NAT. HIST. BULL. SIAM. SOC. 59(2): 91–107, 2013

WILDLIFE CONSERVATION IN PROTECTED AREAS IN THAILAND: LESSONS FROM CHIEW LARN, KHAO SOK AND KHLONG SAENG

***David S. Woodruff*[1]**

ABSTRACT

Chiew Larn Reservoir in southern Thailand was created in the forested interior of Khao Sok National Park and Khlong Saeng Wildlife Sanctuary in 1987. A study of small mammals isolated on the islands in the reservoir showed the near complete local extinction of the fauna in the 25 years after forest fragmentation. Wildlife conservation management and protected area policy implications of this study of fragmented forests are discussed as they will affect the next 50 years of Thai protected area management.

Keywords: area effect, conservation, environmental policy, extinction, genetic erosion, habitat fragmentation, invasive species, mammals, protected areas, sustainability

INTRODUCTION

In the September 29th, 2013, issue of *Science* magazine an international team reported the results of a 25-year study of small mammal populations in a protected area in southern Thailand (GIBSON *ET AL.*, 2013). The story was carried by the New York Times, the BBC, the U.S. National Public Radio, the Bangkok Post (MANOPAWITR, 2013), and numerous other media outlets including the other leading science journal, *Nature* (GONZALEZ, 2013). The study focused on the survival of small mammals isolated on the islands that formed in Chiew Larn reservoir when the Khlong Saeng valley was flooded in 1987. The surprising result was that wildlife disappeared from the forest fragments inside the protected area at 2–3 times the expected rate. Although this is bad news for conservation, there is much to be learned from the observations of relevance to the second 50 years of the Thai protected area system.

The Chiew Larn reservoir lies between Khlong Saeng Wildlife Sanctuary and Khao Sok National Park. Together with adjacent protected areas, this is the largest contiguous forest area in southern Thailand (>3,500 km^2). The location is just south of the Isthmus of Kra and west of the town of Surat Thani and lies in the north of the Peninsula Floristic Province (WELZEN *ET AL.*, 2011). This great forest provided habitat for rhinoceros, tiger, bears and elephants until recently. Although the last local rhinoceros was shot in the 1950's, the area still provided habitat for gibbons, deer, bear and elephants when the rising waters flooded the valley leaving about 100 forested hilltops in the lake (Fig. 1). The reservoir covers 165 km^2 and most of the islands are in the remote top or western end of the lake about 50 km from the Rajapraha

[1] University of California San Diego, CA, USA. E-mail: dwoodruff@ucsd.edu
Received 19 October 2013; accepted 2 December 2013.

Dam wall. Only a few hundred people were living in the forested Khlong Saeng valley when it was flooded, making the area ideal for studies of nature and natural processes.

THE KHLONG SAENG BIODIVERSITY PROJECT

The purpose of the Khlong Saeng Biodiversity Project was to use the flooding as a natural experiment to study the effects of forest fragmentation on wildlife (Woodruff, 1992). The islands in the reservoir were all created at about the same time and many were covered by relatively undisturbed natural evergreen rain forest. The plan was to observe populations of small mammals and monitor the effects of their isolation. Initially, there were 17 species of small mammals in the valley and these were studied as models of other species of greater interest to wildlife managers, but which are more difficult to observe. These small mammal populations were expected to decline slowly over time as a result of the ecological and genetic effects of range fragmentation. First, the *area effect* (large areas will have more species than small areas at equilibrium) was expected to result in species loss on the smaller islands faster than on the large islands. Second, the very small populations were expected to show genetic decline (*genetic erosion*), as a result of increased inbreeding and the loss of genetic variability (Woodruff, 1989; Young & Clarke, 2000). Together, the area effect and genetic erosion were expected to cause local species extinction (*extirpation*) over a period of 50–100 years.

Beginning in 1990, we selected 12 islands and 12 comparable (size and topography matched) forest areas on the adjacent mainland as sites for intensive study. As the mainland sites lay in undisturbed protected areas they served as controls for the experimental island sites. At each site, we live-trapped (and released) small mammals on or close to the ground until we were reasonably sure we had determined what species were present (Fig. 1). Of the 17 species of small mammals present 12 were trappable (8 murid rodents, 1 scuirid rodent, 2 insectivores, and 1 tree shrew); 3 arboreal squirrels and 2 extremely rare shrews were not included in the study. We trapped in the short hot dry season (January – March) during years 5, 6, 7, and 8 post-isolation, and we also trapped in the wet season of year 6. More than 40,000 trap-nights of effort went into the initial survey of years 5–8. In 1990, the ecological area effect was well understood in both theory and practice, but genetic erosion was less well known to wildlife managers and had never been monitored in real time before.

The initial trapping site selection and ecological monitoring was conducted by Tony Lynam, a Ph.D. student at the University of California (UC) San Diego (Lynam, 1995). He found 12 species of small mammals in the mainland species pool and 12 species on the largest island (56 ha), 7–9 species on medium-sized islands (10–12 ha), and less than 3 species on the smaller islands (<5 ha) during years 5, 6 and 7 post-isolation (Lynam, 1997). The predictions of area effect theory were confirmed: native mammal species declined on medium and small islands and went extinct on very small islands. Species did not respond to the disturbance independently but rather in groups; if one species was missing, specific others were probably also missing. This suggested that species similar to one another ecologically were likely to go extinct locally when community-level ecological processes began to change. The results of this ecological research are published (Lynam, 1996, 1997; Lynam & Billick, 1999; Lynam & Woodruff, 1993a, 1993b; Lynam *et al.*, 1992).

The initial studies of genetic erosion were conducted by Sukamol Srikwan from Chulalongkorn University as part of her Ph.D. at UC San Diego (Srikwan, 1998). Using

Figure 1. Rain forest covered islands in Chiew Larn reservoir (A–D) were originally inhabited by 12 species of small mammals. As a result of forest fragmentation, the area effect, and the invasion of a rat species not found in undisturbed forest, all native species went extinct locally in less than 25 years. (E) Dr. Sukamol Srikwan with a live-trapped rat and (F) releasing a pencil-tailed tree-mouse back into the forest. Photos: (A) Tony Lynam, (B–F) David Woodruff.

DNA samples collected noninvasively by Lynam and herself in years 5–8, she was able to characterize the genetic variability of several small mammal populations. The technique of noninvasive or nondestructive genotyping was first introduced using Thai examples (using gibbon hair, elephant dung, and hornbill feathers) and enabled us to study the genetics of wild animals without disturbing them, without bleeding them or taking internal tissue samples (Woodruff, 1990, 1993, 2003; Morin *et al.*, 1994; Morin & Woodruff, 1996; Srikwan & Woodruff, 1998; Woodruff & Srikwan, 1998). Three species of native mammals were sufficiently common to use for genetic studies: red spiny rat, *Maxomys surifer*, pencil-tailed tree-mouse, *Chiropodomys gliroides* (Fig.1), and treeshrew, *Tupia glis*. As these animals were previously unstudied genetically, she first had to do significant laboratory work to identify informative genetic markers of nuclear variation (SRIKWAN & WOODRUFF, 1996, 1997; SRIKWAN *ET AL.*, 1996, 2000). By comparing isolated island populations with those on the undisturbed mainland in years 5–8, she was able to demonstrate a loss of variation in the fragmented (island) populations of each species by year 8. Furthermore, as predicted by theory (WRIGHT, 1931), she found populations on small islands lost more variation than those on larger islands (SRIKWAN & WOODRUFF, 2000). Of greater significance was her finding that recently fragmented populations lost variability faster than expected and that genetic erosion accompanied demographic decline in two species and commenced before the onset of obvious decline in numbers in the tree-mouse. Genetic responses to fragmentation were species-specific with population size, generation time, and dispersal behavior affecting the response of each species. Her reports (SRIKWAN & LYNAM, 1996; SRIKWAN & WOODRUFF, 1998a, 1998b, 2000) were the first to show that genetic erosion can be monitored and her approach is now used by others around the world.

So the initial studies at Chiew Larn were successful in that we began to see population *extirpations* (local extinctions) of some species on the smaller islands and we were able to provide the first demonstration of a new way of monitoring the genetic health of wild populations (WOODRUFF, 1999, 2006; WOODRUFF *ET AL.*, 1996, 1998). Our results were in agreement with both ecological and genetic theory and showed that most of the islands were too small to support their original native mammal community. Extinction proneness was species-specific and more associated with tolerance of disturbance, to change in microclimate and microhabitat, than with initial abundance (LYNAM, 1997). We left the sites in 1997 with every intention of returning when additional funds became available.

Our observations during years 5–8 suggested that local extinctions were occurring faster than expected and we attributed this to two unexpected processes. First, *edge effects* quickly reduced the forest habitat area on each island. Bamboo rapidly spread around the edge of each island in response to the open habitat. Unfortunately, bamboo also readily caught fire during the dry season. Although a few fires were due to lightning strikes, the majority was caused accidentally by fishermen leaving untended fires. The incidence of such fires increased dramatically and, by the dry season of 1994, the lake was often blanketed by smoke for weeks. LYNAM (1997) estimated that 30 km^2 of forest bordering the reservoir was permanently damaged by fire or illegal selective timber cutting. Second, we discovered an *invasive species* was altering the natural community. We observed the Malayan field rat, *Rattus tiomanicus* [then identified as *Rattus rattus*], in traps on the more disturbed islands. This aggressive species is associated with villages and agriculture fields in the peninsula and is not found in undisturbed rainforest. It was probably brought in inadvertently on fishing boats as soon as the reservoir filled. By year 5 it had become hyperabundant on small islands and, by year 7, it was the only species on the small islands. We thus completed our initial five-year study apprehensive that the fire exacerbated edge effect and the invasion of the introduced rat might accelerate local extinction processes.

We were able to re-visit the islands in 2011–2012, 25 and 26 years after their formation. Our goals were to obtain more compelling evidence for genetic erosion in the commoner species and see if the surviving species had broader ecological niches and changed diets in the absence of their former competitors. Unfortunately, we were unable to achieve either goal.

After 25 years all the original native mammal species had disappeared from the 16 islands studied; there was nothing left to measure. This 25-year follow-up study was conducted by Luke Gibson who completed his Masters at UC San Diego before transferring to the National University of Singapore to complete this research for his Ph.D. His results are described in the report in *Science* (Gibson *et al.*, 2013), the focus of this commentary.

Gibson *et al.*, observed the near-complete extinction of native small mammals from the islands 25 years after forest fragmentation. The original small mammal community was replaced on every island by the Malayan field rat, *Rattus tiomanicus*. Between year 8 and year 25 the invasive rat had replaced the native forest species and is now the only species on half the islands surveyed. Aside from the rat, only 13 individual small mammals were encountered in 7,000 trap nights in the year 25 re-survey; only 9 individuals were observed in 5,000 trap nights in the year 26 re-survey; less than one individual per island on average. Using an island biogeographic (area effect) model, we estimated the mean extinction half-life (50% of resident species disappearing) to be about 14 years on these islands and full relaxation to just one species to occur within 40 years. In contrast, the mainland forest control sites showed no such decline in species richness.

In summary, we documented a case of rapid *faunal relaxation* (Gonzalez, 2013), a process that will, over time, diminish the biotas of all but the largest protected areas in Thailand. A disturbance tolerant species replaced the other community members at Chiew Larn and the resulting community is now impoverished and in *ecological melt-down* (Estes *et al.*, 2011). As this pattern of impoverishment is repeated around Thailand and the world, the planet's biota becomes more homogeneous and the simplified communities become less stable than the natural ones they replaced (Woodruff, 2001a).

CONSERVATION LESSONS AND POLICY IMPLICATIONS

Thailand sits in one of the most biologically important regions of the planet; ranking among the top hotspots for irreplaceability and threat (Dijk *et al.*, 2004; Joppa *et al.*, 2013). Protected area officials have a remarkable record of conservation stewardship to show for their first 50 years. To say they face enormous challenges would be an understatement. They are working with only 20% of the natural habitat remaining and in a political environment that has traditionally sought to control or exploit nature. Fortunately, they do not work alone; a consortium of major international donors called the Critical Ecosystem Partnership Fund (CEPF) is also interested in regional conservation. The CEPF is designed to safeguard the world's biologically richest and most threatened regions. It is a joint initiative of the French development agency, Conservation International, the Global Environment Facility, the Government of Japan, the John D. and Catherine T. MacArthur Foundation, and the World Bank. Regionally, CEPF found the threats to wildlife in and out of protected areas are, in order of importance: (1) hunting and trade in plant and animal products, (2) conversion of natural vegetation to agro-industrial plantations, and (3) hydropower dams (CEPF, 2012). Within Thailand the CEPF identified agricultural encroachment by smallholders, unsustainable exploitation of non-timber forest products (poaching), habitat loss and fragmentation as the biggest threats. To this list we must also add invasive species, genetic erosion in small populations, pollution, and climate change. Dealing with each of these threats over the next 50 years will require rethinking and restructuring many government policies, programs and agencies. I will argue here that these coming changes are part of the much bigger global societal transformation from exploiting nature to sustaining both wildlife and people. As a guest researcher in Thailand, I will not be so presumptuous as to intrude on Thai affairs with unsolicited advice, but I shall point out some of the implications of our observations.

The bigger lessons of Chiew Larn have little to do with rats and mice and forest fragments and more to do with the sustainability of biodiversity at the national level. Thailand is a party to the Convention of Biological Diversity (CBD) that was formalized at the 1990 Rio Earth Summit. Under this international Convention, Thailand is obliged to conserve and sustain biodiversity. Goals and metrics were established and, in 2010, the Parties met and announced that they had failed. Fortunately, instead of giving up, they agreed to give themselves another 10 years. The Parties, including Thailand, re-formulated their goals as the *Aichi Biodiversity Targets for 2020* (see CBD, 2013). There are 20 Targets and I will briefly discuss how the Chiew Larn experience is related to at least seven of them.

It is fortunate that, in Thailand, most of the Critically Endangered and other threatened species of greatest concern under the CBD occur in existing protected areas (IUCN, 2013). These protected areas have undoubtedly kept Thailand off the lists of countries with the most threatened biota. Although none of Thailand's 148 protected areas rank among the top-200 sites on earth for the irreplaceability of their overall faunas (threatened *and* non-threatened amphibians, birds and mammals), Khao Yai National Park ranks first nationally, and 260th among the 194,880 protected areas analyzed world-wide (Le Saout *et al.*, 2013). It is interesting to note, however, that by this criterion of species irreplaceability, Khlong Saeng, Khao Sok and the adjacent Khlong Nakha National Park are all more important in terms of protecting threatened and endangered species than is Khao Yai (Le Saout *et al.*, 2013).

Implications for Conservation in Fragmented Forests

The Chiew Larn experiment shows that forest fragments less than 100 ha in area are too small to sustain the short-tailed gymnure, *Hylomys*, the long-tailed giant rat, *Leopoldamys* and the treeshrew *Tupia*; too small to sustain viable populations of the original forest small mammal community. Local extinctions were very rapid because of the combined effects of area, edge, and an invasive species. Now isolated, many of the remaining trees will slowly die and the original biota will vanish. This results in what is known as the empty forest syndrome; the trees are still there, but the mammals and birds are gone. The conservation lessons are not surprising: to sustain wildlife, managers need, first and foremost, the largest possible areas to work with. Secondly, they need to actively minimize the effects of habitat degradation (by edge effects and invasive species), and to maintain habitat connectivity between fragments. Fortunately, in the Chiew Larn case, managers did not also have to counter the degradation caused by unregulated tourism or a large resident human population.

These conservation lessons are well understood by wildlife officials; comparable effects of habitat fragmentation have been documented in Panama, Brazil, and California (Bolger *et al.*, 1991; Laurance & Bierregaard, 1997; Laurance *et al.*, 2002). Other teams of researchers have obtained similar results to ours elsewhere after observing primates, birds and butterflies. This is important as we are often asked: who cares about rodents? It was never our purpose to help save the rats and mice of Thailand. We were using these small mammals as models to learn more about natural processes that affect all types of plants and animals. Although we could not study the large mammals of traditional concern as most of them had already been extirpated by hunting, our results are directly relevant to their conservation elsewhere. And, although small mammals are ignored by most protected area managers and visitors, they play essential ecological roles in forest dynamics and the functioning of natural communities. Rodents, for example, are the dispersal agents of vesicular arbuscular mycorrhizal fungi (associated with plant roots) upon which all trees depend for their nutrition. Small mammals also disperse seeds upon which the forest depends for restoration after disturbance. They, in turn, provide food for numerous mesopredators (mammals, birds and reptiles). The small mammals are thus both essential to the functioning of the entire natural community and excellent surrogates for other groups that may be more difficult to study; trophic downgrading of the entire ecosystem follows their disappearance (Estes *et al.*, 2010).

The importance of habitat connectivity was underappreciated until the 1990's. Protected areas are at best static solutions to dynamic problems – species ranges and species assemblages are changing and protected areas, that are by definition fixed in location, may doom their inhabitants to extinction if they cannot move in response to environmental changes. Contiguous protected areas are crucial for the future evolvability of plants and animals, especially under on-going climate change (Welzen *et al.*, 2011; Blois *et al.*, 2013; Diffenbaugh & Field, 2013; Moritz & Agudo, 2013; IPCC-5, 2013). In this regard, Thailand is in better position than many countries as it has already set aside several large contiguous protected areas including the western forest block (Thung Yai – Huai Kha Khaeng), the central forest block (Dong Phayayen – Khao Yai), and a mid-peninsula block which includes the Chiew Larn site (Khao Sok, Khlong Saeng, Khlong Yan, Khlong Nakha, Kaeng Krung and Sri Phangnga). After consulting many Thai stakeholders the CEPF prepared maps showing the connections between current Protected Areas that can be used to set priorities (CEPF, 2012: Fig. 11a, b). These corridors and habitat connections are critical for the survival of landscape level species like elephant and tiger. The issue now is whether these contiguous forests can be managed holistically or whether bureaucratic traditions, policies and regulations will hinder such management?

It has been suggested that our Chiew Larn experiment has little to teach us about wildlife management, as our study sites were too small to be of any value. We acknowledge that they are at the lower end of the spatial scale of protected areas and especially prone to edge and area effects. Our publisher, *Science* magazine, raised this question in a short commentary entitled: "Futile Forest Fragments" (*Science* 341: 1429). This is an understandable but unfortunate cliché as it is not entirely true. These and other small fragments may be all we have left, and they may, if managed properly, have significant conservation value. In particular, if fragments are connected with one another by corridors, or non-hostile habitats that some plants and animals can cross, they can play a real role in permitting re-colonization and adaptation to climate change. Small fragments are certainly more valuable for some taxa (like amphibians, reptiles, butterflies, snails and flowering plants) than others and they can still sustain ecological processes and provide some ecological services. Left alone, however, fragment area and the eternal external threat associated with edge effects and invasive species will doom their biota. Populations in fragmented forests will require active ecological and genetic management if they are to survive. Unfortunately, less than 20% of the Thai peninsula remains under forest cover and the median size of the remaining mostly unprotected remnants is only about 100 km^2, smaller than those in other parts of Thailand (Brockelman & Baimai, 1993). If this is still the case, the government should be encouraged to enlarge its protected area inventory in the south. Overall, Thailand has already met the Aichi Biodiversity Target No. 11 (CDB,

2012) of *setting 17% of its land aside as protected areas* (see: http://www.protectedplanet.nat/ and Bertzky et al., 2012), but, at least in the peninsula, some protected areas are too small and too far apart to sustain viable populations of plants and animals. If the conservation of biodiversity is important and, if sustaining ecological services is a national priority, then protecting the largest possible areas remains the single best investment. It is most unfortunate that this is going on at the same time that unprecedented anthropogenic climate change will significantly reduce the amount of coastal land available for conservation, agricultural, urban and other purposes (Woodruff & Woodruff, 2009).

I have focused above on the effects of forest fragmentation in a protected area and not on their root cause: the flooding of the valley to generate a small amount of electricity. As noted above, the CEPF (2012) found that hydropower dams were the third most significant threat to regional biodiversity. As a result of unsustainable fishing practices, invasive species, habitat alteration and loss, and the cessation of the flood-pulse cycle, freshwater communities are under greater threat in Southeast Asia than anywhere else on earth (Dudgeon, 2002, 2011). This is important as the region is the third richest in the world in terms of freshwater fish diversity and, paradoxically, this biodiversity is not the responsibility of the Department of National Parks, Wildlife and Plant Conservation, even in protected areas.

The initial decision to flood the Khlong Saeng in the interior of a protected area was made in the 1980's and was based in part on the argument that the intact forest and native fish fauna had negligible economic value (EGAT, 1980). Today, that finding would be disproven; various NGOs have exposed serious deficiencies in the EIR prepared by TEAM Consulting Engineering and Management Co., Bangkok. For example, power generation is now at best only 50% of capacity (perhaps because of dam wall structural concerns) and fishing yields are only 20% of those projected in the EIR. Based, in part on the Chiew Larn experience, many people in Thailand have rejected such other ill-conceived hydropower dams as the Nam Choan (within Huai Kha Khaeng and Thung Yai Naresuan Wildlife Sanctuaries), the Mae Wong (that would flood Mae Wong National Park in the Western Forest Complex), and the Pak Mun (which flooded part of Kaeng Tana National Park). Today, the verifiable valuation of biodiversity loss and ecological service degradation would have to be taken into account (Daily & Ellison, 2002; Kareiva *et al.*, in press) and one would conclude that the initial decisions were not based on all the evidence. In future, Thai planners will have to pay more attention to the country's commitment to meet Aichi Biodiversity Target No. 2, that "*by 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes*," and Target No. 7, that "*by 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity*".

Implications for Research in Protected Areas

Given that protected area staff rarely monitor small mammal populations one can also ask whether the Chiew Larn experiment has any relevance to the conservation of the larger animals that Thais hope to save? The answer is that it does, as even the largest protected areas will lose species populations, albeit more slowly. Saving the charismatic mega-vertebrates will require active management, based on principles of modern genetics, ecology, behavior and evolution (Woodruff, 2001a). Conserving such species requires that managers understand how the natural communities in which these species live are structured and function. Such understanding usually comes from population and habitat viability analyses based on intensive long-term field studies (Westley & Miller, 2003). Currently, Thai government agencies do not have the capacity to conduct such investigations and have to turn to academic scientists for help. Strengthening the linkages between agency staff and academics would clearly make it easier for the former to do their jobs. So, at the level of the agencies, the lessons of Chiew Larn include the urgent need for more local research on sustaining biodiversity and ecosystem functions.

Creating stronger connections between the academic and management communities would definitely help in the future. Protecting nature requires technically competent management and protected area staff need more training, resources, authority, and help from both natural and social scientists in academia. At Chiew Larn, illegal logging and hunting, water pollution from mining in the watershed, and fires associated with fishing of introduced species fostered by another government agency, all distracted wildlife managers from their core functions. Conservation is not simply setting aside land, stopping poaching and encroachment, and letting nature take care of the details; it requires far more pro-active management. Community restoration (see Elliott *et al.*, 2013), invasive species removal, managing dispersal in fragmented landscapes, population rescue following extirpation by reintroduction, countering genetic erosion in small populations and fire suppression, all require technical skills not related to traditional monitoring, anti-poaching and anti-encroachment activity.

Historically, national regulatory procedures have made it difficult to conduct research in protected areas. Thai academics face problems if their interests are undervalued by site managers or their superiors. Foreign scientists and students face additional regulatory hurdles to collaborate with their Thai academic or government colleagues. Permits for foreign researchers are managed by the National Research Council of Thailand to protect Thai interests; this is important and conforms to international practice. For example, ensuring that voucher specimens remain in country, protecting biodiversity from bio-pirates under the Nagoya Accords (CBD, 2013), requiring the training of Thais as part of a research project, and protecting the native biota from harm are all reasonable requirements. Unfortunately, the current permitting process is still too slow for many investigators and funding agencies, especially when multiple areas or jurisdictions are involved. Unfortunately, although it may be in the national interest to encourage collaborative international research activities, the permit process deters some from offering their expertise. Further review of these procedures could facilitate both the work of Thai researchers and foster a closer, more beneficial interaction between scientists and the staffs of the protected areas.

Closer technical ties between researchers and managers are essential if the latter are to succeed. In 2013, the Department of National Parks, Wildlife and Plant Conservation organized a successful meeting between the two groups that focused on Khao Yai National Park. Khao Yai was Thailand's first protected area and opened in 1962. It is famous internationally as a site for long-term research on hornbills and gibbons (Tunhikorn *et al.*, 1994; Poonswad, 1998; Brockelman *et al.*, 2011; Brockelman, 2014). Both researchers and managers benefitted from their interaction and the activity provides a useful model that should be rolled-out nationwide. Organizing annual gatherings for protected area staff and academics (Thai and visiting) will encourage the participants to build professional and productive networks. Furthermore, having chiefs and policy makers attend at least some of the sessions is critical in order for them to understand their staff's needs. Creating a Knowledge Action Network is an efficient way of getting all the stakeholders together informally to build trust and cooperation. The network building approach is being adopted throughout the science and technology world (e.g. Kennel & Daultrey, 2010, Woodruff & Falk, 2012, STS, 2013) as a better, more productive way forward, than that involving traditional competitive or antagonistic relationships. The IUCN is a mature example of network effectiveness (see e.g., Westley & Miller, 2003). Facilitating greater collaboration between agency staff and local scientists would be a clever strategy for the Thai agencies.

Implications for the Management of Biodiversity at the National Level

The biggest development in the field of conservation in the last 30 years has not been the amazing advances in scientific understanding, but rather the realization that to save species one first has to save people. Protected area managers are forever frustrated and sidetracked if the needs and aspirations of local people are not addressed. In Thailand, many years of conservation effort have been lost to the still unresolved issues surrounding the man-in-the-forest and the people-at-the-forest-edge situations. Debates over biodiversity and natural resource management were unfortunately re-framed as pitting trees against universal human rights (Fahn, 2003; Woodruff, 2001b, 2006). Given that it is now clear that what goes on around a protected area is in many cases more important than what goes on inside a reserve's boundary, managers must in future pay more attention to poverty alleviation among people living around protected areas. This requires the recognition by policy makers that the choice between people and wildlife is a false dichotomy; conserving wildlife and natural resources requires the understanding and cooperation of local people. In addition, protected area staff will require more training in communication and the social sciences than are taught in traditional natural resource management programs. With hindsight, the extirpation rates, logging and poaching observed at Chiew Larn may have been reduced if there had been a more integrated approach to meeting the needs of neighboring people. Nationally, such concerns have to become a more significant part of the mission of the protected area agencies (Srikosamatara & Brockelman, 2002; Western *et al.*, 1994).

The Department of National Parks, Wildlife and Plant Conservation and other natural resource agencies are challenged by the prediction, based on the area effect and resulting faunal relaxation, that 21–24% of Thailand's biota is threatened with extinction by 2030 (Wright & Muller-Landau, 2006). These agencies help Thailand meet her obligations under the CDB and the forest fragments at Chiew Larn illustrate the problems identified in Aichi Biodiversity Target No. 5 (*reducing the rate of loss of natural habitats…and their degradation and fragmentation*), Target No. 9 (*invasive alien species…are controlled*), and Target No. 12 (*the extinction of species has been prevented*). Although the rate of deforestation has declined in Thailand, the existing protected areas cannot help the nation meet these goals without much more active management with technically well-trained staff.

The Chiew Larn experience raises a bigger issue about natural resource management: are current government agencies equipped to tackle the societal transformation from resource exploitation to sustainable use? Does the Department of National Parks, Wildlife and Plant Conservation of the Ministry of Natural Resources and Environment (MoNRE) have the power to do what it is being asked to do? How well does it work with the other bodies with environment-related remits including the Department of Marine and Coastal Resources, the Royal Forest Department and the Office of Natural Resources and Environmental Policy and Planning (all within MoNRE), the Department of Fisheries, and the Department of Agriculture?

The Office of Natural Resources and Environmental Policy and Planning is responsible for developing and coordinating national and international environmental plans and policies. It hosts the secretariat of the National Biodiversity Board, functions as a clearing house for the Convention on Biological Diversity, and supports research and programs relating to access to and sharing of benefits from biodiversity use. Most developed countries are finding it necessary to elevate the status of their environmental agencies as the political and economic costs of past environmental policy mistakes become understood and as interagency coordination become mission-critical.

Can the Department of National Parks, Wildlife and Plant Conservation help the nation meet the CBD Aichi Biodiversity Goals? Can it fully engage the nation to make the changes necessary to achieve the 2020 targets? Consider specifically *Aichi Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society. Target 1: By 2020…people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably* (CBD, 2013). At first, this seems to have little to do with protected area management. But the ultimate question is whether Thais want their protected areas to be revenue-generating centers or whether they want to see these areas sustained as the providers of ecological services for local people, Thai and foreign eco-tourists, and the nation. This is a tough problem to solve in a democracy as each government agency and each sector of society will advance its own self-interest. Although the attitudes of educated Thais have changed dramatically in last 50 years, many people are still not aware of the linkages between ecology and their own family's wellbeing. The Department of National Parks, Wildlife and Plant Conservation should encourage the government to provide more visits to protected areas for school children as is done in other countries. Urban children in particular are growing up with very little appreciation of the value of nature. Introducing children to protected areas is important as ultimately some of them will become the champions of nature conservation and sustainability in the next generation. Education may produce better results in the long-term than prevention.

The realization that biodiversity and ecological services have very significant economic value is bringing about a major shift in public attitudes towards nature (Mulongoy & Gidda, 2008). Annual costs of global environmental damage are now estimated to be in the US$5 trillion range. Natural capital accounting puts the value of ecological services provided (clean water, oxygen liberation, carbon sequestration, recreation) at ten times that amount (TEEB, 2010; Sukhdev, 2011; Kareiva *et al.*, in press), or $33 trillion per year according to Costanza *et al.*, (1997). Such valuation has necessitated a rethinking of the purpose of protected areas.

In the USA and elsewhere, national parks were not established for wildlife conservation even though many people today often think that is their purpose. Typically, they were set aside to preserve spectacular scenery for public enjoyment. In contrast, Wildlife Sanctuaries, with more limited public access, obviously involve conservation as their primary mission. Problems arise when the two types of protected areas have different regulations and lie adjacent to one another as at Khao Sok National Park and Khlong Saeng Wildlife Sanctuary which share a watershed. Conservation management of plants and animals and their natural communities is not well served by regulatory distinctions on either side of artificial boundaries. The growing need for higher-level inter-agency cooperation and coordination was clear at Chiew Larn where, again, logging, hunting, mining, fishing, fire, introduced species, and tourism, all played out across three or more jurisdictions. Similarly, conducting scientific research in the interests of conservation across these boundaries is more difficult than necessary. Greater coordination between agencies will become even more essential as connections and corridors become part of national strategies to protect biodiversity from climate and other environmental changes. This is especially important for Thailand's trans-boundary protected areas. In this regard, the recent creation of the ASEAN Wildlife Enforcement Network linking police, customs and environment agencies of all member countries is a welcome development.

The great societal transformation to sustainability has begun in Thailand, as in other countries, but traditional government agencies are still too compartmentalized in competitive, counter-productive ways to effectively manage natural resources. This is not just a Thai problem; everywhere people are trying to deal with twenty-first century problems using twentieth century institutions. Although some Thai forest management regulations go back 100 years, the enabling laws establishing the protected area system date to 1960 and 1961, when their only function was to prevent encroachment and poaching. Much progress has been made since then but the under-pinning legal framework is increasingly dated. For example, Thailand has a National Biodiversity Strategy and Action Plan, as required by the CBD, but its implementation is hindered by the limited resources and political power of the responsible agencies, and by existing disincentives for cooperation between them.

The Next 50 Years of Protected Area Stewardship: Sustaining Life in a Post-Natural World

What happened on the islands at Chiew Larn was predictable. What makes the story unusual and newsworthy was the unexpected speed of local extinctions. Fragmentation, coupled with the arrival of an invasive species, accelerated the rate of species loss 2–3-fold. If that result is general, then we have less time than we thought (~100 years) to conserve Thailand's biodiversity, even in the larger protected areas. For that reason, it is imperative to strengthen the agencies responsible for managing protected areas. Unfortunately, they are poorly positioned to do this without further changes in national attitudes towards nature. Unless the agencies can become more powerful politically, more proactive with respect to conservation management, and more coordinated in their efforts, Thailand will continue to lose species and functional ecosystems. This situation requires a shift towards more holistic management and a re-thinking of the agencies so they can deal with changed environmental circumstances and valuation. Again, this is not just a Thai problem; but one faced by most countries, as they shift focus from exploitative to sustainable use of natural resources. This great societal transformation will take a few decades if we are intelligent and lucky. Furthermore, as little new land can now be added to the protected area network, Thais will have to manage the surviving biodiversity more actively and scientifically than they have in the past. In fact, because of on-going sea level rise, there will be less land to shelter Thailand's biodiversity (Woodruff & Woodruff, 2008). In the interim, threatened and endangered species like tigers, tapir, Eld's deer, gibbons, rhinoceros hornbills, Gurney's pitta, Mekong giant catfish and the tree *Aquilaria crassna* (the source of *mai hom* or aloewood; Zhang *et al.*, 2008) (to name just eight examples) all deserve more attention from researchers as their plight is symptomatic of the bigger problem that our ecological footprint has exceeded the planet's capacity to sustain our future.

The next 50 years will be exciting ones for the management of protected areas in Thailand. Although there is much depressing news about the threats to biodiversity, it is important to remember that a great societal change in attitudes has begun. The pace of this change and the increased roles of community-based civil society organizations (NGOs) are remarkable. So, this is a difficult decade for ecologists; to quote Charles Dickens (1859) "It is the best of times, it is the worst of times." The good news is that we are discussing these issues and recognizing the need to take action at four levels: species, sites, corridors and education. The great news is that the growth of the human population is slowing; the rate of deforestation is declining; people are moving to the cities, taking pressure off remaining natural habitats; greenhouse gas emissions has moved onto the international stage; alternatives to fossil fuels are under active development; pro-poor community-based conservation has been shown to work; activism coupled with a free press has accelerated the rate of social change; and, most importantly, the real value of nature as the provider of ecological services is becoming more widely appreciated (Woodruff, 2012). The United Nations has declared this the "Decade of Biodiversity" and opened a new agency: the Intergovernmental Platform on Biodiversity and Ecological Services, hosted by Germany, to deal specifically with the issues (IPBES, 2013). All the signs suggest the protected areas of Thailand will eventually get the societal support they need to sustain biodiversity and ensure human wellbeing. Thais should be guarded optimists about their future—they should celebrate the fact that, in one generation, they and the international community, have come to recognize the importance of protected areas, of biodiversity and the ecological services it provides, as vital to maintaining the habitability of the planet.

ACKNOWLEDGEMENTS

Our studies at Chiew Larn were permitted by the National Research Council, the Royal Forest Department, and the Department of National Parks, Wildlife and Plant Conservation, and could not have occurred without the support of the Chiefs of Khao Sok National Park and Khlong Saeng Wildlife Sanctuary and local EGAT officials. We are also grateful to more than 24 local Thais who assisted Tony Lynam (currently the Bangkok-based Regional Advisor, Asia Programs, Wildlife Conservation Society), Sukamol Srikwan Jakobsson (currently the co-founder of the Silicon Valley computer network and security company, Extricatus, LLC) and Luke Gibson with their fieldwork.

I am personally indebted to the late Seub Nakhasathien and Sawai Wanghongsa (both former officers at Khlong Saeng Wildlife Sanctuary), and the late Jarujin Nabhitabhata (former director, National Science Museum) for their assistance in getting the Khlong Saeng Biodiversity Project started (Woodruff, 1990), and to Sara Bumrungsri (Prince of Songkhla University) for his collaborative support of the year 25 re-survey. Khun Seub, was appointed wildlife evacuation project leader for the Chiew Larn dam project in 1986 and carried out a heroic and well-intended wildlife rescue to save drowning animals from the rising waters. In his own opinion, the effort failed because of inadequate resources and personnel training (Nakhasathien, 1988, 1989) and our results are an extension of his observations of the unnecessary deaths of many animals. He went on to become the Superintendent of Huai Kha Khaeng Wildlife Sanctuary (Thailand's premier sanctuary and now a World Heritage Site), and his tragic death in 1990 precluded his further involvement the project.

I also much appreciate advice on Thai wildlife conservation over the years from Visut Baimai, Warren Brockelman, Stephen Elliott, George Gale, Jeff McNeely, Chira Meckvichai, Wina Meckvichai, Pilai Poonswad, Parntep Ratanakorn, Phil Round, Sompoad Srikosamatara, Ronglarp Sukmasuang, Kumthorn Thirakupt, Schwann Tunhikorn, and many other Thai colleagues and friends.

My research at Chiew Larn was initially supported by the U.S. National Science Foundation and the UC San Diego Academic Senate. Gibson's year 25 re-survey was supported by the UCSD Jeanne Messier Memorial Fund, the UCSD Academic Senate, the National University of Singapore, and the Ah Meng Memorial Conservation Fund.

REFERENCES

BERTZKY, B., C. CORRIGAN, J. KEMSEY, S. KENNEY, C. RAVILIOUS, AND C. BESANÇON, N. BURGESS. 2012. *Protected Planet Report 2012: Tracing Progress Towards Global Targets for PAs*. IUCN, Gland. Available at: http://www.unep-wcmc.org/ppr2012_903.html

BLOIS, J. L., P. L. ZARNETSKE, M. C. FITZPATRICK, AND S. FINNEGAN. 2013. Climate change and the past, present, and future of biotic interactions. *Science* 341: 499–504.

BOLGER, D. T., A. C. ALBERTS, AND M. E. SOULE. 1991. Occurrence patterns of bird species in habitat fragments: sampling, extinction, and nested species subsets. *American Naturalist* 137: 155–166.

BROCKELMAN, W. Y. 2014. Gibbon studies in Khao Yai Park: some reminiscences. *Nat. Hist. Bull. Siam Soc*. 59(2): 109–135.

BROCKELMAN, W. Y., AND VISUT BAIMAI. 1993. Conservation of biodiversity and protected area management in Thailand. Proceedings of Skill Transfer Workshop by MIDAS Agronomics Co. (The World Bank GEF Preinvestment Study), MIDAS Agronomics Co., Bangkok, 75 pp.

BROCKELMAN, W. Y., A. NATHALANG, AND G. A. GALE. 2011. The Mo Singto forest dynamics plot, Khao Yai National Park, Thailand. *Nat. Hist. Bull. Siam Soc*. 57: 35–56.

CBD [Convention on Biological Diversity]. 2012. National Action for Protected Areas: Key messages for achieving Aichi Biodiversity Target 11. Secretariat of the Convention on Biological Diversity, Montreal, Canada. 60 pp. See: http://www.cbd.int/doc/publications/pa-national-action-en.pdf

CBD. 2013. See: http://www.cbd.int/ For *The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* see: http://www.cbd.int/abs/

CEPF [Critical Ecosystem Partnership Fund]. 2012. *Ecosystem Profile. Indo-Burma Biodiversity Hotspot*. 381 pp. See: http://www.cepf.net/SiteCollectionDocuments/ indo_burma/ IndoBurma_ecosystemprofile_2011_update.pdf

COSTANZA, R., R. D'ARGE, R. DE GROOT, S. FARBER, M. GRASSO, B. HANNON, S. NAEEM, K. LIMBURG, J. PARUELO, R. V. O'NEILL, R. RASKIN, P. SUTTON, AND M. VAN DEN BELT. 1997. *The value of the world's ecosystem services and natural capital*. *Nature* 387: 253–260

DAILY, G. C., AND K. ELLISON. 2002. *The New Economy of Nature: The Quest to Make Conservation Profitable*. Island Press, Washington, DC.

DICKENS, C. 1859. *A Tale of Two Cities*. Chapman & Hall, London.

DIFFENBAUGH, N. S., AND C. B. FIELD. 2013. Changes in ecologically critical terrestrial climate conditions. *Science* 341: 486–492.

DIJK, P. P. VAN, A. W. TORDOFF, J. FELLOWES, M. LAU, AND M. JINSHUANG. 2004. Indo-Burma. Pages 323–330 *in* R. A. Mittermeier, P. Robles Gil, M. Hoffmann, J. Pilgrim, T. Brooks, C. G. Mittermeier, J. Lamoreaux, and G. A. B. da Fonseca (eds.), *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Conservation International, Washington DC.

DUDGEON, D. 2002. The most endangered ecosystems in the world? Conservation of riverine biodiversity in Asia. *Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie*. [Internat. Soc. Limnology] 28**:** 59-68.

DUDGEON, D. 2011. Asian river fishes in the Anthropocene: threats and conservation challenges in an era of rapid environmental change. *Journal of Fish Biology* 79: 1487–1524.

EGAT [Electricity Generating Authority of Thailand]. 1980. Chiew Larn Project: environmental and ecological investigation. Final Report, Volume II: main report. EGAT, Bangkok.

ELLIOTT, S., D. BLAKESLEY, AND K. HARDWICK. 2013. *Restoring Tropical forests: a Practical Guide*. *Royal Botanic*

Gardens, Kew, UK. 264 pp.

Estes, J. A, J. Terborgh, J. S. Brashares, M. E. Power, J. Berger, W. J. Bond, S. R. Carpenter, T. E. Essington, R. D. Holt, J. B. C. Jackson, R. J. Marquis, L. Oksanen, T. Oksanen, R. T. Paine, E. K. Pikitch, W. J. Ripple, S. A. Sandin, M. Scheffer, T. W. Schoener, J. B. Shurin, A. R. E. Sinclair, M. E. Soulé, R. Virtanen, and D. A. Wardle. 2011. Trophic Downgrading of Planet Earth. *Science* 333: 301– 306.

Fahn, J. D. 2003. A Land on Fire. *The Environmental Consequences of the Southeast Asian Boom*. Westview/Perseus, Boulder, CO. 365 pp.

Gibson, L., A. J. Lynam, C. J. A. Bradshaw, F. L. He, D. P. Bickford, D. S. Woodruff, Sara Bumrungsri, and W. F. Laurance. 2013. Near-complete extinction of native small mammal fauna 25 years after forest fragmentation. *Science* 341: 1508–1510.

Gonzalez, A. 2013. The ecological deficit. *Nature* 503: 206–207.

IPBES [Intergovernmental Platform on Biodiversity and Ecological Services]. 2013. http://www.ipbes.net/

IPCC-5 [Intergovernmental Panel on Climate Change]. 2013. *The physical science basis*. http://www.ipcc.ch/

IUCN [International Union for the Conservation of Nature]. 2013. http://www.iucn.org/about/work/programmes/species/news/?13690/Action-to-tackle-Southeast-Asias-Extinction-Crisis

Joppa, L. N., P. Visconti, C. N. Jenkins, and S. L. Pimm. 2013. Achieving the Convention on Biological Diversity's goals for plant conservation. *Science* 341: 1100–1103.

Kareiva, P. K., H. Tallis, T. H. Ricketts, G. C. Daily, and S. Polasky (eds.) In press. *The Theory and Practice of Ecosystem Service Valuation*. Oxford Univ. Press, Oxford.

Kennel, C. F., and S. Daultrey. 2010. Knowledge Action Networks: connecting regional climate change assessments to local action. Pdf of this Cambridge Univ.-UC San Diego workshop report available: http://ssi.ucsd.edu/index.php?option= com_content&view=article&id=406&Itemid=18

Laurance, W. F., T. E. Lovejoy, H. L. Vasconcelos, E. M. Bruna, R. K. Didham, P. C. Stouffer, C. Gascon, R. O. Bierregaard, S. G. Laurance, and E. Sampaio. 2002. Ecosystem decay of Amazonian forest fragments: a 22–year investigation. *Conservation Biology* 16: 605–618.

Laurance, W. F., and R. O. Bierregaard (eds.). 1997. *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities*. Univ. Chicago Press, Chicago. 616 pp.

Le Saout, S., M. Hoffmann, Y. Shi, A. Hughes, C. Bernard, T. M. Brooks, B. Bertzky, S. H. M. Butchart, S. N. Stuart, and T. Badman, A. S. L. Rodrigues. 2013. Protected areas and effective biodiversity conservation. *Science* 342: 803–805.

Lynam, A. J. 1995. *Effects of habitat fragmentation on the distributional patterns of small mammals in a tropical forest in Thailand*. Ph.D. thesis, University of California, San Diego.

Lynam, A. J. 1996. Effects of habitat fragmentation on the distributional patterns of small mammals in a tropical forest in Thailand. In Sukmasuang, R. (ed.), *Summary of Research Conducted at Khlong Saeng Wildlife Sanctuary, Surat Thani Province, Thailand*. Royal Forest Department, Bangkok.

Lynam, A. J. 1997. Rapid decline of small mammal diversity in monsoon evergreen forest fragments in Thailand. Pages 222–240 *in* W. F. Laurance, and R. O. Bierregaard (eds.), *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities*. Univ. Chicago Press, Chicago.

Lynam, A. J., and I. Billick. 1999. Differential responses of small mammals to fragmentation in a Thailand tropical forest. *Biological Conservation* 91: 191–200.

Lynam, A. J., S. Srikwan, and D. S. Woodruff. 1992. Species persistence and extinction following rainforest fragmentation at Chiew Larn. *18th Congress Science & Technology, Thailand*. Abstracts pp 570–571.

Lynam, A. J., and D. S. Woodruff. 1993a. Extinction of small mammals in rainforest fragments in Chiew Larn reservoir, Thailand. *Association of Tropical Biology, San Juan, Puerto Rico*. Abstracts pp 109–110.

Lynam, A. J., and D. S. Woodruff. 1993b. Local extinctions of small mammals following fragmentation and fire disturbance in a tropical forest in peninsular Thailand. *International Theriological Congress, Sydney*. Abstracts p 192.

Manopawitr, Petch. 2013. A lesson in sustainability. *Bangkok Post,* June 10th.

Morin, P. A., and D. S. Woodruff. 1996. Noninvasive genotyping for vertebrate conservation. Pages 298–313 *in* T. B. Smith, and R. K. Wayne (eds.), *Molecular Genetic Approaches in Conservation*. Oxford Univ. Press, Oxford.

Morin, P. A., J. Messier, and D. S. Woodruff. 1994. DNA extraction, amplification and direct sequencing from hornbill feathers. *J Science Soc. Thailand* 20:31–41.

Moritz, C., and R. Agudo. 2013. The future of species under climate change: resilience or decline. *Science* 341: 504–508.

Mulongoy, K. J., and S. B. Gidda. 2008. *The Value of Nature: Ecological, Economic, Cultural and Social Benefits of Protected Areas*. Secretariat of the Convention on Biological Diversity, Montreal, 30 pages. Available at: http://www.cbd.int/doc/publications/cbd-value-nature-en.pdf

Nakasathien, S. 1988. The first wildlife rescue operation in Thailand. *Thai J. Forestry* 7: 250–265.

Nakasathien, S. 1989, Chiew Larn Dam wildlife rescue operation. *Oryx* 23: 146–154.

Poonswad, Pilai (ed.). 1998. *The Asian Hornbills: Ecology and Conservation*. Thai Studies in Biodiversity 2: 1–336. BIOTEC, NSTDA, Bangkok.

Srikosamatara, Sompoad, and W. Y. Brockelman. 2002. Conservation of protected areas in Thailand: a diversity of problems, a diversity of solutions. Pages 218–231 *in* J. Terborgh, C. Van Schaik, L. Davenport, and M. Rao (eds.), *Making Parks Work: Strategies for Preserving Tropical Nature*. Island Press, Washington DC.

Srikwan, Sukamol. 1998. *Genetic erosion in small mammal populations following rain forest fragmentation in Thailand*. Ph.D. thesis, University of California, San Diego.

Sukamol, S., and A. J. Lynam. 1996. The Khlong Saeng Biodiversity Project: Population viability and biodiversity following rainforest fragmentation. *Bull. Ecological Soc. America* 77: supplement pt 2: 489.

Srikwan, S., and D. S. Woodruff. 1996. Genetic erosion detected by microsatellite analysis of small mammal populations following recent tropical forest fragmentation in Thailand. *Bull. Ecol. Soc. Am.* 77(3) suppl. pt 2: 419.

Srikwan, S., and D. S. Woodruff. 1997. Molecular genetics and conservation – new tools to save Thailand's wildlife. [in Thai]. *Thai J. Science* 51: 113–119.

Srikwan, S., and D. S. Woodruff. 1998a. DNA sequence variation and hornbill conservation. Pages 69–82 in P. Pooswad (ed.), *The Asian Hornbills: Ecology and Conservation*. BIOTEC, Bangkok.

Srikwan, S., and D. S. Woodruff. 1998b. Monitoring genetic erosion in mammal populations following tropical forest fragmentation. *Society for Conservation Biology, Sydney*. Abstracts p. 65.

Srikwan, S., and D. S. Woodruff. 2000. Genetic erosion in isolated small mammal populations following rain forest fragmentation. Pp. 149–172 *in* A. Young, and G. Clarke (eds), *Genetics, Demography and Viability of Fragmented Populations*. Cambridge Univ. Press, Cambridge.

Srikwan, S., D. Field, and D. S. Woodruff. 1996. Genotyping free-ranging rodents with heterologous PCR primer pairs for hypervariable nuclear microsatellite loci. *J. Sci. Soc. Thailand* 22: 267–274.

Srikwan, S., K. Hufford, L. S. Eggert, and D. S. Woodruff. 2000. Variable microsatellite markers for genotyping tree shrews, *Tupaia*, and their potential use in genetic studies of fragmented populations. *ScienceAsia* 28: 93–97.

STS [Science and Technology in Society] 2013. The annual STS Forum in Kyoto is a gathering of world leaders aimed at creating a network focused on the future of humankind. See: www.stsforum.org

Sukhdev, P. 2011. Putting a price on nature: The economics of ecosystems and biodiversity. *Solutions* 1(6): 34–43.

TEEB [The Economics of Ecosystems and Biodiversity]. 2010. *The Economics of Ecosystems and Biodiversity for Local Policy Makers and Administrators* [online]. www.teebweb.org.

Tunhikorn, S., W. Y. Brockelman, R. Tilson, U. Nimmanheminda, R. Ratanakorn, R. Cook, A. Teare, K. Castle, and U. Seal (eds). 1994. Population and Habitat Viability Analysis Report for Thai Gibbons: *Hylobates lar* and *Hylobates pileatus*. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, Minnesota.

Welzen, P.C. van, A. Madern, N. Raes, J.A.N. Parnell, D.A. Simpson, C. Byrne, T. Curtis, J. Macklin, A. Trias-Blasi, A. Prajaksood, P. Bygrave, S. Dransfield, D.W. Kirkup, J. Moat, P. Wilkin, C. Couch, P.C. Boyce, K. Chayamarit, P. Chantaranothai, H.-J. Esser, M.H.P. Jebb, K. Larsen, S.S. Larsen, I. Nielsen, C. Meade, D.J. Middleton, C.A. Pendry, A.M. Muasya, N. Pattharahirantricin, R. Pooma, S. Suddee, G.W. Staples, S. Sungkaew, and A. Teerawatananon. 2011. The current and future status of floristic provinces in Thailand. Pages 219–247 *in* Yongyut Trisurat, R. P. Shrestha & R. Alkemade (eds.), *Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications*. Information Science Reference (IGI Global), Hershey, PA.

Western, D., R. M. Wright, and S. C. Strum (eds.). 1994. *Natural Connections. Perspectives in Community-based Conservation*. Island Press, Washington, DC.

Westley, F. R., and P. S. Miller (eds.). 2003. *Experiments in Consilience. Integrating Social and Scientfic Responses to Save Endangered Species*. Island Press, Washington DC. Describes the IUCN/SSC/Captive Breeding Specialist Group (CBSG) collaborative network process including the 1994 Thailand Gibbon Workshop in Khao Yai NP.

Woodruff, D. S. 1989. The problems of conserving genes and species. Pp. 76–88 *in* D. Western & M. Pearl (eds), *Conservation for the Twenty–first Century*. Oxford Univ. Press, New York.

Woodruff, D. S. 1990. Genetics and demography in the conservation of biodiversity. *J. Science Society of Thailand* 16: 117–132.

Woodruff, D. S. 1992. Genetics and the conservation of animals in fragmented habitats. Pages 258–272 *in: In Harmony with Nature*. Proc. Intl. Conf. Tropical Biodiversity. Malay Nature Society, Kuala Lumpur.

Woodruff, D. S. 1993. Non–invasive genotyping of primates. *Primates* 34: 233–246.

Woodruff, D. S. 1999. Biodiversity: conservation and genetics. Pages 589–598 in *Proc. 2nd Princess Chulabhorn Science Congress,* Chulabhorn Research Institute, Bangkok.

Woodruff, D. S. 2001a. Declines of biomes and biotas and the future of evolution. *Proc. Nat. Acad. Sci. USA* 98: 5471–5476.

Woodruff, D. S. 2001b. Sustainable agriculture and biodiversity conservation. Pages 55–62 *in* Suthipradit, S. et al. (eds.), *Sustainable Agriculture: Possibility and Direction*. National Science and Technology Agency, Bangkok.

Woodruff, D. S. 2003. Non–invasive genotyping and field studies of free–ranging non-human primates. Pages 46–68 *in* B. Chapais and C. Berman (eds), *Kinship and behavior in primates*. Oxford Univ. Press, New York.

Woodruff, D. S. 2006. Keynote talk: Genetics and the future of biodiversity. Pages 20–29 *in* Proc. 9th Biodiversity Research & Training Program, Annual Conference, Khon Kaen, Thailand, October 10–12.

Woodruff, D. S. 2012. A tale of two planets: biodiversity and environmental sustainability before and after Rio+20. *J. Environment & Development* 21: 21–24.

Woodruff, D. S., and J. Falk. 2012. *International workshop on coastal cities, climate change and sea level rise. Report to the Presidents, Assoc. Pacific Rim Universities*. APRU Sustainability and Climate Change Program. University of California San Diego. Available at: http://ssi.ucsd.edu/scc/

Woodruff, D. S., and S. Srikwan. 1998. Molecular genetics and the conservation of hornbills. Pages 257–263 *in* P. Pooswad (ed.), *The Asian Hornbills: Ecology and Conservation*. BIOTEC, Bangkok.

Woodruff, D. S., S. Srikwan, and A. J. Lynam. 1996. The Khlong Saeng Biodiversity Project: Population viability and biodiversity following rainforest fragmentation. *Bull. Ecol. Soc. Am.* 77: suppl. pt 2: 489.

Woodruff, D. S., S. Srikwan, and A. J. Lynam. 1998. The Khlong Saeng Biodiversity Project: population viability following rainforest fragmentation. *Society for Conservation Biology, Sydney*. Congress Abstracts. pp 66–67.

Woodruff, D. S., and K. A. Woodruff. 2008. Paleogeography, global sea level changes, and the future coastline of Thailand. *Natural History Bulletin of the Siam Society* 56: 1–24.

Wright, S. J., and H. C. Muller-Landau. 2006. The future of tropical forest species. *Biotropica* 38: 287–301.

Wright, S. 1931. Evolution in Mendelian populations. Genetics 31: 39–59.

Young, A. G., and G. M. Clarke (eds.) 2000. *Genetics, Demography and Viability of Fragmented Populations*. Cambridge University Press, Cambridge. 438 pp.

Zhang, L., W. Y. Brockelman, and M. A. Allen. 2008. Matrix analysis to evaluate sustainability: The tropical tree *Aquilaria crassna*, a heavily poached source of agarwood. *Biological Conservation* 141: 1676–1686.

Addendum: The following commentary by two leading conservation biologists on the value of forest fragments and the importance of the Chiew Larn results appeared while this paper was in press:

Pimm, S. L., and T. Brooks. 2013. Conservation: Forest fragments, facts, and fallacies. *Current Biology* 23 (24): R1098–1101. http://dx.doi.org/10.1016/j.cub.2013.10.024