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International collaboration on biodiversity research: a practical, conceptual, and empirical perspective

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Introduction

Scientists interested in investigating biodiversity generally typically exhibit an unbounded curiosity and enthusiasm for observing the natural world and the organisms that live in it. Research on the topic of biological diversity occurred well before the subject was termed biodiversity. International efforts to organize and carry out a variety of activities aimed at observing and documenting biodiversity have taken place for more than 100 years and have involved 1,000's of scientists spanning multiple generations of research. Historically, the primary interest in biodiversity studies was to develop a bioinventory, a list of species, by documenting the species found at certain locations. Presently, the field of biodiversity has developed into a subject where taxonomic expertise across a large assemblage of species (multi-taxa bioinventory) and the dynamics of populations, communities, and ecosytems (multi-scaled ecology) are integrated with one another to better understand the composition of natural and disturbed habitats.

The topic of biodiversity is very broad and very complex with scientific roots in many traditional disciplines of biology. Therefore, to maintain a focused approach to managing my time and goals regarding biodiversity studies I rely on three major themes. These themes serve as my primary objectives for planning biodiversity research. This essay will illustrate these primary objectives by presenting two examples regarding my interests in international collaboration that addresses research on biodiversity that includes long-term monitoring - over multiple years - and large species assemblages - many hundreds to one or two thousand species. The first example will present a brief synopsis of data acquired during a biodiversity project on Lepidoptera (insects: moths and butterflies and their caterpillars) conducted at the HJ Andrews Experimental Forest in Oregon [HJA], USA. The second example will be a discussion on how a biodiversity project, in the context of international collaboration, could be initiated at Naresuan University, Phayao Province, Thailand.

The first objective that I use to help focus my biodiversity research projects is derived from the discipline of biogeography. The main question under this objective is: What are the limiting factors, biotic and abiotic, that determine the distributions of organisms across the landscape? This question is most compelling when the group of organisms under study represents hundreds to more than one thousand species and investigates how their distributions are spread across a gradient of climatic conditions involving a heterogeneous landscape on a scale of 100's to 1000's of square kilometers. Research conducted on a large geographical scale may easily extend across political boundaries and is therefore facilitated by international collaboration with scientists located in or near the study sites.

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The second objective that I use to help focus my biodiversity research projects is derived from the disciplines of population and community ecology. The main question under this objective is: What determines the patterns of abundance in the short term (intra-annual) and the long term (inter-annual)? In other words, how does the abundance of organisms, measured as either individuals of a given species or as species richness, change through time? This question is most compelling when patterns in trend and variance in abundance and species richness are compared to environmental factors such as temperature, precipitation, solar energy, landscape topology, food resources, and natural enemies. In particular, the seasonal patterns (short-term) of greatest interest are those expressed by the timing of life cycle events, such as for insects: egg hatch, pupation, or adult flight periods. Each of these life cycle events is driven by climatic conditions, namely temperature. Data on the seasonal phenology of a large species assemblage is needed to understand climate change impacts on the biota and is well served by sampling at a wide variety of study sites. Similarly, data are needed on abundance and species richness on an inter-annual (long-term) basis as well. Thus, biodiversity studies with a focus on measuring climate change impacts on plants and animals need to occur at locations that represent the wide range of climate conditions from the boreal habitats, temperate conditions, and subtropical/tropical environments. International collaboration is required to achieve studies with a goal of addressing global issues.

The third objective that I use to help focus my biodiversity research projects is derived from the disciplines of ecosystem ecology and natural history. The main question under this objective is: What are the roles of species in ecosystem dynamics? Specifically, what is the role of any given species, and guilds of species, in affecting the rate of ecosystem processes such as carbon dynamics, plant community composition, and species assemblages of consumer-connected primary producers, herbivores, and predators? The approach to each of these questions is to me the essence of the study of biodiversity and requires international collaboration for the synthesis of two major bodies of knowledge: taxonomy and ecology.

From the perspective of blending taxonomy and ecology the approach to conducting research on biodiversity includes four major components: 1) the development of a species list, 2) the measurement of abundance, 3) the establishment of a standardized and consistent protocol for the acquisition of repeated measures of abundance and species richness over a long-term period at multiple sites, and 4) the establishment of conservation goals in the context of preserving maximum biodiversity, conserving species at risk of extinction, policies for sustainable resource utilization, and the development of models to predict the expected results given certain land management policies. Information derived from all four components needs to be integrated into a database that has at its core four attribute fields: species name, location, date, and a measure of abundance. All four components and each of the four attribute fields should be considered as co-dependent (interconnected) units. No one component or attribute field is more important than another and each component and attribute field is necessary to execute an effective biological diversity project.

A synopsis of a lepidoptera biodiversity project, Oregon USA

The study location : western Oregon. A geographical region in North America, best described as western Oregon, has been the area where I have conducted biodiversity studies on Lepidoptera since 1986 (Fig. 1). Western Oregon is defined by the following boundaries. The eastern boundary of western Oregon is defined by the contour of the crest of the Cascade Mountains. The region west of the crest is relatively wet while the region east of the crest (the area not in western Oregon) is relatively dry. Therefore, the eastern boundary marks a distinct change in the flora between western and eastern Oregon. In the south the boundary is the political border with the State of California, but biologically it is the area that includes the Siskiyou Mountains and interspersed watersheds. The vegetation in the Siskiyou area of western Oregon contains the most unique flora when compared to the remainder of the region. The Pacific Ocean defines the western boundary and involves an extensive coastal zone. The northern boundary is the political border with the State of Washington, but there is no biological significance to this boundary, meaning, the biota in the central and north area of western Oregon is very similar to that of western Washington.

Figure 1. A map of the Pacific Northwest of North America showing the distribution of the dominant conifer species and the location of the HJ Andrews Experimental Forest [HJA*]. The Hemlock-Sitka spruce forest is typical of the coastal region. Douglas-fir are the dominant conifer species in forests throughout Oregon and Washington west of the crest of the Cascade Mountains. Pondersoa pine is the dominant conifer species in forests east of the crest of the Cascade Mountains.

A total of 356 trap locations have been established throughout western Oregon. All of the trap locations have been sampled for Lepidoptera for at least one complete season (May-October) at biweekly intervals. Some of the trap locations were arranged in groups creating a transect to document patterns in abundance and species richness on a local basis. The traps arranged in a transect configuration were monitored for periods ranging from three to five consecutive years.

One study in particular documented the dynamics of Lepidoptera biodiversity on a small scale. This study was based on collections of moths and butterflies within the watershed of the HJA, located on the western slope of the Cascade Mountains in western Oregon. The HJA consists of 64,000 ha representing the typical habitats found in a Douglas-fir dominated forest at an elevation ranging from 425-1,500m. Annual precipitation averages 230 cm/year with most of the rainfall or snow occurring between December and March. The plant communities at the lower elevations, below 1,000 m, are dominated by an overstory of Douglas fir, *Pseudotsuga menziesii;* and western hemlock, *Tsuga heterophylla*; with most of the trees creating a canopy 60-80 m high. The understory vegetation at the lower elevations consists of a wide diversity of deciduous hardwood trees and shrubs, including maples, *Acer* spp.; willows, *Salix* spp.; alders, *Alnus* spp.; blueberries, *Vaccinium* spp.; and hazelnut, *Corylus cornuta*. Steep south-facing slopes occur in various areas throughout the watershed, and the vegetation in these warmer and drier habitats consists of a distinct flora including evergreen hardwood trees and shrubs such as manzanita, *Arctostaphylos* spp.; rhododendron, *Rhododendron macrophyllum*; and chinquapin, *Chrysolepis chrysophylla.* The plant communities at higher elevations, above l,000 m, on the eastern ridges support a subalpine forest with a 50-70 m overstory dominated by Pacific silver fir, *Abies amabilis*; and noble fir, *Abies procera*. In addition, extensive subalpine meadows and barren rocky ridgetops occur along the eastern boundary and support a rich diversity of herbs and grasses.

Results. The first objective was to develop a species list (bioinventory) and then assess biogeography. In the context of the large-scale activities the Western Oregon Lepidoptera Biodiversity Project has documented that more than one thousand species of butterflies and moths occur in western Oregon. The distribution of sampling locations has allowed the creation of regional distribution maps for each of these species. One example, with additional data from eastern Oregon, is shown here for the butterfly *Oenis nevadensis nevadensis* and is illustrated in Figure 2. A simple visual inspection of the map immediately reveals that the species occurs in mountain environments, in particular the Cascade Mountains.

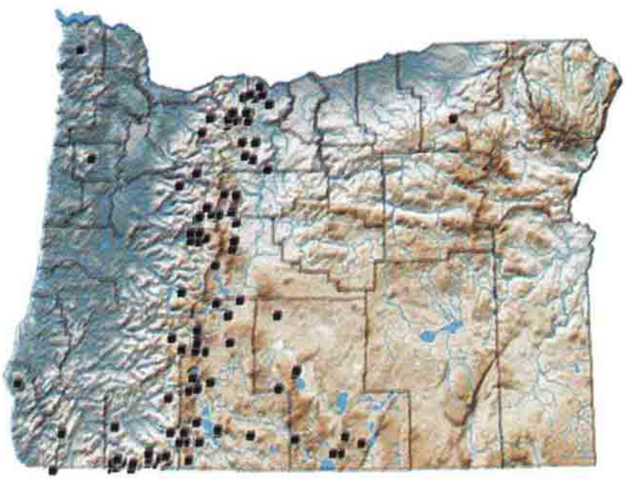

Figure 2. The distribution of a butterfly, *Oenis nevadensis nevadensis*, in Oregon, USA. The distribution of this species is an example of how the north to south alignment of the Cascade Mountains affects where species occur.

In the context of the small-scale studies the HJA Lepidoptera Biodiversity Project has documented, based on 262 trap-sites, that 681 species of butterflies and moths occur within one relatively small watershed in the Cascade Mountains. The distribution of any one of the species at a microhabitat scale also reveals boundaries and limits to its occurrence within a local landscape (Fig. 3). This map shows the local distribution of a moth, *Acronicta hesperida*, within the HJA watershed. The distribution of this species is defined by the occurrence of riparian habitat where the caterpillar foodplant, *Alnus* sp. (alder), occurs.

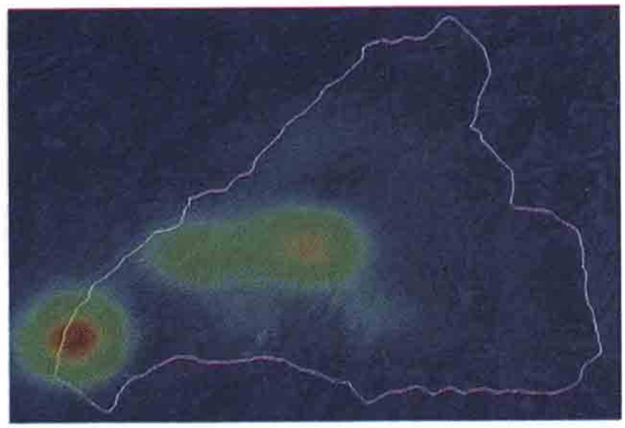

Figure 3. The distribution of a moth, *Acronicta hesperida*, within the watershed of the HJ Andrews Experimental Forest, Oregon, USA. The caterpillar of this moth is a specialist feeder on alder and is primarily distributed along riparian zones in coincidence with the distribution of the foodplant.

Another particularly interesting visualization of data, in addition to individual species maps, is the creation of a map showing where the range of overall species richness occurs (Fig. 4). The location of species 'hot-spots' and 'cold-spots' is easily seen on a map that integrates the presence/absence of all species known to occur within the entire study site.

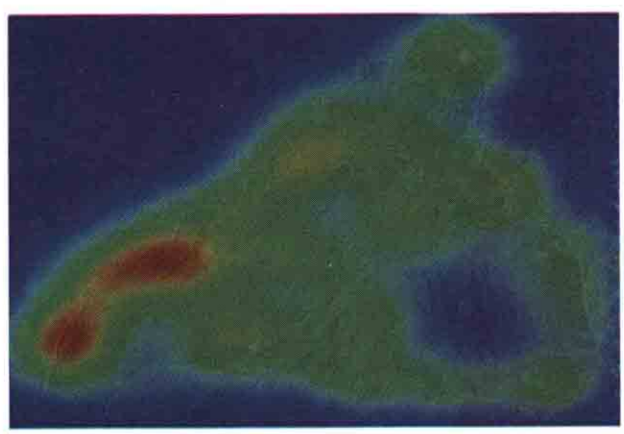

Figure 4. A map illustrating the spatial distribution of moth species richness within the HJ Andrews Experimental Forest, Oregon, USA. The highest species richness occurs along the western ridge (depicted in red) where the species richness of plants classified as angiosperms is relatively high.

The second objective of the western Oregon Lepidoptera Biodiversity Project was to document temporal patterns in abundance of individuals and species richness. The intra-annual pattern of moth species richness documented in the HJA study illustrates the patterns that can be seen in the seasonal occurrence of species richness (Fig. 5). Peak species richness occurs during the last week of July to the first week of August (Julian week 30). Nearly 50% of all the species that occur within the HJA watershed are flying at this time of the year under current climate conditions. One implication from such data is that if a so-called rapid assessment of Lepidoptera biodiversity was to be conducted based on a one-time sampling effort then the time of sampling to measure maximum species richness would be late July to early August, depending on seasonal weather patterns. Another critical aspect of this information relates to monitoring biotic responses to climate change. As climate dynamics change so will the dynamics of the peak occurrence of species richness. In conjunction with other appropriate measures an observed shift in the timing of peak species richness might serve as a benchmark measure to assess impacts due to climate change.

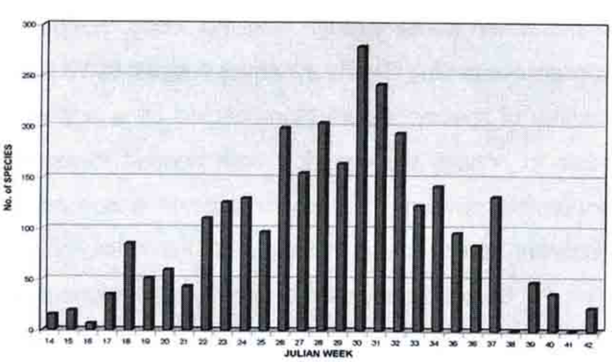

Figure 5. A histogram illustrating the temporal distribution of moth species richness within the HJ Andrews Experimental Forest, Oregon, USA. Peak species richness occurs during Julian week number 30, the last week of July.

The third objective of the Western Oregon Lepidoptera Biodiversity Project was to document the role of species in the ecosystem and understand their natural history. I have addressed this objective by conducting studies to document foodplant relationships of Lepidoptera. I mentioned earlier that to me this is the essence of biodiversity, understanding trophic relationships. As a scientific endeavor the study of foodplant relationships is a means for translating taxonomy into ecology. It is important to take studies of biodiversity beyond the realm of species lists, even beyond species lists with abundance data. One way to do this is to transform the species list into a ledger of functional groups. In the case of Lepidoptera one of the categories of functional groups is based on foodplants for the caterpillars. In turn, one method of classifying Lepidoptera is to separate the species by their feeding habits based on the types of plants utilized as food, such as, use of conifers, hardwood trees and shrubs, herbaceous vegetation, grasses, mosses and lichens, and detritus. The subcategories regarding feeding habits provide a means for better understanding the role of the species in the context of guilds rather than merely names on a list (Table 1).

Table 1. Species richness [N] and the proportion [%] of total species placed into functional groups based on the feeding habits of Macrolepidoptera (butterflies and certain moths) sampled in the HJA forest, Oregon, USA, 1986-2008.

Feeding habits	N	%
Hardwood	237	57
Herb-Grass	128	31
Conifer	35	9
Mixed (conifer+hardwood)	9	2
Lichen-Detritus	3	1

The data on foodplant functional groups reveal that a majority of the species with known foodplant relationships (note: foodplant relationships for many species remain to be discovered) feed on hardwood trees and shrubs. This is a particularly interesting fact since the environment where these species are found is a vast forest of conifer trees. Only 9% of the species are conifer-feeders. The importance of angiosperms in the conifer forest is further supported by the combination of species that feed on hardwood trees and shrubs with the species that feed on herbaceous vegetation and grasses. The percentage of species that strictly utilize a flowering plant, an angiosperm, of one kind or another, totals 89%. The obvious message from these data is that even in a conifer-dominated forest the presence of angiosperm species is critical to biodiversity.

To conclude my presentation of the Western Oregon Lepidoptera Biodiversity Project four topics are important to consider in biodiversity discussions. These four topics are: endemism, rarity, epizootic population dynamics, and exotic species.

Endemism. Species exhibiting a very limited geographic range are typically the result of restricted suitable habitat in conjunction with restricted gene flow among disparate populations. An endemic species, or subspecies, will exhibit unique traits that distinguish individuals in the 'localized' population from individuals in populations located in other areas. Endemic species of Lepidoptera, or for that matter endemic subspecies of Lepidoptera, are not present within the HJA watershed. This observation reinforces the statement that the HJA is a location that is representative of what could be called a typical coniferous forest on the west slope at mid elevation in the central Cascade Mountain Range. Although numerous types of restricted microhabitats occur within the HJA watershed none seem to provide the isolation required for a local population to be considered as an endemic subspecies or species.

Rarity. Species present in extremely low numbers may subjectively be designated as rare species. The issue of rarity is subjective because of the overriding primary question: At what level of abundance is a species deemed rare? Because the abundance of any one species is variable from one place to another and from one point in time to another, a multiple-site long-term monitoring program is needed to provide the most appropriate database for understanding rarity. For example, after ten years of full-season sampling a total of 606 species of macromoths have been observed to occur within the HJA watershed. Each species has been sampled with a corresponding measure of abundance that is summed to obtain an annual count as well as an overall (grand total) count. Among the 606 macromoth species a grand total of more than 100,000 moths have been observed, for 76 (12.5%) of those species their presence is known based on an observation of only one individual over the ten-year sampling period. Similarly, for 26 (4.3%) of the macromoth species their presence is known based on an observation of only two individuals over the ten-year sampling period. These data would suggest that if rarity was based on the criterion of singleton and duet collections then 16.8% of the macromoth fauna would be categorized as rare.

The relevance to understanding rarity is based on the connection between population trends and management needs for the conservation of species, their habitat, and sustainability of ecosystem function. A critical aspect of obtaining long-term monitoring data for a variety of species is that this procedure allows for an assessment of population trends through time. For instance, current concerns regarding climate dynamics suggest that a large number of species should be monitored on a long-term basis to provide the empirical data needed to assess population patterns that would indicate a species is becoming rare, perhaps in danger of local extinction.

Epizootic species. Unusually high abundance, or high population density, defines whether an animal species is exhibiting an epizootic event. Population outbreaks are typically observed among animal species that exhibit rapid inter-generation turnover, such as univoltine and multi-voltine insects. Among the macromoths found in the HJA three species tend to exhibit population outbreaks that may be categorized as epizootic population events. Each of the three species: *Semiothisa signaria*, *Melanolophia imitata*, and *Nepytia umbrosaria*, is a geometer moth, univoltine, ubiquitous within and beyond the boundaries of the HJA, and their caterpillars feed on species of Pinaceae, in particular Douglas-fir and western hemlock. The sample numbers among these species may exceed an annual total of 1,000 individuals among a pool of hundreds of species typically observed by a count of 1-15 individuals. Rarely is the high sample count sustained for more than two consecutive years. Typically, caterpillar diseases result in a decline in numbers of individuals with a subsequent return to high numbers in future years.

Exotic species. A particularly interesting and important component of the biodiversity of any given place is the number of species that are categorized as exotic. In this context an exotic species is a species that is indigenous to a region that is far removed and typically separated by a major geophysical barrier such as an ocean or a major mountain range. As evidenced by numerous plants and animals, the colonization of new habitats by exotic species can result in negative impacts on the populations of native species. The most notable examples are weeds, insect pests, and plant pathogens. The HJA biota contains a variety of exotic insect species, most of which to date have shown little negative impact on native species. While some exotic insect species require management to provide suppression, if not eradication, other exotic insect species provide positive impacts on populations of resident species. For instance, the geometer moth, *Aplocera plagiata*, is an exotic insect species that was intentionally released at multiple sites distant from the HJA for the biological control of an exotic and noxious weed, *Hypericum perforatum*. The first observation of *A. plagiata* within the HJA was in 2004 with subsequent observations every year to the present.

The proposition of an insect biodiversity project in the north Provinces of Thailand

A proposal is currently being pursued to create an insect/plant biodiversity project in north Thailand within and near the area of the Naresuan Phayao University [NPU] campus. This proposal has numerous objectives that may be classified into two categories: administrative and research/teaching. The administrative objectives are to: 1) identify additional participants and establish their role in the overall project; 2) establish primary and secondary facilities and field sites to serve as locations for the sampling, specimen processing, data processing, and organizational activities; 3) create a list of objectives for the primary research, perhaps modified from those mentioned in the HJA discussion; and 4) address teaching activities so the participants and host institutions may dedicate/solicit appropriate funds for establishing long-term studies. The objectives of the research/teaching activities are to: 1) conduct a bioinventory of all insects (in my case initially addressing the Lepidoptera), 2) develop a museum to house the voucher material representing each species, 3) acquire quantitative measures based on standardized and repeated field sampling protocols, 4) study biological relationships, in particular, foodplant associations for plant-consuming species, 5) integrate technology for rapid and accurate identification of extremely large (in excess of 1,000 species) species assemblages, 6) assess spatial and temporal patterns in abundance and species richness, 7) provide information gained from the project via hardcopy publications and online websites, 8) involve students and the public through the development of a variety of hands-on exercises for instruction in the classroom and public forum.

The study location : north Thailand. The region of interest for this proposal is the territory of the north Provinces in Thailand. This region provides an excellent location for biodiversity studies with objectives to conduct a biodiversity project, including bioinventory to explore life history relationships, such as, foodplants; and to relate the taxonomic diversity/life history patterns (in particular phenology) to short-term and long-term climate patterns. The insect biodiversity project will focus on the Provinces of Chiang Rai, Phayao, Nan, and Uttaradit. The eastern section of this region includes parts of the greater Mekong River Basin. The Mekong River Basin is currently considered one of the world's finest and least explored biodiversity hotspots.

The management of the main field research and educational activities of this project will be located at Naresuan Phayao University. However, the regional scope of the field studies will span from Maesa, in the north, southward to just north of Loei. The general climate is wet (770 mm) and warm (average daily low-high of 22-31^{0}C) from June through September; it is dry (70mm) and warm (19-29^{0}C) in October and November; dry (15mm) and cool (13-27^{0}C) in December, and dry (15mm) and hot (21-35^{0}C) from January to May. Thus, the seasonality of vegetation growth: bud break, leaf replacement, flowering, and fruiting; exhibits a strong climatic signal that drives synchronized patterns in the life stages seen in the biota. These relationships create an ideal set of environmental conditions for biodiversity/ climate change studies.

Species richness is high, more than 1,000 species of trees occur in northern Thailand. The vegetation in the vicinity of NPU is dominated by a dipterocarp forest, with a high proportion of deciduous trees in a fire adapted plant community. Examples of plant species that have been previously sampled for insects, and found to yield caterpillars (Fig. 6, 7, 8), during sampling efforts in October and December of 2008 include: *Acacia pennata, Aegle marmelos, Albizia chinensis, Albizia lebbeck, Albizia odoratissima, Alstonia scholaris, Amalocalyx microlobus, Annona squamosa, Antidesma acidum, Aporosa octandra, Aporosa villosa, Aquilaria crassna, Ardisia nervosa, Arundo donax, Balakava baccata, Bauhinia purpurea, Calotropis gigantea, Canarium sublatum, Carallia brachiata, Chromolaena odorata, Chrysalidocarpus lutescens, Colona winitii, Commelina diffusa, Corchorus capsularis, Crassocephalum cripidioides, Cratoxylum formosum, Croton roxburghii, Cucurbita moschata, Dalbergia cultrata, Dalbergia foliacea, Dalbergia stipulaceae, Delonix regia, Dimocarpus longan, Dioscorea alata, Dioscorea cylindrica, Dipterocarpus obtusifolius, Dipterocarpus tuberculatus, Ficus benjamina, Ficus hispida, Gardenia obtusifolia, Gigantochloa albociliata, Globba obscura, Glochidion kerrii, Gluta usitata, Gnetum montanum, Lagerstroemia macrocarpa, Lannea coromandelica, Lantana camara, Litsea glutinosa, Macaranga tanarius, Michelia alba, Mimosa pigra, Morinda coreia, Moringa oleifera, Mucuna puriens, Musa accuminata, Nicotiana tabacum, Ochna integerrima, Onisqualis indica, Oroxylum indicum, Paretta indica, Pennisetum pedicellatum, Phyllanthus acidius, Phyllanthus columnaris, Phyllanthus emblica, Physalis minima, Psidium guajava, Pueraria mirifica, Sandoricum koetjape, Senna fistula, Senna garrettiana, Sesbania grandiflora, Shorea obtusa, Shorea siamensis, Solanum aculeatissima, Solanum nigrum, Solanum torrum, Spatholobus parviflorus, Spondias pinnata, Sterculia foetida, Synedrella nodiflora, Syzygium jambos, Tamarindus indicus, Terminalia manataly, Thysanolaena maxima, Triumfetta bartramia,* and *Urena lobata.*

Figure 6. The caterpillar of *Cyclosia papilionaris*. A remarkably patterned zygaenid caterpillar found on the NPU campus, Phayao Province, Thailand, feeding on the foliage of *Aporosa octandra*, Euphorbiaceae; October, 2008. The foodplant and the appearance of aposematic coloration indicate that this caterpillar is toxic to predators

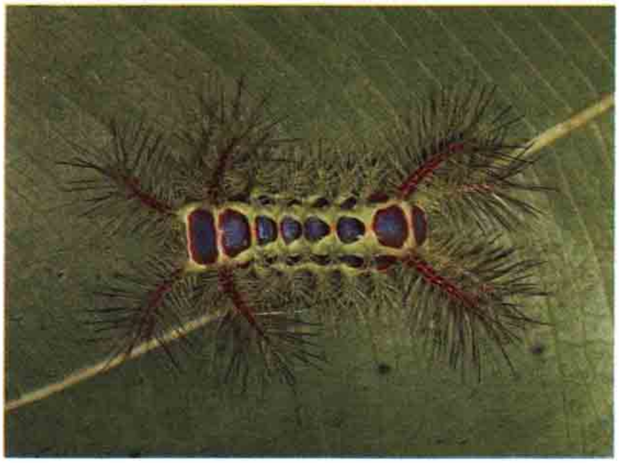

Figure 7. The caterpillar of *Phocoderma velutina*. A limacodid caterpillar, with stinging hairs, found near the NPU campus Phayao Province, Thailand, feeding on the foliage of *Spondias pinnata*, Anacardiaceae; October, 2008.

Figure 8. The caterpillar of *Lymantria mendosa*. A lymantriid caterpillar that exhibits very general feeding habits and is very commonly found on the foliage of many plant species; NPU campus, October, 2008.

Information on insect species richness, seasonal patterns in abundance, and relationships (specialist and generalists) with this vegetation lacks documentation. In particular, little information is available regarding the location and characteristics of species richness hotspots and identification of the plant species/plant communities that serve as primary sources for insect species richness.

Taxonomic scope. The bioinventory component of the project will involve the sorting (either to Order or in certain cases Family) of representative specimens of all 'primary' and 'secondary' insect taxa collected during a variety of field activities. The 'primary' taxa of interest will not only be intensively studied for descriptions of new species, species diagnosis, molecular sequences, phylogenetic analyses, biology, and identification, but also measures of abundance across space (local and regional) and through time (seasonal and inter-annual). The primary taxa are: Coleoptera (beetles), Heteroptera (true bugs); Lepidoptera (moth and butterflies with an emphasis on caterpillars); and soil arthropods, with an emphasis on Oribatidae (mites) and Collembola (springtails). The choice of the 'primary' taxa is founded on: 1) their sensitivity to vegetation and climate change, 2) available taxonomic expertise, 3) current global interests in DNA sequencing, 4) they are amenable to standardized, repeated sampling protocols, 5) their extensive species richness, and 6) the range of low to high abundances in the field at various times of the year and the variance in species richness and abundance across years. The 'secondary' target taxa will not be used in detailed ecological analyses but they will be kept as voucher specimens and made available to taxonomic experts. A critical aspect of a biodiversity study, especially one involving insects, is to collaborate with international experts in taxonomy and to determine where the archive samples representing all of the taxa will be stored. It is essential to create a local insect museum and also to collaborate with numerous insect museums in other countries.

Incorporation of novel and innovative technology as a taxonomic aid. Taxonomic expertise in many insect groups is limited to only a few specialists, many of whom may not be available for this study. Identification of the insect specimens obtained from field samples is a serious practical problem, in part due to the vast diversity in the Class Insecta and the limited availability of expert taxonomic services. Therefore, for the Lepidoptera at least, computer image analysis software will be developed for identification of specimens in the field-collected samples. Development and testing of an automated process to acquire rapid and accurate identification of thousands of species offers a high profile international opportunity to apply current research in computer image analysis to solve a global need for providing accurate insect identification.

Sampling methods. Techniques, equipment, frequency, and intensity in sampling protocols are important issues in the design of field studies with a goal of representing and documenting habitat heterogeneity as well as seasonal variability in species richness and abundance. The protocols that will be put into place will result in the collection of a broad array of arthropod taxa representing a vast gradient of environmental conditions. The sampling techniques and tools will involve: visual search, aerial nets, sweep nets, Malaise traps, pitfall traps, litter/soil grab samples coupled with Berlese extraction, UV light traps, and baited traps.

Each technique/tool will result in the collection of numerous insect specimens representing nearly all the major insect Orders, plus spiders, mites, millipedes, centipedes, etc. However, only a restricted number of locations and only certain species or species assemblages among the primary target taxa will be numerically assessed. This will be accomplished by adapting select sampling protocols to conform to a standardized, consistent, repeated measures activity that will occur at select locations determined suitable for long-term monitoring. Early stages of planning must consider which species assemblages and which sites should be considered for long-term monitoring. An example of a quantitative sampling activity is the establishment of a timed-distance/area visual search effort to assess abundance of true bugs, scarabs, caterpillars, and butterfies. Multiple visual search transects will be required to accomplish these tasks. Also, certain traps are suitable for assessing abundance on a per trap-time effort, such as documenting numbers of taxon "X" per pitfall trap per week. The quantitative data will be integrated into a relational database (see below) for access over the internet and to serve the purpose of integrating taxonomically-based bioinventory projects with ecologically-based long-term monitoring projects.

Natural history : foodplant relationships and quantitative assessment. A database consisting of taxonomic and ecological information will be designed. The attribute fields of primary interest include: 1) arthropod taxonomic hierarchy - Class, Order, Family, Genus, species, subspecies, and authors at species and subspecies levels; 2) trap site, 3) sample dates; 4) abundance by life stage; 5) foodplant - Family, Genus, species, author; 6) foodplant common name; 7) physiognomic category of foodplant, and 8) images (dorsal, ventral, male, female, life stages, behavior, etc.).

The database will be structured to run queries to assess patterns in species relationships (biological and numerical) within and among sites. For example, a query may ask which species of plants provide the foodplant resources that sustain the highest number of insect species. Another query will ask on what date is insect species richness the highest/lowest. Numerous variations will be possible regarding the resolution of these queries based on insect taxon, plant taxon, date, site, and abundance. Also, we are interested in determining which functional groups (herb-feeders, hardwood-feeders) are the dominant units in various regions, sites, and plant communities. The database will be interactive through the internet. This means the database will support data entry via a website and capable of interacting in either Thai or English. On a larger scale, this project will be designed to be part of an program to link international efforts in biodiversity assessment, focusing on insects in Asia.

Seasonal patterns. Because the expression of seasonal conditions, namely photoperiod and the co-occurrence of temperature and precipitation, provide a relatively predictable climatic pattern for the plants and animals that reside within or migrate to the NPU region the phenological patterns of the plants and animals is also predictable. One of the objectives of long-term ecological research is to monitor "first occurrence" of a biological event, such as butterfly flight, over multiple years. Currently, general interest in global climate change suggests that such population/community monitoring can contribute valuable data to understanding the biotic response to abiotic changes. The objective here is to gather empirical data from field studies on the timing of multiple events and compare these events across years, across habitats, and across taxa to assess trends in phenology that would address questions regarding climate change. This activity would need to include the development of degree-day models that are typically based on data derived from lab studies designed to discover thresholds for development and summations of heat-unit requirements for development. The models then serve as a standardized method for assessing patterns in shifts in climate and the biotic response to those shifts. For example, if the climate in north Thailand was to continually progress into warmer conditions we will, over time, observe a shift to earlier dates in certain biological events.

Inter-annual patterns : species richness. A fundamental component of biological diversity concerns the dynamics of species richness through time, a topic often addressed in the context of plant community succession and long-term monitoring of animal species assemblages. Long-term monitoring studies provide data not only on change in species richness through time but such studies also create the baseline for understanding the degree of temporal variance in species richness. Without a baseline as a reference point it is nearly impossible to infer the trend in community composition across years. The most basic of studies regarding inter-annual documentation of species richness requires a standardized sampling protocol.

Integration of international research and education

Integration of research with international collaboration and education is a primary goal of this project. Students from both the US and Thailand will be involved in the conduct of this project. The research activities will provide a field-based scientific experience founded on comparative measures of the biotic and abiotic components of the environment in the context of cultural diversity and team cooperation. This project will integrate student involvement into the overall conduct of the study by: 1) working at research sites in the US and in Thailand; 2) rotating assignments in student responsibilities to the team through development and execution of the research plan, data discovery, and synthesis and delivery of information to professional and public audiences; 3) interacting socially and professionally with other students from a variety of ethnic backgrounds as scientific colleagues and as cultural ambassadors, and 4) having students create a web-based presentation on the topic of insect biodiversity for the general public.

Project impacts

The impacts of the proposed research will include: 1) enhancing knowledge about local, regional, and global patterns in species richness, abundance, and distribution; 2) international standardization of scientific methodology; 3) integration of insect taxa into other ecological projects, such as floral biodiversity studies; 4) conservation/land management; 5) education of students; 6) education of the public.

By demonstrating the utility of a simple, standardized, and easily implemented field-sampling protocols the methods we propose can be adopted into numerous studies providing an ever-expanding database amenable to comparison because they were collected using a common platform. In fact, we hope to use the success of the NPU Biodiversity Project to stimulate similar projects in other countries throughout southeast Asia. The highly speciose taxa that comprise the insects can be integrated into other projects because identification techniques will be universally available via image analysis and the internet. Our work will stimulate the building of species image libraries for further advancing machine learning to expand software-based identification techniques. It is our hope that the successful execution of our approach using image-based identifications will open a path for large-scale long-term projects involving invertebrates in other subtropical and tropical environments. This project will show how well suited the macromoths are for use in long-term studies on global climate change.

Conservation and land management is in dire need of natural history information and the synthesis of that information into trophic relationships, such as plant-herbivore associations. By identifying foodplant relationships we are developing a database that will contribute valuable information to the decision-making process involving conservation and land management, such as restoration practices. For instance, if the re-establishment of insect biodiversity and insectivorous birds is a management goal then knowledge about caterpillars and their food plants could be used to determine what plants should be restored after a disturbance (i.e., fire).

The impact on education will be seen in our influence to stimulate students to think about large-scale projects in the context of time, space, taxa, and concepts, and how to administrate such a project logistically, sociologically, and scientifically. Public perception of insects is by-and-large negative. The public needs to be educated on the existence of insect biodiversity and why conservation is important. The public also needs to be educated on the importance of insect diversity in the functioning of the environment. We will impact this education process by demonstrating the diversity of form and function in the macromoths. Previous seminars on caterpillars have shown that an otherwise information-neutral audience is enthralled with the nuances of insect life and comes away with an improved understanding of how and why insects are more than nuisance pests.

Perhaps the most important impact a study on biodiversity may have is the relevance of the data obtained during the research on land-use policy and management, in particular: 1) the practice of sustainable use of natural resources such as vegetation, minerals, and water, and 2) the restoration of land previously degraded by the extraction of natural resources or damaged by (semi-) natural disturbances such as fire, floods, and high winds, and 3) preservation and conservation of land by designating an area as protected against commercial use. Biodiversity studies not only provide the data for assessing the need for land-use policy but also the benchmark measurements used to assess the progress following the implementation of land management practices to see if the practices are successful in the context of project goals.

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