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Conserving Biodiversity in Vietnam: Applying Biogeography to Conservation Research

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Vietnam has recently become the focus of renewed research efforts, whose results have highlighted the country's endemic biota and intrinsic species richness. The roots of this diversity are multiple and include Southeast Asia's complex geological and climatic past, Vietnam's wide range of latitudes (23° to 8°30′N) spanning a subtropical-tropical transition zone, and the country's relatively hilly and mountainous topography. The region has attracted the interest of biogeographers since the mid-nineteenth century and a variety of biogeographic units and hypothesized distribution patterns has been derived from studies of Southeast Asia's diversity. Multitaxon surveys were undertaken in three little-studied and currently unprotected areas to aid in conservation efforts by adding to species diversity and distribution records and by examining the underlying patterns of biodiversity distribution. Results include new taxa, generic revisions, new country records, and significant range extensions. Data are consistent with some but not all of the proposed biogeographic patterns; both geographic scale and taxonomic group appeared to influence the results.

Situated along the eastern margin of the Indochinese Peninsula, Vietnam covers roughly 329,500 km^2 and is bordered to the north by China, to the west by Lao People's Democratic Republic (Laos) and Cambodia, and to the east by the South China Sea (known in Vietnam as the East Sea). Vietnam lies at a crossroad of biological diversity. A north-south orientation of more than 1650 km incorporates biotic regimes from the temperate Himalayas and the Chinese Palearctic zone in the northwest and northeast, the northern Indian zone to the west, and the tropical Malaysian zone to the south.

In the early to mid-1990s, Vietnam achieved global recognition for its unique and endemic species, generated in particular by a rush of large mammal species "discoveries" and rediscoveries emanating from the Truong Son Mountain Range (also known as the Annamite Range or Annamite Cordillera). These findings encompass six mammal species,[1] including the 85–100-kilogram saola (*Pseudoryx nghetinhensis*), an entirely new genus in the oxen family and the largest land-dwelling mammal described since 1937 (Amato et al. 1999; Pham Mong Giao et al. 1998; Pine 1994; Schaller and Vrba 1996; Surridge et al. 1999; Vu Van Dung et al. 1993). In addition to larger mammals, an impressive array of other organisms have recently been uncovered in this and other areas of Vietnam between 1992 and 2004, including over 200 taxa of vascular plants (Regalado in litt.

[1] Large-antlered muntjac (*Muntiacus vuquangensis*), Annamite muntjac (*Muntiacus truongsonensis*), Roosevelt's muntjac (*Muntiacus rooseveltorum*), saola (*Pseudoryx nghetinhensis*), Heude's pig (*Sus bucculentus*), and Annamite striped rabbit (*Nesolagus timminsi*).

2003), three birds,[2] three turtles, four snakes, 14 lizards, 31 frogs, and, since 2000 alone, 29 fish and over 500 invertebrates (Bain et al. 2003; Eames et al. 1999a; Eames et al. 1999b; Eames and Eames 2001; Zoological Record 2002).

These discoveries are coming to light now for several reasons. First, there has been a general increase in scientific research as Vietnam emerges from decades of political strife. Second, scientists — both Vietnamese and foreign — have increasingly, if sporadically, been given greater access to sensitive military buffer zones along the border with contiguous countries, where much of Vietnam's remaining naturally forested areas lie.

A third and related factor contributing to the large number of new species is the country's intrinsically high rate of species richness and endemism. Using data from the World Atlas of Biodiversity (Groombridge and Jenkins 2002) on plant, bird and mammal species richness per unit area, Vietnam ranks 25th in the world in terms of species richness. Examples of this diversity can be found across taxonomic groups. Vietnam's vascular plants have remarkable levels of species richness and endemism for such a small country, particularly in light of the taxonomic work that still needs to be done. Botanists estimate there to be around 13,000 species of vascular plants in Vietnam, 8,000 of which have been identified to date. This represents a little over 2% of the world's currently described species (Lecointre and Le Guyader 2001; Rundel 2000). Within the family Cycadaceae, Vietnam harbors 24 species of cycad, representing over 12% of the world's cycad species and subspecies (Donaldson 2003; Nguyen Tien Hiep and Phan Ke Loc 1999). Another example of elevated species richness can be found in the primate community. Twenty-seven primate taxa (19 species and eight subspecies) in the families Loridae, Cercopithecidae, and Hylobatidae live in Vietnam, seven of which are endemic to the country (Brandon-Jones et al. 2004).

Patterns of endemism in Vietnam are not well researched, but to date elevated floral endemism has been recorded in the northwest's Hoang Lien Son Range, the limestone regions of Cao Bang Province, Pu Mat and Pu Luong Nature Reserves in the northern Truong Son range, the Da Lat Plateau and adjacent montane areas of the southern Truong Son range, and the forested dunes and semi-arid slopes along the south-central coast near Nha Trang, Cam Ranh and Phan Ranh (Rundel 2000; Fig. 1). In some parts of Vietnam, such as the Fan Xi Pan massif in the northwest, the rates of vascular plant endemism rise to 40% (Nguyen Nghia Thin and Harder 1996). Faunal endemism in Vietnam is the highest in Indochina (Vietnam, Laos, Camboidia) (MacKinnon 1997). This may be due in part to a sampling artifact: Vietnam is currently better known than the other countries.

Historical and Current Conditions

Vietnam's wealth of biological diversity stems from its complex geology and climate and its geographic location. The dynamic nature of these conditions both now and in the past has strongly influenced the biological richness of the country. Geologically, Southeast Asia is one of the world's most complex regions, at the interface of three converging continental plates: Eurasia, Indo-Australia and the Philippine Sea plates (Hall 1998). Vietnam itself comprises a collage of continental fragments that broke off sequentially from the "supercontinent" Gondwanaland 400–200 million years ago and migrated north to fuse at higher latitudes (Metcalfe 2001). Due to this complex geological history, Vietnam's mountains are composites of marine sediments, rocks of metamorphic and volcanic origin, and ancient uplifted basement formations (Fontaine and Workman 1978; Hutchinson 1989).

[2] Black-crowned barwing (*Actinodura sondangorum*), golden-winged laughingthrush (*Garrulax ngoclinhensis*), and chestnut-eared laughingthrush (*Garrulax konkakinhensis*).

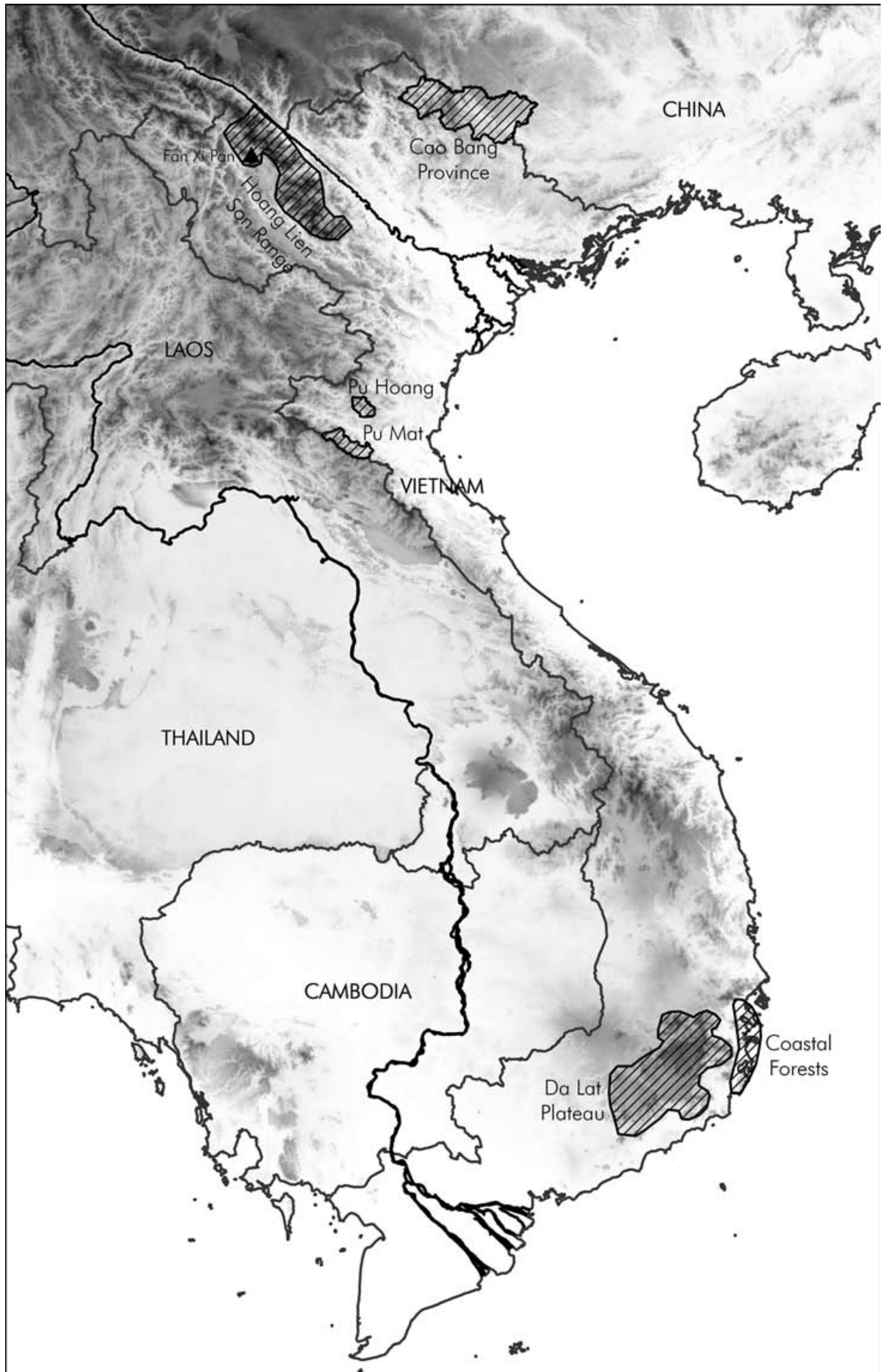


FIGURE 1. Areas of Vietnam (shaded) with high recorded floral endemism. All boundaries are approximations.

A more recent geologic event, the India-Eurasia collision about 50 million years ago, had profound impacts on Southeast Asia's evolutionary history, introducing new groups of organisms, creating dispersal barriers and modifying the climate (Hall 1998; Morley 2000). The rising of the Himalayas over the last 20 million years effectively cut off the exchange of species between the Palearctic and Indo-Malayan realms. This barrier, reinforced by increased climatic cooling after the Miocene, isolated Indo-Malaya and created conditions for species divergence (Jablonski 1993; Macey, et al. 1998). Additionally, the rise of the Tibetan Plateau as a result of this impact shifted rainfall, winds and other climatic patterns in East and Southeast Asia to become more monsoonal and strongly seasonal, increasing habitat diversity (An 2000; Clift et al. 2002).

Long-term oscillations in climatic conditions seem to have greatly affected distribution and dispersal of species in Southeast Asia. Starting in the Tertiary, global cooling events led to falling sea levels and an increase in the amount of exposed land area (Bennett 1997; Hewitt 2000). Unlike large land masses, such as South America, where sea levels 70 or 100 m below present levels had little effect, the smaller land areas and island archipelagos of Southeast Asia lie on the shallow Sunda Continental Shelf and their connectivity is strongly affected by sea level fluctuations (Heaney 1991). At 75 m below present level, the submerged shelf formed a bridge that likely served as a corridor between mainland Southeast Asia and the Sunda Islands, including Sumatra, Java, and Borneo (Voris 2000; Fig. 2).

Increased land area, coupled with a reduced South China Sea, led to decreasing moisture content of monsoon winds, resulting in cooler, drier conditions (An 2000; Zhou et al. 1996). Montane forest vegetation descended to lower levels, supplanting lowland evergreen rainforest forms, and grassland biomes replaced rainforests in more seasonal areas. During interglacial periods, the climate became warmer, wetter and less seasonal, and evergreen rainforest habitats expanded to retake higher elevations and latitudes; sea levels also rose to cover continental shelves, cutting off the land bridges (Kershaw et al. 2001; Morley 2000). These changes allowed populations in Southeast Asia to go through cycles of divergence and re-colonization, contributing to the high levels of species richness and endemism that now characterize the realm (MacKinnon 1997).

Contemporary seasonal climate fluctuations also shape Vietnam's biodiversity. Seasonality increases as one moves from south to north, away from Southeast Asia's perhumid core centered on Borneo, Sumatra, and the tip of Peninsular Malaysia. The dominant climatic feature is the monsoon circulation pattern, which directly influences the seasonality of rainfall. In the winter, strong north-east monsoon winds are produced as air flows from cold high pressure areas in Asia along the eastern edge of the Tibetan Plateau towards a hot low pressure zone over Australia, bringing dry winds to some of Vietnam. In the summer, southwestern monsoon winds flow from high-pressure areas over Australia and the Indian Ocean towards the interior of China, releasing water picked up over the seas as summer rains (An 2000).

These dynamic circulation patterns interact with regional land and ocean configurations, exposing Vietnam to a wide variety of rainfall regimes. Vietnam's hilly and mountainous topography influences the distribution of species and biotic communities by mediating temperature and humidity both locally at different altitudes and at a landscape level via rain shadow effects. Vietnam's elongated shape covers 14 degrees of latitude north to south, encompassing a wide range of climates and topographic relief overlying a variety of rocks and soils. The combination of local microclimates and the soil and substrate complexity has, in turn, shaped vegetative communities (Rundel 2000). Vietnam's major topographic feature, the Truong Son Range, runs roughly north to south along the Vietnam-Laos border and into south-central Vietnam. It forms an important barrier between the moist uplands of Vietnam and the drier monsoon forests of Laos and Cambodia and traverses the transition zone between the subtropical northern and the tropical southern climates.

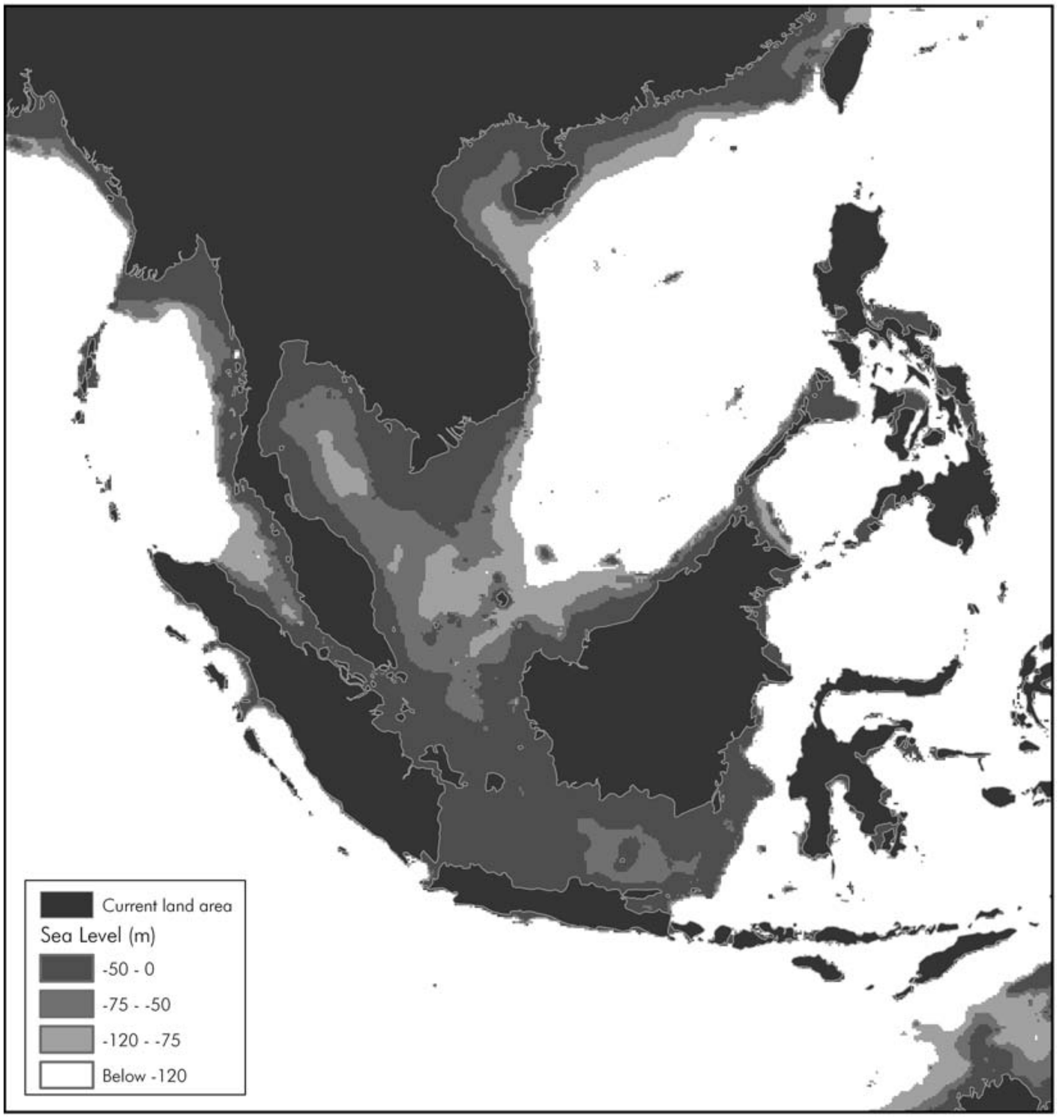


FIGURE 2. Map of Southeast Asia illustrating depth contours at 50, 75 and 120 m below current sea level. After Voris (2000). Reproduced with permission of the Field Museum of Natural History.

Broad biogeographic patterns reflecting these varied conditions have been identified and are frequently referenced when describing Vietnam's biodiversity (e.g., Eames et al. 2001; Hill 2000; Nguyen Nghia Thin and Harder 1996). Vidal (1960), Udvardy (1975), and MacKinnon (1997) have each defined biogeographic units within the Indochinese subdivision of the Indo-Malayan biogeographical realm. The most recent and detailed of these works places Vietnam at the convergence of four bio-units: Indochina (northwest and north-central Vietnam), South China (the northeast), Annamese Mountains (two regions in the central and southern Truong Son), and Coastal Indochina (the majority of central and southern Vietnam) (Fig. 3). Evolutionary and ecological evidence for these units is still being gathered. What evidence is there to date supporting these divisions and the

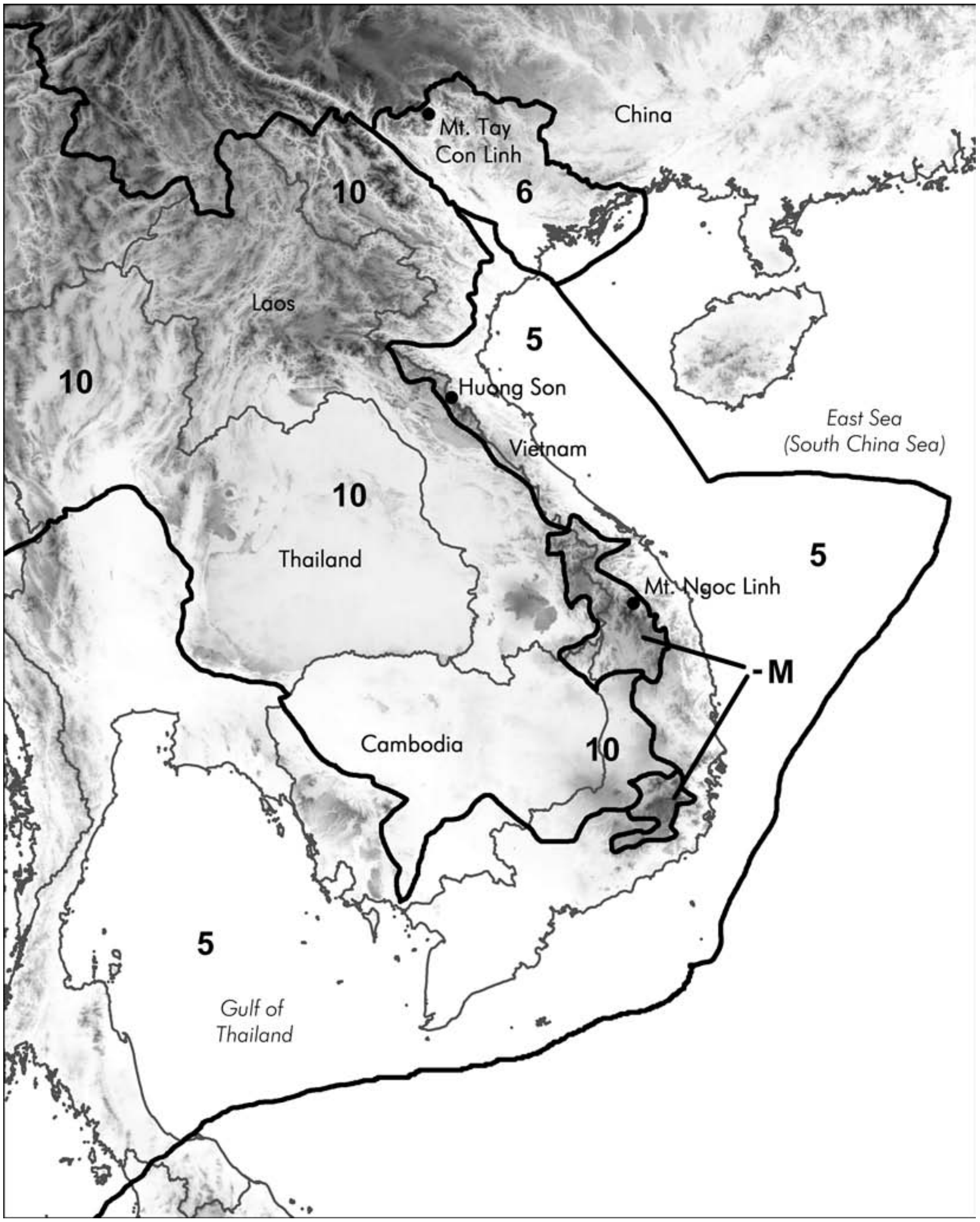


FIGURE 3. Map illustrating Vietnam's major bio-units (after MacKinnon 1997) and primary multi-taxon survey sites. The biogeographic units are: Coastal Indochina (Unit 5), Southern China (Unit 6), Indochina (Unit 10) and the Annamese Mountains (Unit -M). Study site localities were: Mt. Tay Con Linh, Cao Bo Commune, Vi Xuyen District, Ha Giang Province (22°46′N, 104°52′E; surveyed 2000 and 2001); Rao An, Huong Son District, Ha Tinh Province (18°22′N, 105°13′E; surveyed 1998 and 1999); and Mt. Ngoc Linh, Tra My District, Quang Nam Province (15°11′N, 108°02′E; surveyed 1999).

specific roles of the region's geological and climatic history in shaping its biodiversity?

One supporting example comes from recent research in Vietnam and Laos. The ranges of the recently described Annamite striped rabbit (*Nesolagus timminsi*) and the newly rediscovered Heude's pig (*Sus bucculentus*) are both currently restricted to small areas of the northern Truong Son range bordering Laos and Vietnam. Their likely closest relatives, the Sumatran striped rabbit (*Nesolagus netscheri*) and the Javan warty pig (*Sus verrucosus*), respectively, live approximately 2500 km to the south, on the islands for which they are named (Groves et al. 1997; Surridge et al. 1999; Fig. 4). Genetic data suggest that the two rabbit species have been diverging for approximately eight million years (Surridge, et al. 1999). A similar pattern is seen in the distribution of Lovi's reed snake (*Calamaria lovii*) whose four subspecies are distributed allopatrically, one each in Vietnam's central Truong Son, Peninsular Malaysia, Java and Borneo (Darevsky and Orlov 1992). These may represent relict populations of formerly widespread ancestral species once connected by the emergent Sunda Shelf and isolated when seas rose and fell and forests expanded and contracted.

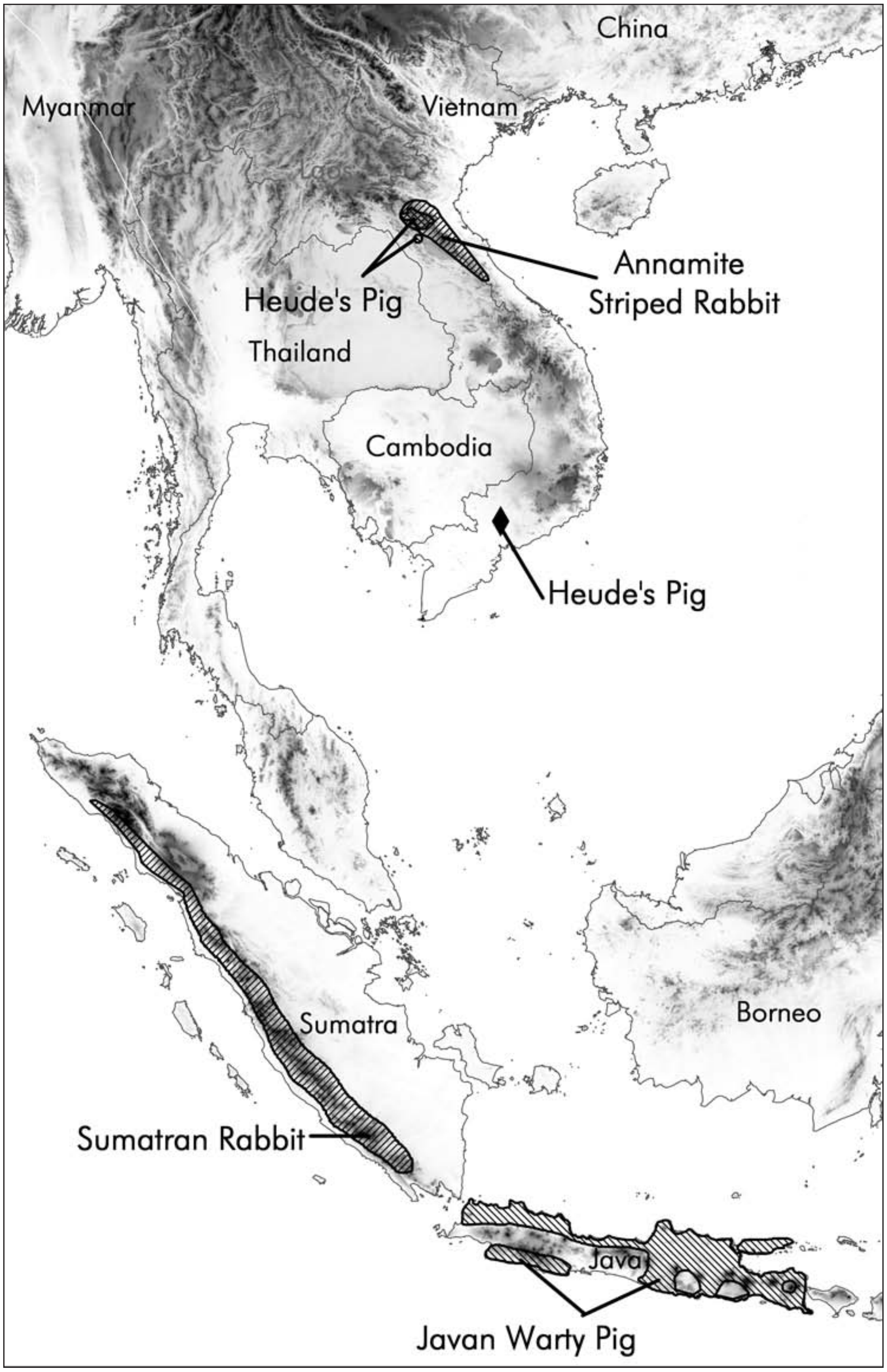
Within Indochina there is also a tentative suggestion that ancient climate fluctuations have influenced Vietnam's species diversity. Analyses of overlapping species distribution patterns in mainland Southeast Asia for a number of different taxonomic groups have led scientists to suggest that the Truong Son range served as a refugium for forest-dwelling species during cooler, drier times (Brandon-Jones 1996; Groves and Schaller 2000; Rabinowitz 1997; Surridge et al. 1999; Timmins and Trinh Viet Cuong 2001; but see Gathorne-Hardy, et al. 2002 for an alternative list of refugia). The refugium theory was first put forth to explain patterns of species richness in South America (Haffer 1969). In its initial formulation, the theory infers that observed diversity patterns stem from cycles of rainforest habitat contraction (forming refugia) and expansion that repeatedly isolate populations and lead to speciation events. Some scientists have challenged and revised this theory, suggesting instead that long-term climatic stability in refugia leads to high species diversity by facilitating both the evolution of recent 'neo-'endemics and the persistence of older "paleo"-endemics (Colinvaux et al. 2000; Fjeldså et al. 1999; Fjeldså and Lovett 1997). The two theories are not mutually exclusive.

The Kon Tum and Da Lat Plateaus of the Truong Son Range are both recognized as areas of high bird endemism, and the range is the home to three large mammal species considered relatively "primitive" members of their respective lineages (saola, Heude's pig, and the Annamite striped rabbit) (Flux 1990; Groves et al. 1997; Hassanin and Douzery 1999; Stattersfield et al. 1998; Tordoff et al. 2000). Elucidation of potential refugia in mainland Southeast Asia lies in future phylogenetic analyses of potentially informative taxa.

Current Conservation Efforts

Clearly, extensive research remains to be done on Vietnam's biodiversity and biogeography. This research has both theoretical and practical implications. Vietnam faces considerable challenges in attempting to conserve its rich and endemic biodiversity. Species distributions remain poorly known (as evidenced by the high number of rediscoveries), population data are lacking for almost all organisms, and ecosystem-level interactions are practically unknown. Vietnam harbors

FIGURE 4 (right). Map illustrating the historical ranges of the Sumatran rabbit (*Nesolagus netscheri*) and the Javan warty pig (*Sus verrucosus*) and the current known distributions of the Annamite striped rabbit (*Nesolagus timminsi*) and Heude's pig (*Sus bucculentus*). The two specimens on which the initial description of Heude's pig was based originated in southern Vietnam; it is unclear if these were collection localities or points of purchase. All ranges are approximations. Data from Dang N. Can, et al. (2001); Flux (1990); Groves and Schaller (2000); and Oliver (1993).


China
Myanmar
Vietnam
Laos
Annamite
Striped Rabbit
Heude's Pig
Thailand
Cambodia
Heude's Pig
Sumatra
Borneo
Sumatran Rabbit
Java
Javan Warty Pig

five of the world's 25 most endangered primates, four of which are endemic to the country and one, the grey-shanked douc (*Pygathrix nemaeus cinerea*), only described in 1997 (Conservation International 2002; Nadler 1997). Vietnam's rich biodiversity currently exists in a precarious and fragile state, and there are realistic fears that some of it will be lost before it is identified (Vo Quy and Le Thac Can 1994). Our understanding of Vietnam's diversity is burgeoning just as its species and ecosystems are facing increasing pressure brought on by the country's high human population (80 million people) and far-reaching political and economic changes.

In 1986, the government of the People's Republic of Vietnam initiated *Doi Moi*, heralding individual responsibility in agriculture and more encouragement of commerce (Werner and Bélanger 2002). The market economy has brought new levels of prosperity to Vietnam and made possible expanded rates of consumption. It has also created severe disparities of income. Vietnam now stands at a crossroads as it adjusts to an opening international market economy. The country's accelerating pace of development raises serious concerns for the minority populations and for the long-term prospects for the country's unique natural resources.

Current threats to Vietnam's biodiversity include direct exploitation through logging and hunting (both for subsistence and for national and international markets) and habitat degredation (Compton and Le Hai Quang 1998; DeKoninck 1996; Nguyen Nghia Bien 2001; Pham Binh Quyen and Truong Quang Hoc 2000; Poffenberger and Nguyen Huy Phon 1998). Habitat loss and degradation result from conversion of natural lands to agriculture (including the expansion of cash crops: Vietnam is now the world's second largest coffee exporter; Stein 2002), hydropower projects, urbanization and pollution (BirdLife International in Indochina 2003; Dudgeon 2000; Vo Tri Chung et al. 1998).

The Vietnamese government has a relatively long history of trying to address the problem of environmental degradation. In 1962, Ho Chi Minh established one of Vietnam's first protected areas, Cuc Phuong National Park. By 1990, the number of forest reserves had grown to 90, covering 1.3 million hectares (about 4% of the country). In 1995, The Ministry of Agriculture and Rural Development (MARD), the government arm charged with protected area development and administration, set a finite target of two million hectares for protection of forested areas (Birdlife International, 2001). The government simultaneously initiated a review of current and proposed protected areas aimed at removing degraded, non-forest lands from the current network and achieving equal representation of all Vietnam's habitats and associated biodiversity (Wege et al. 1999).

Biogeography and Conservation Research

In an effort to contribute to Vietnam's restructuring of its protected area system, the Center for Biodiversity and Conservation at the American Museum of Natural History (CBC-AMNH) collaborated with a number of other organizations on multi-taxon surveys of currently unprotected forested areas in Vietnam. Collaborators included the Institute of Ecology and Biological Resources (Hanoi) (IEBR), Vietnam National University (Hanoi) (VNNU), the Forest Inventory Protection Institute in the Ministry of Agriculture and Rural Development (Hanoi) (FIPI-MARD), Missouri Botanical Garden (MBG), World Wildlife Fund (WWF), and BirdLife International. Our goals were to survey three areas outside of the current protected area network to determine the diversity of plants and animals found in them, to identify cultural and subsistence uses of the areas for local populations, and to assess the conservation value of these areas in the context of both existing protected areas and additional proposed ones.

Study area selection was guided by a number of criteria. Areas had to be poorly known, forested, relatively undisturbed but still accessible for field work, and representative of biotic communities inadequately covered by the current protected areas network. We also used a biogeographic framework in combination with previous research to select areas potentially rich in biodiversity and ones where survey results could further elucidate the structure of diversity and its distribution in Vietnam. Our goal was to test two biogeographic hypotheses using survey results from study sites along north-south and east-west gradients: (1) the contributions of different biota (Sino-Himalayan, southern Chinese and Indo-Malayan) to regional diversity across the country, and (2) the existence of an endemic focus along the eastern flank of the Truong Son Range (Baltzer et al. 2001; MacKinnon 1997; Stattersfield et al. 1998; Timmins and Trinh Viet Cuong 2001). We also looked at elevation gradients to examine the relative roles of latitude and altitude in defining communities.

The most northerly site, Mt. Tay Con Linh in Ha Giang Province, lies in the South China bio-unit, east of the Red River and close to the Chinese border (Fig. 3). Habitats include submontane to montane evergreen and mixed deciduous evergreen forests typical of northern Vietnam's granitic mountains with a high diversity of conifers (Birdlife International 2001; Bain and Nguyen Quang Toruong 2004a; Harder, *in litt*. 2001). Vietnam west of the Red River has been better surveyed than the northeast (e.g., Bourret 1936, 1941, 1942; Delacour 1930; Delacour et al. 1928a; Delacour et al. 1928b; Eames and Ericson 1996; Osgood 1932); complementary efforts on the eastern side allow us to examine whether or not the Red River is an important barrier structuring diversity (Geissmann et al. 2000; MacKinnon 1997; Orlov et al. 2001). The most southern site, Mt. Ngoc Linh in Kon Tum Province, is part of the central Truong Son Range, a region known as the Western or Central Highlands, and it lies within the northern Annamese Mountain bio-unit (Fig. 3). Mountain plateaus in this region have elevated rates of endemism and BirdLife International has recently designated the Kon Tum Plateau an Endemic Bird Area (Vietnam's fourth) following the description of three new babbler species from it (Eames and Eames 2001; Eames et al. 1999a; Eames et al. 1999b; MacKinnon 1997; Tordoff et al. 2000). The forest sampled here is composed of low to medium montane broadleaf evergreens. The third site, Huong Son in Ha Tinh Province, lies roughly midway between the other two study areas in the northern Truong Son Range, within the Coastal Indochina bio-unit (Fig. 3). The low mountains in this area, which run along the Vietnam-Laos border, have been the site of some of the recent large mammal descriptions, e.g., saola (Vu Van Dung et al. 1993). The Huong Son study area encompassed lowland to lower montane broadleaf evergreen forests.

Researchers from the AMNH and collaborating institutions surveyed mammals, birds, amphibians, reptiles, freshwater fish, invertebrates and plants. At each of the major study sites, scientists sampled three to five locations along an elevation gradient. Whenever possible, workers on different taxonomic groups directly coordinated their sampling methods at each elevation. Taxon-specific sampling methods were employed with the general project goal of maximizing recorded diversity, including potentially undescribed species and species not yet known from the area. Collected specimens have been deposited at the AMNH, MBG, and IEBR. A detailed summary of study areas, methods, personnel, and results to date is available elsewhere (Hurley 2002).

Data from the 1998-2000 survey collections are still being analyzed, and most results remain preliminary. As with many other recent surveys, we collected previously undescribed species and recorded significant range extensions for both relatively well-known (e.g., Mrs. Gould's sunbird *Aethopyga gouldiae*) and recently described (e.g., an endemic glass snake *Ophisaurus sokolovi*) taxa. Notable descriptions (all in progress except the mammal) include a new shrew (*Chodsigoa caovansunga*), a new babbler (*Jabouilleia* sp.) and a minimum of four new anuran species (Bain and Nguyen Quang Truong2004a, b; Lunde et al. 2003; Sweet and Vogel, in prep.; Vogel et al. 2003). Results from the 1999 amphibian collections at Mt. Ngoc Linh illustrate the potentially high productivity of continued surveying in Vietnam. Of the 26 species recorded, 10 are restricted-range species, four represent range extensions of more than 200 kilometers for species endemic to Vietnam, two have been described as new and two more are currently being described (Bain and Nguyen Quang Truong 2004b; R. Bain, pers. commun. 2003; Hurley 2002).

Results are consistent with the hypothesis that there may be elevated rates of endemism in the central part of the Truong Son Range. As mentioned above, 10 (40%) of the amphibians collected at Mt. Ngoc Linh are currently known only from a small area, and the new taxa represent possible additional endemics (Bain and Nguyen Quang Truong, in prep.). The new babbler species, collected at the northern site (Mt. Tay Con Linh), necessitates a revision of the endemic Vietnamese genus *Jabouilleia*, types of which are known (currently as subspecies) from along the Truong Son Range (Sweet et al., in prep.). The likely result of these revisions is the elevation of one or more of these subspecies to the species level, adding to recorded endemism in the central Truong Son (Robson 2000). This revision may also contribute to understanding the regional evolutionary processes that have produced differentiation between Vietnam's central and northern avifauna. No additional, clear evidence of faunal endemism was found in the surveys of Huong Son in the northern Truong Son although the presence of three recently described and endemic mammals was recorded (Large-antlered muntjac, *Muntiacus vuquangensis*, saola, and Annamite striped rabbit) (Timmins and Trinh Viet Cuong 2001).

There is preliminary support for the contribution of biota from different biogeographical zones, although this varies with the geographic scale of the analyses. The two major biogeographic units intersecting in Vietnam are the northerly Sino-Himalayan and the southerly Indo-Malayan, with South Chinese influence in the northeast and endemic areas in the Truong Son Mountains (de Laubenfels, 1975; MacKinnon 1997). At a broad scale, collections from the northern (Huong Son) and southern (Mt. Ngoc Linh) Truong Son sites generally include elements of both major faunal groups whereas those from northeastern Vietnam (Mt. Tay Con Linh) show a strong affinity for the fauna of southern China.

At a smaller geographic scale, however, the results are less clear. One factor that disrupts these simple predictions of north-to-south diversity gradients is endemism. The presence of endemic species in the collections from Mt. Ngoc Linh adds a unique component to the fauna, reducing its similarity to the other two sites. For some taxonomic groups (frogs, gibbons) the Red River has been proposed to be a potentially significant geographic barrier, separating divergent eastern and western fauna in northern Vietnam (Geissmann et al. 2000; Orlov et al. 2001). If true, this has strong implications for conservation priorities and protected area designation in the region. Collections from Mt. Tay Con Linh in northeastern Vietnam support this hypothesis for some taxonomic groups but not for others. Insectivora species, collected during the small mammal surveys, include a number of species (e.g., *Scaptonyx fusicaudus, Blarinella griselda*) with stronger affinities to the fauna of southeastern China and Hainan Island than to the rest of Vietnam (Lunde, et al. 2003). However, both bird and amphibian and reptile surveys recorded a large number of range extensions across the Red River to northeastern Vietnam (Bain and Nguyen Quang Truong 2004a; Vogel et al. 2003). These results are not surprising as the newly recorded species fall within expected ranges, and they caution against assuming divergence between regions experiencing different surveying efforts. Our mixed evidence both supporting and refuting this hypothesis suggests that the taxonomic group being considered is an important consideration in the application of biogeographic theory to conservation.

Endemism and species distributions are important components in both biogeographic hypotheses and conservation decision-making. On a cautionary note, care should be taken in attributing full endemic status to new species as well as those known only from intensively surveyed areas. They may represent "bastard endemics," species which, because of habitat loss or exploitation, now occupy only a subset of a formerly larger geographic range (e.g., the Indochinese Javan rhinoceros *Rhinoceros sondaicus annamiticus*) (Corbet and Hill 1992). Alternatively, they may be more widely distributed but not yet recorded from other areas because of undersurveying, because they were not previously recognized, or for both reasons.

Our experiences incorporating biogeographical information into conservation and biodiversity research have been positive. The surveying efforts were facilitated by our selection of study areas potentially high in species diversity and endemism and ones that might be informative in elucidating Vietnam's underlying patterns of diversity. Results from these surveys and analyses can inform conservation efforts, guiding decisions specifically about the current study areas and more broadly about other locations and communities in Vietnam. They also provide data for testing and refining biogeographical hypotheses, including the geographic and taxonomic scales at which they are applicable. These, in turn, can be used to refine and focus additional research and conservation efforts. An important component to continuing this natural history collections-based work is training and capacity building in Vietnam. Throughout the surveys, AMNH scientists provided equipment and training in standard field data collecting procedures and in the curation of the resulting collections to their counterparts at IEBR and university students. This work has already been productive: IEBR biologists used camera trapping to rediscover the hairy-nosed otter, *Lutra sumatrana*, in Vietnam, a Sundaic species thought to be extinct in Vietnam (Nguyen Xuan Dang, et al. 2000).

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Mission Possible: ALL Species Foundation and the Call for Discovery

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With approximately 1.7 million species currently named and as many as 9 to 99 million more to go, it is clear that there is a lot yet to be known about Earth's biodiversity. In 2000, the non-profit ALL Species Foundation was formed to call for the discovery, identification, and description of all the remaining species on Earth within one human generation — 25 years. ALL Species attracted proponents quickly and was embraced by the taxonomic community for its bold and audacious approach and the potential of new funding. ALL Species' global scientific endeavor is distributed on a wide geographical scale with diverse multinational participants. ALL Species endorses the principles and application of industrial business methods to biological inventory. ALL Species supports the knowledge of all species for all people. Unable to raise significant new funds for discovery, ALL Species reduced in 2002 to one staff member and shifted emphasis to promotion of tools and technology that accelerate the practice of taxonomy (e.g., digital imaging of type specimens, field-based microbiology equipment and molecular field sequencers, pattern recognition software, data rich identification keys, rapid publishing, and comparator tools). The mission? Possible.

The ALL Species Foundation began as an intellectual discussion among friends and rapidly grew into a project with the endorsement of approximately 100 prominent scientists from around the world. The mission: to accelerate the discovery of the planet's entire biodiversity in 25 years — one human generation.

What is ALL Species?

ALL Species is a decentralized and non-bureaucratic global initiative, based on science-driven business models, and affiliated with entrepreneurial and catalytic scientists. Its purpose is to promote and accelerate the collection and systematic analysis of all biodiversity information and make it freely available on the internet.

How Many Species are Out There?

Most scientists accept that about 1.7 million species have been named and described over the last 250 years, yet estimates of how many species exist on Earth vary from 10 to 100 million. The huge range between these last two numbers keenly demonstrates the immensity of the knowledge gap — we don't even know what we don't know.

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If we accept the fact that there are 6000–7000 practicing taxonomists describing two new species a year, the current rate of description is 15,000 per year. At this rate, describing 10 million new species will be completed in 2555. Obviously, a lot has to change to describe what remains within the timeframe challenge of ALL Species. For reasons outlined in this short paper, this rate of taxonomic discovery does not equate to the global significance of biodiversity.

What are the Priorities of Scientific Discovery to Biologists?

Most biologists believe the current extinction rate exceeds background and that Earth faces a "biodiversity crisis" due almost exclusively to human activities. This drives the imperative to know all species before many wink out of existence. Humans are a deeply curious species, but the dichotomy between our complacent acceptance of knowing only ten percent of life on Earth and our well-funded quest to discover life somewhere else in the universe is troubling. As far as we can tell, space is not under the same threat as Earth. Think about these incongruities:

- If you were sick with a life-threatening illness, would you want your physician to know only ten percent of the possible ways to save you; or possess only ten percent of the ability to diagnose what disease ails you?
- Would you hire an investment manager whose financial knowledge spectrum was only ten percent; someone who only read ten percent of the *Wall Street Journal*; someone whose advice was limited to a mere ten percent of the potential stock options available to you?
- What good is a library if you have access to only ten percent of what is there, whereas the remaining 90 percent is closed due to lack of funding; or even more disturbing, this resource is closed due to lack of use?
- What CEO of a corporation makes short-term or long-term buying, selling, or production decisions knowing only ten percent of its inventory or ten percent of its market? The life expectancy of a CEO in this position is highly endangered.

If enough energy and funds were dedicated to an Earth life search, ALL Species and its advisors believe the mission could be accomplished in 25 years. What if just a portion of the billions of dollars spent on SETI or NASA was redirected towards the search for life on Earth for the next 25 years? Many of the same creative scientists and engineers could be utilized to design sophisticated sampling robots for harsh earth environments, imaginative field- and lab-oriented tools for discovery, sequencing, and identification, and novel approaches to information analysis and storage.

Why Does Knowing All Species Matter?

The impact of knowing all species, or most species at least, would be profound. Nearly every useful compound, food, fiber, or process used by humans was produced from either an idea inspired by observation of the natural world or by direct manipulation of some biological object or activity (Beattie and Ehrlich 2001). In the United States alone, 56 percent of the top 150 prescribed drugs is linked to discoveries made in the wild, yet less than one percent of the estimated 250,000 tropical plants has been screened for pharmacological properties (UNEP 2002).

Both biomimicry and nanotechnology are revolutionizing how we invent, compute, heal, harness energy, repair, conduct business, and feed the world. Research conducted at numerous labs around the world concentrates on the development of new products and materials derived from marine and terrestrial organisms. Some of these products or materials include new enzyme catalysts, novel bioadhesives, improved biosensors, optoelectric/catalytic and microelectronic devices, and microlaminate composites (Marine Biotechnology Center, University of California Santa

Barbara website). The discovery of more species equates to more models to observe and more sources to tap for scientific breakthroughs to improve the quality of life (Benyus 1997). Molecular level assays (receptor binding and enzyme inhibition) offer brand new perspective and potential for nature as a source of new pharmacologies (Verpoorte 2003).

Evolutionary biologists and ecologists have different perspectives than the average citizen about why knowing all species matters. From the scientific point of view, understanding biological mechanisms and evolutionary and ecological relationships is the best way to inform conservation and management decisions. This understanding is the best support for accurate priority setting and sustainable environmental policy. As E.O. Wilson says, knowing all species represents the true maturation of biology.

Actually, knowing all species ultimately represents long-term security for *Homo sapiens*. All agree that bio-security certainly has new meaning since 9/11. Pests and diseases are shared globally at an unprecedented level. Yet we know very little about species interactions that affect crop yields or the life cycles of vectors and the predators of vectors. Some believe that the most threatening crisis humanity faces is antibiotic-resistant bacteria in our own hospitals. However, it is significantly odd that the number of protist taxonomists remains very small relative to the number that study birds or plants.

Why is the Mission Possible Now?

Many of the past impediments to global species discovery have been eliminated with modern advancements. Driven by Moore's Law, the continued exponential development of technologies and their decreasing cost over time provides the threshold for today's scientists to identify all life on Earth in their lifetime. Progress will be slow at first but once the inflection point of the curve occurs, mo-mentum will gather speed. Table 1 lists some of the reasons why ALL Species ad-visors believe the mission is possible within the 25-year time frame.

Table 1.Some of the reasons why ALL Species advisors believe the mission is possible within the 25-year time frame

Past Impediments	*Current Solutions*
Travel difficulty	Advances in transportation
Glacial pace of information transfer	Internet
Access to collections/library	Online databases
Need to physically examine type specimens	Digital images reduce need
Delay/expense in publication	E-publishing
Limited compare/analyze tools	Rapid sequencing/Phylogenetics
Few experts	Capacity building initiatives

What Has to Happen to Find ALL Species?

For ALL Species' mission to succeed, societal changes must occur. National and international leadership must be demonstrated and pressure must be exerted upwards from the biological community about the value of taxonomy and the value of discovery. Barring a cautionary catastrophe that would inject a crisis mentality and jump start these changes, a critical fundament to the requirements is an abundance of 21st century thinking. Of course, the mission requires substantial funds, but almost more importantly it also requires:

- Evolution of the practice of taxonomy and systematics
- New tools, technologies, and training
- Unprecedented knowledge transfer to megadiverse countries

- A new corps of taxonomists
- Transformation of the culture within natural history sciences
- Increased public awareness

What is the History and Current Status of ALL Species?

From its inception in 2000, ALL Species has seen itself as a neutral instigator and catalyst, a promoter and broker, and a fundraiser. After two international meetings in 2001 that framed the scope of the mission, advisory and governing boards were established. The advisory boards helped identify the first five-year goals that would either accelerate the process of taxonomy or provide testing ground for field inventory methods and protocols. These goals are listed in Table 2.

Table 2. The first five-year goals that would either accelerate the process of taxonomy or provide testing ground for field inventory methods and protocols

First Five-Year Goals of ALL Species
Image and web enable 50 percent of the primary type specimens
One global inventory of a taxonomic group
Quadruple the rate of species description
One comprehensive all-taxa biodiversity inventory
Increase the taxonomic capacity of developing nations twofold

Funding from The Schlinger Foundation in 2001 allowed the hiring of a small staff that set about forging partnerships and supporters to frame the discussion about how best to accomplish the mission. This staff also began creating tools to accelerate the business of taxonomy — such as a search engine. Within three months, this search engine <*http://www.speciestoolkit.org/index.jsp*> became the largest publicly available resource indexing a total of 873,979 species and 1,124,819 names. Full design and deployment of the Toolkit were put on hold in November 2002. However, the code is freely available under the GNU Public License at SourceForge at <*http://speciestoolkit.sourceforge.net/*> where the code and more extensive documentation are available. The ALL Species staff also designed and promoted a prototype Encyclopedia of Life — a consolidation of all biological information about species where every species has a web page and every web page is a portal to varying levels of biodiversity information about that species — from specimens to identification keys to experts to distribution maps.

ALL Species hosted one digital imaging workshop at the California Academy of Sciences during spring of 2002. From the success of that workshop, the E-Type and E-Description Initiative was launched — an effort to spearhead the digital imaging of primary type specimens and its original literature when possible. Through NSF supplemental funding, ALL Species co-hosted two E-Type Initiative Strategic Workshops at the Smithsonian (November 2002 and May 2003) where researchers from the major collections in the United States and Europe and the developing world discussed the benefits and goals of the Initiative and mapped preliminary strategies for the Initiative and for specific taxon groups.

Unable to raise significant additional funds for the young organization with big ideas, ALL Species was reconfigured in late 2002. Hoping to keep the mission alive until a more auspicious economic climate, four institutions stepped forward to provide support for one staff person to concentrate on the E-Type and E- Description Initiative and other ALL Species activities through 2003 and possibly into 2004: California Academy of Sciences, Field Museum, Missouri Botanical Gardens, and Museum of Comparative Zoology — Harvard. ALL Species' advisory boards remain active on a volunteer basis.

As of June 2003, ALL Species had met with considerable success on at least two of these first goals. Through Conservation International, a one-year all-taxa biodiversity inventory is slated to occur in Los Amigos, Peru following protocols and methodologies designed by Terry Erwin of the Smithsonian (former ALL Species Science Chair). At the instigation and urging of ALL Species, in 2002 the National Science Foundation launched a brand new $14 million program called Planetary Biodiversity Inventories (PBI) to support the global inventory of major taxonomic groups. The first four awards will cover catfish, eumycetozoans (slime molds), solanum (nightshade family of plants), and plant bugs. Even in its reduced state, ALL Species was able to contribute $25,000 to the PBI effort.

Is the Mission Possible?

Every biologist needs to be part of this mission whether they are an ALL Species advisor, a previously quiet supporter at the sidelines, or someone reading this text by accident. We all need to promote the need to know. Each of us needs to take every opportunity wherever we can to stress the value of discovery and the value of knowing, and to broadcast the importance of taxonomy and taxonomic products to society. Useful new tools and developments that accelerate the practice of taxonomy need to be fostered and promoted. In short, ALL Species challenges each of us to become biodiversity diplomats. We need to coordinate across disciplines and to collaborate at new levels. We need to speak up and speak out and to mobilize. Is the mission possible?

Only if we each follow Mahatma Gandhi's advice and "Be the change you wish to see in the world."

Update: August 2004

Unfortunately and anticlimactically, ALL Species is currently without staff and the foundation is dormant. Attempts over the past six months to find an organization in the mutually strategic position to adapt the assets of ALL Species have been unsuccessful. The good news is that E-typing is far more common and the Smithsonian's new Encyclopedia of Life will take ALL Species' and E.O. Wilson's idea of a web page for every species and try to make it happen.

So, the vision will continue, for after ALL, vision is what makes any mission possible.

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