the Guiana plateau to that of the lowlands, particularly the relationships existing between the Faunas of the upper and the lower Potaro". The publication starts off with a traditional fauna complete with species descriptions and keys to the species as well as illustrations and photos. However, on page 95 Eigenmann asks questions concerning the fish fauna of the Potaro Plateau: "1) Of what does it consist? 2) Whence did it come? and 3) How did it get there?" Then again on page 99 he elaborates on question two, asking: "Whence did the fauna of the plateau come?

A. Is it the nucleus of the original fauna of Guiana? Or
B. Have the Faunas on the plateau and the lowland developed from a common nucleus? Or
C. Is it a relict of a more abundant modern fauna? Or
D. Does it consist of recent immigrants? Or
E. Is it a mixture?

To assist in answering these questions 1 give the species of the plateau with their distribution in the Potaro and also their general distribution in South America".

Eigenmann has a variety of tables that show lists of all the taxa and their locations and he uses those to try and answer his questions. He conducted field work and used the faunal data to ask questions about biogeography. In another publication (1909) Eigenmann used information from recent and museum collections to ask questions about the origin of the fish fauna of South America. He began by making tables that listed the fish fauna from many places and then he looked at the total distribution of each species. He drew maps of the distribution of many groups of fishes and he came to the conclusion that "the North American fish fauna is entirely distinct [p. 363] and that the South American and African elements must have been derived from some intermediate landmass or ...land bridge. This land connection must have existed before the origin of existing genera and before many existing families [p. 369]".

Hooker and Eigenmann were not alone in using Floras and Faunas to discover interesting and important things for science, there are many that could be on the list including: Carl Linnaeus (1707–1778), Antoine de Jussieu (1748–1836), Augustine Pyrame de Candolle (1778–1841), Alphonse de Candolle (1806–1893), George Bentham (1800–1884), Charles Darwin (1809–1882), and Alfred Russel Wallace (1823–1913). All of these individuals, botanists and zoologists alike, had something in common; in the course of working of Floras and Faunas they asked questions about other topics such as classification, the structure of nomenclature, biogeography, and evolution.

Just recently we have begun to see papers using Floras, checklists, and collections to ask a variety of

questions. For example Lim & Engstrom (2001), Kelloff & Funk (2004), and Clark & Funk (2005) all used lists of species to look at species diversity, implications for conservation, and affinities of Floras and Faunas for bats and plants. Several papers in Joseph (2005) address the diversity of an important conservation area in Guyana. Others such as Rahbek & Graves (2001) and Graves & Rahbek (2005) used museum collections to study the evolution of the birds of South America, and Price (2004) examined the influences of area, environment and paleogeography on Hawaiian plants using checklists he augmented with ecological and geological information. New efforts provide additional data such as checklists for terrestrial vertebrates (Hollowell & Reynolds, 2005) and plants (Hollowell & al., in press) of the Guiana Shield.

Using Floras (checklists and databases) to answer non-traditional questions is not new. The biodiversity questions that looked so different at the beginning of this discussion now seem to be a reasonable extension of Floras. Floras are useful for identifying organisms; they are a source of pride for the areas they cover; useful for environmental studies and excellent public relations. But they can be much more; they can be used to answer questions about evolution and biodiversity. There exists a wealth of floral and faunal information and we need to make better use of these data. We can see from the past what the future may hold.

FROM EXPEDITIONS TO MONOGRAPHS AND CONSERVATION STUDIES

Floras as part of a continuum. — To increase support for Floras we must stop thinking of them as an end unto themselves and look at them as a part of a continuum. Expeditions lead to specimen collections (i.e., vouchers) and identifications which lead to checklists which produce Floras which are the underpinnings of biodiversity studies, monographs and revisions (Table 1). This continuum has a single goal, to understand the plant diversity of an area. These data are important for conservation issues because biodiversity studies depend on accurate identifications, otherwise their conclusions are suspect. The best way to identify plants is using a flora that includes the area in question, the smaller the area of the flora, the better. The second best way is a checklist. Both require an herbarium to check the identification. This failure to see the link between checklists and Floras and biodiversity studies and conservation has resulted in a lack of recognition that Floras are worthy of our time. A note of caution: one must beware of producing checklists from on-line databases. Unless a special effort has been made to check the identifications, such databases are full of errors.

Many evolutionary biologists do not see checklists as a scientific exercise. Perhaps the overwhelming success of cladistics and the stressing of clade-based taxonomy as the only type of systematics able to answer questions about evolution have contributed to this division between clade-based and area-based studies. However, today there is a trend back toward looking at assemblages of taxa and not just clades (Miller, 2000). There are differences: Clade-based studies ask questions about all the descendents of a common ancestor; area-based studies ask questions about all organisms in a certain geographic area. Clade-based studies have information on taxa from a clade that are in one or more areas; area-based studies contain many different lineages only some of which have a known phylogeny. Both clade-based and area-based studies provide answers to questions on evolution and biodiversity; they approach the questions from different directions. Lately clade-based studies and area-based studies have become interconnected. One can inform the other. Some questions that span the distance between the two include: "Are the members of a clade within a study area part of a radiation or do they have independent histories?", "Do the clades from the base of the phylogeny differ in their environmental parameters from those that are highly nested?", and "Is an organism or clade from the study area basal or highly nested?". Some scientists have suggested that scientific questions can only be answered using clade-based studies; this misconception has devalued area-based studies. In some ways systematists are a victim of our own success; we have convinced the world that one must have a phylogeny and now the funding agencies and our colleagues want to see one. It seems clear that both types of studies are necessary if we are to understand the evolution of life on earth.

Biodiversity studies have much in common with checklists and Floras. Take for instance the *Center for Tropical Forest Science* (see list of web sites). This project has assisted in setting up large scale plots around the world. At each site they inventoried the plants, set up an herbarium for identification purposes, trained local staff to collect and identify plants, and connected with experts around the world. In addition, they data based the collections, and tagged and data based the plants, and geo-referenced their locations. Then they began to ask questions about change over time, seeding growth, and other ecology and conservation topics. The systematics work was done first, before the ecology began. The same is true for systematists, in order to understand the morphology of a group of plants and how the taxa are related we have to understand something about their environment and the geology of the area where they live and we must be mindful of their interactions with other organisms.

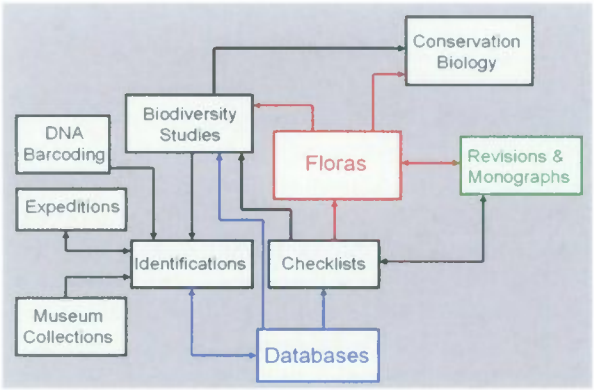

Fig. 4. A network showing the relationships among the various categories of systematics centered on "Floras" (Figure 4) and databases (Figure 5).

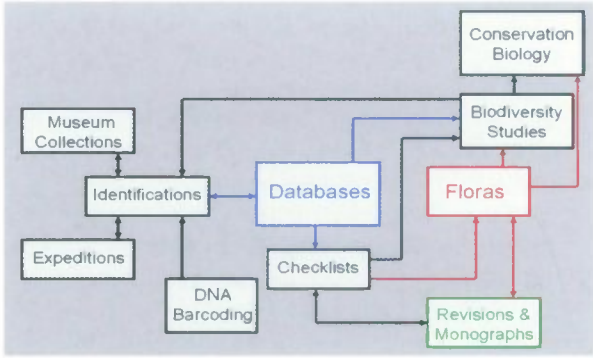

Fig. 5. A network showing the relationships among the various categories of systematics centered on "Floras" (Figure 4) and databases (Figure 5).

Figures 4–5 illustrate the inter-connectivity of the various types of studies. Expeditions, biodiversity studies, and museum collections produce specimens which are identified, data based and used to produce checklists and Floras. The information feeds back into the biodiversity studies and is used for conservation decisions. Information from checklists and Floras can be used in monographs and revisions. One can also take information from the database to plan expeditions (Funk & al., 2005). Figure 4 shows the relationships among these categories; it is centered on "Floras". Figure 5 centers the network on "databases" and illustrates why having a database is crucial to every type of study. Databases help to explain biodiversity and its importance and they are useful for policy makers, industry (product discovery, development, and enhancement), and society as a whole (health, ecosystem processes, understanding). The network could also be centered on other components. Two items should be noted: first that DNA barcoding is under development and while it has potential as an identification tool it is currently not in use in a general way, at least not in plants, and second that additional arrows could be drawn in these figures, such as one from "Floras" to "identifications".

Biological collections form the best information available to assist in supporting systematic and taxonomic research, understanding what lives where on the planet for a variety of purposes, e.g., controlling invasive alien and pest species, protecting endangered species, enabling countries to document their biota and implement the Convention on Biological Diversity, understanding the anthropogenic impact on species distribution over the past 200+ years, and predict future distributions of species in light of different climate change models.

Some scientists think of biodiversity studies as ecology and not systematics. However, many who conduct biodiversity studies have become the biggest proponents of Floras, Faunas, and checklists, and ecology has now become part of systematics and evolutionary biology. The power of area-based studies combined with clade-based studies is pulling the disciplines together. More and more it becomes clear that John Muir was correct when he said *Tug at a single thing in nature, and you will find it connected to the Universe.*

THE IMPEDIMENTS TO TAXONOMY

The great need for Floras and Faunas (as well as checklists and monographs) has led some to complain about how long it takes to finish projects, describe new taxa, and produce publications. The United Nations Environment Program (UNEP) in biodiversity coined the term "the taxonomic impediment" to refer to the critical lack of global taxonomic expertise that prevents the initiation and completion of biodiversity research programs (e.g., see Blackmore, 1996 and Brooks, 2000). This delay is sometimes attributed to taxonomists when in reality it has many causes, including: the lack of electronic access to specimens and literature, decreasing number of taxonomists, little administrative commitment to long term projects, low funding for alpha taxonomy, the under-appreciation of the work by the scientific community, and the lack of strong leadership.

Some advances are being made especially in electronic access.

Specimens. — Providing on-line access to lists of specimens or even to images of them speeds up the work. Sometimes these databases even have geo-referencing. Australia's *Virtual Herbarium* is a collaborative project at all levels of the government and among all herbaria in Australia. It is an on-line botanical information resource providing access to plant specimens in each Australian

herbarium. Another such resource is *TROPICOS* from the Missouri Botanical Garden. In addition to specimen information it provides nomenclature, bibliography, and chromosome information. Both of these resources and others like them are making it much easier and faster to locate material and to plan field trips.

Types. — The New York Botanical Garden and the US National Herbarium, among others, have their type collections available on-line via high resolution images. Other institutions have a database of the types. All on-line access to type information is an immeasurable help in quickly checking type citations.

Nomenclature. — Several sites are available to help with nomenclature. The most useful thing plant taxonomists have done along these lines is the *International Plant Names Index*, a project of the Royal Botanic Gardens, Kew, The Harvard University Herbaria, and the Australian National Herbarium. This index covers the names and associated basic bibliographical details of all seed plants. It has saved countless hours of searching. Another such resource is the *Index Nominum Genericorum (Plantarum)*. The ING is a collaborative project of the IAPT and the Smithsonian Institution and it is a compilation of generic names published for all organisms covered by the international code of Botanical Nomenclature. Also helpful is TL-2 Online, an electronic version of *Taxonomic Literature*, 2nd edition which covers plant taxonomic literature from Linneaus until 1940.

Literature and images. — *JSTOR* is a scholarly journal archive. It has made available back issues of selected journals and it has a 3–5 year moving wall. The recent issues of many journals are now available on-line and one can check out *Systematic Botany*, *Taxon*, *Brittonia*, *Systematic Biology*, *Annals of the Missouri Botanical Garden*, etc. However, there are quite a number of taxonomic journals that are not available on-line. Older literature and books are still a problem and even famous authors, like J. D. Hooker, have only a few things on-line and almost none are the large Floras or other descriptive work. One exception is the electronic version of the *Biological Centrali-Americana*, a collaborative project between the Natural History Museum, London and the Smithsonian. It brings to the screen images of animals and plants from this difficult to access publication. Eventually it will have 50,000 descriptions and 18,000 images. There are a variety of sites that individuals and societies have developed for images.

General information. — One of the most useful on-line sites botanists have is the *Index Herbariorum*, a detailed directory of more than 3,200 public herbaria of the world and the staff associated with them. The last published edition was in 1990 but the on-line version is kept up to date as the information is sent in by institutions. IH is a collaboration between the New York Botanical Garden and IAPT. Also, Rod Page has developed a species search engine called *Ispecies* that finds information (and up to five images) about any taxon.

Databases. — Just about every flora project either runs on a database or would like to. Collections around the world are trying to database their current and incoming specimens as well as their ancillary collections such as original illustrations and paintings. Perhaps the largest plant database is at *TROPICOS*. But most database projects are under-funded and many are floundering.

GIS. — The development of programs such as ARC-GIS, which is used with geo-referenced databases, is extremely useful for planning expeditions and producing maps.

On-line keys and information. — There are several programs and sites that help with keys such as *Discover Life* by John Pickering and the USDA site for *Legume Rusts* by John Farr (Farr, 2006).

Personal websites. — Many scientists have developed websites that give information on particular groups of organisms or areas such as the one on *Neotropical Blueberries* developed by Jim Luteyn at the New York Botanical Garden and the *Biological Diversity of the Guiana Shield* (T. Hollowell and V. Funk) at the Smithsonian.

On-line availability of Floras. — Many Floras are now being made available on-line. Missouri Botanical Garden has put some Floras up on a site called *E-Floras*. On this site Floras, such *Flora of China* and *Flora of North America*, have their volumes available on-line as soon as they are published. Others, such as *Flora MesoAmericana*, have each treatment posted as it is accepted. The next step, and one that has been taken by the *Flora of the Marquesas Islands*, is that the contributors actually write their treatment on-line. Once the description has been approved by the editors it is available to the public. As taxonomists move toward conducting Floras in more interactive ways we will find that the differences among checklists, Floras, biodiversity studies, conservation biology, and monographs are even less pronounced.

All the above efforts increase access and speed but they are limited by time and money, and personnel, especially the big projects such as data basing and literature scanning and of course, web and database design and maintenance. There are efforts to help with some of these costs. Groups such as GBIF, IOPI, and All Species are trying to increase access to data. One new group is LINNE (Legacy Infrastructure Network for Natural Environments; Page & al., 2005) the goal of which is "to accelerate taxonomic research and improve biological collection infrastructure so that reliable information on biological diversity is available to all branches of science and society". This organization was developed by a

series of workshops sponsored by NSF and would sponsor a network of cyber-laboratories distributed across the U.S.A. that would have electronic access to databases of specimens, scanned literature, and electronic equipment. When *taxonomists* and biological collections are linked, research will be conducted more efficiently on a regional, national, and global scale.

Future possibilities include bringing on-line images of all specimens and relevant literature along with databases of all specimens in museums. All of these innovations will save time but the taxonomist still has to look at the material and make slides, for example, in order to describe new material and ponder the results.

CONCLUSION

Floras and Faunas have an extensive history, one that has provided the scientific community with some of its fundamental concepts (e.g., evolution, biogeography, classification). The failure to see the potential for such studies as part of the answer to questions about evolution and biodiversity has left the impression that area-based studies are not important and not critical to the sciences. We increase our use of Floras, Faunas, and checklists to answer questions and we must seek additional ways to use these data such as combining them with clade-based studies to advance our understanding of evolution and diversity.

We have to change our view of Floras from static to part of a continuum that involves all of systematics and biodiversity. More than anything else we need a *unified vision* of what taxonomy, systematics, and biodiversity should be, and then we need to use available -and yet to be developed- resources to make that vision a reality. We need a way to connect all Floras, checklists, and biodiversity studies, so that one can have access to the latest information. Perhaps we should approach the taxonomy societies for assistance with developing such a *unified network* of flora and faunal sites. As taxonomists we have to work more with ongoing global efforts to interconnect and make data available.

We need to clear the Impediments to Taxonomy: increase the number of taxonomists, support the careers of people who work on area-based studies, and support efforts to increase long-term administrative support and funding for flora projects. More than anything else we need a *unified front* to push for these goals. We need to be assertive about the nature and importance of what we do (Page, 2005). The important word in all of this is "unified" and I think that symbolizes a move toward the breaking down of barriers and points toward Floras being an integral part of biodiversity studies.

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