Lydeard et al 2003

THE GLOBAL DECLINE OF NONMARINE MOLLUSKS

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The Global Decline of Non-marine Mollusks

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MS # 03-0094 - Version 1

Condensed Abstract

An overview of biodiversity and conservation on terrestrial and freshwater (non-marine) mollusks is provided. In addition, three specific regional case studies about the malacofauna from around the world are discussed. Recommendations are provided as to what can be done to improve the situation for mollusks and ecosystem recovery.

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Although knowledge of the interactions necessary to sustain our planetary life-support system has increased tremendously over the past two decades in such areas as ecosystem function (Chapin et al. 1997, McGrady-Steed et al. 1997, Symstad et al. 2003), global climate change (Hall and Fagre 2003) and nutrient cycling (Galloway et al. 2003, Smith et al. 2003), it remains extraordinarily incomplete. One issue compounding our inability to fully understand these systems is the tremendous human-induced loss of biodiversity. The loss and decline of many charismatic vertebrate species such as mammals and birds, and even perhaps less charming creatures like amphibians and reptiles (e.g., Wake 1998, Gibbons et al. 2000) has been documented and prominently featured in the popular media. However, many invertebrate species, which comprise nearly 99% of all animal diversity (Ponder and Lunney 1999) and typically occupy a lower, yet equally important, trophic level in the ecological pyramid of energy (Wilson, 1992), are extinct or nearly so. Proper ecosystem function and health and the well being of species occupying higher trophic levels, including *Homo sapiens,* requires conserving a large proportion of all species (e.g., Petchey and Gaston 2002). These interactions can be subtle, for example, impaired reproduction caused by the production of thinner eggshells than those normally produced by forest passerine birds (i.e., a popular group for bird enthusiasts) is associated with a decline of terrestrial gastropods, whose shells provide the calcium needed in the diet of the birds (Graveland et al. 1994). The terrestrial gastropod decline, in turn, is associated with decrease in soil calcium from the effects of acid precipitation (Graveland et al. 1994). Such ecologically complex interactions among vertebrates, invertebrates, and plants, including bottom-up, top-down, and lateral factors, often act in concert, but few studies have examined these interactions in detail (e.g., Bailey and Whitham 2003). As representatives of the Mollusc Specialist Group (MSG) Species Survival Commission (SSC) of the World Conservation Union (IUCN), the Freshwater Mollusk Conservation Society, and several regional malacological societies, including the international umbrella organization UNITAS Malacologia, we would like to spotlight the plight of what is arguably one of the most imperiled groups of animals: terrestrial and freshwater (i.e., non-marine) mollusks. First, we will provide a brief overview of non-marine molluscan diversity and conservation status and subsequently illustrate our case with specific documented examples.

Overview of non-marine diversity and conservation

Non-marine mollusks are members of the second most diverse phylum of animals and include a number of phylogenetically disparate lineages and assemblages that represent two molluscan classes--Bivalvia (clams and mussels) and Gastropoda (snails, limpets, and slugs). Global estimates of non-marine molluscan species richness, like estimates of all molluscan species vary widely. Estimates of the total number of valid described plus undescribed mollusk species range from 50,000 to 200,000 (van Bruggen 1995), although most recent estimates tend to favor the higher end of the range (e.g., Ponder 1992, Gaston and Spicer 1998, World Conservation Monitoring Centre 1992). Three major factors hinder efforts to accurately estimate the number of valid molluscan species: (1) disagreement over synonymy rates within the vast array of nominal forms described by early taxonomists using shell morphology alone, which may or may not reflect real biological taxa; (2) the vast regions of the world that remain unexplored for many undiscovered, yet to be described species and; (3) there are too few scientists doing molluscan taxonomy. Thus for a few taxonomic groups and/or geographical regions, we may have overestimated diversity due to over naming, but for most areas and groups the diversity is heavily underestimated. Despite this uncertainty and given these caveats, if we assume an estimate of 200,000 molluscan species, we suggest that there are approximately 24,000 described terrestrial molluscan species and about 7,000 valid freshwater species. Moreover, there are probably at least 11,000 and perhaps as many as 40,000 undescribed terrestrial gastropods, and at least 3,000 and perhaps as many as 10,000 undescribed freshwater mollusks (Figure 1) based on extrapolations from data of Boss (1971), Solem (1978, 1984), Van Bruggen (1995) and Gaston and Spicer (1998).

A total of 708 freshwater and 1,222 terrestrial mollusk species are listed on the IUCN Red List 2002 (amended from website 16th May 2003: http://www.redlist.org) for a total of 1,930 listed non-marine mollusks (Figure 2). The total number of non-marine mollusks on the Red List is nearly one-half the total number of all known amphibian species, over twice the number of all shark and ray species, and nearly seven times the number of turtle species. In contrast, only 41 marine mollusks are Red Listed, despite the greater diversity of marine mollusks (>120,000 valid + undescribed species), which shows that the number of listed mollusks is not simply a correlate of species richness.

Mollusks have the dubious honor of being ranked number one as the taxonomic group with the most documented extinctions. A staggering 42% (n=291) of the 693 recorded extinctions of animal species since 1500 AD are mollusks (i.e., 260 gastropods, and 31 bivalves), which is more than all terrestrial vertebrates combined (n=231) (Figure 3). Ninety-nine percent of all molluscan extinctions are of non-marine species. Although terrestrial vertebrate species extinctions are well documented, most invertebrate and particularly molluscan extinctions go unnoticed by the general public, most biologists, and many conservation agencies. Only a tiny fraction (<2%) of known molluscan species have had their conservation status properly assessed, so the state of molluscan imperilment is certainly much worse than currently documented. Given that many undescribed minute-to-small-sized tropical terrestrial gastropods occupy tropical regions, many of which are being rapidly deforested (e.g., Madagascar, Emberton 1995; Tanzania, Emberton et al. 1997; Austalia, Ponder 1997a), and that many of these taxa occupy small ranges, it is certain that the proportion of threatened species is much higher and will continue to grow.

Pacific Island Gastropods

The native land snail fauna of the Pacific islands is highly diverse and geographically structured, exhibiting extreme levels of single-island or single archipelago endemism. Given the relatively little permanent freshwater habitat on Pacific islands, the land snail fauna is much more diverse than its freshwater counterpart (Haynes 1990, Cowie 1996) and there are no native bivalves, so our focus will be on terrestrial gastropods. However, it is worth noting that there are areas where very narrow range freshwater taxa are threatened (e.g., New Caledonia, Haase and Bouchet 1998 and Lord Howe Island, Ponder 1982). The Partulidae, a family endemic to the Pacific islands, is the flagship of Pacific island invertebrate conservation (Cowie and Cook 2001, Cowie et al. 2002). Both the Partulidae and the endemic Hawaiian Achatinellinae, all of which are colorful and highly variable tree snails, have been the subjects of a number of popular articles (e.g., Hart

1978, Gould 1991). However, these two groups are only a small fraction of the vast diversity of the snails on the islands of the Pacific, which, although dominated by relatively few families, exhibit spectacular evolutionary radiation (Cowie 1996).

There is no single compilation of overall numbers of Pacific island land and freshwater snail species. A number of lists are available for various island groups, some recent, others more than 100 years old. All suffer from the problem that there are many undescribed species and many others that have been described as different species more than once. Nevertheless, it is possible to arrive at a rough estimate of diversity. Cowie et al. (1995) listed 752 native Hawaiian land snail species. Of these all but four or perhaps fewer are endemic to the archipelago. Cowie (1998a) listed 94 native land snail species in the Samoan fauna, with about two-thirds of them endemic. The Pitcairn Island group (Preece 1995, 1998) harbors about 30 species of native land snails. Peake's (1981) numbers on each of the Society Islands (French Polynesia) lead to an estimate of a total fauna of about 160 species, assuming 90 % single island endemism. The tiny island of Rapa in the Austral archipelago (French Polynesia) harbors 98 native species (Solem 1983). In the Northern Mariana Islands, Bauman (1996) recorded at least 39 native species on Rota, and Kurozumi (1994) recorded at least 16 on the islands north of Saipan. Further south, Lord Howe Island, only 14.6 km^2, has at least 85 valid endemic terrestrial species (Ponder, unpubl. data).

have been recorded

Other island groups, even those for which there are lists or compilations, remain less well known. Solem (1959) recorded about 130 species in Vanuatu, but this is a serious underestimate because some islands in the group remain poorly investigated (Cowie 1996). Other island groups are even less well known. About 110 species have been listed from New Caledonia (Franc 1957, Solem 1961), but Tillier and Clarke (1983) and Solem et al. (1984) considered the real number to be 300-400. Even the better known archipelagoes still yield many new island records when thoroughly surveyed. For instance, new island records of the generally well-documented partulid tree snails have been reported recently from Ofu (Cowie 2001a) and Olosega (Cowie et al. 2002) in

American Samoa; and the known land snail fauna of Aunu'u, also American Samoa, was recently increased from 2 to 22 species (Cowie and Rundell 2002).

It is beyond the scope of this article to attempt an accurate compilation of species numbers from the widely spread taxonomic literature. However, using the numbers above as a guide, and given the extremely high levels of endemism among oceanic Pacific island land snails, an estimate of about 4,000 native species seems reasonable. This number excludes the continental islands of New Zealand, which harbors an estimated 1,350 native species (Barker 1999), and New Guinea, which probably harbors at least 1,000 (Cowie in press).

These unique native snail faunas are disappearing rapidly (Solem 1990, Bauman 1996, Cowie 2001a, Cowie and Robinson 2003). Many species are extinct or severely threatened, and often confined to high elevation refugia. For instance, the Amastridae, an endemic Hawaiian family of more than 300 species (Cowie et al. 1995) may now be reduced to as few as ten or so species existing in tiny, highly localized, remnant populations. The Endodontidae, probably the most diverse Pacific island family (Solem 1976), appear to be completely extinct or reduced to sparse remnant populations of a few species on all the islands they formerly inhabited.

Destruction of habitat (beginning with prehistoric Polynesian colonization; e.g., Christensen and Kirch 1986, Hadfield 1986, Preece 1998) for agricultural and urban development is an important cause of this decline. Likewise, modification of habitat by the replacement of native plant species suitable for the snails with exotic plants on which the native snail species cannot survive is a problem. Alien predators (and perhaps competitors) are another major cause of decline. Rats introduced by Polynesians (*Rattus exulans*) and Europeans (*Rattus rattus*, *Rattus norvegicus*) have heavy impact on native snails (e.g., Hadfield 1986, Hadfield et al. 1993). Similarly, Solem (1976) suggested that introduced predatory ants have had a serious impact, especially on ground-dwelling species such as the Endodontidae.

A particularly important cause of the demise of the native snails has been the deliberate introduction of predatory snails, most notably *Euglandina rosea*, the so-called "cannibal snail" or "rosy-wolf snail" (Cowie 1997, 1998b), in ill-conceived attempts to control another introduced snail, the giant African snail, *Achatina fulica* (Cowie 2001b). Populations of the giant African snail have not been reduced by the carnivorous snails (Christensen 1984, Civeyrel and Simberloff 1996), but native snail populations, especially of the slow-growing and slow-reproducing Partulidae and Achatinellidae, have been devastated (Clarke et al. 1984, Hadfield and Mountain 1981, Hadfield 1986, Murray et al. 1988, Hadfield and Miller 1989, Hadfield et al. 1993, Coote et al. 1999, Coote and Loève 2003).

A more recent and very serious threat is the introduction of an exotic predatory flatworm, *Platydemus manokwari*, which was another purposeful and equally ill-informed attempt to control the giant African snail (e.g., Hopper and Smith 1992). Reports that it can control *A. fulica* remain correlative, and the individuals promoting its use as a biological control agent either consider it harmless to native snail species (incorrect) or simply appear not to care about native species (Muniappan 1987, 1990, Muniappan et al. 1986). In the Pacific islands, *P. manokwari* has been reported from Guam, the Northern Marianas, Palau and Hawaii (Eldredge 1994, 1995), and more recently from Samoa (formerly Western Samoa) (Anonymous 2000). Much of the "evidence" that these predators can control populations of *A. fulica* is based on a poor understanding of ecological principles. That the predators will *prey* on *A. fulica* is not evidence that they can *control* its populations; other factors (e.g., food) may be limiting, even to the extent that heavy predation has no effect on numbers of the extremely fecund and rapidly reproducing *A. fulica*. The aforementioned factors are leading to replacement of the highly diverse and geographically structured native Pacific island snail faunas with a relatively small number (100-200) of mostly synanthropic, disturbance-tolerant and now widespread species.

Unionoid Mussels–Silence of the Clams

The freshwater bivalve superfamily, Unionoidea, is nearly cosmopolitan, but reaches its greatest diversity in North America, particularly the southeastern United States (Bogan 1993, Lydeard and Mayden 1995, Neves et al. 1997, Neves 1999). Unionoid mussels represent an extraordinary evolutionary bivalve radiation, which possess an obligate parasitic stage on the gills or fins of a host fish or in one known case, an aquatic salamander (Bogan, 1998). However, much remains to be learned about the host species of most unionoid species (Watters 1994). The total global species richness remains uncertain, although it is thought to fall somewhere between 860 (i.e., the currently recognized number of valid species) and 4,843 (i.e., the number of available names) (see Graf and Cummings; The Mussel Project – http://clade.acnatsci.org/mussel).

Despite uncertainty regarding the exact number of unionoid species world-wide, in many countries where more thorough biotic surveys have been conducted, one thing is certain, the group is highly imperiled. A total of 200 unionoid species are Red Listed globally with five in Eurasia, five in Brazil, one in Australia and the remaining 189 species in the United States. Within the United States and Canada, 202 of the nearly 300 species are listed by the Natural Heritage Network (using a different conservation coding scheme) as either presumed extinct, possibly extinct, critically imperiled, imperiled or vulnerable (Williams et al. 1993, Master et al. 2000). Thirty-seven species are presumed or possibly extinct (Master et al. 2000) in the United States alone.

The most diverse unionoid mussel fauna ever known was located in the middle reaches of the Tennessee River in northern Alabama in an area called Muscle (*sic*) Shoals (Ortmann 1924, Garner and McGregor 2001). Sixty-nine species were reported from the area during the early twentieth century, but 32 species have not been documented since the river was dramatically altered following the construction of a series of dams by the Tennessee Valley Authority in the early 1900s. Further environmental insult came with the introduction of two exotic non-unionid species, the Eurasian zebra mussel, *Dreissena polymorpha* and the Asiatic clam, *Corbicula fluminea*. *Dreissena polymorpha,* in addition to fouling and reducing native mussel species, also foul every other available surface, having a huge economic impact on industry (US$4 billion losses each year). The other major threats are habitat loss through dredging and wetland drainage, causing local extinctions. Although the mussel fauna of Muscle Shoals has somewhat stabilized, the species community composition has been altered dramatically and now includes largely reservoir-tolerant species (Ahlstedt and McDonough 1993).

Another extraordinary radiation of unionoid mussels occurred in the Coosa watershed, which drains parts of Tennessee, Georgia, and eastern Alabama. For example, in the upper Coosa basin, the Etowah River of Georgia has lost as much as 65 percent of the 51 unionoid species historically found in the watershed (Burkhead et al. 1992, Burkhead et al. 1997). Extinction in the Coosa drainage is not limited to unionoid mussels. Of the approximately 82 freshwater gastropod species historically documented in the basin, 26 species and four entire genera (*Clappia*, *Gyrotoma*, *Amphigyra* and *Neoplanorbis*) are presumed extinct (Bogan et al., 1995). Only one or two species of the original 11 species of *Leptoxis* are extant (Lydeard et al. 1997). The primary cause of extinctions, like Muscle Shoals, can be directly attributable to the construction of reservoirs. Although the negative impacts of dams have been documented (Nilsson and Berggren 2000, Pringle et al. 2000, Rosenberg et al. 2000) and some dams have been removed to restore rivers (Hart and Poff 2002), and a call for an international preservation network of free-flowing river systems has been pronounced (Dynesius and Nilsson 1994), numerous proposals for the construction of dams of dubious value are still being considered.

In addition to impoundments, other direct assaults on stream ecosystems are affecting their aquatic faunas. These include dredging, channelization, point and non-point pollution, and sedimentation and siltation from poor agricultural, silvicultural, highway/bridge construction, inter-basin transfer schemes, and other land-use activities (e.g., Allan and Flecker 1993, Richter et al. 1997, Watters 2000).

Indications are that the decline of freshwater mollusks is probably a global phenomenon, but there is little hard data from most areas other than North America, Europe, and Australia. Other freshwater groups such as fishes (e.g., Stiassny 1996, Walsh et al. 1995, Williams et al. 1989) and crayfishes (Crandall 1996, Taylor et al. 1996) are also declining globally, thus indicating that the world's freshwaters are collectively experiencing accelerating rates of qualitative and quantitative degradation (Wetzel 1992). Few people realize that the world's rivers and lakes, which contain a tremendous amount of global biodiversity, constitute only 0.01% of the Earth's global water supply (Stiassny 1996). Further losses and degradation of freshwaters can be controlled only partially by proper economic, social and environmental/ecological valuation of freshwater. Because our knowledge of freshwater ecosystems is inadequate, we are unable to ascertain whether we have passed the point of irreversible damage with aquatic ecosystems being unable to assimilate additional contaminants (Wetzel 2001). Ecological and societal needs for freshwater should be of concern to everyone (Gleick 1993, Baron et al. 2002).

Snails of the Australian "Outback"

Up until about 1980, conventional wisdom held that the native freshwater molluscan fauna of Australia was comprised of relatively few, variable, widespread species. This so-called "wisdom" has since been emphatically overturned particularly for one notable group, the family Hydrobiidae. The Hydrobiidae is a world-wide family of caenogastropods that probably are derived from brackish-water ancestors in the middle part of the Mesozoic (Hershler and Ponder 1998). Australia is home to about 267 known hydrobiid species and 118 formally described species-group taxa, representing a 10-fold increase in recognized species since 1980.

One fascinating radiation of Australian hydrobiids is the spring-snails of the Great Artesian Basin (GAB), which is the largest artesian basin in the world (Ponder et al. 1989, 1995, Ponder and Clark 1990, Ponder 1995). Numerous freshwater springs are found in the GAB. Restricted to the arid "outback" areas, including some of the driest parts of the continent, these springs are fed by continuous seepage from the artesian basin. Hence, the water supply permanently provides a unique set of small oasis-like environments in the desert for numerous endemic fishes, crustaceans, worms, and spring-snails (Ponder 1986). Some of the animals found in the springs are unlike any others known in Australia or the world.

First reports of these snail faunas appeared as recently as the late 1970s and subsequent research (e.g., Ponder et al., 1989, 1994, 1995, 1996; Ponder and Clark 1990; Colgan and Ponder 1994, 2000) demonstrated that the springs have a relatively large fauna with 26 described species, with some springs, or small groups of spring, having one to several unique species and more species continue to be discovered. Five genera of spring snails are recognized; three of these are endemic to their respective spring groups.

Nearly all of the described artesian spring-snails are considered threatened (Ponder 1995) and have been Red Listed by IUCN; several are restricted to only a single spring or spring system. Many are not in protected areas, but are found on pastoral leases. Remarkably, snails have persisted in some springs where cattle have destroyed most of the bank vegetation. However, population numbers in these springs are vastly reduced compared with healthy springs where the snails can reach enormous densities within their tiny habitats, often only a few square meters in extent. Heavy usage of artesian water and an ever-increasing demand for water has and will continue to cause extinction of many springs, including their unique aquatic fauna (Ponder 1992, 1994, 1995, 1998; Ponder and Walker 2003). In many instances, it is only a matter of time before unprotected populations become extinguished.

An ecologically analogous situation exists in the arid, western United States, which is home to several evolutionarily independent lineages of hydrobiid gastropods. As late as 1980, the primary reference for North American freshwater snails listed about 30 western hydrobiid species (Burch and Tottenham 1980). However, subsequent biotic surveys and modern taxonomic monography has resulted in the description of more than 150 hydrobiid species-group taxa (e.g., Hershler 1994, 1998). In both Australia and the

United States, many springs have gone extinct in the recent past due to the non-sustainable extraction of artesian water. For most of these springs, no historical record of their fauna exists; however, given the endemicity in extant springs, it is likely that many extinctions have occurred.

Biodiversity Hotspots

Given the limited resources and impracticality for species-by-species conservation approaches, it has been suggested that conservation biologists identify "biodiversity hotspots", where exceptional concentrations of endemic species are found and which may be undergoing rapid extinction or decline resulting from loss or degradation of habitat, invasive species, and other human-caused mechanisms. Recently, numerous hotspots for conservation prioritization have been identified and arguments made to focus our limited resources and conservation planning on these regions (Myers et al. 2000). An assumption of the biodiversity hotspot identification approach is that all organisms track the pattern of diversity exhibited by the usual surrogate species chosen for analyses (i.e., birds, mammals, and vascular plants). Although invertebrate species represent about 99% of animal diversity (Ponder and Lunney 1999), they rarely serve as indicator species (Ponder 1992, 1994) and are even highly underrepresented in conservation research (Clark and May 2002). Justification for failure to use invertebrate indicator species has been our lack of basic biological knowledge about most invertebrate faunas around the world and is in part due to the grossly disproportionate distribution of taxonomic effort towards vertebrates and higher plants (Gaston and May 1992). Certainly many invertebrate species would be protected by default using vertebrate and vascular plant-based hotspots, but equally certain, because of the restricted range of many species, ~~some~~ many would undoubtedly be omitted (Ponder 1997a, Lawler et al. 2003). One study in the tropical rainforest biota of eastern Australia has shown that snails and insects were strong predictors of conservation priorities for vertebrates, but not vice versa (Moritz et al. 2001). Quite frankly, it is difficult to imagine how we can protect an ecosystem and its function without knowledge and understanding of its parts. Better use of the huge ~~amount of~~ data based in museum collections will greatly assist in facilitating our studies on molluscan biodiversity by assisting with inventory, the identification of hotspots and in documenting extinctions.

Non-marine Molluscan Conservation Strategies

General issues relating to molluscan conservation strategies (e.g., Kay 1995, Ponder 1995, Wells 1995, Killeen et al. 1998) and regionally oriented, non-marine malacofaunas of Australia, South Africa and the Pacific Islands (e.g., Ponder 1997, Herbert 1998, Ponder and Walker 2003, Cowie, in press) have been discussed in several specialized journals or symposium volumes. Many of the general and specific issues are applicable worldwide and are ~~as follows:~~ summarized below.

Research: Biotic surveys, and taxonomic studies remain critically important particularly in poorly inventoried areas of Central and South America and Africa, if we are to have an accurate picture of the true levels of species richness and extinction. Even supposedly better known regions warrant further investigation. For example, Thompson (2003) based, in part, on recent taxonomic studies (e.g., Thompson 2000, Mihalcik and Thompson 2002) estimates that ~~only~~ about half of the species of hydrobiid snails, and that 30-50% of the freshwater snail genus *Elimia* from the southeastern United States remain undescribed. This will, of course, require the proper training of more taxonomists, but this must be done quickly before the few remaining taxonomic experts go extinct. In addition to taxonomic studies, molecular phylogenetic and phylogeographic research is necessary to understand how genetic variation is partitioned spatially and temporally. The United States National Science Foundation offers the Biotic Surveys and Inventories Program and more recently, a special competition named Partnerships for Enhancing Expertise in Taxonomy (PEET) (Rodman and Cody 2003). Together these programs serve as a model for overcoming the molluscan taxonomic and conservation impediment.

In addition to traditional reductionist approaches employed to *describe* biodiversity, scientists need to truly broaden their research horizons to encompass the interrelationships between living things at all levels and integrate environmental research across disciplines. In addition to documenting species richness, it is extremely important to understand and eventually predict the ecological impact that the process of species extinction may play on communities and ecosystem function (e.g., Tilman et al. 1994). The director of the National Science Foundation of the United States, Dr. Rita Colwell, has developed a new program that attempts to accomplish this task referred to as *Biocomplexity* (Colwell, 2001). Indeed, current conservation approaches argue the need to focus at multiple scales that sustain the full complement of biota and their supporting natural systems (e.g., Angermeier and Karr 1994, Poiani et al. 2000).

Conservation Management: Non-marine molluscan-based hotspots need to be identified and delineated for the establishment of appropriately managed nature reserves. For example, analyses of the geographic ranges of 662 snail species (along with reef fish, lobsters, and corals) recently helped to delineate global, marine biodiversity hotspots to help prioritize conservation efforts (Roberts et al. 2002). Museums and other biological research collections should provide valuable data for conducting such studies (Mikkelsen and Bieler 2000, Ponder 1999, Ponder et al. 2001), although care must be taken to ensure that historical collection efforts accurately reflect regional and local species diversity (Bouchet et al. 2002).

Regional and/or species-specific conservation action plans should be based on the results of appropriately designed scientific studies. Furthermore, greater integration and coordination among government agencies and universities and other appropriate stake-holders ~~should be informed~~ of management plans prior to implementation should be implemented to avoid any disastrous ecological, economical or legal consequences.

Education and Outreach: It is imperative that scientists help to educate the general public, and influence politicians, business and funding agencies ~~about~~ the role different organisms, particularly the inconspicuous ones, such as non-marine mollusks play in ecosystems and the value of natural systems for maintaining and providing clean air, water and food. The current wave of excitement and buzz generated from the sequencing of the human genome and development of functional genomics and

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proteonomics has lead to the impression that virtually every gene that is linked to a human disease will be discovered soon, and a cure developed shortly thereafter. However, it is important to realize that many diseases may be environmentally linked to our production of hazardous wastes (e.g., endocrine-disruption contaminants, etc.; PCBs, etc.), so eliminating the *cause* of a disease by maintaining a healthy ecosystem should be an integral part of public health issues. Molluscan diversity is an integral component of healthy ecosystems.

Acknowledgments

Manuscript preparation was aided in part by support from the National Science Foundation (CL, ES), National Geographic Society (CL and WFP), and Smithsonian Institution (RH). Thanks to Wallace Holznagel and Patricia J. West for providing comments on the manuscript, and W. Holznagel for preparing figures 1, 2, and 3 for publication.

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Figure Legends

Figure 1. The estimated number of terrestrial and freshwater described and undescribed mollusks assuming a total of about 200,000 molluscan species..

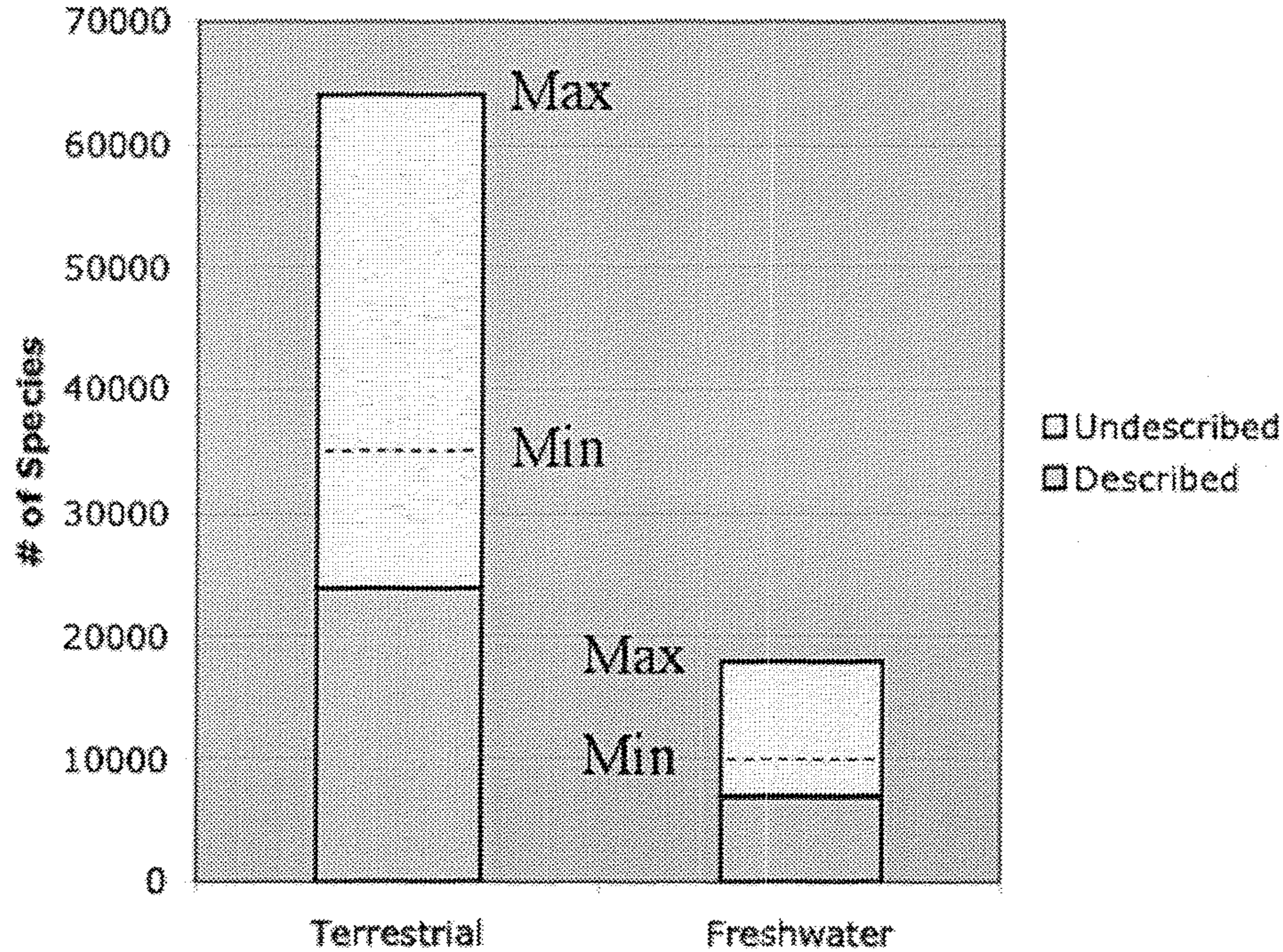
Figure 2. The total number of freshwater and terrestrial mollusks listed on the IUCN Red List 2002 (amended from http: www.redlist.org).

Figure 3. The proportion of recorded extinctions by major taxonomic groups of animals (IUCN Red Data Book 2002).

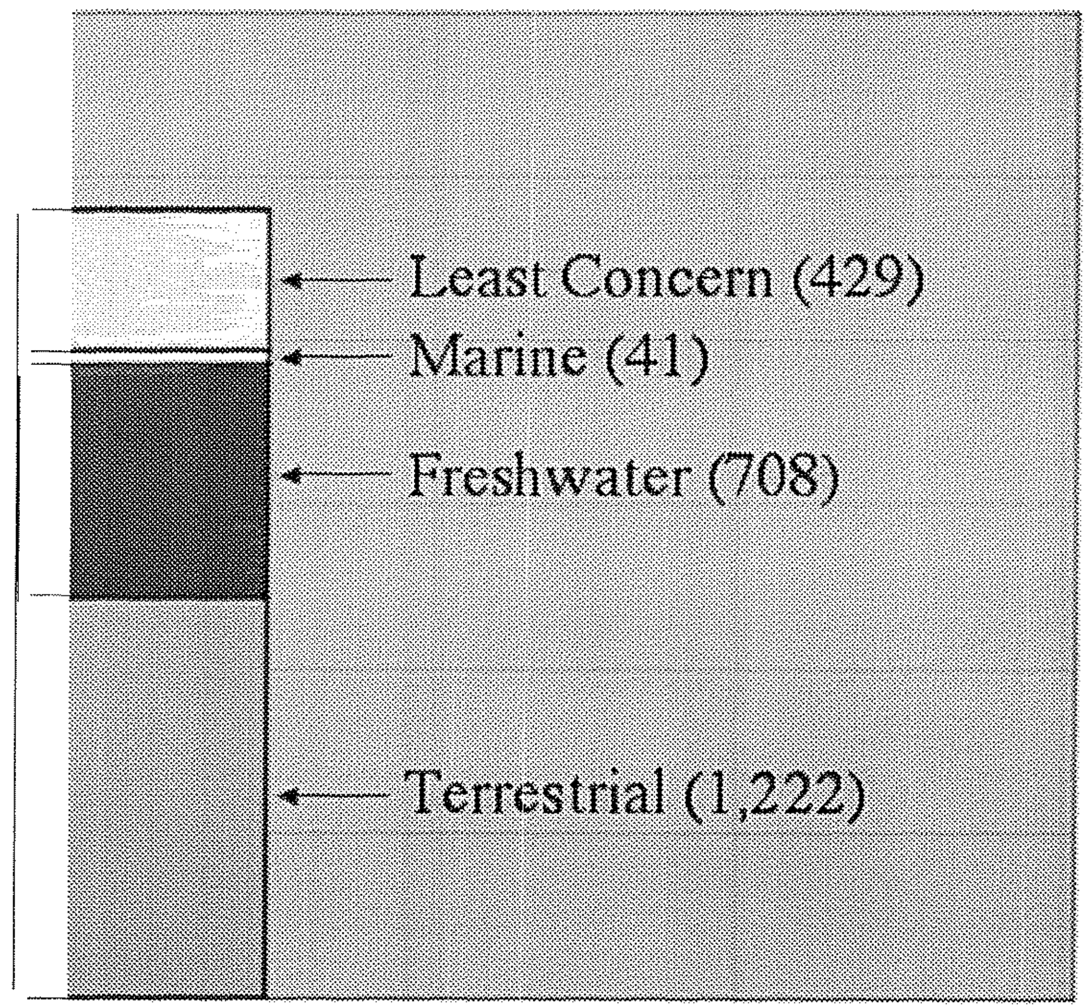
Cover: This endemic species of Partulidae from Raivavae (Austral Islands, French Polynesia) only subsists in a small remnant of native forest. Fortunately, the carnivorous Euglandina has not (yet) reached this island.

NOTE: I am currently compiling a few color photographs of living threatened mollusks to include as additional figures should the manuscript be accepted for publication.

Non-Marine Molluscan Diversity



.isted Mollusks



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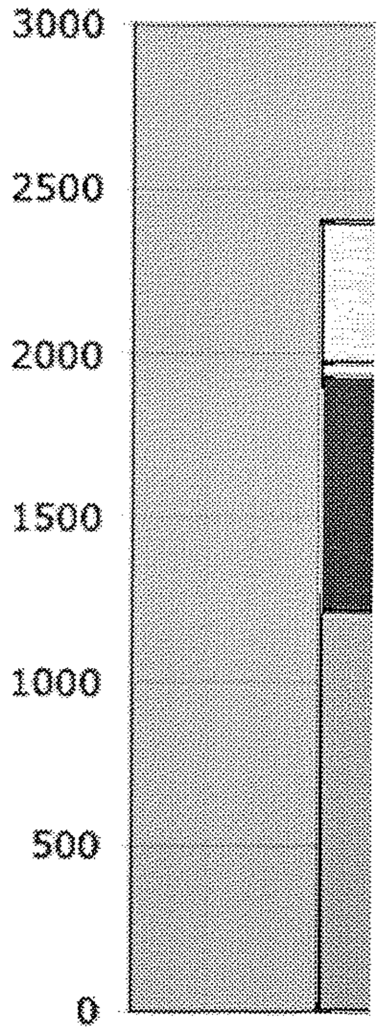
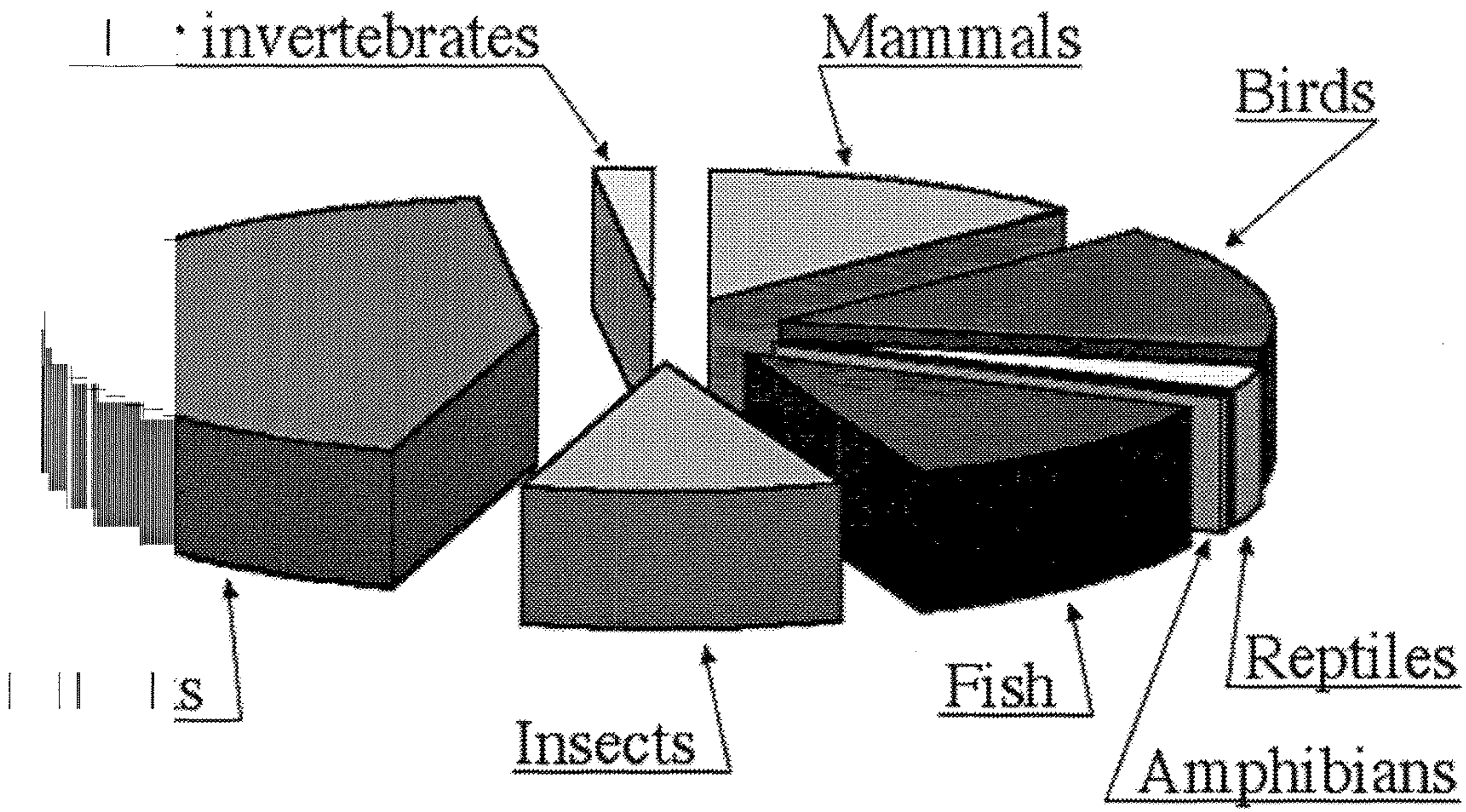


Recorded Extinctions



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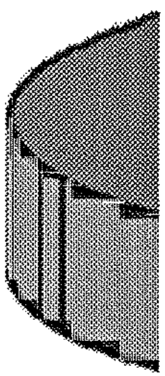

Mollusk