NATURE AND HUMAN SOCIETY

The Quest for a Sustainable World

Peter H. Raven, Editor
Tania Williams, Associate Editor

Proceedings of the 1997 Forum on Biodiversity

Board on Biology
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

HAWAII BIOLOGICAL SURVEY: MUSEUM RESOURCES IN SUPPORT OF CONSERVATION

ALLEN ALLISON
Hawaii Biological Survey, Bishop Museum,
1525 Bernice Street, Honolulu, HI 96817
SCOTT E. MILLER
International Center of Insect Physiology and Ecology,
Box 30772, Nairobi, Kenya

INTRODUCTION

HAWAII—because of its geographic isolation, rich volcanic soils, and enormous topographic and climatic diversity—has produced a biota with a very high percentage of endemism among multicellular terrestrial organisms. The native biota includes about 18,000 species (Eldredge and Miller 1998) (table 1). The 8,500 terrestrial and aquatic plants and animals might have evolved from as few as 1,000 original colonists (Gagné 1988; see also Sakai, and others 1995) in the absence of many biotic influences that are present on larger land masses (such as grazing herbivores), and they have proved vulnerable to extreme population reduction and even extinction owing to introduced predators, competitors, and diseases. Although Hawaii accounts for only about 0.2% of the land area of the United States, it has 31% of the nation's endangered species and 42% of its endangered birds. Of the 1,023 species of native flowering plants 73 are down to about 20 or fewer individuals in the wild, and nine are down to one (US Fish and Wildlife Service 1999). Almost 75% of the historically documented extinctions of plants and animals in the United States have occurred in Hawaii.

About 15 years ago, as the dimensions of this extinction crisis were beginning to become clear, a wide array of state, federal, and private organizations, catalyzed by The Nature Conservancy and the Hawaii Audubon Society, redoubled their efforts to develop effective mitigative measures. More recently, a formal consortium of agencies developed the Hawaii Conservation Biology Secretariat, which has raised the profile of these important issues and helped to coordinate responses.

TABLE 1 Numbers of Species Known from Hawaii and Surrounding Waters[a]

	Total Species	Endemic Species	Alien Species	Species at Risk	Extinct Species
Algae and other protists	1,939	4	5	0	0
Fungi and Lichens	2,080	240	?	0	0
Flowering plants	2,074	908	1051	546	91
Other plants	763	241	44	0	
Mollusks	1,650	956	86	115	500?
Insects	7,998	5,245	2,589	308	
Other arthropods	2,109	324	577	2	
Other invertebrates	2,281	824	71	1	
Fish	1,197	139	73	1	0
Amphibians	5	0	5	0	0
Reptiles	27	0	23	3	0
Birds	294	63	46	39	50+
Mammals	44	1	19	2	1
Totals	22,462	8,864	4,598	1,017	642+

[a] Endemic species are restricted to Hawaii; nonindigenous alien, (includes introduced) do not naturally occur in Hawaii. Total includes endemic, alien, and indigenous (occur naturally in Hawaii but not endemic) species and species of unknown status. "Species at risk" include federally endangered, threatened, and candidate species, plus "species of concern." "Extinct" includes pre-Captain Cook extinctions.
Source: Based on Eldredge and Miller 1998.

Those efforts have been seriously hampered by lack of fundamental information. The basic taxonomy of many groups has not been fully worked out, and information on the ranges or identities of many species was until recently available only from scattered research publications or museum collections. Although a substantial amount of information has been assembled on endangered plants, vertebrates, and a few invertebrate taxa, successful efforts to manage Hawaiian ecosystems requires information about *all* species, native and alien. In fact, the greatest threat to Hawaiian organisms and to the integrity of Hawaiian ecosystems is posed by alien species. To address the information need, the Hawaii legislature in 1992 designated the Bishop Museum, which houses the world's largest natural-history collections from Hawaii (nearly 4 million specimens) as the Hawaii Biological Survey (HBS) and charged it with the task of compiling comprehensive information on the entire biota of the state (Allison and others 1995).

The Bishop Museum developed a six-stage process to implement the biological survey. Briefly, this involves, for each major group of organisms,

- developing a computerized database of the literature;
- preparing a species checklist based on the literature, collections, and consultation with experts;
- developing a database of the collections, including coding localities to facilitate geographic information system (GIS) analysis and presentation;

• developing a database of information from other collections or from other organizations that are conducting biological surveys (or establishing computer linkage to such information);
• directing research efforts to high-priority needs; and
• filling gaps in information through additional field surveys.

In practice, many of these are concurrent activities. The literature databases and species checklists developed by HBS scientists and collaborators provide a firm foundation for the computerization of specimen-based data from collections. When specimen data are computerized and incorporated into an environmental information system, one can easily determine the range of a species, document how it has changed, identify broad multispecies patterns of distribution and diversity (ecosystem characteristics), and evaluate how these features are related to various environmental factors (such as climate and soils) and have been or are likely to be affected by resource-management and land-use strategies. It is important to emphasize that specimen collections constitute the most accessible and cost-effective source of data for the development of comprehensive environmental-information systems (Allison 1991; Nielsen and West 1994). Those information systems, involving GIS and other spatial-analysis and database technology, are crucial to the efficient management of Hawaii's fragile ecosystems and are in use by all the state's natural-resource management and land-use agencies.

In its role as HBS, the museum is providing a service to the scientific and local communities as an information clearinghouse. It gathers, processes, synthesizes, and distributes to a variety of partners information related to the biological resources of Hawaii. Information from the collections is crucial to provide authority files, data points for distribution maps, additional ecological information, and a historical perspective on the biota of Hawaii. Inasmuch as completeness is necessary for functionality, HBS also plays a crucial role in centralizing and facilitating distribution of information from partner organizations. The overall strategy is to streamline the process of developing information products while continuing the development of longer-term projects and continuously improving and refining all products.

In this paper, we discuss the overall strategy of HBS and its accomplishments to date. Although our efforts arose out of an urgent need to address critical conservation issues in a relatively small geographic area, we feel that they can serve as an effective model for the role that museums can play in understanding and managing biodiversity. Our overall theme is that museum collections and associated databases are crucial information resources for understanding and managing biological diversity. With more than 400 million specimens in US museums alone, and perhaps 2 billion museum specimens worldwide (Duckworth and others 1993), the implications are enormous.

INFORMATION MANAGEMENT

The information-management strategy developed for HBS is represented schematically in figure 1. Information sources for HBS include those listed on the left

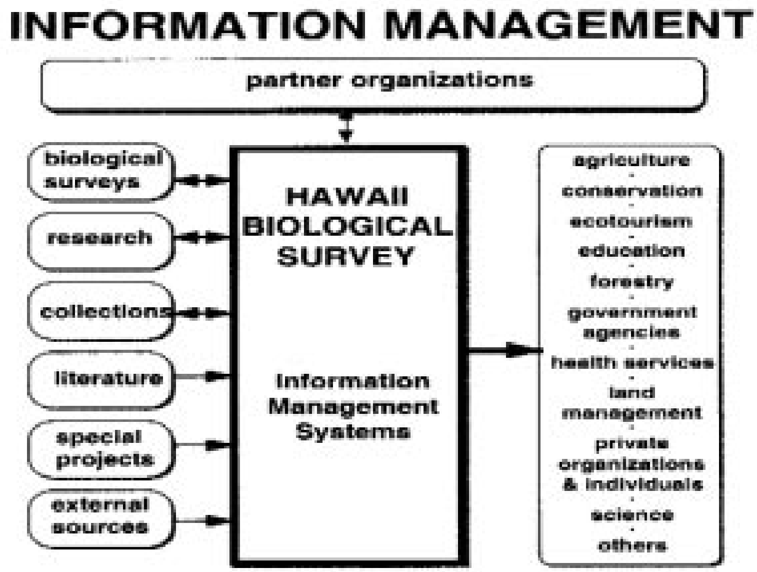

FIGURE 1 Hawaii Biological Survey obtains data from a variety of sources and processes them into information useful to diverse stakeholders.

side, including biological surveys, research projects, existing collections, existing literature, and special projects (such as syntheses undertaken with collaborators). In many cases, the flow of information is reciprocal; this is especially true for the collections, where there is constant interaction between scientists producing reports based on the collections, which result in improved quality of identifications and localization. HBS activities are undertaken in collaboration with an array of partner organizations. The collaboration in some cases is formalized at an institutional level, and an informal network of collaboration by scientific staff extends internationally, especially in systematics research. HBS information-based products are used by government, commercial, and private clients for a variety of purposes, including agriculture, conservation, education, fisheries, forestry, health services, land management, quarantine and regulatory services, and other research, as shown on the right side of figure 1.

Some of the primary partners of HBS in recent years have been state and federal natural-resource management agencies (Hawaii Department of Agriculture, Hawaii Department of Land and Natural Resources, US Department of Agriculture, and US Department of the Interior, especially the Fish and Wildlife Service and the former National Biological Survey, now part of the US Geological Survey), conservation organizations (Center for Plant Conservation, Ducks Unlimited, Hawaii Conservation Biology Forum, and The Nature Conservancy), educational organizations (Hawaii Department of Education and University of Hawaii), and other biodiversity research organizations (including Cornell University, National Tropical Botanic Garden, New York Botanic Garden, and Smithsonian Institution). Many of these organizations maintain specialized databases related to specific applications in conservation or agriculture or to specific taxonomic groups. Rather than duplicate these efforts, we seek to link with them through the development of authority files, data standards, and information models (http://www.bishop.hawaii.org/asc-cnc/).

FIVE-YEAR ACCOMPLISHMENTS

During the last 5 years, HBS has developed comprehensive bibliographies and species checklists of all major groups of plants and animals and some fungi, protists, and algae in Hawaii—terrestrial, freshwater, and marine. Hawaii is the only state in the United States other than Illinois (Post 1991) and the only large tropical area in the world in which the total number of described species is accurately known (Eldredge and Miller 1995, 1997, 1998; Miller and Eldredge 1996; http://www.bishop.hawaii.org/bishop/HBS/hispp.html).

HBS provides a venue for disseminating work of individual scientists to a variety of users. Most individual researchers do not have at their disposal the contacts, time, or technology needed to deliver their products to all potential users, especially land managers. A researcher might be the world's expert on a particular taxon that occurs in Hawaii but have neither the time nor the means to circulate research results widely within the state. HBS provides an efficient and cost-effective means of disseminating varied research products and extending the useful life of datasets beyond the funding of a particular project or the career of an individual investigator (for example, Helly and others, 1996; US National Committee for CODATA 1995; http://www.sdsc.edu/compeco_workshop/report/helly_publication.html).

The products of HBS take various forms to meet our diverse user community, as shown in figure 2. We see our primary product as information on our World Wide Web (WWW) server. The WWW server makes large amounts of information available worldwide 24 hours a day, and we can update or post information immediately at low cost. Information on the WWW should be our most recent version and should end confusion about versions of information distributed in other media or the use of outdated information that might have been gathered from our collections years ago. The "self-serve" approach also lowers our personnel costs in handling frequently asked questions. Other products beyond the WWW include information services provided directly by staff, enhancements of collections (for example, returning improved identifications of specimens), such technical publications as checklists (Cowie and others 1995; Nishida 1997) and systematic monographs (Gagné 1997), popular publications like our nascent series of user-friendly identification handbooks (Polhemus and Asquith 1996), contributions to formal and informal education, exhibits and internships, and products developed from various partnerships.

One of the products of HBS is the annual publication of a compilation of changes in our understanding of the status and distribution of the Hawaiian biota

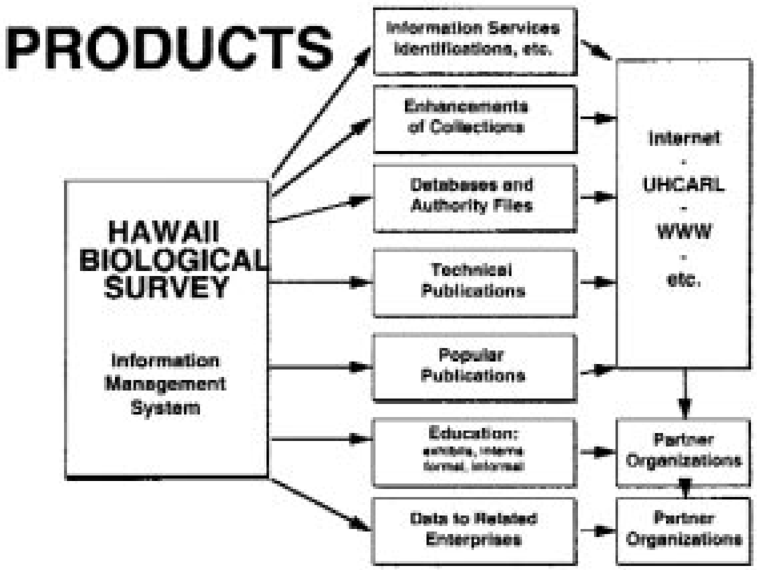

FIGURE 2 Data managed by Hawaii Biological Survey are made available to others and synthesized into various information products. Data and products are generally accessible through the World Wide Web.

titled *Records of the Hawaii Biological Survey*. *Records* is published annually in the journal *Bishop Museum Occasional Papers*. It has been especially effective at providing a publishing vehicle for short papers to document distribution or taxonomic changes that are important in the Hawaii context but might not have an appropriate venue elsewhere in the scientific literature. A number of agencies use the information from HBS to support their own products. One, the Hawaii Ecosystems at Risk project, a consortium led by the US Geological Survey Biological Resources Division, depends on *Records* as its primary source of documentation of new records of weeds and of taxonomic validation of these records.

We have largely completed the first two of the three levels of databases that provide the foundation for HBS. The first is literature databases. These focus on the taxonomic and distributional literature but include any other publications and reports that come to our attention. The second is taxonomic authority files or species checklists. These databases, compiled largely from the literature with extensive consultation with specialists, provide an index to and synthesis of what has been learned in over 100 years of biological research on Hawaii; without them, much historical information would remain unrecognized or inaccessible. The third is databases of Hawaiian specimens in the Bishop Museum's extensive collections (table 2). Progress in each category of database for each taxon depends on the level of knowledge of the taxon, the expertise available to help, funding priorities, and the curatorial condition of our collections.

DISCUSSION

Biological surveys are fundamental to the documentation of the plants and animals of the earth (Blackmore and others 1997) and are one of the major reasons for the founding of the world's great natural-history museums (Cotterill 1997; Lane 1996; Raven and others 1993). Early biological surveys were closely associated with exploration of the earth during the last three centuries and had as their purpose documentation of the general biota of scientifically unexplored areas (see, for example, Viola and Margolis 1985). As major biological features of Earth became known, museums' scientific interest shifted more toward detailed taxonomic studies of plant and animal groups. Government agencies were formed to manage natural resources, and they have conducted much of the biological survey work during the last century; for example, in 1939, the Bureau of Biological Survey, an agency in the US Department of Agriculture that developed in close association with the Smithsonian Institution, was, with the Bureau of Fisheries, transferred to the Department of the Interior and later became the Fish and Wildlife Service). With rising human populations and increasing demand for land and natural resources, public and private agencies are now facing tremendous challenges in their efforts to obtain sufficient information to manage and preserve the world's biodiversity.

With the advent of modern database technology, the information in museum collections can be made available for a wide range of uses. This has led to the development of new and strengthened partnerships between museums and resource-management agencies, for example, creation of the National Biological Survey in 1993. These partnerships have focused mostly on the need for detailed information on the distribution of plants and animals to support management

TABLE 2 Estimated Numbers of Hawaiian Collection Records (Specimens or Specimen Lots) in Bishop Museum Databases As of March 1999

Organisms	Units in Databases[a]	Total Units[a]	Percent Complete
Birds and mammals (recent)[b]	7,000	7,000	100
Fossil birds	100	10,000	1
Reptiles and amphibians	400	900	44
Fish (mostly marine)	5,000	5,000	100
Mollusks (terrestrial and marine)	68,000	140,000	49
Insects and mites	40,000	500,000	8
Other invertebrates (mostly marine)	25,000	25,000	100
Algae (mostly marine)	25,000	25,000	100
Fungi and lower plants	3,000	6,000	50
Vascular plants	45,000	145,000	31
TOTALS	218,500	863,900	25

[a] Units are specimens, except for fish, invertebrates, and mollusks, which are in lots (one or more conspecific specimens with identical data).

[b] The Bishop Museum also maintains a database of some 55,000 sighting records of Hawaiian birds.

efforts. Museums are the primary repositories of such information. For example, although the systematics of vascular plants of the United States is reasonably well known, precise distributional details on many species are not readily available, and many of the data reside in museum collections; it is therefore urgent to mobilize information from museum collections into databases and to link the databases into information systems.

The major strength of HBS is its comprehensive approach and the fact that its activities are undertaken in close partnership with management agencies. This helps to ensure that HBS products and services meet user needs. In addition, working with partners helps to ensure that collections are built in a purposeful way (see Hawksworth 1991) and have maximal utility. We have emphasized conservation applications in this paper, but biological surveys also have important applications in agriculture, medicine, and recreation (Klassen 1986; Roberts 1992).

The approach of HBS is unique in attempting to provide at least basic information on all organisms while focusing more detailed surveys or products on taxa of concern to specific users. The All Taxa Biodiversity Inventory (ATBI) approach is similar in covering all organisms (Miller 1993; Yoon 1993), but the approaches differ in that HBS synthesizes the literature first and then undertakes surveys to update data and fill gaps, whereas the ATBI emphasizes intensive surveys in smaller areas.

Although many conservation agencies are moving away from efforts to protect individual species and are instead highlighting the need to protect entire ecosystems (Kirlin and others 1994), the classification of ecosystems tends to be rather arbitrary. In a promising alternative approach that has been recently developed (Kiester and others 1996; White and others 1997), species occurrence data (presence or absence) are assembled into map layers and grouped into classes. This method, which can readily use museum-specimen data, involves a high level of objectivity and therefore has many advantages, particularly in public-policy debates, over the use of classed data, such as on vegetation. A particular strength of this approach is that it facilitates analysis and modeling of the risk to biodiversity, including individual species and populations, posed by different land-use strategies.

The scientific importance of museum collections has been well documented (Nudds and Pettitt 1997), but this value is poorly reflected in public policy. Indeed, most museums initially began computerizing their collections to gain internal management efficiency and have been slow to develop scientific products and services outside the traditional research enterprise. The systematics community has also been slow in providing authority files in readily accessible forms, although the recent production of a checklist of almost 100,000 species of North American insects shows what can be done (Poole and Gentili 1997). We agree with Lane (1996) that computerization of collections is central to an expanded role for museums in serving science and society, and nowhere is that more urgent than in the conservation of biodiversity. New organizations throughout the world—such as INBio, ERIN, and CONABIO (Anonymous 1994; Gámez 1991; Soberón and others 1996)—and long-established organizations, such as the Illinois Natural

History Survey (Anonymous 1996), have proved the importance of museum collections for understanding and managing biodiversity. The recent formation of the US Organization for Biodiversity Information (USOBI) signifies a trend to unite individual institutional efforts into a federation to achieve economies of scale and develop standards and common gateways to highly dispersed data (NRC 1993:94–5).

ACKNOWLEDGMENTS

We thank our many collaborating individuals and institutions, especially the John D. and Catherine T. MacArthur Foundation and the National Science Foundation for major funding. Gordon Nishida prepared the figures.

REFERENCES

Allison A. 1991. The role of museums and zoos in conserving biological diversity in Papua New Guinea. In: Pearl M, Beehler BM, Allison A, and Taylor M (eds), Conservation and environment in Papua New Guinea: establishing research priorities. Washington DC: The Government of Papua New Guinea and Wildlife Conservation International. p 59–63.

Allison A, Miller SE, and Nishida GM. 1995. Hawaii Biological Survey—a model for the Pacific Region. In: Maragos JE, Peterson MNA, Eldredge LG, Bardach JE, and Takeuchi HF (eds). Marine and coastal biodiversity in the tropical island Pacific region. Vol 1, p 349–55. Honolulu HI: East-West Center.

Anonymous. 1994. Collaboration with biodiversity agencies. Erinyes 20:1–8.

Anonymous. 1996. Illinois Natural History Survey Annual Report 1995–1996. Champaign IL: Illinois Natural History Survey, 55 p.

Blackmore S, Donlon N, and Watson E. 1997. Calculating the financial value of systematic biology collections. In: Nudds JR, and Pettitt CW (eds). The value and valuation of natural science collections. Proceedings of the International Conference, 1995, Manchester UK. London UK: Geological Society. p 17–21.

Cotterill FPD. 1997. The second Alexandrian tragedy and the fundamental relationship between biological collections and scientific knowledge. In Nudds, JR & Pettit, CW(eds), Proceedings of the International Conference on the Values and Valuation of Natural Science Collections. p. 227–241. Manchester: Manchester Museum.

Cowie RH, Evenhuis NL, Christensen CC. 1995. Catalog of the native land and freshwater molluscs of Hawaii. Leiden Netherlands: Backhuys Publ. 248 p.

Duckworth WD, Genoways HH, Rose CL. 1993. Preserving natural science collections: chronicle of our environmental heritage. Washington DC: National Institute for the Preservation of Cultural Property Inc. 140 p.

Eldredge LG, Miller SE. 1995. Records of the Hawaii Biological Survey for 1994. How many species are there in Hawaii? Bishop Mus Occas Pap 41:1–18.

Eldredge LG, Miller SE. 1997. Numbers of Hawaiian species: supplement 2, including a review of freshwater invertebrates. Bishop Mus Occas Pap 48:3–22.

Eldredge LG, Miller SE. 1998. Numbers of Hawaiian species: supplement 3, with notes on fossil species. Bishop Mus Occas Pap 55:3–15.

Gagné WC. 1988. Conservation priorities in Hawaiian natural systems. BioScience 38:264–71.

Gagné WC. 1997. Insular evolution, speciation, and revision of the Hawaiian genus *Nesiomiris* (Hemiptera: Miridae). Bishop Mus Bull Entomol 7: i–x, p 1–226.

Gámez R. 1991. Biodiversity conservation through facilitation of its sustainable use: Costa Rica's National Biodiversity Institute. Trends Ecol Evol 6(12):377–8.

Hawksworth DL (ed). 1991. Improving the stability of names: needs and options. Regnum Vegetabile No. 123. Königstein : Koeltz Scientific Bk.

Helly JT, Case T, Davis F, Levin S, Michener W(eds.). 1996. The state of computational ecology. San Diego CA: San Diego Supercomputer Center. 20pp. [also at http://www.sdsc.edu/compeco_workshop/report/helly_publication.html].

Kiester AR, Scott JM, Csuti B, Noss RF, Butterfield B, Sahr K, and White D. 1996. Conservation priorization using GAP data. Cons Biol 10(5):1332–42.

Kirlin JJ, Asmus P, Thompson R. 1994. Species conservation through ecosystem management. California Policy Choices 9:143–171.

Klassen W. 1986. Agricultural research: the importance of a national biological survey to food production. In: Kim KC Knutson L (eds). Foundations for a national biological survey. Lawrence KS: Assoc of Systematics Collections. p 65–76.

Lane MA. 1996. Roles of natural history collections. Ann Missouri Botan Gard 83:536–45.

Miller SE. 1993. All Taxa Biological Inventory workshop. Assoc Syst Coll News 21(4): 41, 46–7.

Miller SE, Eldredge LG. 1996. Number of Hawaiian species: supplement 1. Bishop Mus Occais Pap 45:8–17.

Mlot C. 1995. In Hawaii, taking inventory of a biological hot spot. Science 269:322–3.

NRC [National Research Council]. 1993. A biological survey for the nation. Washington DC: NatlAcad Pr. 205 p.

Nielsen ES, West JG. 1994. Biodiversity research and biological collections: transfer of information. In: Forey PL, Humphries CJ, Vane-Wright RI (eds). Systematics and conservation evaluation. Oxford UK: Clarendon Pr. p 101–21.

Nishida GM. 1997. Hawaiian terrestrial arthropod checklist. Third edition. Bishop Mus Tech Rep 12.

Nudds JR, Pettitt CW (eds). 1997. The value and valuation of natural science collections. Proceedings of the International Conference, Manchester, 1995. Manchester UK: Manchester Museum. p xii + 276.

Polhemus D, Asquith A. 1996. Hawaiian damselflies: a field identification guide. Hawaii Biol Surv Handbook. Honolulu HI: Bishop Museum Pr. 122 p.

Poole RW, Gentili P (eds). 1997. Nomina Insecta Nearctica: a check list of the insects of North America. Rockville MD: Entomological Information Services. CD-ROM. Also published as check list in four paper volumes. 1996–1997.

Post SL. 1991. Native Illinois species and related bibliography. Illinois Nat Hist Surv Bull 34:463–75.

Roberts L. 1992. Chemical prospecting: hope for vanishing ecosystems. Science 256:1142–3.

Sakai AK, Wagner WL, Ferguson DM, Herbst DR. 1995. Origins of dioecy in the Hawaiian flora. Ecology 76:2517–29.

Soberón J, Llorente J, Benítez H. 1996. An international view of national biological surveys. Ann Missouri Botan Gard 83:562–73.

US Fish and Wildlife Service. 1999. US Fish and Wildlife Service Species List, March 23, 1999. Honolulu: unpubl.

US National Committee for CODATA, Committee for Pilot Study on Database Interfaces. 1995. Finding the forest in the trees: the challenge of combining diverse environmental data: selected case studies. Washington DC: Natl Acad Pr. 129 p.

Viola HJ, Margolis C. 1985. Magnificent voyagers: the US Exploring Expedition, 1838–1842. Washington DC: Smithsonian Inst Pr. 303p.

White D, Minotti PG, Barczak MJ, Sifneos JC, Freemark KE, Santelmann MV, Steinitz CF, Kiester AR, Preston EM. 1997. Assessing risks to biodiversity from future landscape change. Cons Biol 11(2):249–360.

Yoon CK. 1993. Counting creatures great and small. Science 260:620–2.