Genetics and the Future of Biodiversity

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The 10th anniversary of the BRT program is both a time for the celebration of accomplishments and a time for reflection on the goals for the next ten years. I congratulate the program's leaders and grantees who, together, have achieved so much. Thailand is the richer for your efforts as the nature and significance of the country's biodiversity is now better understood. Just as Thailand has changed in the past 10 years so has the value to society of the BRT program. As the Kingdom moves to democratic governance and a knowledge-based economy the research and training fostered by this program become ever more important. I hope that BRT's next decade is even more productive scientifically, and that the ecological services provided by biodiversity are increasingly factored into the political calculus of national development.

This paper is based on a talk for general audience and therefore departs from the traditional style of formal scientific papers. In the talk I used 86 slides and I apologize for the fact that the reader cannot see the figures and charts. For clarification of my remarks I invite correspondence by email.

I was trained in Australia as a zoologist and have been privileged to conduct collaborative research in Thailand for 22 years. I use genetic methods to study the evolution and conservation of animal species. I was invited to discuss the role of genetics in the broader program of the BRT and I used this opportunity to discuss why Thai biodiversity and the conservation of natural resources are so worthy of national attention. Biodiversity, through its organization into species, natural communities and ecosystems, provides the ecological services that are essential to improving and sustaining the quality of human life in Thailand. Studies of DNA and chromosomes of microbes, fungi, plants and animals can have a significant and beneficial impact on the future of life in Thailand.

Key words: genetics, biodiversity

The Biodiversity Crisis

At the outset it is important to recognize that we live during an instant of time in which the rate of species extinction is at its highest level in the last 65 million years (Wilson, 2002). Today, species of plants and animals are disappearing at 1000 times the background rate. Thailand's original forests declined from covering 60% to less than 20% of the land in the last century. 50% of Thailand's mangroves have been destroyed, resulting in significant losses of beach and coastal infrastructure protection and fish productivity. 40% of the earth's coral reefs were lost or degraded in the last 50 years. Around the world, habitats are being destroyed at a rate of about one football field every two seconds. This unprecedented loss of habitat results in the local extirpation and the global extinction of species. Island biogeographic theory allows us to predict that a 10-fold decrease in habitat area may result in a loss of half the species originally present. In turn, this allows us to make some predictions about the future of biodiversity in Thailand.

We live during an extinction spasm that may become a great Mass Extinction and change the biosphere forever. In Thailand and elsewhere during the next 100 years many species will go extinct as a result of habitat alteration, over-harvesting, the elimination of pollinators and dispersers, and from competition with introduced species (Woodruff, 1991). We already notice the weeds, generalists and introduced species replacing the natives. There are largely irreversible changes in species diversity underway and they are occurring at an accelerating rate. Globally, the distribution of species is becoming more homogeneous as a result of our movement of species. Eco-journalists write of our living in the dawn of the Homogecene Period.

In addition to the global decline in species, the population sizes and geographical ranges of surviving species are also declining. Predicted faunal collapse threatens up to 50% of the large vertebrates; 5% of the earth's biota is at risk of extinction in the next 20 years. This is especially serious in the tropics as two thirds of the planet's 10 million species are thought to live in the tropics. Consider what these predictions mean for the biota of Southeast Asia: 329 species of mammals (22% endemic), 1170 birds (12%), 484 reptiles (42%), 202 amphibians (56%), and 13,500 flowering plants (52%) (Sodhi et al., 2004). Tiny Singapore has already lost 50–90% of the species in these five groups (Brook et al., 2003). Although no comparable estimate has been made for Thailand, my own research on mammals in recently isolated forest fragments illustrates how rapidly extirpation can occur on a local scale (Lynam, 1997; Lynam and Billick, 1999). We studied small mammals on the islands in Chiew Larn reservoir, between Khlong Saeng Wildlife Sanctuary and Khao Sok National Park, and found that all native mammals were lost from small (<5 ha) forest fragments in less than 5 years following their isolation by the flooding of the reservoir. The medium-sized and large mammals were also gone in less than 5 years.

Generalizations about Thai biodiversity endangerment were not appreciated by many academics or government officials 20 years ago. The first conference on conservation biology in Southeast Asia was held in Bangkok in 1987 (Bawa et al., 1990) coincident with the first documentation of the threats to Thai animals (Round, 1988; Humphrey and Bain, 1990; Ecological Research Department, 1991; Woodruff, 1991). The Science Society of Thailand (1991) declared that biodiversity was the country's most undervalued and neglected resource. Internationally, the U.N. Conference on Environment and Development (Earth Summit) convened in Rio de Janeiro in 1992, and the Convention on Biological Diversity was drafted in 1993, addressing the conservation and sustainable use of biodiversity and its underlying genetic resources. The BRT program has its historical roots in this period of increasing national recognition of the significance of the global biodiversity crisis. In this paper I will argue that the program will become even more important as the links between biodiversity, ecological services and sustainability are recognized by economists, politicians and the educated public.

Genetic Contributions to Characterizing Thai Biodiversity

The BRT Program has provided a welcome national response to the biodiversity crisis. Numerous genetic studies of microbes, fungi, plants and animals have been fostered in the first 10 years. Such research has contributed to the identification of evolutionarily significant units (ESU's: species and subspecies), and to the genetic characterization of the population variability and structure, phylogeography and phylogenetic relationships of selected species (Woodruff, 1999). For species of economic or public health importance, and for those of conservation concern, genetic studies also provide information useful for management or future commercial development. Not having a list of BRT-funded genetic projects, I will illustrate some of these applications using examples from my own research.

Allozyme electrophoresis and the characterization of ESU's. Multilocus genotyping using allozymes permited the recognition of cryptic species, the suppression of ill-defined taxa, and the identification of phylogenetic relationships. Suchart Upatham and I used this technique to good effect in studies of trematodes of medical significance and their intermediate host snails (Woodruff and Upatham, 1993). We found that the blood fluke that causes human intestinal schistotosomiasis in Asia was not a single species *Schistosoma japonicum*; the Malaysian and Mekong valley *Schistosoma* are now recognized as distinct species (Merenlender et al., 1987; Woodruff et al., 1987). Similarly, the taxonomy of the intermediate host snails also required revision (Woodruff et al., 1988, 1999; Staub et al., 1990). In the above cases genetics revealed greater diversity in the Thai fauna; in contrast, another study led to the lumping of 21 nominal species of economically important freshwater clams. Our genetic studies showed that interpopulation variation in clam shells was actually rather misleading, and that numerous different looking "species" were actually all referable to a single widespread Asian species (Kijviriya et al., 1991; Woodruff et al., 1993).

Noninvasive genotyping using mtDNA sequences. The invention of the PCR made it possible to perform direct sequencing of DNA extracted from diverse organisms. The further development of noninvasive genotyping reduced the need for collecting whole animals for blood or tissue samples, and permitted the study of animals that were rare or hard to capture. The first demonstration of the noninvasive approach actually involved Thai flagship species: gibbons and hornbills (Woodruff, 1990). Collaborations with Warren Brockelman and Pilai Poonswad led to the demonstration that DNA sequences could be obtained from shed and plucked hair and feathers. This advance was widely adopted and led to numerous significant discoveries reviewed elsewhere (Morin and Woodruff, 1996; Woodruff, 2003). We were able to contribute the first phylogeographic characterizations of the chimpanzee (Morin et al., 1993; Gagneux et al., 1999) and the African elephant (Eggert et al., 2002). In both cases, we discovered that these well-known "species" were actually species complexes made up of 2–4 parapatrically distributed species-level taxa. In Thailand our research on mtDNA variation in hornbills led to the first glimpses of their phylogenetic tree (Morin et al., 1994; Srikwan and Woodruff, 1998; Woodruff and Srikwan, 1998). More extensive phylogenetic studies of gibbons are now resolving issues of species identification and phylogeographic relationships (Garza and Woodruff, 1992; Woodruff et al., 2005).

Microsatellite genotyping. In addition to informative mtDNA and nuclear coding sequences, geneticists discovered a class of hypervariable nuclear DNA loci called microsatellites or simple sequence repeats (SSR) (Goldstein and Schlotterer, 1999). Microsatellite genotyping has revolutionized behavioral and ecological genetic studies of both wild and domestic plants and animals. Multilocus surveys of microsatellite variability permit the characterization of the innate variability of natural populations, a feature important in individual fitness and population evolvability. Individual heterozygosity is often associated with growth rate and size, metabolic efficiency, fertility, survival of new diseases, and survival in a changing environment. Conversely, the lack of genetic variability in a population may contribute to reduced fitness and ultimately extinction (O'Brien, 2005).

Monitoring genetic erosion using microsatellites. Small isolated populations can lose genetic variability as a result of chance loss of alleles (genetic drift) and inbreeding. This process is called genetic erosion and has been understood in theory for 75 years but it was not until multilocus microsatellite genotyping became possible that we were able to show that the process can be monitored in real time (Woodruff, 1992b). Sukamol Srikwan collected DNA noninvasively from the small mammals on the islands in Chiew Larn reservoir in years 3–8 after these forest fragments became isolated and demonstrated that these populations were beginning to lose their genetic variability (Srikwan et al., 1996, 2002; Srikwan and Woodruff, 2001). We hope to further test the prediction that rate of change in heterozygosity is $H = 1/2N_e$ after 20 years of isolation. We used small rodents and tree shrews in these studies as models for larger mammals of greater national interest.

Genetic censusing using microsatellites. Microsatellites are so variable that they can also be used to identify individual organisms and, as each individual has a unique multilocus genotype, to census uncountable animals. In Africa, for example, we were able to estimate the number of elephants in a small isolated national park. These animals are too dangerous to approach and could not be counted directly in the forest. However, by genotyping seven microsatellite loci amplified from 150 dung samples collected throughout the park over 15 days, we estimated that 223 elephants were present (Eggert et al., 2003). In addition, the use of a sex-linked gene enabled us to establish the numbers of males and females in our sample. This work will facilitate comparable surveys of the last herds of wild elephants in Thailand (study underway by Chomcheun Siripunkaw, Chalita Konkrit and Eggert).

Genetics in BRT's Second Decade

Almost all the various technologies used by biodiversity researchers to characterize and study genetic variation are now available in Thailand. Before discussing several areas of research activity that may be prominent in the next decade it is important to note that older and relatively inexpensive methods like simple chromosome analysis and allozyme electrophoresis are still perfectly good approaches to many questions. While newer methods will always appeal, and are sometimes essential (Srikwan and Woodruff, 1997), I commend the BRT program for supporting a spectrum of genetic approaches.

Cloning comprises various reproductive technologies for producing genetically identical offspring from an individual or a cell line. Cuttings and tissue culture permit cloning of plants routinely. Nuclear transplantation in animals is much more difficult and expensive and, so far, success has been limited to a few individuals of domesticated animals. Newspapers have popularized the idea of cloning extinct species from salvaged fragments of their DNA, but the prospects for recreating a dinosaur are zero (because of the natural decay rate of fossilized DNA) and the prospects of revitalizing a mammoth from tissue frozen for 10,000 years are equally small. Genetic resurrection for the kouprey, Schomburgk's deer and white-eyed river martin is beyond our current scientific capabilities. Nevertheless, cloning may play a small role in saving a few endangered species in cases where cross-fostering by a related domesticated species is possible. For example, a banteng at the San Diego Zoo was cloned in 2003 from fibroblast cells frozen 12 years earlier when it's "father" died. Other cases of cross-fostering endangered species embryos (gaur in cattle, wild cats in domestic cats) involve reproductive technologies, but are not cloning. The relevance of all these methods to the present mission of the BRT is marginal.

Genetically modified organisms (GMO's) and evolutionary engineering. Recent advances in technology have made it much easier to create GMO's that may be of great benefit to humans but always carry risks of causing harm to biodiversity. Under the Convention on Biological Diversity, of which Thailand is a member, the future handling and use of any living modified organisms (LMO's) are regulated by the Cartagena Protocol on Biosafety and, in time, by a Thai Biosafety Law. I will not discuss LMO/GMO's here as such issues generally fall outside the mission of the BRT program. In contrast, the unintentional human acceleration of the processes of evolution is seldom recognized as a threat to biodiversity. Yet, in the U.S., our inadvertent acceleration of evolution is estimated to cost the economy $50 million annually (Palumbi, 2001). Examples include over-treatment leading to the evolution of human drug resistance, plant and animal resistance to pesticides, rapid changes in invasive species in their new environment, life history changes in commercial fish induced by fishing methods, and pest adaptations to bioengineered pathogens like *Bt*. Scientists supported by the BRT program should watch for such evolutionary changes in Thai biodiversity.

Genetic barcoding is a new name (actually a metaphor, like DNA *fingerprinting*) for mtDNA sequencing of the cytochrome oxidase 1 or CO1 gene. Barcoding involves using this one particular DNA sequence to try to uniquely characterize every living species. The CO1 sequence from an otherwise unidentified organism or tissue sample might permit its identification in a few hours while traditional taxonomic consultation might take weeks or months. Barcoding could permit the rapid identification of a mosquito species, a plant pathogen, a macroparasite or a protected species or its derivatives (meat). CO1 sequencing is fostered by the Consortium for the Barcode of Life (CBOL, 2005) whose mission is to speed compilation of DNA barcodes of all known species, establish a public library of sequences, and promote development of portable devices for DNA barcoding. Accuracy of barcoding depends on the extent to which the regional biota has been characterized and the cost depends on the scale, but a regional center could provide affordable forensic identifications in a few hours.

Genomics. The completion of the human genome project was a signal event in the history of human medicine but has little to do with the interests of the BRT program or the conservation of biodiversity (Ryder, 2005). Similarly, although the sequencing of the chimpanzee, rice, and chicken genomes may lead to enormous payoffs in terms of human health, improved rice strains, and perhaps the development of influenza resistant chickens, it is difficult to see how Thailand would benefit from playing a lead role in such expensive projects.

Community genomics involves the rapid estimation of the number of unique DNA sequences (microbial or fungal) representing different unknown species in a random sample of a biotic community e.g. in a gram of soil or a liter of water. Results reveal far more biodiversity than previously suspected. This approach to bioprospecting is being used commercially to discover new varieties of enzymes of potential commercial interest. The biotechnology company Diversa Inc. screened unknown microorganisms inhabiting hot springs for variants of a common enzyme and discovered dozens of previously unknown esterases that could potentially speed up commercially important reactions.

Endosymbiont genetics. The realization that trees, and in fact all plants, are composite organisms whose health and success is dependent on endosymbiotic fungi has opened a new field of biodiversity research. Horizontally transmitted mutualists now appear crucial to host defense from pathogen infection and damage (Arnold et al., 2003). The molecular genetic research on fungal diversity by Gareth Jones and his colleagues at BIOTEC shows just how important the endophytic fungi are to the ecology of Thai plants, and how little is yet known about these interactions. Future forest, mangrove and coral reef restoration projects and toxic soil remediation will require a much greater understanding of these cryptic symbioses involving fungi or bacteria.

Phylogeographical surveys. Patterns of genetic variation in space reveal much about the history and relationships of populations. Exciting discoveries regarding the history of our own species in Southeast Asia come from recent surveys of variation in genes on the X and Y chromosomes (Oppenheimer, 2003). Establishing phylogeographic patterns may permit the tracing of invasive species to their sources and detecting climate change induced shifts in distribution. Accurate locality maps backed up by archived voucher specimens are essential for this type of work. The sheets in the national herbarium are a prime example of this type of irreplaceable resource, as are the specimens in the national museum and various university collections. Verified occurrence reports of birds provide an equally valuable database (Round et al., 2003) the analysis of which has just begun (Hughes et al., 2003).

Genome resource banks. There is a growing international recognition that more resources must be devoted to storing cells, gametes, embryos and purified DNA for future genetic reference. Archival tissue cryopreservation is now routine in many medical centers and museums. The San Diego Zoo's Frozen Zoo provides a unique collection of cell lines of nearly 300 species (Ryder et al., 2000). I hope that the BRT program encourages the archiving of irreplaceable tissue and DNA samples by all its grantees, and that the Thai government will do more to create a dispersed system of national genome resource banks, before it is too late.

Conservation genetics. Frankham et al. (2002) provide an excellent introduction to the application of genetics to the study and management of small populations in the wild and captivity; such interventive management will become increasingly necessary to sustain Thai biodiversity.

Beyond Genetics: Why Does Biodiversity Matter?

Biodiversity has direct material, economic and spiritual benefits for Thais. More generally, biodiversity is essential for our continued habitation of the planet. It is a requirement for future biological evolution and most importantly it is essential for the ecological services we take for granted. If biodiversity is to continue to provide humans with the ecological services they expect, geneticists will have to play a larger role in the management of the process of evolution. They will increasingly be asked to assist with the future evolution of individual species (endangered, desirable or pestiferous) and the functioning of communities (natural, disturbed, and agricultural). Geneticists, together with ecologists and systematists, also have an obligation to become more involved with environmental policy and the shaping of development projects. This is particularly necessary in Thailand which suffers the Asian Tiger Syndrome, a disregard for the environment during a period of rapid economic growth (McNeely and Dobias, 1991; WGBU, 1997; NRC, 1999:287; Fahn, 2003). Hydropower generation and reforestation are two current examples of regionally significant large-scale environmental activities that have profound effects on Thai biodiversity.

The controversy over the construction of the Pak Mun dam 15 years ago is an excellent example of a development project that impacted biodiversity when the developer ignored complaints from Thai scientists trying to prevent the loss of a global biodiversity hotspot. With over 1,200 species of fish present in the middle Mekong River and its tributaries this small hydropower dam threatened one of the three richest freshwater fish communities in the world. The dam disrupted upstream spawning migrations from the Mekong into the Mun river (Roberts, 2001b) and nine years later local fish catches had declined 80%, with 96 species in the catch vs. 256 before. Although the academic and civic protests failed to stop dam construction, and the damage to Thai biodiversity was done, the protests changed the ways government agencies approach issues effecting biodiversity. In a broader context the Pak Mun showed that the government's assessment of the environmental impacts of development projects needed to be transparent to avoid costly social and political unrest. Unfortunately, in retrospect, if the benefits and costs had been adequately assessed it is unlikely that the dam would have been built (Amornsakchai et al., 2000).

Now a second hydropower development project, the Chinese construction of eight dams on the mainstream of the Mekong River coupled with their Mekong Navigation and Channel Improvement Project, presents an even greater threat to Thai biodiversity and resources (Roberts, 2001a; Dudgeon, 2002; Round, 2002; Brockelman, 2003; Mekong River Commission, 2003; Hogan, 2004; Campbell, 2004). The Chinese reservoirs will impound the upper Mekong and the downstream flow will be regulated so as to even out the flow of water throughout the year. To date, the Chinese have ignored transboundary effects and argue that their regulation of the river will reduce the damage and disturbance caused by annual flooding in the middle and lower Mekong. Unfortunately, that argument ignores both the fish and the people in four countries that are dependent on the flood and the nutrients it brings. The Great Lake of Cambodia, the Tonle Sap, currently provides Cambodians with about 25% of their protein. This diverse ecosystem is totally dependent on the Mekong flood for its annual recharging. The Tonle Sap could disappear within 25 years according to some analyses (Roberts, 2001a). Unfortunately no international treaty has yet been adopted that will reduce such transnational imperialism and China is not a member of the Mekong River Commission. Thailand is compromised as it has taken a pro-dam position in Laos and took no interest in transnational impact of its own Pak Mun dam. Biologists are assessing the probable impacts of the coming environmental changes in Vietnam and Cambodia and I encourage the BRT program to foster similar research in Thailand. The genetic aspects of managing smaller populations of physically constrained fish are poorly known and it is unclear whether flood-dependent migratory species (the majority) will breed in the regulated river or perish.

A different set of threats to biodiversity is presented by the on-going policy debates over the use of the remaining forests in the hills of northern Thailand. Are hill tribes practicing sustainable agriculture or are they responsible for destroying wildlife, deforestation, erosion, poor downstream water quality and the loss of watershed ecological services? Clearly there are many ecologically different hill tribes; some are very recent refugees (Hmong) and others (Karen) have lived in the hills for centuries. The policy debate have been complicated by the fact that the hill forests have recently been designated as forest reserves or national parks by the government which does not recognize the citizenship or land rights of the half million residents. Should these people be forcibly relocated? How does biodiversity conservation figure in this human drama? Here, I can only summarize more detailed discussions of this complex issue (Watershed, 1999; Woodruff, 2001a; Fahn, 2003; Brockelman, 2005) and relate the implications of agricultural development and reforestation to regional biodiversity.

Although some rotational shifting cultivation is sustainable, the implementation of agricultural systems and integrated resource management in the hills is frustrated by the economic, social, and political problems of the half million people who live in what have become increasingly regulated protected areas. The divisive nature of the debate over shifting cultivation is illustrated by the government's use of the phrase *rai lu'an loy* to describe the diverse resource management practices and systems of knowledge of upland ethnic communities as "destructive slash and burn agriculture". In contrast, some ethnic communities use the phrase *rai mun wian* to communicate the benefits and productivity of their natural resource management systems. Interestingly, the Thai press and NGO's have portrayed the extreme positions as being held by people they label with fruity epithets, as Watermelons or Bananas (Fahn, 2003). These epithets are mentioned here as they apply to many other disputes over biodiversity and natural resource management in Thailand that pit Preservationists (called Bananas) and Environmental Democracy Movement members (called Watermelons) (Table 1). To understand this dichotomy the non-Thai reader must know that the Buddhist idea of Nature differs from the Western concept of wilderness, in holding that there is no land on which man has not set foot. In Thailand the concepts of Nature and of forests are very similar, but forests are not considered separate from people. In Buddhist thought nature and man are always intertwined (Kabilsingh, 1998) while to some Western conservationists nature (good) should be protected from people (bad). In the Thai caricature, Bananas are yellow (Asian) on the outside but white (Western) on the inside and Watermelons are green outside (environmentalists) but red (socialists) on the inside. In reality, this is a false dichotomy, but the epithets are more useful to those concerned with the biodiversity crisis in Thailand than the academic jargon: utilitarian anthropocentrism versus intrinsic-value ecocentrism (Borgerhoff Mulder and Coppolillo, 2005).

Table 1. Contrasting approaches to nature in the Man-and-Forest [*khon kap paa*] debate in Thailand. This caricature is based on Fahn (2003:156–159) and, as discussed in the text and by Brockelman (2005), neither side is invariably right.

	Preservationists	Environmental democracy movement
Nature's purpose	For resource exploitation	For local use
Proponents	Royal Forest Department	NGO's, green monks
Academics proponents	Ecologists	Sociologists
Primary goal	Watershed protection	Human rights, Community Forest Act [proposed]
Secondary goal	Wildlife protection	Rural development
Philosophical approach	A foreign concept of wilderness	People living in harmony with nature
Attitude	People are a threat to nature and officials	Government is a threat to people
View of the other side	Romantic wishful thinking	Deep green imperialism
Solution	Resettle the people	Foster sustainable use
Fruity epithet	Bananas	Watermelons

In each of the above cases biodiversity seems to sit in the way of progressive development. In fact, development can take many courses and not all involve damaging biodiversity (Woodruff, 1992a). In the case involving agriculture and agroforestry in the northern hills it is clear that sustainable agriculture should not be based on further land transformation. Deforestation dries out a region, increases the frequencies of fires, and results in even more forest, biodiversity and crop loss. The challenge in the north is to foster sustainable agriculture through a combination of technical intensification and social empowerment rather than by greatly expanding the land area required (Matson et al., 1997). More sustainable agriculture/agroforestry will involve among other things: polycultures and intercropping rather than monocultures, integrated pest management instead of pesticides, the elimination of perverse subsidies, knowledge-based intensive management, and community-based conservation (Woodruff, 2001a). Sustainable agriculture in the hills cannot be achieved unless local human societal needs are met and biodiversity is conserved. Biodiversity science itself must evolve, and there must be greater integration of the biological and the social sciences in order to influence mainstream policy makers (Dirzo and Loreau, 2005). Geneticists have a role here in explaining the importance of the evolutionary processes that sustain life in all it diversity.

Biodiversity, Ecological Services and the Future

The connection between biodiversity and ecological services is well described in the U.N. Millennium Ecosystem Assessment (2005). This assessment of the earth's ecosystems was the largest ever undertaken and involved 1360 scientists in 95 countries. Analysts recognized 24 kinds of ecosystem services: some can be classified as provisioning and include providing humans with food, water, fuel, and fiber; some are regulating and involve the prevention of soil erosion and floods; some serve our cultural needs and provide for our recreation and spiritual values; and some provide for our basic support and are responsible for the oxygen we breath, for soil formation, and for plant transpiration and rain. Almost all human societies have taken these ecological services for granted, especially since people moved off the countryside and into cities and towns. Yet collectively, these ecological services have an unappreciated annual value of more than U.S.$33 trillion (Costanza et al., 1997; Daily et al., 2000).

The Millennium Ecosystem Assessment found that 60% of the ecological services were already degraded. We as one species among millions use an astounding 50% of the earth's gross primary productivity (Vitousek et al., 1997). As suggested above, current trends are such that we can confidently make some upsetting predictions about the decline of Thailand's biodiversity, biomes and ecological processes. Furthermore, these predictable changes come at a bad time as anthropogenic climate change will make matters worse for the surviving species as they will not be able to disperse freely. By fostering the discovery of Thailand's biodiversity before it is lost the BRT program is preparing the nation for a future in which the ecological services will require more management.

Although the loss of species is tragic the ecological consequences of the declines are more worrisome, Will ecological services fail? Can we predict the nature and significance of our impacts on ecosystem function as a result of habitat loss, degradation, and fragmentation? What will happen to the biogeochemical cycles as we further simplify ecosystems (physically and biologically) and shorten food chains? We can expect an increase in nutrient enriched niches and the ascent of the microbes. We can predict biotic homogenization and the ascent of domesticated species, weeds, generalists and commensals. We can predict the further inadvertent genetic modification of organisms as a result of their loss of genetic variability, the fragmentation of geographic ranges, the reduction of effective population sizes, and the elimination of predators and competitors, pollinators and dispersers. We cannot yet predict what the new disharmonious communities [assemblages of species] will look like 100 years from now, or how the surviving species will adapt to on-going environmental changes. Significantly, almost every one of the above processes involves genetics. The processes of evolution have not changed but the pattern has. The genetic consequences of small population sizes and the genetic erosion of adaptability will become far more significant.

While most futurists are concerned with extrapolating current trends we should be far more concerned with nonlinear changes, with unpredictable changes. Catastrophic examples involving biodiversity include the recent (and so far irreversible) collapse of two of the world's largest fisheries (Peruvian anchovy fishery, 20% of the world's catch, in 1972; and the Atlantic cod stocks off

Newfoundland in 1992). Other recent nasty surprises include the 1997-1998 cholera epidemics in East Africa, the emergence of Ebola, SARS and H5N1 viruses, and the discovery of marine offshore dead zones in the Gulf of Mexico. After the fact, we can often explain why these sudden changes make sense (e.g. the cholera outbreaks were associated with an El Nino, the marine dead zones are caused by anthropogenic nutrient loading that can cause sudden, widespread algal blooms that suffocate animals, and the emergent diseases all involve genetic shifts), but they are still nasty surprises and we have to expect more of them. The Precautionary Principle requires that as we seek to further develop and manage natural resources we do so in such a way as to avoid serious or irreversible environmental harm (Dickson and Cooney, 2006).

At a recent conference on the future of evolution the participants made a number of recommendations that directly impact both biodiversity and the human condition (Woodruff, 2001b). First, regardless of whether we are geneticists or taxonomists we should all work towards reducing human population growth and unsustainable resource use. Other recommendations are more in line with what we might expect to hear at a BRT program policy workshop: improve ecological education; alert the public (science alone cannot protect biodiversity); promote research on describing biodiversity before it is lost; promote research on ecological processes so as to ensure continued ecological services; do more to foster protection of freshwater and marine ecosystems; promote the creation and maintenance of national databases on species abundances and geographic ranges; and promote the creation and maintenance of national tissue banks or genetic depositories.

Sustainable development is the reconciliation of society's development goals with its environmental limits over the long term (NRC, 1999:22). It is the most recent conceptual focus linking the collective aspirations of the world's peoples for peace, freedom, improved living conditions, and a healthy environment. The latter links sustainability directly to the interests of the BRT program as the main areas to be sustained are nature, life support systems, and communities. Humans depend on life support systems provided by the biosphere. These ecological services include the obvious cleansing of water by plants and microbes and the fertilization of soil by microbes and fungi and invertebrates. They also include providing for our aesthetic and recreational needs and desires. Sustaining desirable lifestyles for Thai people will require a more complete understanding of how the Kingdom's biodiversity and ecological communities provide these ecological services. The conservation of biodiversity, and its genetic underpinnings, are thus important determinants of the future quality of life. To quote from the Earth Charter Preamble 'The resilience of the community of life and the well-being of humanity depend upon preserving a healthy biosphere with all its ecological systems, a rich variety of plants and animals, fertile soils, pure waters, and clean air. The global environment with its finite resources is a common concern of all peoples. The protection of Earth's vitality, diversity, and beauty is a sacred trust' (Earth Charter Initiative, 2000). Appropriately, the Charter received the endorsement of the 3rd IUCN World Conservation Congress held in Bangkok in November 2004. I wish the BRT program every success for the next 10 years as it helps prepare a new generation of Thais for their roles as environmental stewards and bioneers.

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