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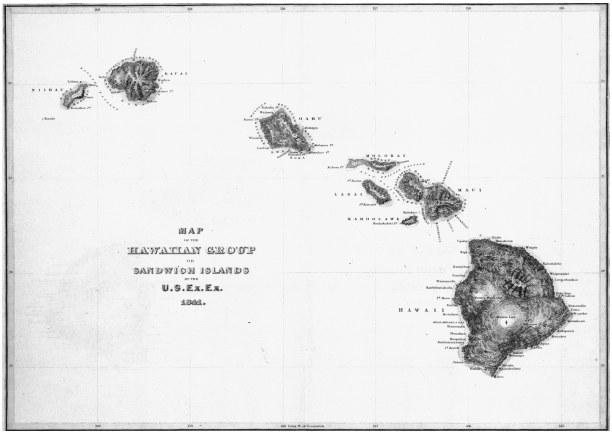
LUCIUS G. ELDREDGE AND
NEAL L. EVENHUIS



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Hawaii's Biodiversity: A Detailed Assessment of the Numbers of Species in the Hawaiian Islands

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Background

The Hawaiian Islands have long been known to harbor an extremely diverse and speciose assemblage of plants and animals found nowhere else on Earth. Its extreme isolation from continental source areas, its possession of high islands with virtually every ecosystem except arctic tundra, and its geologic youth have lured biologists from all corners of the globe to research this "living laboratory of evolution". Only in Hawai'i can one find stinkless stinkbugs, nettle-less nettles, no-eyed big eyed spiders, numerous flightless flies, and carnivorous caterpillars.

Confounding this incredible biodiversity and the numerous examples of speciose groups of plants and animals is the unfortunate moniker that Hawai'i has garnered as the extinction capital of the world. Hawai'i overwhelmingly has more species extinctions per square area of land than anywhere else on the globe. Land snails and birds have taken the biggest hits over the millenia with the loss of numerous species of the endemic O'ahu landsnail genus *Achatinella* and over two-thirds of the land birds having gone extinct. Many of the extinctions have come as a result of introductions of rats, predators, and from human intervention and urban development.

To help resource managers better manage the lands upon which they act as stewards and to assist researchers with the knowledge of the faunal and floral constituency of the islands, the Hawaii Biological Survey embarked on a study of the numbers of species that occurred in these islands. In response to the complaint that "you cannot conserve what you do not know", we scoured the published literature and databased the names of species of all the plants and animals that were reported to occur in Hawai'i. The results of those efforts was the first tabulation of the numbers of species in Hawai'i by Eldredge & Miller (1995). It provided a detailed table by kingdom, phylum, and class of the numbers of species per group that were known from the Hawaiian Islands. Each year subsequent to that study, supplements were published in the annual *Records of the Hawaii Biological Survey* summarizing in an abridged format the changes in the consituent fauna and flora of the islands (Eldredge & Miller, 1997, 1998; Miller & Eldredge, 1996; Eldredge, 1999, 2000; Eldredge & Evenhuis, 2002).

Criteria used for inclusion of tabulation of species

Only extant non-domesticated and non-cultivated taxa at the species level are included in the tabulation. Infraspecific taxa (subspecies, varieties, etc.) are only included if they are the only representative of a species in Hawai'i (e.g., when the nominate subspecies does not occur). We also do not count visitors, vagrants, and any other "non-established" pop-

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ulations (those that do not breed). For example, dozens of adventive arthropods and plants are reported each year from the Hawaiian Islands through quarantine interceptions and elsewhere, but until there is evidence of these populations having become established (natural breeding populations), they are not included in our tabulation.

Definitions

Endemic species are those that are known only from the Hawaiian Islands. The fact that a species is known only from Hawai‘i may mean that occurs elsewhere but has not been reported outside of Hawai‘i. For terrestrial species the boundaries are easily demarcated; while for marine species, the ocean environment provides a pathway for dispersal.

Indigenous species (= ***native species***) are those that naturally occur in the Hawaiian Islands but are not endemic to the islands, i.e., they also occur naturally elsewhere.

Nonindigenous species (NIS) are those species that do not naturally occur in the Hawaiian Islands and have arrived either accidentally or intentionally through biological control efforts, agricultural imports, etc. These species have also been referred to as ***alien***, ***exotic***, ***adventive***, ***naturalized***, or ***introduced*** species.

Cryptogenic species are those species that are neither demonstratively native nor nonindigenous; their origin is unknown.

For birds, ***visitors*** are considered infrequently occurring nonresident species; ***migratory*** birds follow a repeatable pattern of occurrence in the islands. Only resident breeding species were included in the tabulation of species.

Subfossil/fossil species in Hawai‘i are used in the context of birds, bats, and mollusks that have become extinct prior to European contact. True fossils in a continental sense are extremely rare (due to the geological youth of the islands) and are not included.

Extinct species are those that no longer exist in their natural habitat. It is difficult to attempt a tabulation of how many of the species originally described from the Hawaiian Islands have become extinct through natural processes or with the advent of humans and the concomitant destruction of native habitats and associated species through time. Data on known extinct vertebrates may be annotated in the notes but are not included in Table 2.

Numbers of Species in Hawai‘i

In this study, we give a detailed breakdown (Table 2) of species by higher category (phylum, class, order, suborder or, in rare cases, even to superfamily level) with virtually the same detail as our original tabulation in Eldredge & Miller (1995) and with further expanded detail in certain areas. In addition, recent similar enumerations have taken place in a few other places around the world, and we compare the faunas and floras of those areas with Hawai‘i (Table 1).

Significant changes have taken place in tabulating some of the groups in the ensuing years since the first counts were made. Primary among these changes is standardizing our counts based solely on true species and not including infra-specific taxa. This alone has resulted in some large reductions in count totals for certain groups (e.g., insects: roughly 700 infraspecific taxa were identified in our databases and removed from this tabulation). Other factors in standardization that have factored into count changes include reporting

only those species that are published in the literature. For the most part, the Table 2 records the numbers of species for each taxon based on HBS checklist database records (i.e., literature-based checklists; not specimen-based checklists). Augmenting these data are taxa not yet entered into our databases that are found in the current literature (see Table 2; under sources).

Although we rigorously scour the current literature for new records of Hawaiian plants and animals, we cannot assume that we encounter everything that has been printed (especially those records of Hawaiian taxa that are listed in various gray literature articles including contract reports and survey results). We therefore encourage all authors working on Hawaiian biota to send us all pertinent literature regarding floristic and faunistic works and taxonomic accounts that record presence of taxa in Hawai'i (or deletion of misidentified taxa) to ensure that we have a record of the biota occurring in these islands that is as accurate and up-to-date as possible.

The biota of the Hawaiian Islands is 25,615 species (Table 2). This is an increase of 1,935 over the last tabulation (Eldredge & Evenhuis, 2002) and an increase of more than 4,232 since the original compilation (Eldredge & Miller, 1995). A total of 1,175 endemic species and 639 nonindigenous species have been added to the biota since 1995. However, because of standarizing our methods of tabulation for all areas in this iteration and rechecking our totals based on a more detailed breakdown within phyla, some totals for groups of organisms have been reduced while others are much higher than previously thought (the latter previously based on best estimates of specialists in those particular fields). Nearly 40% of the total number of species are endemic and 20% are nonindigenous (these levels have not changed substantially since our original tabulation in 1995). Additionally, more than 7,000 (27%) of the total are found in the marine environment.

Other Species Surveys

The founding of the Hawaii Biological Survey in 1992 by the State of Hawaii, which mandated an inventory of all the species of plants and animals in the Hawaiian Islands, has ultimately led to the establishment of other similarly conducted biological surveys (e.g., Bermuda, Guam, Papua New Guinea) and the planning of others (e.g., Africa, Himalayas). The resulting data assembled by certain of these surveys now allows us to make comparisons across groups to show similarities or differences due to geographical origin or habitat limitations (e.g., Illinois does not have a marine component as do oceanic islands). Table 1 shows such gross comparisons of the biota of Hawai'i as compared to the Canary Islands (terrestrial biota only), Bermuda, Galápagos, and Illinois. The numbers in Table 1 for some groups may reflect more the levels of taxonomic activity (or lack thereof) rather than actual species totals in those groups (e.g., nematodes, protozoans, and small invertebrates are missed or ignored by most surveys or are not well studied taxonomically as are other groups such as flowsering plants and vertrbrates). In Illlinois, only the groups without estimates (indicated by a "~") are those in which specialists are actively working (D. Thomas, pers. comm.).

In spite of these caveats, there are still some interesting observations that can be made. For its size, Hawai'i has a significantly larger number of species of certain groups

Table 1. Comparison of Numbers of Species Between Hawai‘i and Other Areas

Taxon	Hawaii	Canary Is[1]	Bermuda[2]	Galápagos[3]	Illinois[4]
Cyanobacteria (bl-gr. algae)	201	?	65	333	112
Algae	1118	145	742		972
Other protists	1229	?	304	?	~730
Fungi (incl. lichens)	3185	2783	747	?	~20000
Flowering plants	2142	1921	987	1750	1955
Other plants	639	538	184		619
Cnidarians	457	1	250	> 47	11
Other inverts	2215	?	691	854	789
Mollusks	2163	246	936	849	274
Crustaceans	1512	131	1149	387	207
Insects	8155	6042	1218	1616	~17000
Other arthropods	1060	801	112	296	~10500
Lower chordates	76	?	99	?	0
Fish	1245	?	434	447	187
Reptiles	29	17	8	40	6
Amphibians	7	2	3	0	41
Birds	183	96	*345	58	204
Mammals	44	23	43	24	68
totals	25615	12746	8299	6701	~53700

* Includes non-breeding species; true resident population much less.
1. Terrestrial species only (data from Izquierdo et al., 2001).
2. Data from Sterrer (1998).
3. Data from James (1991) and Bensted-Smith (2002).
4. Data from Illinois Natural History Survey (1997).

per square area of land than other islands that are also geographically “remote” (isolated from continental land masses). Some striking examples include the algae, mollusks, insects, and birds. Hawaii’s land area is 16,636 square kilometers. Comparable land area from the other areas in Table 1 are Canary Is (7,242 km^2), Bermuda (54 km^2), Galápagos (45,000 km^2), and Illinois (145,934 km^2).

Algae speciation in Hawai‘i is such that there are roughly 0.67 per 10 km^2. The level of algae diversity per 10 km^2 in the Canary Is is 0.20 per 10 km^2 and the Galápagos is 0.07 per 10 km^2. The smaller numbers in the Galápagos and the Canaries are most likely due to either lack of taxonomic activity (Galápagos), or the fact that marine taxa are not listed in Table 1 (Canaries). Bermuda* has the highest diversity with 137.4 per 10 km^2.

Mollusk diversity in Hawai‘i shows possibly the most striking example of speciation among all the groups of plants and animals. There are over 1.30 species per 10 km^2 in Hawai‘i compared to 173.0 in Bermuda, and 0.18 in the Galápagos (only terrestrial mollusks are listed from the Canaries in Table 1 and thus cannot be compared). Chief among the Hawaiian mollusks are the endemic land snails in the genus *Achatinella*. They are

* Bermuda’s biota consists of 97% non-endemic species (Sterrer, 1998), thus the high biodiversity per land area figures listed here are not as much a reflection of high endemism as they are in the other areas being compared.

known only from the island of O'ahu and have had over 300 species-group names applied to them over the years. It is not known how many of these have gone extinct since their description, but because of the serious threats to their survival by predation by rats and predatory snails as well as human disturbance, 41 species in this genus are currently on the federal Endangered Species List. An additional 42 species in the endemic Hawaiian genus *Partulina* are considered Species of Concern.

Insects are by far the largest component of the Hawaiian fauna (32% of the total biota). There are numerous examples of speciose genera in hawaiian insects. Notable among these is the genus *Drosophila* (over 400 species), including some of the most striking and gigantic members of the genus in the world (some species in Hawai'i are over 5 times the size of the cosmopolitan *D. melanogaster*, commonly used in genetic research). Other speciose genera in Hawai'i include the moth genus *Hyposmocoma* (350 spp.); the predatory fly genus *Campsicnemus* (155 spp.) as well as the parasitic wasp genus *Sierola* (180 spp.) and the beetle genus *Protorhinus* (176 spp.). The diversity of insects in Hawai'i is roughly 4.90 per 10 km^2 compared to the 8.34 per 10 km^2 in the Canaries, 0.36 per 10 km^2 in the Galápagos, and 225.6 per 10 km^2 in Bermuda. Illinois has an estimated 17,000 species of insects, which calculates to 1.16 per 10 km^2.

The comparatively high numbers of species in Hawai'i is due in part to the remoteness of the islands (4,000 km from the nearest continental land mass. The Canaries are 100 km from the African continent, the Galápagos are 1,000 km from the South American continent, and Bermuda is 1,000 km from the North American continent. The remoteness of the Hawaiian Islands has resulted in a high degree of endemism and adaptive radiation to exisitng environmental conditions and resources.

Latitude, altitude, and age of the Hawaiian Islands are also chief reasons for the diversity of its biota. Lying in essentially a subtropical latitude with year-long equitable weather allows for a number of species to easily become established and to evolve after each founding event. The high islands (highest elevation 4,204 m) harbor a vast array of ecosystems (all execpt alpine tundra) and accompnying ecological niches for evolving species to fill; and the relatively young age of the islands (Hawai'i Island ca. 100,000 years old) contributes additional new niches and opportunities for newly evolving species.

In comparison, Bermuda lies at roughly 32° N latitude and exhibits more of a temperate biota than a tropical or subtropical one. Its highest elevation is only 79 m. The Canary Islands lie at 28° N latitude and compare favorably to many of the terrestrial groups found in Hawai'i. The highest elevation in the Canaries is 2426 m on Tenerife, and this lower elevation than the highest in Hawai'i has possibly contributed to a lesser amount of ecological niches for evolving species to fill or which to adapt. The Galápagos have always been the subject of biologists with respect to evolution and adaptive radiation. The highest elevation in the Galápagos is 1645 m on Isabela. The islands also lie at 1°53' S latitude, which is much more tropical than Hawai'i.

Table 2. Estimates of the Numbers of Known Species of Hawaiian Biota

Taxon	Total	Endemic	NIS	Primary Source(s)
MONERA				
Viruses (not surveyed)				
Bacteria (not surveyed)				
Cyanobacteria (blue-green algae)				
Freshwater	143	11	?	Sherwood, in press
Marine	58	0	?	HBS database (unpubl.).
PROTOCTISTA				
Algae				
Marine	578	80	19	HBS database (unpubl.);
Freshwater	540	24	?	Sherwood, in press.
Myxomycota	158	0	?	Eliasson, 1991
Acrasiomycota	10	?	?	Landolt & Wong, 1998
Oomycota (water molds)	48	1	?	Raabe et al., 1981
Plasmodiophoromycota	1	?	?	Raabe et al., 1981
Protozoa				
Foraminifera	755	?	?	Burch & Burch, 1997
Other protozoa	257	?	?	Miller & Eldredge, 1996; Eldredge & Miller, 1997
FUNGI				
Chytridiomycota	43	2	?	Raabe et al., 1981
Ascomycota				
Non-lichenized	1356	229+	5+	HBS database (unpubl.)
Lichens	856	668	5+	Elix & McCarthy, 1998
Basidiomycota				
Agaricales	267	46	1+	HBS database (unpubl.)
Uredinales (rusts)	111	15	?	Gardner, 2003
Ustilaginales (smuts)	21	4	?	Gardner, 2003
Lycoperdales	32	0	0	Smith & Ponce de Leon, 1982
Other basidios	448	7	?	HBS database (unpubl.)
Zygomycota	51+	1	?	HBS database (unpubl.)
PLANTAE				
Bryophytes				
Mosses	247	112	13	Olsen, 1999a, b
Liverworts	223	?	3	Hall et al., 1995; Yoshida & Smith, 1976
Fern Allies	17	8	3	Palmer, 2003
Ferns	145	106	11	Palmer, 2003; Kato, 2001; Wilson, 2002
Gymnosperms	7+	0	7+	Oppenheimer, 2002
Angiosperms	2142	896	1139	HBS database (unpubl.)

Table 2 (continued)

Taxon	Total	Endemic	NIS	Primary Source(s)
ANIMALIA				
Phagocytellozoa				
Placozoa	1	0	0	Pearse, 1989
Parazoa				
Porifera				
Marine	122	24	24	Eldredge & DeFelice, 2002
Freshwater	1	0	1	Svihla, 1941
Eumetazoa				
Cnidaria				
Hydroida				
Marine	85	31	37	HBS database (unpubl.)
Freshwater	2	0	2	Matthews, 1966
Siphonophora	1	1	0	Eldredge & Devaney, 1977
Chondrophora	2	0	0	Eldredge & Devaney, 1977
Scyphozoa	18	0	6	Devaney & Eldredge, 1977; Cooke, 1984; Burch & Burch, 1995; Matsumoto et al., 2002
Anthozoa				
Octocorallia	100	17	1	Grigg & Bayer, 1976; Muzik, 1978; Versevelt & Bayer, 1988; Bayer, 1990
Coralliomorpharia	2	1	1	Cutress, 1977; D. Gulko, pers.comm.
Actiniaria	28	5	2	Eldredge & DeFelice, 2002; D. Fautin, pers. comm.
Scleractinia				
Shallow water	72	17	0	J. Maragos, pers. comm.
Deep-water	54	26	0	Cairns, 1984
Zoanthidea	12	4	0	Eldredge & DeFelice, 2002
Antipatharia	16	1	0	Grigg & Opresko, 1977
Ceriantharia	1	0	0	Cutress, 1977
Ctenophora	8	0	1	Eldredge & DeFelice, 2002
Playthelminthes				
Free-living	49	24	4	Poulter, 1987; Eldredge & Miller, 1997
Parasitic	627	371+	?	Miller & Eldredge, 1996; Eldredge & Miller, 1997; Whittington et al., 2001

Table 2 (continued)

Taxon	Total	Endemic	NIS	Primary Source(s)
Nemertinea				
Marine	49	?	0	Devaney & Eldredge, 1987; Gibson, 1995; Roe & Norenburg, 1999
Freshwater/terrestrial	2	0	2	Howarth & Moore, 1983; Norenburg, 1996
Gnathostomulida	8	4	0	Sterrer, 1991
Rotifera				
Marine	3	0	0	Hope, 1987
Freshwater	171	9?	?	Jersabek, 2003; Turner, 1996
Kinorhyncha	1	0	0	Bailenson, 1997
Nematoda				
Marine (free-living)	54	23	0	Hope, 1987
Other nematodes (free-living)	242	?	?	HBS database (unpubl.)
Zooparasitic	149	0	0	HBS database (unpubl.)
Nematomorpha	2	2	0	Eldredge, 2000
Acanthocephala	5	0	5	Miller & Eldredge, 1996; Eldredge & Evenhuis, 2002
Priapulida	1	0	0	J. Bailey-Brock, pers. comm.
Mollusca				
Gastropoda				
Marine	1033	247	22	Moretzsohn & Kay, 1995; Paulay, 1996
Terrestrial	831	759	63	Cowie et al., 1995; Cowie, 1997
Freshwater	37+	7	22	Cowie, 1997; R.H. Cowie, pers. comm.
Bivalvia				
Marine	171	83	21	Moretzsohn & Kay, 1995; Paulay, 1996
Freshwater	1	0	1	Burch, 1978
Polyplacophora	4	3	0	Kay, 1979
Scaphopoda	3	0	0	Kay, 1979
Cephalopoda	77	2	0	Eldredge & DeFelice, 2002
Aplacophora	6	0	0	Kay, 1979
Annelida				
Oligochaeta				
Marine	26	11	3?	Erséus & Davis, 1989; Erséus, 1990
Terrestrial/Freshwater	20	0	20	Nakamura, 1992; Reynolds, 1999
Archiannelida	2	0	0	Bailey-Brock, 1987

Table 2 (continued)

Taxon	Total	Endemic	NIS	Primary Source(s)
Hirudinea				
Marine	3	0	3	Eldredge & DeFelice, 2002
Terrestrial/freshwater	6	0	6	Eldredge & DeFelice, 2002
Polychaeta	295	70+	?	Eldredge & DeFelice, 2002
Pogonophora	2	2	0	Southward, 1980
Echiura	6	0	0	Edmonds, 1987
Sipuncula	14	0	0	Edmonds, 1987
Arthropoda				
Insecta (non-marine)				
Blattaria	20	0	19	Nishida, 2002
Coleoptera	1951	1332	606	Nishida, 2002; HBS 01-02; Kumashiro et al., 2002; Liebherr, 2001
Collembola	168	95	71	Nishida, 2002
Dermaptera	24	9	14	Nishida, 2002
Diptera	1518	1108	396	Nishida, 2002; HBS 01-02; Kumashiro et al., 2002; O'Grady et al., 2001
Heteroptera	412	297	110	Nishida, 2002; Kumashiro et al., 2002
Homoptera	714	364	345	Nishida, 2002; Kumashiro et al., 2002
Hymenoptera	1363	643	702	Nishida, 2002; HBS 01-02; Kumashiro et al., 2002
Lepidoptera	1150	948	199	Nishida, 2002; Kumashiro et al., 2002
Neuroptera	55	45	8	Nishida, 2002
Odonata	38	27	8	Nishida, 2002
Orthoptera	294	260	31	Nishida, 2002; HBS 01-02; Kumashiro et al., 2002
Phasmatodea	1	0	1	Kumashiro et al., 2002
Phthiraptera	116	5	60	Nishida, 2002
Psocoptera	124	79	42	Nishida, 2002
Thysanoptera	155	29	126	Hill et al., 2001; Nishida, 2002; Kumashiro et al., 2002
Remaining orders	48	4	44	Nishida, 2002; HBS 01-02; Kumashiro et al., 2002
Acari				
Terrestrial	637	151	469	Nishida, 2002; Kumashiro et al., 2002
Marine	19	17	2	Nishida, 2002

Table 2 (continued)

Taxon	Total	Endemic	NIS	Primary Source(s)
Araneae	248	144	104	Nishida, 2002; Gillespie, 2002; Hormiga, 2002; Proszynski, 2001
Chilopoda	28	11	17	Nishida, 2002
Diplopoda	31	16	15	Nishida, 2002
Palpigrada	1	0	1	Nishida, 2002
Pauropoda	2	0	2	Nishida, 2002
Symphyla	1	0	1	Nishida, 2002
Pseudoscorpionida	17	15	2	Nishida, 2002
Schizomida	1	0	1	Nishida, 2002
Scorpionida	1	0	1	Nishida, 2002
Crustacea				
Branchipoda	23	0	21	Eldredge & DeFelice, 2002
Ostracoda				
Marine	37	?	?	Eldredge & DeFelice, 2002; Nishida, 2002
Freshwater	6	1	5	Nishida, 2002
Pentastomida	2	0	0	Eldredge & DeFelice, 2002
Copepoda				
Marine	191	?	3	J. Reid & A. Robertson, pers. comm.
Freshwater	10	?	?	J. Reid & A. Robertson, pers. comm.
Cirripedia	48	?	4	W. Newman, pers. comm.
Stomatopoda	20	18	1	Ahyong, 2002
Mysidacea	20	?	1	Eldredge & DeFelice, 2002
Tanaidacea	10	7	3	Eldredge & DeFelice, 2002
Isopoda				
Marine	39	?	8	Eldredge & DeFelice, 2002
Terrestrial	55	18	36	Nishida, 2002
Amphipoda				
Marine	187	?	4	Eldredge & DeFelice, 2002
Terrestrial	16	11	4	Nishida, 2002
Euphausiacea	29	?	0	Eldredge & DeFelice, 2002
Cumacea	2	0	2	Eldredge & DeFelice, 2002
Decapoda				
Penaeoidea	60	0	0	Eldredge & DeFelice, 2002
Stenopodidea	5	0	0	Eldredge & DeFelice, 2002
Caridea	212	?	1	Eldredge & DeFelice, 2002
Astacidea	1	0	1	Eldredge, 1994
Thalassinidea	16	?	1	Eldredge & DeFelice, 2002
Palinura	22	2	0	Eldredge & DeFelice, 2002
Anomura	73	?	0	Eldredge & DeFelice, 2002
Brachyura	323	?	14	Eldredge & DeFelice, 2002

Table 2 (continued)

Taxon	Total	Endemic	NIS	Primary Source(s)
Pycnogonida	15	?	1+	Eldredge & DeFelice, 2002; A. Child, pers. comm.
Tardigrada	33	4	29	Nishida, 2002; McInnes, 1994
Phoronida	5	0	0	Bailey-Brock & Emig, 2000
Bryozoa	168	?	20+	Eldredge & DeFelice, 2002; Zabin, 1999
Entoprocta	2	0	0	Eldredge & DeFelice, 2002
Brachiopoda	3	0	0	Emig, 1987
Chaetognatha	9	0	0	Eldredge & DeFelice, 2002
Echinodermata				
Crinoida	16	15	0	Eldredge & DeFelice,.2002
Asteroidea	90	53	0	C. Mah, pers. comm.
Echinoidea	84	35	0	Eldredge & DeFelice, 2002; Mooi, pers. comm.
Holothuridea	58+	19	0	Eldredge & DeFelice, 2002; G. Paulay, pers. comm.
Ophiuroidea	61	28	0	Eldredge & DeFelice, 2002; G. Hendler, pers. comm.
Hemichordata	3	1	0	Eldredge & DeFelice, 2002; Hadfield & Young, 1983
Chordata				
Cephalochordata	3	0	0	Eldredge & DeFelice, 2002
Urochordata (Tunicata)				
Thaliacea	2	0	0	Eldredge & DeFelice, 2002
Larvacea	2	0	0	Eldredge & DeFelice, 2002
Ascidiacea	70	?	?	Eldredge & DeFelice, 2002
Pisces				
Marine	1197	153	12	B. Mundy, pers. comm.
Freshwater	48	4	43	B. Mundy, pers. comm.
Amphibia	7	0	7	F. Kraus, pers. comm.
Reptilia	29	0	26	C. Kishinami, pers. comm.
Aves	183	63	55	Pyle, 2002
Mammalia				
Terrestrial	20	1	19	Tomich, 1986
Marine	24	1	0	Tomich, 1986
totals	**25615**	**9987**	**5175**	
percentages of total		**38.9**	**20.2**	

Abbreviation: HBS 01-02 = articles in the *Records of the Hawaii Biological Survey* for 2001-2002 (Evenhuis & Eldredge, 2003a,b).

Further Reading

The publications cited in the sources column of Table 2 are the primary references from which our numbers have derived and are, for the most part, very specific in their scope. However, some publications of a more general nature or those covering a broad field of interest dealing with various aspects of the Hawaiian biota that have recently appeared include a guide to Hawaii's invasive species (Staples & Cowie, 2001), a guide to the mushrooms of Hawai'i (Desjardin & Hemmes (2002), a guide to the ferns of Hawai'i (Palmer, 2003), and a general biological text on the natural history of Hawai'i (Ziegler, 2002).

NOTES ON THE TAXA

The following are explanations of the figures in Table 2 plus annotated information on the recent literature since the last tabulation of species numbers.

Viruses

Pletneva *et al*. (2001) analyzed the phylogenetic relationships of the "Norwalk-like" virus Hawaii virus (HU/NLV/GII/Hawaii virus/1971/US) with other members of the Calciviridae based on its genome.

Algae: **Cyanophyta and Chlorophyta**

Sherwood *et al.* (2003a, b) recorded 12 new records of freshwater blue-green and green algae from the Hawaiian Islands. A complete checklist of the freshwater algae known from the Hawaiian Islands based on the literature will be published in next year's *HBS Records* (Sherwood, in press).

Algae: **Rhodophyta**

Abbott & McDermid (2001) described a new species (*Dudresnaya babbittiana*) from Midway Atoll. Abbott & McDermid (2002) recorded two new red algae of the genus *Kallymenia* from Hawai'i, one (*K. thompsonii*) described as new to the islands.

Myxomycota

Previous tabulations of myxomycotes did not include the fact that Acrasiomycota were a sseparate higher category. They are now included in the table separately.

Fungi

Previous numbers of Hawaiian species of fungi were based partly on rough estimates and have been found to be extremely low for some groups. Additionally, the current classification of fungi and related groups had not been kept up-to-date. For this tabulation, we have databased all names of fungi (*sensu lato*) that have been recorded in the literature,which has resulted in a increase of roughly 1,200 names. Some of the major references consulted are annotated below. Verification of the names in our database has been partly completed and will be ongoing as we continue to enter new data from the literature. We follow the classification in Kirk *et al*. (2001).

Ko & Ko (2001) recorded a new twig blight of *mamaki* caused by the fungal

pathogen *Botryosphaeria ribis*. Rogers & Scott (2001) described a new species (*Xylaria pisonae*) from *Pisonia* leaves. A new species of Hypocreaceae (*Cylindrocladium pacificum*) was described from Hawai'i by Kang *et al*. (2001). Gilbertson *et al.* (2002) gave a list of 400 species in 160 genera of wood-rotting basidiomycetes occurring in Hawai'i, of which about 10% cause brown rots. Lachance *et al*. (2001) described 1 new species of yeast (*Metschnikowia lochheadii*) isolated from insects associated with flowers in Hawai'i and Costa Rica. Three species of Hawaiian fungi (*Ascovirgaria occulta, Jumillera hawaiiensis*, and *Lopadostoma hawaiianum*) are described by Rogers & Ju (2002). Desjardin & Hemmes (2001) described 5 new taxa of Agaricales from the Hawaiian Islands (*Volvariella bombycina* var. *ciliomarginata, Mycena papyraceae, Physalacria angustispora, Propoloma bambusarum*, and *Stropharia variicolor*). Gilbertson & Ryvarden (2002) described a new species of *Inonotus* (*I. hemmesii*) from Hawai'i. Taylor *et al*. (2001) recorded 13 new records of fungal pathogens of Proteaceae in Hawai'i, 7 of these are described as new. Crous & Rogers (2001) described 2 new fungi associated with *Eucalyptus* on Moloka'i. Gilbertson *et al*. (2001) surveyed 71 species of fungi associated with the *mamane-naio* vegetation zone on the slopes of Mauna Kea; of these, 16 are new records to Hawai'i and 9 are described as new. Gardner & Flynn (1998) described a new species of rust fungi from *Xylosma* (*Uredo maua*) on the Big Island. Hemmes & Desjardin (2002) is an identification guide to the selected mushroom fauna of Hawai'i in a popular color-publication format. The numbers of endemic and noinindigenous species have not yet been thoroughly ascertained and are undoubtedly much higher than indicated in the table.

Lichens

All known Hawaiian lichens are lichenized Ascomycota, but are often kept as a separate group. Elix & McCarthy (1998) catalogued the Pacific island lichen flora and provided a complete checklist of 841 lichens occurring in Hawai'i, of which 665 are endemic to the islands — the latter a much higher number than we had recorded previously. Coppins & Kondratyuk (1998) described one new species (*Opegrapha trassii*). Marbach (2000) reviewed the genera allied to *Buellia* worldwide and described 4 new species occurring in Hawai'i. Moon *et al*. (2001) reviewed the genus *Rimelia* in Hawai'i, described one new species (*R. albinata*), and recorded one new record for the state [*R. ramescens* (Zahlbr.)]. Kashiwadani *et al.* (2002) described 2 new species of *Ramalina*. Smith (2001) reviewed the genus *Umbilicaria* in the Hawaiian Islands. Inoue (2002) recorded 4 boreal species of *Lecidea* as new to the Hawaiian Islands. One species of *Fuscopannaria* (*F. sorediata*) described as new from Hawai'i, China, and India (Jorgensen, 2000). One species (*Staurolemma weberi* Hennsen & Jorgensen) described as new (Jorgensen & Hennson (1999).

Bryophyta

The taxonomy of *Sphagna* in Hawai'i is reviewed (Karlin, 2001). Type specimens of three coritcoid taxa are examined and discussed, clarifying the status of Hawaiian species (Nakasone, 2000). A revised checklist of Hawaiian mosses is in preparation by HBS staff members. Preliminary data indicate the level of endemicity is much lower than previously reported by Hoe (1974).

Ferns and Fern Allies

A detailed review of the pteridophytes of the Hawaiian Islands (Palmer, 2003) gives the most recent numbers of species of ferns and fern allies from the islands. Kato (2001) described a new species of Woodsiaceae (*Deparia cataracticola*). One adventive fern species listed in Wilson (2002) (*Marselia crenata*) was appended to Palmer's (2003) treatment of Hawaiian ferns but did not make it to his tabulation of total numbers of fern species in the islands.

Gymnosperms

Oppenheimer (2002) documents 7 species as fully naturalized and mentions 2 additional species that are "sparingly reproducing" on Maui. As other islands are surveyed the number of naturalized gymnosperms will likely increase

Flowering Plants

Dransfield & Marcus (2002) described a new species of palm (*Dypsis carlsmithii*)* for the species previously known locally as *Dypsis* "stumpy". *Pseudognaphalium attenuatum* (Asteraceae) newly recorded from Hawai'i (Nesom, 2001). A new *Cyrtandra* (*C. paliku*) described by Wagner *et al*. (2001). McDermid *et al.* (2002) recorded *Halophila decipiens* Ostenfeld (Hydrocharitaceae) as a new record for the state.

Protozoa

The total of 257 "other" protozoans in the table includes free-living marine, soil, and freshwater species and parasitic species (Miller & Eldredge, 1996; Eldredge & Miller, 1997).

Porifera

New record of boring sponge, *Thoosa amphiasterinia*, in the octocoral *Corallium* from Midway (Calcinai *et al*., 2001)

Platyhelminthes

Of the total listed, 41 are marine species and 8 are freshwater/terrestrial species. The acoel *Notocelis gullmarensis maculata* is raised to rank of species *N. maculata* Karling *et al*., 1972 (Kozloff, 2000).

Nemertea

The species numbers reflect an increase of 23 pelagic nemerteans, previously unreported in Hawaiian waters from an overlooked publication of Roe & Norenburg (1999).

Nematoda

The "other" nematode species include parasitic and freeliving soil, plant, and animal species based on a working, unpublished checklist database.

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* not included in sp. numbers table because it is cultivated.

Cnidaria: **Scleractinia**
Balanophyllia hawaiiensis Vaughan, 1907 is now *Balanophyllia* (*Balanopyllia*) *gigas* Moseley (Cairns, 2001).

Cnidaria: **Scyphozoa**
Third species of the cubomedusa *Carybdea* [*C. sivickisi* (Stiansy)] reported (Matsumoto, *et al*., 2002). Larval metamorphosis of Hawaiian specimens of *Mastigias papua*, *Cassiopea* spp., *Cephea cephea*, and *Phyllorhiza punctata* show identical modes of asexual reproduction (Hofmann & Crow, 2002).

Annelida: **Polychaeta**
Hawaiian stream dynamics are discussed as related to freshwater polychaetes (Benbow *et al*., 2001). *Pseudobranchiomma punctata* (Treadwell) redescribed (Nogueira & Knight-Jones, 2002). Qualitative observations of the occurrence, size ranges, and habitat of 2 species of Hawaiian freshwater polychaetes are reported (Benbow *et al*., 2001).

Acanthocephala
One acanthocephalan reported from a native passerine identified as *Aporothynchus hemignathi* in the *'akialoa* by Perkins (1903).

Mollusca: **Gastropoda**
New nudibranch described, *Thorunna kahuna* Johnson & Gosliner (Johnson & Gosliner, 2001). The spondylid species *Spondylus hawaiiensis* Dall, Bartsch & Rehder is synonymized with *S. candidus* Lamarck (Lamprell *et al*., 2001).

Mollusca: **Bivalvia**
Two freshwater clams added from an ancient, continuously cultivated taro pond complex (Burky *et al*., 2000).

Arthropoda: **Insecta**
The fourth edition of the Hawaii terrestrial arthropod checklist synthesized the published literature for Hawaiian arthropods through June 2001 and forms the basis of the tabular figures presented here. Additionally, new insect immigrants presented in Kumashiro *et al*. (2002) have added 43 taxa; and the final results of two-year monitoring at Kahului Airport on Maui (Howarth & Preston, 2002) recorded 34 new state records of insects and mites.

Arthropoda: **Insecta**: **Diptera**
Hardy *et al.* (2001) reviewed the *haleakalae* species group of *Drosophila* (Drosophilidae) in Hawaii and described 18 new species, resurrecting one species from snynonmy and newly synonymized two others. Evenhuis (2003) reviewed the Kauai species of *Campsicnemus* (Dolichopodidae) and described 18 new species. O'Grady *et al*. (2001) described new species of *Drosophila* in the *rustica* species group. Okadome (2002) recorded the introduced heleomyzid fly, *Tephrochlamys japonica*, from Haleakalā Crater on Maui.

Arthropoda: **Insecta**: **Coleoptera**
Liebherr (2001) described a new species of *Blackburnia* (Carabidae) from Moloka‘i.

Arthropoda: **Insecta**: **Heteroptera**
Polhemus (2001) described two new species of Lygaeidae from Moloka‘i and West Maui. Bremmer & Lattin (2001) recorded the anthocorid *Buchananiella continua* from the Big Island.

Arthropoda: **Insecta**: **Homoptera**
Beardsley (2002) recorded the armored scale, *Fiorinia proboscidari* (Daispididae) as a new introduction. Martin (2001) described *Paraleyrodes pseudonaranjae*, a whitefly that affects agriculture in Hawai‘i, Florida, and Hong Kong. Beardsley & Uchida (2002) recorded the first notice of the eucalyptus psyllid pest, *Blastopsylla occidentalis* on Kaua‘i and O‘ahu. Beardsley (2001) described a new species of Pseudococcidae, *Nipaecoccus paranipae*, from Hawai‘i.

Arthropoda: **Insecta**: **Hymenoptera**
Beardsley & Triapitsyn (2002) recorded the encyrtid *Anagyrus agraensis* as a new introduction. Arakaki *et al*. (2002) verified the establishment of the bee *Pithitis smaragdula* (Apidae) on O‘ahu. Beardsley & Rasplus (2001) described a new species of agaonid, *Josephiella microcarpae*, based on specimens reared from Hawai‘i, California, and the Canary Islands.

Arthropoda: **Insecta; Lepidoptera**
Robinson & Sattler (2001) reviewed the species of *Plutella* (Plutellidae) occurring in the Hawaiian Islands and described two new species.

Arthropoda: **Insecta**: **Thysanoptera**
Hill *et al.* (2001) give details on the release and establishment of the thrips, *Sericothrips staphylinus* Haliday, as a biological control agent for the pest weed, gorse, in New Zealand and Hawai‘i.

Arthropoda: **Acari**
Swift & Goff (2001) summarized sampling of mites in two protected areas on Kaua‘i, resulting in 164 species of mites.

Arthropoda: **Araneae**
Gillespie (2002) described five new species of *Tetragnatha* (from the “spiny-leg clade”) from the Hawaiian Islands. Hormiga (2002) described a new genus *Orsonwelles*, and 11 new species of fat linyphiid spiders from the Hawaiian Islands. Berry & Proszynski (2001) described a new genus (*Hakka*) of jumping spiders (Salticidae) and record one new species record in the genus [*Hakka himeshimensis* (Doenitz & Strand)] from the Big Island. a second new genus of jumping spiders (*Havaika*) ocurring in the Marquesas and Hawai‘i is described and one new species (*H. jamiesoni*) is also described (Proszynski,

2001).

Arthropoda: **Crustacea**: **Copepoda**
New calanoid copepod, *Brachycalanus flemingeri* n. sp. (Ferrari & Markhaseva, 2000).

Arthropoda: **Crustacea**: **Stomatopoda**
Hawaiian stomatopods were reviewed by Ahyong (2002), reporting a total of 20 species with one new species (*Alima maxima*) and two new island records [*Heterosquilloides insignis* (Kemp) and *Busquilla plantei* Manning].

Arthropoda: **Crustacea**: **Decapoda**
The pontoniine shrimip *Coralliocaris tridentata* of Edmondson (1946), now all referable to *Periclimenaeus quadridentatus* Rathbun (Bruce, 2002). *Psathyrocaris hawaiiensis* Rathbun is redescribed by Lin & Chan (2001). New species of crangonid shrimp, *Philocheras breviflagella* Komai described (Komai, 2001). Three Hawaiian species of Nematocarcinidae are reviewed (Burukovsky, 2001). The Indo-Pacific scyllarine lobsters were reviewed by Holthuis (2002)—*Galearctus aurora* (Holthuis) is newly combined includes *Scyllarus timidus* of Tinker (1965) not *S. timidus* Holthuis; *Chelarctus cultrifer* (Ortmann) confirmed from Hawai'i; *Eduarctus* m*odestus* (Holthuis) newly combined includes *Scyllarus martensii* of Edmondson (1946); *Biarctus vitiensi*s (Dana) newly combined includes *Scyllarides tumidus* of Colin & Arneson (1995). The hermit crab *Catapaguroides setosus* (Edmondson) is reinstated and rediagnosed and *C. hooveri* n.sp. McLaughlin & Pittman is described (McLaughlin & Pittman, 2002). New records of dromiid crabs: *Dromia wilsoni* (Fulton & Grant) and *Cryptodromiopsis plumosa* (Lewinsohn) from McLay (2001). The portunid crab *Thalamita wakensis* Edmondson has been synonymized with *Thalamita seurati* Nobili (Crosnier, 2002). New species of xanthid crab *Paramedaeus octogesimus* n. sp. Ng & Clark from Lāna`i (Ng & Clark, 2002). In a world-wide revision of the sand crab family Albuneidae, Boyko (2002) reported on *Albunea speciosa* Dana and *A. danai* Boyko, noting that *A. danai* is known only from O`ahu.

Rotifera: **Monogodonta**
A total of 144 freshwater monogodont rotifer species were collected from 81 sites on the main Hawaiian Islands (Jersabek, 2003)

Echinodermata: **Asteroidea**
Of the 90 species, 64 are found in deeper water; 50 species are endemic to deeper waters (Fisher, 1906).

Echinodermata: **Holothurioidea**:
Additional, unpublished, reports of species are known (G. Paulay, pers. comm.); of the

species reported, 24 are from deeper waters.

Echinodermata: **Crinoidea**
Sixteen species are reported; there are no shallow-water forms (Clark, 1908).

Echinodermata: **Echinoidea**
Of the 84 species, 21 are found in shallow waters (R. Mooi, pers. comm.).

Echinodermata: **Ophiuroidea**:
Of the 61 species reported, 23 are found in shallow water, 24 in deeper water (G. Hendler, pers. comm.).

Chordata: **Pisces**
A total of 1245 species are reported, including 28 species occurring at Johnston Atoll but not the Hawaiian Islands. Four species of *Eustomias* (Stomiidae) reported by Clarke (2000) and *Bassozetus zenkevitchi* Rass, recorded from a locality between Midway and Kure Atolls by Nielsen & Nerrett (2000) were not included in Eldredge & Evenhuis (2000). Clarke (2001) described 9 new *Eustomias* species and one new Hawaiian record. Three other new species were described in 2001-2002: *Antennatus linearis* n. sp. (Randall & Holcom, 2001 (Antennariidae); *Scorpaenopsis pluralis* n. sp. (Randall & Eschmeyer, 2001) (Scorpaenidae, an endemic species); *Aseraggodes holcomi* n. sp. (Randall 2002) (Soleidae). *Trimma milta* n. sp (Gobiidae) described from Society Islands with an O‘ahu record (Winterbottom, 2002). The first record of *Ophichthus bonaparti* (Kemp) (Ophichthidae) reported from Hawaiian Islands (McCosker & Randall, 2001). First records for the Hawaiian Islands for *Myripristis murdjan* (Forsskal) (Holocentridae) from Midway and Kure and *Girella leonina* (Richardson) (Girellidae) from Midway (Randall & Stender, 2002). Randall & Randall (2001) confirmed the presence of two flagtail species (Kuhliidae) from Hawaiian Islands. Randall & Greenfield (2001) confirmed the presence of two eyebar gobies in the genus *Gnatholepis* (Gobiidae). Randall & Earle (2002) revised the razorfishes (Labridae), placing species of *Xyrichty*s into *Iniistius* and placing *Novaculichthys woodi* Jenkins in *Xyrichtys* and reported a new record for the Hawaiian Islands. Three species previously thought to be widespread Pacific or Indo-Pacific taxa were redetermined to be endemic to the Hawaiian Islands: *Scorpaenopsis brevifrons* Eschmeyer & Randall (Scorpaenidae) by Randall & Eschmeyer (2001); *Apogon erythrinus* Snyder (Apogonidae) by Greenfield (2001); *Ctenochaetus strigosus* (Bennett) (Acanthuridae) by Randall & Clements (2001). The Hawaiian Islands population of deep-water pigfish (Labridae) previously identified as *Bodianus vulpinus* (Richardson) or *B. oxycephalus* (Bleeker) was determined to be an undescribed endemic species (Gomon, 2001). McCosker & Randall (2001) determined that the crocodile snake eel (Ophichthidae) *Brachysomophis henshawi* (Jordan & Snyder) is widespread in western and central Pacific; most authors have considered it be an endemic species. *Parupeneus insularis* Randall & Myers (2002) described as a new species from Oahu; this species has long been recorded in Hawaii as *P. bifasciatus* (Lacepede). The small barracuda, *Sphyraena helleri*

Jenkins, status was clarified (Senou, 2001). Parin & Belyanina (2002) established the identity of the flyingfish previously misidentified as *Hirundichthys rondeletii* (Valenciennes) as *H. gilberti* (Snyder). Two nonindigenous species were recorded in open waters in Hawai'i in 2001–2002: the palette surgeonfish *Paracanthurus hepatus* (Linnaeus) (Acanthuridae) by Randall (2001) and the emperor snapper *Lutjanus sebae* (Cuvier) (Lutjanidae) by Huynh (2001); only a single specimen of the snapper was captured and only a few of the surgeonfish were seen; the origins of these fish are unclear, but they were probably released here and are unlikely to have established reproducing populations in the state.

Chordata: **Amphibia**

The eight species previously listed must be reduced to seven, since one, *Eleutherodactylus martinicensis*, is not considered a valid determination (Kraus, pers. com.)

Chordata: **Aves**

A total of 309 full species are recorded from the Hawaiian Islands including Midway (Pyle, 2002). Endemic subspecies of a species that are also found outside of Hawai'i are not included in this count.

Chordata: **Mammalia**

Killer whales (*Orcinus orca*) were sighted west of Ni'ihau (Mobley *et al*., 2001), which marks the first confirmed sighting in Hawaiian waters since 1979.

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