THE CONSERVATION CHALLENGE IN AGRICULTURE AND THE ROLE OF ENTOMOLOGISTS

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ABSTRACT

Conservationists and agriculturists must work together toward the common goal of satisfying growing human population needs while maintaining natural resources and ecological processes critical to long-term human survival. The study of invertebrates has perhaps the greatest potential for contributing to this goal through theoretical, practical, and educational advancements. I discuss my view of the resulting challenge to entomologists with emphasis on insect conservation, sustainable agriculture, and environmental education.

Key Words: Insect conservation, sustainable agriculture, landscape ecology, environmental education.

RESUMEN

Los conservacionistas y los agricultores deben trabajar juntos hacia el objectivo común de satisfacer las necesidades crecientes de la población humana mientras mantienen los recursos naturales y los procesos ecológicos críticos para la supervivencia humana a plazo largo. El estudio de los animales invertebrados tiene el máximo potencial para contribuir a este objectivo por adalantemientos teóricos, prácticos y educacionales. Yo discuto mi punto de vista del reto resultante para los entomólogos con un énfasis en la conservación de los insectos, la agricultura sostenible, y la educación ambiental.

Agriculturists are attempting to feed the world's population in a sustainable manner. Conservationists are attempting to halt the exponential increase in the loss of species and the ecological processes they perform. These goals can be seen as the flip sides of the human population growth problem. Recent changes in the scale of environmental degradation have resulted in a philosophical shift in both groups. History, methods, language, lack of knowledge, and political, economic, and social constraints have kept conservation biologists and agriculturists antagonistic until very recently. In this paper I will discuss the negative effects of these factors on natural and managed ecosystems, and future prospects for attaining sustainable agricultural practices while maintaining biological diversity. The success of conservationists and agriculturists hinges on the cooperation and success of each other. Neither can succeed in the long run without reducing human population growth and per capita resource use.

The rate of human-induced species extinction is considered unacceptable and thought to threaten ecological processes necessary to sustain human food, water, shelter, recreation, and aesthetic needs (Ehrlich & Wilson 1991, Wilson 1985, 1988). Predictions of future worldwide species extinction rates range up to 50,000 species per year (Mann & Plummer 1992). This rate is over 400 times that recorded throughout geological history (Wilson 1985). At this rate we would lose almost one-tenth the number of extant described species over the next 20 years (Paoletti et al. 1992, Reid & Miller 1989). As detrimental as these losses may be in terms of direct and indirect benefits of biological diversity, conservation concerns simply cannot be addressed in the absence of fulfilling human needs.

Modern agricultural practices are major contributors to the loss of biological diversity and environmental degradation. Agricultural land managers, including farming, rangelands, animal production and forestry systems, manipulate approximately 70 percent of terrestrial ecosystems. Human settlements co-opt another 25 percent, leaving less than 5 percent for primarily conservation-directed management (Reid & Miller 1989, Pimentel et al. 1992, Western & Pearl 1989). Clearly we cannot maintain biological diversity and ecological processes without broadening agricultural practices to include more conservation concerns, and vice versa (Gall & Orians 1992).

Combining agricultural and conservation goals will not be easy. Humans are already co-opting about 40 percent of terrestrial biological productivity, and that percent is rising (Vitousek et al. 1986). Yields of staple food crops must soon more than double just to maintain current per capita consumption. To meet the growing demand for food, approximately 16 million hectares of forests are currently being converted to agricultural lands each year (Pimentel et al. 1986). This land conversion is necessary not only because there are more and more people to feed but because currently managed agricultural lands are deteriorating under modern agricultural practices (Corson 1990, Soulé et al. 1990). We cannot continue this strategy. We are already approaching the limits of arable land conversion and increasing productivity on those lands (de Zeeuw 1988, Ehrlich & Ehrlich 1991, Pimentel et al. 1992, Plucknett 1993, Soulé & Piper 1992).

Although the short term goals of agriculture and conservation are more and more in opposition due to human population pressures, they remain interdependent. Successful management of preserved areas is dependent on surrounding, mostly agricultural, land practices. And ultimately, the success of agriculture depends on the maintenance of surrounding and distant natural systems. Short-term goals have kept these two camps from cooperating. Long-term interdependence has just recently been appreciated in terms of policy, research and education, and is our hope for the future.

Entomologists should take a leading role in combining agriculture and conservation biology. We have an obligation, as resource managers, to the conservation of nature (Dourojeanni 1990, Noss 1989, Summer 1921). Our responsibility rests on three conditions. First, entomologists must contribute to the development of ecologically-based management strategies if we are to meet future challenges of food and fiber production. Second, insects represent most species diversity and are key players in ecosystem structure and function, and so, deserve our attention. Third, the study of insects provides unique, diverse, and relatively unexplored opportunities to develop public environmental literacy necessary to support future conservation and agriculture goals.

The Endangered Species Act

In the U.S., conservation policy rests on the Endangered Species Act (ESA) of 1973. The federal list of endangered or threatened species is over 1,000, with 3 times that many awaiting sufficient study for listing (Salwasser 1991, Scott et al. 1987). This species by species approach to conservation focuses on those species on the verge of extinction (McIntyre et al. 1992). It is costly, slow, and biased, and does not adequately address the loss of biological diversity.

Many practical problems limit the ESA. It rests on concepts such as species, habitat, and minimum viable population. These are critical, yet undefined concepts (e.g., see Rojas 1992). The act generally focuses on taxonomic species without considering genetic distinctiveness of individuals or populations making up those species (Crother 1992, Ehrlich 1988). Populations and metapopulations are protected only in special circumstances. It does not provide strong enough habitat protection (Murphy 1991, Rohlf

1990, Sidle & Bowman 1988). Ecosystem function is not effectively addressed using the single species approach (Csuti et al. 1987, Hutto et al. 1987, McIntyre et al. 1992, Salwasser 1991, Scott et al. 1987). Long-term and far-reaching factors are not included in the listing process (Rohlf 1990). Legally, the ESA considers all species of equal value, but, practically, efforts are highly biased toward more glamorous species that may be of little significance ecologically. There is no means to address particular species that are considered especially significant ecologically. Recovery plans, required by the ESA, are high-tech, costly, slow to be developed, approved, and implemented. These obstacles often prevent population recovery. To date, only five species have been taken off the ESA list (U.S. General Accounting Office 1988, in Wilcove et al. 1992), while global species loss continues to rise exponentially. Recovery success will continue to decline as the list grows rapidly.

Support for the ESA has been weakened by political ploys that focus on individual glamorous species to save larger systems (Mann & Plummer 1992). Also, human affinities for large, cuddly, vertebrates have dominated support for conservation and negatively affect the efforts of the U.S. Fish and Wildlife office. We cannot hope to expand such emotionally-based consideration to the number or variety of species that we must address in future conservation efforts.

Time, information, and resource limitations prevent the ESA from addressing the loss of biological diversity and ecosystem function (Noss 1991). The conservation community now generally advocates an hierarchical approach to the conservation of biological diversity, addressing all biological heterogeneity, from genes to landscapes. This approach broadens the scope of the ESA and includes monitoring and managing the composition, structure, and function of ecological systems at multiple levels of biological organization. These include genetic, population and species, community and ecosystem, and landscape levels (Noss 1990b).

The major reasons advanced for concerns about the loss of biological diversity are ecological (Cairns 1993, Ricklefs et al. 1984, Wilson 1988). Ecological processes include physical and biological processes that influence ecosystem diversity, dynamics, and evolutionary pressures that in turn act on the biological components of the system (Ricklefs et al. 1984).

Conservation biology grew out of wildlife and park management, where managing small populations of animals of game interest was a primary objective (Ginsberg 1987). As a result, ecosystem conservation has been aimed at habitat protection for particular species, usually large animals. Rarely are ecological processes objectively considered in land preservation. If we are to devote most attention to those species making up most biological diversity, and those that are most important to the persistence of higher levels of biological organization and ecological function, we must focus more on invertebrates.

Salwasser (1991) lists 4 elements necessary to build a successful ecosystem approach to conserving biological diversity. These include, 1) integrative research, technology and development, 2) design of adaptive management and monitoring strategies, 3) policy development, and 4) public education beyond glamour species. This larger-scale approach in conservation biology reinforces the need for conservation biologists and agriculturists to work together. Not only does most biological diversity occur on agricultural and other managed lands, but management practices directly affect the success of conservation efforts across multiple levels of organization and spatial scales.

Insect Conservation

"If insects (and other arthropods) were the size of birds, or people the size of mice, 'bugwatchers' would be as prevalent as bird watchers, and entomologists would command the budget of the Defense Department." (H. E. Evans 1985)

Arthropods represent approximately 90 percent of all species including plants (Pimentel et al. 1992b), with insects accounting for approximately 80 percent of all animal species diversity (Samways 1992). Together with micro-organisms, insects make up most animal biomass, and they show, by far, the greatest diversity of ecological roles (Coulson & Crossley 1987). They are also known to be especially vulnerable to small-scale habitat destruction (Ehrlich & Murphy 1987, Murphy et al. 1990). Yet, until recently, this group has been neglected by conservation biologists (Dourojeanni 1990). This neglect has some just bases. Insect life histories are generally characterized by short lifetimes, rapid and high reproductive rates, and high re-colonization rates (IUCN 1983). These attributes contribute to their resilience and recovery potential from human disturbance.

Unjust biases have also contributed to the neglect of this significant group. Invertebrates fare particularly poorly under the ESA. The law provides for listing and protection of any threatened or endangered species of plant or animal. Yet, to date only 28 species of insects, 11 crustaceans, 3 arachnids, and 68 gastropods receive federal protection. These account for only about 26 percent of animal species listed, underrepresenting their importance in species diversity. Unlike vertebrates, distinct populations of invertebrates are not given protection (Murphy 1991).

As with vertebrates, expenditures are not consistent among species. Glamour-species, mostly butterflies, receive disproportionate attention from conservationists and the general public (Pyle 1976). Public support of the ESA will diminish as the listing process includes more and more 'ugly' insects. This will further undermine the single species approach.

Although approximately 1,200 invertebrates have been proposed for listing, practical obstacles will likely limit their inclusion (Bean 1993). These include a lack of information on diversity, abundance, ecological roles, and methods for monitoring them. These obstacles limit the rate of data processing and increase the likelihood of mistakes in identification. For most invertebrates, data necessary to demonstrate a decline in the population size or the spatial distribution are not available, even for relatively well-studied species. Many life histories have not previously been considered. Methods for data collection and interpretation are not well developed. And finally, human effects on invertebrates are often less well understood.

To date, no invertebrate species has recovered to population levels sufficient to be taken off the list. In fact, as of 1990, only 2.5 percent of the then-listed 81 invertebrate species were regarded as improving, while 41 percent were still declining (Bean 1993). This is partly a reflection of a vertebrate-biased expenditure of funds for recovery plans.

There are important moral problems with the species approach to conservation that become evident when we focus on insects. Without an ecological perspective we cannot expect the general public to understand and support the need to eradicate one pest species, import another alien species for biological control, and spend a lot of money and time to preserve yet another.

The Value of Insects

Insects have long been valued for the goods and services they provide to humans. These are reviewed in IUCN (1983), Morris et al. (1991), Murphy (1991), Pyle et al. (1981), and include scientific models in research, medicine, and education, genetic resources, foods, products, wildlife trade, and agricultural services. Beyond direct and indirect economic uses, insects continue to be valued for aesthetic and cultural benefits.

Unlike vertebrates, which are better valued economically and aesthetically (Morris et al. 1991), invertebrates are most important in conservation biology because of the ecological services they provide. Most are neutral or beneficial, and some crucial to agriculture. Their services include pollination, biological control, and waste management.

Yet entomologists focus primarily on the relatively few, but important pests. As agriculture becomes more diversified, entomologists will focus more on insects in natural systems and therefore will contribute more to invertebrate conservation.

The value of invertebrates as environmental monitors is only beginning to be appreciated (Magurran 1988, Oliver & Beattie 1993, Pearson & Cassola 1992). Indicator species are used to assess environmental effects of human activities, to determine regional patterns of biological diversity, to measure changes in community structure and function, and to estimate land value (Hutto et al. 1987, Murphy et al. 1990, Noss 1990b, Pearson & Cassola 1992). Insects show great potential as environmental indicators because they are often specialized, easily observed and monitored in the field, and their needs are often correlated with other species needs (Samways 1989b, Wilson 1988). The abundance and diversity of aquatic insects as an indicator of water quality is probably the most established monitoring system. Butterflies are currently receiving much attention in conservation because of their potential as indicator species. They may provide good indicators of landscape structure necessary for land acquisition and reserve planning (Kremen 1992, Murphy 1991, Pyle et al. 1981). Their value rests in their familiarity, aesthetic qualities, established systematics, developed monitoring techniques, and close association with plants characteristic of this group (IUCN 1983, Pyle et al. 1981, Thomas 1991).

According to Oliver & Beattie (1993), the major shortcomings of using invertebrates as indicators are the shortage of taxonomists, the undeveloped systematics characteristic of most groups, lack of distributional knowledge, and lack of monitoring techniques. They suggest a method for rapid assessment of biological diversity that is based on recognizable taxonomic units assessed by trained technicians. This method saves time and reduces costs without significantly sacrificing accuracy. Such new developments in monitoring methods, together with increased focus on large scale conservation approaches, will increase the need for input by entomologists in conservation.

Insects as Key Players in Ecosystems

The diverse and pervasive ecological roles of invertebrates are sometimes subtle, generally little understood, and often difficult to value economically. It is their significance in the composition, structure and function of ecosystems that most clearly ties them to conservation biology (Ricklefs et al. 1984, Wilson 1987). These influences occur primarily through the direct and indirect effects of insects on primary production, consumption, and decomposition.

Invertebrates are the most abundant and diverse herbivores and detritivores in most terrestrial ecosystems, and most parasite-host and predator-prey associations involve invertebrates. Furthermore, insect specialization and diverse ecological associations are believed to affect larger scale structure and function (Ehrlich & Mooney 1983, Price 1988, Seastedt & Crossley 1984). They are thought to contribute significantly to stability and resilience of many communities (Morris et al. 1991, Wilson 1987). A better understanding of the ecological roles of insects, and their broader influences on ecosystems and landscapes, are crucial to the future development of viable conservation strategies and sustainable agricultural practices.

Human Threats to Insects

Invertebrates face the same general human threats that vertebrates face. These include, 1) changes to the land, including conversion for agriculture, urbanization and industrialization 2) changes to the water, including drainage and impoundment, 3) pollution to the air or water, 4) critical community changes, such as the loss of a host or invasion by exotics, and 5) specific threats to species, including over-collection and pesticide applications (IUCN 1983, Pyle et al. 1981). Modern agricultural practices are considered major contributors to all of these threats.

Based on distribution estimates for tropical species, a large number of insect species is thought already to be extinct (Dourojeanni 1990). Of the threats in common with vertebrates, over-collecting and non-target effects of pesticide applications are generally considered negligible to invertebrates (Pyle et al. 1981). Over-collecting is thought to be a potential problem only in unique circumstances (e.g., when the species is already at the brink of extinction due to severe habitat loss), or when a species life-history strategy makes it especially vulnerable (e.g., species that are relatively sessile, long-lived, and/or with low regeneration rates) (IUCN 1983).

Habitat loss is considered to be by far the most significant threat to insect conservation, and agricultural conversion is considered the most significant contributor (Samways 1992). Lovejoy (1980, in Dourojeanni 1990) estimates that approximately one-third of all tropical insect species may be extinct by the year 2000 due to deforestation. Eighty percent of worldwide deforestation is to clear land for agriculture (Pimentel et al. 1986). Although such land conversion is thought to represent a great threat in the tropics, it is considered of little importance in temperate areas due to the lower incidence of precinctivism (sensu Frank & McCoy 1990). Prairie adapted insects of North America may be especially vulnerable to population decline when those lands are converted to agriculture (IUCN 1983, Pyle et al. 1981). Island invertebrate fauna, such as in Hawaii, may be especially vulnerable to extinctions resulting from land conversion to agriculture (Howarth 1991). Reforestation practices that reduce diversity can also threaten insect species.

Small-scale habitat loss, including overgrazing or changes in grazing ecology associated with animal production, can lead to the loss of associated insects. For example in Europe, myxomatosis was introduced in the 1950s to control rabbit grazing. Resulting changes in grass ecology led to a decrease in at least three lepidopteran species. Likewise, over-grazing by sheep in Australia has threatened an uncommon grasshopper (IUCN 1983). Small-scale and highly specialized adaptations in insects point to the problems of managing an area 'for' certain species. Errors in management scale can lead to unforeseen and unwanted changes in community structure.

Agricultural management practices that disrupt water systems, such as drainage of forest bogs, can threaten insect populations (IUCN 1983). Extensive pesticide and fertilizer use and associated landscape simplification are thought sometimes to harm beneficial insects. However, invertebrate extinctions resulting from pesticide application, except through their association with hosts or symbionts, appear to be rare. This is probably partly a reflection of relatively low insect diversity in monocultures, and methodological problems of documenting extinctions (Morris et al. 1991, Pyle et al. 1981). Because agricultural lands are disrupted and simplified, they can be especially vulnerable to invasion by exotics, which in turn leads to reduced populations of native negative insects (Carroll 1990).

Unique Needs of Insects for Reserve Management

Besides vulnerabilities in common with vertebrates, recent work has shown that insects have unique needs that must be considered in land management planning. Insects are successful because of their small size, short life cycles, and ability to locate and adapt to specific environments (Wilson 1987). These same specializations make them generally susceptible to abiotic population regulation factors (Murphy et al. 1990). Endangered insects may therefore be more likely to become extinct than vertebrates, and require larger minimum viable populations (Thomas 1990). Ecological specializations, such as a close evolution with particular plant species, sometimes distinct and specific needs during different life stages, and often small distributional ranges, can also contribute to vulnerability to extinction when these local habitats are destroyed (Dourojeanni 1990, Gilbert 1980, Moore 1991, Murphy 1991, Pyle et al. 1981). Insect specialization and small-scale habitat needs can also make them good candidates for relatively inexpensive, conservation efforts (IUCN 1983).

Insects differ significantly from vertebrates in their population dynamics, ecological roles, and habitat requirements. The importance of temporarily unoccupied habitat for invertebrate recolonization is little understood, but likely differs from that of vertebrates. Furthermore, many natural areas have been reduced and fragmented to the extent that they do not possess vertebrate species of similar range and habitat needs as invertebrates and plants (Murphy 1991). If land management strategies do no take into account these differences, important invertebrates may be lost in otherwise legitimate efforts to manage land for the conservation of larger, broader-ranging vertebrates (Ehrlich & Murphy 1987, IUCN 1983, Murphy 1991).

Ehrlich & Murphy (1987) list research needs for development of management strategies aimed at invertebrates. These include investigations of, 1) demography and gene flow, including migration and recolonization by ecologically connected reservoir populations, 2) the importance of habitat diversity and specific habitat requirements, including host requirements, and habitat linkages, and 3) the role of abiotic and biotic factors in population regulation. They also stress the need for long-term studies of representative invertebrate groups, and the need to educate the public about the need to focus on populations rather than species. Thomas (1990) also suggests that minimum viable population estimates should be an order of magnitude above those for vertebrates to ensure comparable protection. Establishing safety margins is especially difficult because of the paucity of data on invertebrate abundance and distribution.

The Future

Insects are most important because of their ecological roles. Disruptions of these roles are not directly tied to the currency of species or extinctions. With limited resources, knowledge, and time, we cannot expect to discover, let alone save, the smaller organisms using a laundry list approach; even with improved methods taking into account differences in extinction threats and land management needs.

Ginsberg (1987) noted a bias toward larger animals by authors presenting at the first Society for Conservation Biology's inaugural meeting in 1987. Excluding aquatic organisms, of 53 papers and posters, there was an evident bias toward birds (10%) and mammals (18%). Plants (8%) and insects (4%) received little attention. Clearly, insects receive too little consideration by conservationists. This is largely a reflection of traditional conservation strategies that are vertebrate-based, as evidenced by the bias toward glamorous butterfly species (Pyle 1976).

Insect conservation will be best addressed by larger-scale research and management strategies that combine conservation and agricultural goals. As conservation biologists develop ecosystem approaches to conservation, they will seek to understand natural systems, what makes them resilient, how do they recover from stress, and how do we monitor these systems. As agriculturists attempt to develop sustainable land management practices, they will model natural systems and include natural areas in their management strategies. In both cases the most important animal group to study will be the insects. These changes in philosophy of both conservationists and agriculturists will provide unique opportunities and challenges for entomologists to contribute to insect conservation efforts (Dourojeanni 1990).

MODERN AGRICULTURE

Humans influence biological diversity primarily through habitat loss and fragmentation, over-exploitation, the introduction of exotic species, pollution, and climate change (Soulé 1991). Modern agricultural practices, including farming, fishing, animal production, and forestry systems, are significant contributors to all of these problems. Biological diversity is also threatened through the economic and social effects of agriculture. Because sustainable agricultural practices ultimately rest on intact ecosystem processes, upcoming shortages of water, land, and soil will increase these negative effects and emphasize the direct interest of agriculture in preserving biological diversity.

Although agricultural practices have affected nature for many centuries, until recently these effects were small in degree and temporally and spatially localized. Environmental effects worsened significantly as agricultural practices changed dramatically and rapidly after World War II (Gall & Orians 1992, Soulé & Piper 1992). Large scale, intensively managed agricultural industry largely replaced smaller farms and moved agriculture onto more marginal lands, leading to increased conflict between agriculturists and conservationists (Carroll 1990).

Modern agricultural practices affect the conservation of nature in two general ways. First, natural habitats are being converted to agricultural lands at an exponential rate, reducing and fragmenting land available for conservation, and reducing genetic resources critical to agricultural development. As prime arable land is lost to human settlement, agriculture is forced onto less and less optimal lands (Canter 1986, Corson 1990, Ehrlich & Ehrlich 1991). So far, this transition has been possible without losses in productivity due to heavy reliance on outside inputs into the agricultural system.

Secondly, agricultural practices affect the conservation of nature by the intensiveness of land use characterized by simplification, specialization, and mechanization. Management practices are built on large capital investments and continuous inputs of non-local, non-renewable inputs such as fossil fuels, fertilizers, and pesticides (de Zeeuw 1988, Plucknett 1993). These large-scale human substitutions for ecosystem services are generally unsustainable (Byrne et al. 1984, Ehrlich & Ehrlich 1991), decrease biological diversity on that land and surrounding ecosystems, and cause environmental degradation (Carroll 1990, Dahlberg 1992, Orians & Lack 1992, Reganold et al. 1990).

Large-scale, single commodity-oriented agricultural research and management strategies address problems in isolation and in series. The agricultural field is treated like an isolated laboratory rather than an integral part of an ecosystem. Landscapes are simplified (Eijsackers 1988, Gardener et al. 1991). Natural processes are unlinked and natural resources are replaced with technological alternatives (Ricklefs et al. 1984). Evaluation of production-maximization practices are assessed economically in the short-term. Farmers become trapped by the need to develop more land, make more capital investments, and add more non-renewable resources, putting themselves at higher and higher risks to environmental and social changes.

A prominent unsustainable feature of modern agricultural practices is the extensive use of fossil fuels. Heavy reliance on fossil fuels not only contributes to the loss of biological diversity, but promotes climate change. The use of fuels to clear land, the loss of tree coverage, and direct use of fossil fuels in food production, contribute significantly to the build up of CO^2 (Gilpin et al. 1992). Energy costs through fertilizer, pesticide, and water additions are rising sharply while giving diminished economic returns in many developed areas (Ehrlich & Ehrlich 1991, Pimentel et al. 1992a). Consumer demands and demographic problems associated with the large-scale nature of farming systems contribute to the energy costs of agriculture. As energy constraints are approached, population pressures could cripple agriculture unless we can develop alternative, more energy-efficient ways to produce and distribute food and learn to eat lower on the food chain (Gilpin et al. 1992).

Pesticide applications continue to dominate pest control methods (Morris et al. 1991). Approximately 2.5 billion kg of mostly broad-spectrum synthetic pesticides are used in agriculture and public health each year (Pimentel et al. 1992b). Pesticide use is costly, affects human and animal health negatively, causes environmental degradation, and destroys beneficial organisms leading to further pesticide reliance. Paoletti et al. (1992) cite evidence that pesticide residues affect beneficial invertebrates negatively in agricultural systems. Pesticides are also thought to alter the structure and function of whole ecosystems (Pimentel et al. 1992b). The toxic effects of pesticides on soil organisms, and resulting loss of soil fertility, are already troublesome to agriculture. The direct, environmental, and social costs of pesticides in the U.S. total approximately $12 billion with a saving of approximately $16 billion in crop value (Pimentel et al. 1992a).

Considerations of the risks associated with modern agriculture call for more research into ecological methods of pest control. Integrated pest management efforts, with strong biological control elements, are probably the best examples of the use and protection of biological diversity in modern agriculture. However, there remains much room for improvement. Though based strongly on ecological principles, IPM programs still rely heavily on reductionistic approaches to control single pests on single crops. This together with structural simplicity of the agricultural field leaves chemical control a still-common option. According to Barfield & O'Neil (1984), IPM programs must include large-scale ecological elements and processes, an understanding of mortality factors, an integrated control effort for different pests, incorporation of the dynamic nature of agroecosystems, and development of monitoring methods to meet its goals more efficiently.

Water is not valued nor managed in accordance with its ecological value. Much of the increased production capacity on agricultural lands has resulted from irrigating otherwise unproductive lands. Agriculture now uses approximately 70 percent of our world's dwindling usable water. Between 1950 and 1985 the total area irrigated nearly tripled, but economic costs have since slowed this trend (Ehrlich & Ehrlich 1991). Beyond the water resource limitations, irrigation practices increase energy demands, cause soil degradation from waterlogging and the accumulation of salts, and carry water pollution into nearby streams and lakes. Agricultural practices degrade water quality and contribute significantly to non-point pollution problems (Canter 1986, Hess 1991). Irrigation practices have led to productivity losses in approximately one-third of the world's irrigated farmland (Ehrlich and Ehrlich 1991).

Soil degradation is perhaps most directly linked back to loss of production. It is therefore best documented and best addressed by agriculturists. The management strategies that more than doubled world grain production since the 1950s have cost over 20 percent of our topsoil (Raven 1990). Currently, soil loss due to farm management practices exceeds soil formation by approximately ten-fold (Corson 1990). Soil erosion, loss of organic content, crusting, and loss of inorganic nutrients are also significant problems. Wiggins (1983) reports that soil fertility in Canada has dropped to less than one-half of its original level.

Air pollutants caused by agricultural practices arise from emissions, tillage operations, burning, wind erosion, harvesting and handling operations, pesticide applications, and vehicles (Canter 1986). These affect crop and animal production as well as human health negatively. Ozone depletion has been shown to stunt crop growth (Worldwatch Institute 1993) due to increased UV radiation. According to a recent USDA-EPA study reported by the Worldwatch Institute (1993), the U.S. currently experiences an overall annual crop harvest loss of 5-10 percent due to air pollution at a cost of $3.5 to 7 billion each year.

The introduction and establishment of exotics can be especially problematic in highly disturbed and simplified agricultural lands. Such non-natives can threaten native fauna and flora significantly (Wilson 1988). Alien insects transmit diseases, become crop pests, and negatively affect beneficial and other non-target invertebrate species. According to Sailer (1983) approximately 17 percent of 1500 immigrant insect species in the U.S. became pests requiring control efforts.

However, the researched and planned introduction of exotic organisms for use in biological control should not be criticized because of immigrant species. Furthermore, it is important, especially in sub-tropic, peninsular Florida, that we recognize that the term 'exotic' is relative, being both temporally and spatially scale-dependent (Frank & McCoy 1992, Noss 1990a). This greatly complicates assessing the costs of both the immigration of exotics through agricultural transport, and the encouragement of exotic species by agricultural land use strategies (Pyle et al. 1981). Preventing immigration, understanding ecological consequences, and developing eradication and control tactics for exotics will become increasingly complex and difficult challenges in land management. Entomologists will take a leading role in addressing these problems that affect natural and managed lands.

As the previous discussion suggests, we are still reaping the benefits, but starting to pay the costs of the Green Revolution. Environmental pollutants from agriculture include, heavy metals, dust, plant nutrients, pathogens, pesticides, odors, and sediments (Canter 1986). Farming practices affect soils, vegetation, fauna, water and nutrient cycles, and landscape elements leading to significant losses in biological diversity, reduced profitability, and environmental and human health threats (Paoletti 1992, Reganold et al. 1990).

Intensively managed modern agriculture has failed to create a utopian world by reductionistic approaches that neglect ecological impacts on and by the system. Energy costs and coming fossil fuel shortages, resource depletion, soil erosion, environmental contamination, and social and ecological vulnerability to environmental changes call for locally adapted, diversified agricultural practices built on ecological principles and dependent on intact natural systems. Large-scale agricultural organization, research strategies, and education efforts must be changed significantly. To meet these goals, entomologists must consider the agricultural field within the larger ecological and social context.

It is clear that we must minimize the negative environmental impacts of agriculture. Technical developments and government policy driven by reductionistic approaches and short-term perspectives cannot continue to dominate agricultural research and policy. However, the false hope of technology is alive and well as evidenced by a recent quote with regard to our ability to adjust agricultural practices to meet global climate changes. Gary Evens, the head of U.S. Department of Agriculture's Department of Global Change said, "Technological capabilities in agriculture have proven for the last 50 to 75 years to be able to keep up with any shifts and changes that have taken place" (Monastersky 1992).

Agriculture-Conservation Connection

"The struggle to maintain biodiversity is going to be won or lost in agricultural ecosystems." (McIntyre et al. 1992)

The short-term goals of sustainable agriculture and conservation of biological diversity will necessarily become more and more opposed as population pressures increase (Robinson 1993). It is the ultimate dependence of agriculture on surrounding and distant functioning ecosystems, together with the significant environmental effects of modern agriculture that necessitates cooperation between these groups (see Aplet et al. 1992, Dahlberg 1992, Francis 1990, Paoletti 1992, Paoletti et al. 1992, Pimentel et al. 1992, Pimentel et al. 1992b, Reid & Miller 1989). However, to date most knowledge about the interaction between natural areas and agroecosystems is incidental, disjointed and generally not used for planning and management.

Agricultural systems are dependent not only on ecosystem services from surrounding natural lands but on biological diversity in far away places. Genetic resources are critical for the development of new crops, bases for breeding resistance, increasing productivity, nutritional value, and increasing within crop versatility needed to meet climatic and future management changes facing agriculture (Ehrlich & Ehrlich 1991, Gilpin et al. 1992). Biological control programs ultimately depend on the preservation of natural areas and ecological processes in near and distant lands (Gilpin et al. 1992, Morris et al. 1991). Ecologically-based pest control programs will become even more critical as agricultural lands continue to spread and we face the negative effects of chemical control.

Nature as a Model for Sustainable Agriculture

Sustainable agriculture requires diversification for better use of ecological processes to increase resilience and reduce risks (Ewel 1991, Pimentel et al. 1992b). Nature is our best model. We must move away from maximum production to optimal production strategies that are process- rather than product-oriented. Agroecology, as defined by Stephen R. Gliessman (Soulé & Piper 1992), is the science of ecology applied to agricultural production systems for the development of sustainable agricultural practices. Natural ecosystems generally exhibit some degree of dynamic equilibrium reflecting local adaptations to abiotic and biotic elements, including efficient solar energy budgets and nutrient recycling, and dynamic plant-herbivore and host-disease associations (Soulé & Piper 1992).

Natural systems will provide models for the development of better strategies for pest management, development of better monitoring techniques, more diverse cropping systems, and low-input agricultural systems. These practices will rest on increasing biomass, plant and animal diversity, maintenance of soils and water, and reduction of wastes (de Zeeuw 1988). They require a better understanding of regional dynamics impinging on managed systems, the importance of structure in population size, fluctuations, and community dynamics of beneficials and pests. Promising examples of the potential benefits of imitating natural systems in agriculture are physical models that provide the benefits of emergent properties without detailed knowledge of how these arise or function (Soulé & Piper 1992). To date, most ecological models in agriculture extrapolate only specific natural ecological processes onto an existing production-oriented agriculture structure. This tack-on strategy offers only limited improvements and limited reduction of negative effects.

Beyond the important academic lessons in natural systems, preserved areas and their ecological processes are most critical to agriculture through connecting ecosystem and landscape-scale effects such as water filtering, biological control refuges, natural pollinators, and environmental buffer zones, corridors etc. (Dahlberg 1992, Ehrlich & Wilson 1991, Eijsackers 1988, Gilpin et al. 1992, Pimentel et al. 1992b, Soulé & Piper 1992). Agriculturists must therefore include local natural area management needs and practices. Sattaur (1987, in McNeely et al. 1990) concluded that in the hills of Nepal, approximately each hectare of farmland required 3.5 times that land area of forest to remain sustainable.

Agriculture Contributions to Conservation Biology

Just as agriculture depends on biological diversity, conservationists cannot succeed in the absence of sounder agricultural practices (Pimentel et al. 1992b, Raven 1990). Agricultural lands are the big holders of much of the world's biological diversity (Pimentel et al. 1992b, Sutton & Tittensor 1988). These lands are the major interface between natural areas, and agricultural management practices affect surrounding natural systems (Gall & Orians 1992). Yet conservation efforts are only beginning to focus on agricultural lands (Sutton & Tittensor 1988).

Agriculture is based on applied ecological research, and its success depends on understanding, monitoring, and influencing ecological processes. Agriculturists are probably our most experienced land managers (Plucknett 1993). This wealth of knowledge has been virtually untapped by conservation biology. Although the reductionistic approaches to agriculture have led to some long-term crunches, this approach still has many advantages and has led to important developments at genetic, population, and ecosystem levels in inquiry.

Agroecosystems differ from relatively natural systems by the addition of energy to the system, simplification, dominance of artificial selection, and production-oriented control (Odum 1984a, in Coleman & Hendrix 1988). By monitoring the relatively simplified processes in agricultural systems, we can, perhaps, better interpret adaptation and changes in community composition, structure and function related to global climate changes.

Longer and larger-scale replication problems in natural land management limit ecologists' understanding of ecosystems and landscapes (Gilpin et al. 1992). Agricultural lands vary in, 1) duration and extent of disruption of ecological structure and function, 2) plot size, and 3) surrounding land use patterns. Because agricultural expansion onto natural lands and conversion of land back to a more natural state (e.g., land set-aside projects) can often be anticipated, ecological processes can be investigated at a larger-scale than possible in natural systems (Gall & Orians 1992).

Agricultural systems also offer productive models for understanding theories and concepts important in conservation. These include island biogeography and minimum viable populations, species concepts, metapopulation structure and dynamics, delineation of major pathways of energy and materials in ecological systems, gene flow, scaling problems, disturbance, keystone species roles, impacts of land fragmentation, colonization, extinction rates, competition, genetic drift, and genetic diversity. Now is the time to use agricultural systems as laboratories and experimental plots for understanding concepts in ecology (Saunders et al. 1991). Soon agricultural lands will be further pressed to meet human nutritional needs.

Increased knowledge of the interdependence of agriculture and natural systems is critical to meet future challenges of climate and policy changes, and to create locally attuned, ecologically based, sustainable operations while reducing negative environmental impacts (Dahlberg 1992). Yet, direct studies of the importance of biological diversity on and around agricultural systems are lacking (Paoletti 1992).

Landscape Ecology

Biological diversity exists in a matrix of habitat patches including managed and relatively natural lands. They are ecologically linked and interdependent (Carroll 1990, Pimentel et al. 1992b), and together make up landscapes (Coulson & Crossley 1987). These patches are linked through the movement of materials and energy by physical and biological processes (Rice 1992, Ricklefs et al. 1984, Saunders et al. 1991). These movements are critical to the regulation of local populations, determine the area required to avoid extinction, reduce inbreeding within populations, and preserve normal organization.

Agriculture and conservation goals are linked through landscape level processes (Carroll 1990, McIntyre et al. 1992, Salwasser 1991). By studying, monitoring, and influencing the movement of energy, materials, populations, and ecological processes, functioning ecosystems can be managed proactively (Ricklefs et al. 1984, Scott et al. 1987). As agriculture continues to expand, natural lands become increasingly fragmented, isolated, and farther apart. These effects increase the need to manage natural areas and to integrate regional land use strategies (Carroll 1990, Harris 1984, Janzen 1986). For example, farming practices can provide a source and means of successful establishment of invasive species and disease transmission onto natural lands (Carroll 1990), leading to unwanted changes in ecosystem structure and function affecting both agriculture and conservation goals.

The influence of land fragmentation on populations and processes in natural areas and the role of agricultural lands as corridors between natural areas will become more and more important areas of conservation study. The importance of this structured linkage is exemplified in Costa Rica where, although approximately 25 percent (as opposed to approximately three percent worldwide) of land has been officially preserved and managed for conservation goals, biological diversity continues to decline due largely to modern agricultural practices on surrounding lands (Pimentel et al. 1992b).

Increasing structural diversity in agroecosystems with semi-natural interfaces, such as hedgerows, wetlands, and set-asides, can provide refuges, food sources, and critical linkages among natural areas (Dennis & Fry 1992, McNeely & Norgaard 1992, Noss 1987, Paoletti et al. 1992). Increased structural heterogeneity on field margins can have beneficial or negative effects on weed and pest control (Gall & Staton 1992, Paoletti 1992, and ref. in Booji and Noorlander 1992). Development of agricultural methods to increase biological diversity without undue negative effects on production will require cooperative efforts between agriculturists and conservation biologists. Because insects are key movers of materials and energy, a better understanding of the role of insects in these land interfaces will be critical to the development of future land management.

Stress ecology, the study of human and natural disturbances on ecological systems (Odum et al. 1979, in Coleman & Hendrix 1988) has helped to interface agriculture with ecological study, and will provide important contributions to land restoration (Coleman & Hendrix 1988, Ricklefs et al. 1984). By studying how organisms persist in disturbed and simplified agricultural lands we can understand resilience and recovery better in natural systems. Such large-scale investigations are necessary for developing methods for restoring impoverished areas (Crossley et al. 1992). Land restoration efforts will become more significant as we are forced to rely on now-impoverished lands for preserving biological diversity.

Agricultural practices stand to gain many practical benefits by incorporating a landscape perspective for land management. Management strategies embedded in the regional landscape can maximize the use of natural mechanisms and save time, resources, and reduce risks of continuous intervention, while enhancing long-term resilience and stability of agricultural lands (McNeely et al. 1990, Ricklefs et al. 1984). For instance, because pesticides have far-reaching effects, the success of pesticide application is landscape-, not field-dependent (Orians & Lack 1992). Cooperation among farmers and other natural land managers is essential for effective, ecologically-based pest control strategies (Barfield & O'Neil 1984, Eijsackers 1988, Paoletti 1992).

Multiple uses of managed lands has become less common with the growth of intensive agricultural practices due to short-term economic considerations (Gall & Orians 1992). Resource limitations and environmental degradation have revived interest in integrating land use through both time and space. Flexibility needed for future challenges to both conservation and agriculture can be enhanced by innovative multiple land use strategies (Noss 1983, 1987, Salwasser 1991). Generally, small economic losses are traded for enhanced environmental services and aesthetic value (Gall & Orians 1992).

Economic use of buffer zones around preserved areas could add versatility and resilience to local agricultural production while moderating negative effects of more intensive agricultural practices on surrounding lands. But the potential of multiple land use is relatively unexplored. Indigenous cultures, currently relying on less intensive agricultural practices, provide unexplored lessons for multiple land use strategies.

In the U.S., large landholders such as the Bureau of Land Management, Department of Defense, Fish and Wildlife Service, Forestry Service, and Park Service are just beginning to base multiple use strategies and priorities on ecological principles. The U.S. National Forestry Management Act now incorporates biological diversity considerations through multiple land use provisions. Agro-forestry, sylvi-horticultural and sylvipastoral systems may provide a good start at integrating resource use and resource conservation plans (de Zeeuw 1988).

Climate

Global warming is a common problem threatening stability in both agricultural and natural ecosystems. Climatic changes could alter the abundance, distribution, and interactions among species with significant impacts on the distribution and management of agricultural and natural lands (Ehrlich & Ehrlich 1991, Gall et al. 1992, Gilpin et al. 1992). Adjustments in current practices, such as altering planting dates, changing crop varieties, and increasing irrigation, may offer little relief, especially in developing countries expected to be hit the hardest (Monastersky 1992).

According to Dahlberg (1992), the expected warming climate could drive the U.S. grain belt northward into areas where abiotic and biotic relationships differ from those to which current farming systems are fine-tuned. Land management strategies may need to be altered dramatically to meet these challenges. Agriculturists will depend on natural areas to provide alternative crops, control agents, and models for new management strategies enabling necessary large scale adjustments (Dahlberg 1992, Gilpin et al. 1992).

Changes in current agricultural practices, such as the development of less energy-intensive farming methods and increasing plant biomass on agricultural lands to absorb CO^2, can reduce the risks of climate change. Reducing deforestation rates for acquiring new agricultural lands is also important. This will, of course, increase pressures to intensify production practices on current agricultural lands. Increasing biological diversity in agricultural fields and preventing the loss of diversity in natural areas, where potential cultivars and biological control agents occur, will prove critical to agricultural resilience under changing climatic conditions (Gall & Orians 1992).

Research Needs

The ecological and practical importance of biological diversity is not well-studied by conservation biologists. We do not have an understanding of how species diversity and ecological processes translate to ecosystem dynamics and landscape heterogeneity. We know little of how natural areas benefit agriculture (Gall & Staton 1992). For example, although watersheds are claimed as important to agriculture for flood control and soil conservation, these effects have not been demonstrated clearly (Carroll 1990). We must also go beyond natural systems models aimed at minor modifications of modern agricultural practices. There is much opportunity for agriculturists to provide theoretical and empirical knowledge to conservation efforts while reaping practical benefits.

Especially important in integrating conservation and agriculture goals will be studies of how we can increase diversity at multiple levels on agricultural lands. Equally important will be investigations of how such semi-natural diversity furthers conservation goals and what kinds of diversity are profitable to agriculture. In order to make conceptual and practical strides in these areas, we need to understand how materials and processes move between and influence agricultural and natural systems. These include adaptation, dispersal, migration, nutrient cycling, and climatic and disturbance regimes. The importance of corridors and mosaic structure in these movements must be investigated. We need a better understanding of how small- and large-scale ecological processes affect agriculture, and vice versa (Dennis & Fry 1992).

Consistent monitoring and evaluation techniques (Carroll 1990, Dourojeanni 1990) need to be developed and tested. Current differences in monitoring strategies limit cooperative efforts. Consistent methods will allow long-term monitoring and experimental manipulation of ecological variables built on process-oriented landscape management goals.

Research should be aimed at the development of long-term, landscape-level management strategies that can be adapted constantly according to monitoring results. Such adaptive environmental assessment and management approaches attempt to integrate responsibility and opportunity among agencies to cope with complex, large-scale environmental problems more effectively (Salwasser 1991). Cooperation will be critical to anticipate and respond to the challenges of climate change (Gall & Staton 1992). Such an adaptive planning strategy would rest on a hierarchical approach to understanding, monitoring and managing systems across ecologically relevant spatial and temporal scales (Noss 1990b, Rice 1992). Saunders et al. (1991) list examples of successful landscape-scale approaches to land management.

Gall & Staton (1992) outline general research needs aimed at integrating conservation and sustainable agricultural practices. These include, 1) evaluation of the ethics of agricultural practices, 2) characterization of genetic variation in crops and on agricultural lands, 3) understanding and diversifying boundary structure and function, 4) developing better water management options, 5) increasing large-scale modeling efforts, 6) investigating specific affects of agricultural practices on the surrounding area and vice versa, 7) furthering ecologically-based pest control strategies, 8) increasing studies of land management strategies of indigenous groups, 9) developing adaptive planning approaches, and 10) evaluation of international agricultural philosophy and policy for sustainability attributes. Agriculturists, and especially entomologists, stand to make major contributions in all of these efforts.

Changes in Perception

There are many optimistic opportunities for interaction between agriculture and conservation efforts. Perhaps the biggest obstacle is providing the considerable impetus needed to change reductionistic research and management strategies now in vogue in agriculture and research in general. Changes in social, political, and economic perspective will determine ultimately whether we make the necessary changes.

Public concern that modern agricultural practices negatively affect the environment, food quality, and human and animal health grew significantly in the 1960s as pesticide effects on non-target organisms were first being evaluated seriously (de Zeeuw 1988, Gall & Orians 1992). Economic benefits kept agriculturists defensive of public concerns until environmental effects began to threaten agricultural production more directly. It is not surprising that it is the most direct and evident links between agriculture and conservation where agriculturists are already cooperating with conservationists. These include the loss of soils, deterioration of water resources and water quality, the loss of genetic resources needed for crop breeding programs, and global warming. Less direct and evident interdependencies await research, policy consideration, and will ultimately depend on public pressures arising through increased environmental awareness.

In 1980 The World Conservation Strategy officially recognized that conservation can succeed only if goals are specifically tied to regional development needs. The need to maintain essential ecological processes, to preserve genetic diversity, and to ensure the long-term preservation of natural resources as essential ingredients of sustainable development were emphasized (Green 1989, IUCN 1983, Robinson 1993).

Although ecological concerns in agriculture are probably the oldest conservation concerns addressed by practical land management, it was not until the mid-80s that the Consultative Group on International Agricultural Research (CGIAR), an informal but influential global agriculture policy and research organization, explicitly broadened its goals to include the concept of sustainability (Plucknett 1993). It was recognized that agriculture is ultimately dependent on a diverse and well-functioning earth. Through its extensive impacts on the environment, agriculturists have an obligation to contribute to conservation efforts. And, in order to develop sustainable agricultural systems, land use strategies must incorporate social, economic, and environmental impacts and these must be integrated at the landscape level.

In 1988, the Public Service Research and Dissemination Program of the University of California, Davis, conducted a workshop to address how agriculturists and conservation biologists might better work together. Sustainable agriculture and the conservation of nature were explored through research on environmentally sound land management practices. This workshop, and others that followed (see Benbrook 1991, Paoletti 1992), defined common challenges and called for cooperation between these two mutually dependent groups (Gall & Staton 1992). It was recognized that agriculture must diversify, especially at genetic and landscape levels, if it is to adapt successfully to changes in the environment and in consumer demands. It was through these workshops that agricultural objectives came to include research, policy, and management practices aimed explicitly at increasing biological diversity on agricultural lands.

However, structured interactions and unified land management efforts remain largely unexplored. In order to meet the challenge of growing human resource needs without threatening ecological integrity, we will need to integrate knowledge, share responsibility, and cooperate to find workable solutions. Success will depend on holistic, long-term, and broad-scale approaches to land use. In short, we need resource managers to become conservation biologists and conservation biologists to incorporate resource use needs.

Sustainable Agriculture

"A parasite-host model for man and the biosphere is a basis for turning from exploiting the earth to taking care of it. Survival of a parasite depends on reducing virulence and establishing reward feedback that benefits the host." (E. Odum 1992)

According to Daily & Ehrlich (1992), . . . "a sustainable process is one that can be maintained without interruption, weakening, or loss of valued qualities." In 1980, the World Conservation Strategy popularized the term 'sustainable development' and stressed that development and conservation are mutually dependent (Robinson 1993). The term sustainable agriculture differs from a recent series of in-vogue approaches in agriculture, including alternative, organic, and low-input, in that it defines a goal rather than strategies. Sustainable agriculture, is by definition, vital to long-term human survivorship, and rests on any methods that minimize environmental degradation and nonrenewable resource use (Benbrook 1991).

In 1991, the Technical Advisory Committee (TAC) redefined the objectives of the CGIAR to emphasize the need to achieve sustainable agriculture and to address barriers to achieving this goal. According to the TAC, sustainable agriculture requires the management of natural resources to meet human needs without degrading the environment to the point that degradation reduces the long-term potential of agriculture to remain sustainable. Conservation and management of natural resources, development of sustainable agricultural practices, and lessening socioeconomic pressures that affect sustainable agriculture negatively are the primary objectives (Plucknett 1993). If we include in our definition of human needs, the need for conserving biological diversity at multiple levels of organization and at multiple spatial scales, this utilitarian approach can be considered complete.

The TAC recommends research strategies that include a multidisciplinary approach, consideration of long-term objectives, and more ecologically balanced systems. Yet, to date, CGIAR's policy on the relative importance of these to product-oriented research and improving natural resource management remains unclear (Plucknett 1993). Conservation effort in agriculture has been limited primarily to the development and maintenance of plant and animal germplasm bases and associated breeding programs (Plucknett 1993). Furthermore, most international support goes to large-scale, modern approaches to agriculture (Ehrlich & Ehrlich 1991). In the U.S., the program for low-input sustainable agriculture (LISA) was implemented to reduce the use of non-renewable resources, while increasing ecological bases of agricultural practices and considering environmental consequences of agricultural practices (Reganold et al. 1990). But currently, this program seems to fall short of its goals (Hess 1991). Of the projects funded through the U.S. LISA program in 1988 and 1989, over two-thirds of all funded projects were for traditional approaches to management (Gardner et al. 1991).

Sustainable agriculture must be more ecologically and information-based with less dependence on outside non-renewable resources, especially water and energy. The maintenance of, and incorporation of, ecological processes are prerequisite to development strategies that are sustainable in the long term. We need to diversify within crop systems and across the farm landscape, managing agricultural lands according to local environmental and biological factors. Soil conservation, natural pest controls, and organic recycling will also be emphasized (Paoletti et al. 1992, Reganold et al. 1990). We cannot hope to gain the needed regional flexibility by understanding the details of local systems in the same way we have industrialized modern monocultures. We must depend on larger-scale approaches. Much work remains to be done, especially modeling natural ecosystems.

We can also learn from indigenous agricultural practices that are locally adapted (Pimentel et al. 1992b, Soulé & Piper 1992). These experienced land managers use few or no outside inputs. This has forced them to understand agro-ecological concepts critical to the development of sustainable agriculture. They also have the opportunity and the need to base their decisions of long-term costs and benefits.

Modern management strategies with sustainable elements range from small changes in established production-oriented systems to holistic ecologically-modeled process-oriented systems. Crop diversification, across time (e.g., rotation) or space (e.g., multi-cropping), can increase yields relative to monocropping, reduce soil erosion, pest and disease outbreaks, pollution, utilize nutrients and water better, and provide economic resilience (Soulé & Piper 1992). Management strategies range from simply raising two or more crops together in a field to mimicking complex ecosystem structure. The short-term costs and existing capital investments have prevented the extensive development of more complex cropping strategies. Multiple cropping is limited mostly to planting a second crop interspersed with the main one for a single purpose, such as luring pests away from the main crop (Soulé & Piper 1992).

Soil conservation is perhaps the best example of positive large-scale strides toward conservation agenda in agriculture. This is a reflection of the direct production costs of soil deterioration and soil loss. Soil quality is a reflection of physical, chemical, and biological properties that are interdependent and far-ranging. Agricultural practices that increase or prevent the loss of soil quality can simultaneously increase productivity and biological diversity.

Biological control benefits provide one of the strongest motivations for diversifying agricultural systems. The abundance, diversity, and effect of beneficial insects rest on landscape-scale ecological structure and function. Failures in biological control are usually associated with unforeseen ecological factors encountered in and around the field (Howarth 1991, Soulé & Piper 1992). The preservation or creation of natural refuges, diversification of crops, and a better understanding of the ecology of beneficials will help align pest management and conservation goals (Klingauf 1988). Yet, USDA funds for biological control research have declined (Reganold et al. 1990).

Conservation tillage not only reduces energy use for tillage, but enhances the conservation of micro-invertebrates and encourages mycorrhizal associations, while enhancing soil fertility, nutrient cycling, and water retention. The crop mulch protects the soil from wind and water erosion. However, thus far conservation tillage is less than holistic. Generally, herbicides are used for weed control increasing herbicide costs and environmental contamination (Soulé & Piper 1992). Improvements in conservation tillage will require careful monitoring and accurate timing of tillage. Increasing vegetative biomass in agricultural productions, such as with the use of cover crops, can reduce soil erosion and water runoff, and improve weed control, while providing structural benefits and increasing biological diversity in the soil (Dennis & Fry 1992, Pimentel et al. 1992b).

Of the approximately one percent of U.S. farmers practicing sustainable agriculture in 1980, most were organic farming operations. These farms are characteristically diversified, small-scale, holistic production systems. Such farming strategies represent the best examples of reducing external non-renewable inputs and increasing ecological and information bases in agriculture (Dahlberg 1992, Reganold et al. 1990). Interconnecting whole farm organic operations and actively connecting them with natural landscapes can increase resilience while providing important wildlife refuges and wildlife corridors.

Agroforestry, planting trees and food or forage crops in combination, offers common benefits to agriculture and conservation. The increased biological diversity reduces pest problems and conserves soil and water resources (Pimentel et al. 1992b). Depending on the intensity of extraction and management, these systems can maintain considerably more biological diversity than monocultures while enhancing ecological bases of management practices (Ewel 1986, Pimentel et al. 1992b).

Improved pasture management is another opportunity for simultaneously enhancing livestock production while conserving biological diversity and lessening environmental degradation, especially soil erosion and water pollution. Reducing the use of feed grains and increasing forage rations could help diversify farming systems (Gardener et al. 1991). Livestock manure use in agriculture could be better managed to increase biomass and biological diversity on agricultural lands and reduce water pollution downstream. According to Safley et al. (1983) only about six percent of manure is used. Yet the total amount of nutrients available in manure produced by livestock each year in the U.S. is almost equal to the amount applied as external commercial fertilizers (Pimentel et al. 1992b).

In developed countries, a growing awareness by the general public for food safety and environmental problems caused by modern agricultural practices has been a strong impetus for better aligning agriculture and conservation. However, attaining sustainability in agriculture will require further shifts in farmer and consumer environmental awareness. Wants must be separated from needs and the advantages of diverse diets and alternative food crops must be stressed. Extension programs need to be revitalized to better inform the public and farmers of conservation concerns of agriculture. Farmer networks need to be strengthened and better informed of research in agriculture and conservation. On-farm research should be promoted better to develop regionally attuned and coordinated efforts, involve farmer expertise better, and improve experimental validity (Soulé & Piper 1992). Entomologists can do much to influence consumers' views of insects and their damage, and the assessment of cosmetic considerations.

As resources dwindle and the human population continues growing exponentially, we must incorporate non-monetary factors, such as resource depletion and environmental degradation, and longer term views of costs and benefits into our accounting (Nash 1991, Soulé & Piper 1992). Odum (1992) lists the need to bridge together human and natural goods and services and short-term economically-driven and long-term sustainable management as one of the great concepts in ecology.

The costs of research and development of more ecologically-sound agricultural practices cannot be allowed to fall into the hands of farmers alone. It is the broad-ranging and long-term connections of agriculture, environmental health and safety, and social well-being that ties conservation and agriculture. Finding common ground will require increased support for research, new policy, and more and better public education.

Barriers to Progress

As early as the 1940s Aldo Leopold was calling for long-term, ecologically-based views of land management (Noss 1991), yet such strategies are only beginning to be developed. Various barriers must be overcome if we are to address sustainable agriculture and conservation problems effectively with limited resources and time. These barriers are institutional, social, and economic factors that limit interaction and cooperation in developing long-term, broad-based, ecological approaches and solutions. They include reductionistic approaches to problem solving in science, university, government policy, and granting agency structures, promotion requirements, lack of support for farmers, and lack of a value base for ecological services (Benbrook 1991, Soulé & Piper 1992).

Simply bringing together multiple disciplines will not overcome these obstacles. Future solutions will rest on the need for multiple disciplines to speak the same language, operate on the conceptual framework, and agree on goals and limitations. We will also need increased funding for collecting empirical data, development of models, and progress in ecological theory. Rice (1992) provides an hierarchical conceptual framework to overcome some conceptual and terminological problems in an effort to facilitate integration of agriculture and conservation biology. This approach examines common biological diversity attributes in agriculture and natural areas across multiple time and spatial scales, and focuses on common and divergent methods of these two groups in understanding, impacting, and managing this diversity.

The single crop, production maximization approach grew out of a period of abundant land, natural resources, and young methods. Problems are approached in series and solutions often create further problems. These approaches are no longer appropriate as we move into a period characterized by dwindling land and natural resources and limited technological advancement possibilities (Soulé & Piper 1992). Yet our current approaches are driven by inertia inhibiting change and innovation. Past payoffs of reductionistic, short-term approaches in modern agriculture bias current funding, hindering the development of ecologically-based management practices. Research and management strategies need to be revamped to function better in a stable rather than growth environment.

Current reward systems in academia are based on individual achievements, on quantity rather than quality of the work, and on the ability to attract grant money. Rewards for publishing positive results in a relatively short time biases projects toward clear cut, non-risky research efforts. Group efforts are de-valued as are less-flashy, more difficult and, often, more important projects (Noss 1990a). The peer-review system also promotes status-quo efforts and hinders innovative approaches. Soulé and Piper (1992) note that new journals often arise out of new innovative ideas that aren't accepted in established journals.

Private interest granting agencies generally promote non-ecologically based methods in agriculture. This is evident in biological control efforts where companies promote biotechnology approaches over more ecologically-based approaches to pest control (Benbrook 1991). Government agencies also show biases in their support. According to Soulé & Piper (1992), the USDA supported biotechnology approaches to the problem of nitrogen fixation over more ecologically-based proposals partly because these approaches have the potential to produce profitable products. Even in the LISA program, specifically set up to promote sustainable agriculture, more innovative projects that demand large shifts in current agroecosystem structure are not well funded (Gardner et al. 1991).

Project funding, institutional organization, graduate education, and extension and farmer education all need major revision if we are to meet agriculture's goals of sustainability (Barfield & O'Neil 1984). Yet land grant university departments have generally become more isolated and specialized (Norgaard 1992). Isolation narrows perspective and reduces options. We need ways to promote and reward long-term studies, and to reward researchers involved in such projects. According to Soulé and Piper (1992), 17 land-grant universities have sustainable agricultural research programs. Although most sustainable agricultural programs involve interdisciplinary study graduate programs, these usually fall short of truly integrating information and experience needed to develop holistic problem solving skills.

U.S. agricultural policy, research funding and institutional structure rest on economic interests and on the political power these interests instill. The use of commercially available non-renewable resources to produce commercial agricultural products is promoted. The use of less economically valued information and ecologically-based processes needed to create sustainable agricultural systems are neglected (Norgaard 1992).

The lack of an accounting for the ecological foundation on which economic and political structures ultimately rest is a major obstacle to integrating agriculture and conservation goals and land use strategies (McNeely & Norgaard 1992). Farms are viewed as enterprises rather than ecological systems. Capital investment debts tie modern farmers to old philosophies and methods (Gilpin et al. 1992). Farmers are discouraged from developing or participating in holistic approaches to agriculture by federal farm programs that make shifting practices economically unprofitable (Reganold et al. 1990). Government support agencies are set up to address special interests. We need new approaches to address more diffuse, collective interests that agriculturists and conservationists face (Norgaard 1992). Ultimately these barriers will be overcome only with increased public awareness and social support for merging conservation concerns and farming management practices (Gilpin et al. 1992).

Until recently global and U.S. agricultural policy has both neglected agriculture's direct dependence on the environment and contributed to the loss of biological diversity (Dahlberg 1992, Pimentel 1992b). Energy dependence, industrialization, specialization, and reductionistic approaches have put agricultural systems at considerable ecological and environmental risk (Gall & Orians 1992, Soulé & Piper 1992). Increased research efforts will fall short of the goals of sustainable development unless these changes are fortified with policy promoting environmental responsibility.

Present, often out of date, policies will likely lead to dire consequences economically, socially, and perhaps even further threaten the environment. Most current programs attempt to minimize risks or counter negative effects when risks are realized. These provide agriculturists with information, services, and economic buffers (Dahlberg 1992). Such tack-on approaches are often not well researched, too late, ineffective, and contribute to other problems. Some public policies even penalize farmers for resource preservation and environmental protection efforts (Benbrook 1991). Policy changes have amounted to a series of modifications of agricultural practices to address more and more dire environmental degradation.

Policy development that ties conservation and agricultural goals is in its infancy. Future policies will grow out of interdisciplinary research, better methods to tie ecology and economics, and especially increased environmental awareness by the general public, farmers, and policy makers. We need innovative ways to incorporate long-term and far-reaching environmental costs and benefits effectively in our economic and social policies.

As population pressures continue to put additional pressure on agriculture and the environment, environmental policy will come to put bigger and bigger constraints on agricultural methods. The Clean Air Act, Clean Water Act, Endangered Species Act, and National Environmental Policy Act already influence farm production. Recent changes in the Coastal Zone Management Act are aimed at controlling non-point pollution sources (Organization for Economic Co-operation and Development 1993). This legislation mandates increased scrutiny of current agricultural practices. Future environmental legislation could further threaten productivity as the general public becomes better informed of the environmental consequences of current agricultural practices. To avoid this, agricultural policy must become more integrated and proactive.

Probably the most successful conservation policy in agriculture is the Conservation Reserve Program, a part of the Food Security Act of 1985, designed to address soil degradation. This program ties conservation and agricultural goals directly at the level of landscape structure and function. Farmers are encouraged to place marginal crop lands into wildlife reserves (Gall et al. 1992). Beyond soil conservation, this program has contributed to the reversal of land fragmentation, creation of wildlife habitat, with positive effects on regional processes, and enhanced aesthetics (Dunn et al. 1993). Energy and water conservation policies and programs need to be addressed better in agricultural policy as has soil conservation (Dahlberg 1992). Policies promoting ecological approaches to low-input sustainable farming methods could efficiently address water, energy, soil, and pollution problems simultaneously.

The 1990 Farm Bill extended the 1985 Conservation Reserve Program and further incorporates environmental objectives into farm policy and contributes to long-term conservation goals (Hess 1991). It specifically addressed the need to increase biological diversity and to provide wildlife habitat in the Wetlands Protection Provisions, Conservation Reserve Program requirements, and Water Quality Incentives Program. These programs have at least potential to benefit farmers economically by reducing inputs of non-local non-renewable resources such as pesticides and fertilizers and by increasing non-agricultural value of their lands (Kinsinger 1991).

Pimentel et al. (1992b) recommend several government agricultural policies to encourage development of sustainable agricultural practices. They point to the need to focus on biological control of pests, promote protection of organisms that maintain ecosystem quality, and encourage protection of biological diversity upon which sustainable agriculture ultimately rests. Creative incentives for compliance with conservation goals must be combined with farmer education programs.

Although such policy development should be commended, we must go beyond sustainable development aims in policy if agriculturists are to take full responsibility for their role in the conservation of biological diversity. We need agriculturists to participate more in general environmental policy, especially the design of conservation policy, and to participate in inter-agency land management responsibilities (for European examples, see Organization for Economic Co-Operation and Development 1993). In a step in that direction, the current proposal to create a National Biological Diversity Conservation and Environmental Research Act includes the Agricultural Research Service on its governing board (Blockstein 1988). As conservationists and agriculturists move together in their aims, the study of insects will become more and more critical, yet, to date, there has been little input by entomologists in the creation of such legislation.

EDUCATION

". . . a lot more than better science is required to maintain biodiversity and land health. We need a new ethic, and an ethic put into action." (R. F. Noss 1991)

Environmental education remains the most important and timely challenge in conservation. Public education efforts lag behind changes in philosophy in the conservation movement. Public support continues to rest on emotional rather than intellectual motives. But we cannot hug genes or landscapes (Noss 1991). Fewer than 10 percent of Americans are considered ecologically literate (Kellert 1980a, in Noss 1991). Rather than investing in education of the complexities of ecology, charismatic species are often used as ploys for ecosystem preservation. This is potentially devastating to conservation efforts. Once the species is gone, there is no reason to save the ecosystem.

Public apathy toward invertebrate and ecosystem conservation stems from limitations of current species-oriented public relations programs by conservationists, biased environmental education programs, limitations of reductionistic science, political and economic constraints, and a lack of input by entomologists in conservation and environmental education (Thomas 1978). We must provide the general public with a more sophisticated awareness of ecological concepts and the costs and risks of modern agriculture (Gardner et al. 1991).

Hale (1991) lists 50 of the most important ecological concepts according to professional ecologists [from Cherrett (1989)]. These range from genetic to landscape ecology and include abiotic and biotic processes stressing population ecology and community dynamics. Entomology offers a unique opportunity to teach these concepts and connections that are necessary for informed decision-making (Pyle et al. 1981).

Insects are ubiquitous, diverse, versatile, easy to observe, easy to rear, and intimately tied to plants. Entomology includes the study of most of the world's biological diversity and addresses some of the most crucial of practical problems facing humans. Such a mix of basic and applied objectives provides an unparalleled opportunity to develop an ecologically-based value system needed for simultaneously attaining conservation and sustainable agriculture goals. This need has been largely avoided in science and, so far, neglected in conservation education.

But there are some drawbacks to focusing on insects. Many adults and, soon enough, their children and students associate insects with bad experiences. A lack of information usually leads to negative biases. For example, of 1117 adults surveyed in Arizona, over half disliked or were afraid of arthropods (Byrne et al. 1984). These biases arise partly because the general public is unduly focused on pest insects, as are entomologists. These researchers also found that women are more likely to feel negatively toward insects. Women not only teach their biases to their children, but make unhealthy personal decisions and support policies that reflect those biases. Women in entomology can provide role models for young women and children that will help to alleviate these biases.

In the Arizona study, education level was correlated with positive views of insects, suggesting that exposure to general biological principles translated to specific positive emotional responses. This finding supports the use of entomology to teach general ecological principles. Positive attitudes towards insects are likely to lead to improved environmental decisions. For example, Levenson (1978, in Byrne et al. 1984) found that positive attitudes towards insects were associated with support for non-chemical pest control strategies.

Experiential learning helps to connect resource entities to the larger systems which they influence, and from which they arise, and upon which they ultimately depend. Yet local information and hands-on experiences are rare in most environmental and, especially conservation, education. In the U.S. children and adults are usually taught about tigers and panda bears and rain forests. These teaching strategies encourage separation of information and emotional motivation to act. Meanwhile there is little understanding of how local systems function and provide for human needs.

In an effort to remedy this shortcoming in environmental education, the Ecological Society of America formed a group called Ecologists for Education in Local Natural History. This organization encourages professional ecologists to contribute to teaching local natural history by 1) developing field guides and new instructional materials, 2) adapting and updating materials currently used, 3) helping in teacher training workshops, 4) helping to set up fellowships to promote local environmental education, and 5) providing avenues to enhance communication (Feinsinger 1987). Because the key models available to teach these lessons are insects and insect-plant interactions, entomologists have tremendous potential to assist in these important efforts.

Encouraged by Feinsinger's plea, a group of ecologists from the University of Florida recently developed a local field guide to the schoolyards in north central Florida entitled, Handbook to Schoolyard Plants and Animals of North Central Florida (Feinsinger 1987). This exemplary publication was followed by an activity guide and teacher training workshops. The local schoolyard natural history lessons are accessible and hands-on. These publications will become models for the development of other localized ecological lessons.

University programs, characterized by reductionistic, technologically-based science, generally do not provide students with skills and perspectives necessary for developing holistic approaches to land management (Dahlberg 1987). The limitations of this narrow approach to environmental problems is exemplified by tack-on remedies (Raloff 1993), and the unrealistic hope that technology will continue to solve agricultural problems (Monastersky 1992).

Agriculture provides a productive, but relatively unexplored, model for integrating diverse subject areas through the study of current human issues. All science, including social and economic science can be integrated through sustainable agriculture programs. We also need to further develop interdisciplinary opportunities and inter-department communication in sustainable agriculture programs if we want to build innovative policy, programs, and research goals. Entomologists have much to offer such efforts.

Agriculture and Environmental Education

Most Americans know very little about agriculture and its significance to their lives and to their environment. In 1988 the Committee on Agricultural Education in Secondary Schools provided recommendations for changes in agriculture education. Educational programs directed at agriculture students, such as 4-H and Future Farmers of America, were revamped. But this reorganization was directed primarily at providing skills and experiences appropriate for agro-business. The committee also stressed that agricultural literacy, including economic, social, and environmental significance, should be a part of general education and can be an effective vehicle to develop ecological literacy. Although the treatise of agricultural subjects includes natural resource management, the 1988 recommendations do not specifically tie natural resource preservation, ecology, and conservation with agricultural education. Entomologists have a responsibility to contribute to demonstrating this connection.

In 1981 the USDA initiated 'Ag in the Classroom,' an agriculture education program directed at elementary school students. This program provides information and resources to encourage agricultural study. It includes in-service training programs designed to integrate food and fiber production subject matter into school curriculum (Committee on Agricultural Education in Secondary Schools 1988). Although limited by funding and support, the Ag in the Classroom program could become an effective vehicle for conveying conservation issues in agriculture. An obvious route to teach this connection would be through the study of insects.

In 1989, the Entomological Society of America Standing Committee on Education and Training (ETC) began an outreach program designed to demonstrate how insects can be used to teach diverse subject areas (Akre & Hansen 1992). These programs are accessed through the National Science Teachers Association. The ETC encourages entomologists to develop programs that can be incorporated into the outreach effort. This is a great opportunity to provide teachers with information and materials that demonstrate the need for cooperation between agriculture and conservation. The ETC also provides contacts who are willing to assist teachers to better utilize insects in teaching. Professional entomologists can also contribute by assisting the Committee of Youth Science Development of the ESA to promote the value of entomology to students and the general public (Knutson 1989).

At the university level, Orr (1991) promotes the integration of agriculture and liberal arts colleges to combine abstract and practical intelligence necessary for the future of agriculture and conservation. In the early 1900s, approximately one-third of the U.S. population lived on farms. That percent is now only about 2.2 (Committee on Agricultural Education in Secondary Schools 1988). This dramatic demographic shift was accompanied by a loss of motivation to protect biological diversity. Tangible, relevant ecological lessons offered by small, diverse farms were lost. Orr encourages the use of college farms as interdisciplinary laboratories, a substitute for childhood farm experiences, a resource to help revitalize rural life, and a site for preserving biological diversity. College farms provide unique learning centers based on holistic, experiential, interactive approaches to problem solving. Such alternative learning experiences should encourage the development of sustainable agricultural practices and integrating conservation concerns in agriculture.

Farmers also need better information about sustainable agriculture and the need for integrating conservation and agricultural interests. Only with a broadened perspective including long-term ecological costs and benefits of agricultural practices can farmers, ranchers, and foresters accurately assess profitability (Reganold et al. 1990). The severe on-farm health problem associated with pesticide use is a grave example of the consequences of too little information (Pimentel et al. 1992a, Soulé & Piper 1992). Networks that promote information gathering, assessing and sharing among farmers should be encouraged and supported in agriculture.

The Florida Entomological Society and the Entomological Society of America have long stressed the importance of communicating the relevance of entomology to the general public. However, until recently efforts have lagged behind this philosophy (Price 1991). And even today, educational efforts remain outdated and narrow in view. A noteworthy exception is a tremendously successful summer teacher education course recently developed by Don Hall, of the University of Florida. This course focuses on local insect natural history, and provides an impressive example of the potential that entomologists have to contribute to environmental education. The primary objectives are to enhance awareness and appreciation of insects through hands-on experiences and to broaden opportunities to teach biology, ecology, and natural history using insects. Teachers that attend the course then provide further teacher training programs providing an effective pyramid of information transfer.

The designation of national and state insects could do much to promote entomology and broaden education and research opportunities. I am happy that the ESA is supporting the monarch butterfly to become our national insect. I think the monarch is a good choice for this title because the monarch is well-known, widely distributed, accessible, regularly crosses national boundaries, demonstrates the problem of species-oriented conservation, and, perhaps most importantly, its beauty can open awareness to less attractive invertebrates. But truly the species doesn't matter, a national insect would do much to promote public awareness of more enlightened views of conservation biology and I encourage your support.

The dire need for cooperation among agriculturists and conservationists has heightened our capacity and our responsibility to educate the public about insects. By increasing our attention on insect natural history and conservation concerns, entomologists can help to change the current negative views of entomology as a narrow applied science addressing ugly, unwanted pests. Entomology can be seen as a broad-based, relevant, exciting, and interactive experience. To accomplish this transformation we cannot leave any educational opportunity unexplored, but we will do best to focus on young children, as they are the most open.

ENTOMOLOGISTS' ROLES

Entomologists "seem strangely unstirred as a group by the biological diversity problem." (T. Lovejoy, from Knutson 1989)

Current goals of agriculture and conservation are unattainable unless entomologists move beyond current myopic views of the role of entomology in research, management, and education. We cannot depend only on the valuable lessons from applied entomology to meet these goals. Yet we cannot afford to cut further into the limited support for applied research. The needed boost in support for expanding entomological research goals will come from educating the public and policy makers of the ecological significance of insects.

Raven (1990) estimates that only about five percent of arthropods have been named, and we have significant information on probably less than one percent of those. If we are to conserve biological diversity we need to better understand this group taxonomically, ecologically, and evolutionarily. Without better estimates of the total number of species, estimates of extinction rates remain elusive, and the problems of conservation, therefore, ambiguous. Discrepancies in species number estimates come largely from our lack of understanding the composition, structure and function of ecosystems (Gaston 1991, Paoletti et al. 1992). A better understanding of feeding habits, relative abundance, and size versus number of insects would strengthen our estimates of biological diversity (Helliwell 1982, McNeely et al. 1990). The study of insects will also contribute to our understanding to how human activities translate to extinctions in this and other groups. We need input from insect taxonomists, biogeographers, and insect ecologists to provide such information to policy makers and conservation biologists.

Worldwide, studies of insects aimed at conservation goals are severely lacking relative to the diversity of species and their ecological significance. This reflects difficulties related to the abundance, diversity, and paucity of methods, together with a striking negligence by researchers. This lack of information is most apparent in the tropics, where most biological diversity rests and the least aggressive research occurs. These constraints are probably the most critical barrier to global conservation goals. Entomologists are needed to correct this incongruence (Wilson 1988).

In the U.S., the Endangered Species Act, with its problems, will remain a prominent effort in conservation biology. Proportionately more and more candidate species will be insects (Bean 1993). Successful listing and development of recovery plans rest on our understanding abundance, distribution, habitat needs, and vulnerability to human impacts. This policy will become practically stifled without significant input from entomologists.

Pyle (1976) suggests several areas of research needed to address conservation concerns for insects. These include autecological studies of threatened species, biogeographic surveys of native species, increased investigations of genetics and population biology, and population regulation factors. Pyle encourages involvement of entomologists with the Office of Endangered Species for better use of limited funds to address insect conservation.

Due to their small size, short life cycles, habitat specialization, and relatively small ranges, insects offer probably the best models for furthering theory and methodology in conservation biology. Problems to which entomologists can offer significant contributions include the species concept, speciation, extinction, inbreeding, importance of genetic variation, competitive exclusion, population regulating factors, island biogeography, the ecological impacts of land fragmentation, the role of corridors, the ecology of exotics, and climatic effects on population dynamics and distribution. By studying these systems and comparing them with vertebrate models, we can strengthen management strategies currently based on vertebrate studies.

Research in insect ecology will help us to preserve ecological processes and habitat structure. By studying insect population dynamics at several spatial and temporal scales, we can improve land acquisition decisions, land management, land restoration, and landscape linkages. These will, in turn, provide models for predicting insect population dynamics in agricultural operations. Conservation-oriented research, especially in the tropics, promises practical information on ways that insects can be used for biological control, pollination, environmental monitors, food, medical products, and as tools in research and education (Samways 1988).

Finally, I encourage entomologists to contribute to the development of field-oriented, interdisciplinary programs in entomology, and to participate in interdisciplinary endeavors aimed at addressing long-term agricultural and environmental problems. I also encourage increased efforts by The Florida Entomological Society to provide support, technical advice, information exchange programs, linkages with other groups, and to encourage conservation-oriented research at their annual meetings and in their journal.

Discussion

"Our large brains may have originated 'for' some set of necessary skills. . . , but these skills do not exhaust the limits of what such a complex machine can do. . . Built for one thing, it can also do others, and in this flexibility lies both the messiness and the hope of our lives." (S. J. Gould 1980, p. 57-58, in Williams 1992)

Conservationists have recognized the need to focus on larger-scale approaches to addressing the loss of biological diversity as they begin to value ecological processes beyond habitat protection for endangered species. They await input for defining biological diversity, development of viable monitoring and management strategies, and public support to achieve these goals. Because of the importance of insects in species diversity and ecological roles, entomologists have perhaps the greatest potential and responsibility to contribute to conservation goals simultaneously and cost effectively through theoretical, methodological and educational contributions.

In the next 10 years world population will increase by more than one billion people (Raven 1990). We simply cannot continue our present per capita rate of co-opting most of the net terrestrial primary productivity (Ehrlich & Ehrlich 1991). Non-renewable resource depletion and waste build up stifle the earth's ability to absorb further stresses by humans. Entire ecosystem composition, structure and function are threatened, with support characteristics breaking down.

We need more than an Endangered Species Act and small modifications in agricultural practices. We cannot afford to continue the time consuming and cost ineffective efforts aimed at a handful of species that we're unlikely to be able to save. We would better spend our time investigating how natural systems work, why are they resilient, how they recover from stress, how to best monitor them, how to lessen human-induced stresses, and how to mimic these in agricultural production systems. Successful land management strategies will hinge on long-term studies of invertebrates and their associations. Agriculturists, and perhaps most importantly entomologists, should be key players in such efforts.

The future of agriculture depends on broader perspectives spatially and temporally, cooperation, resource conservation, and holistic, ecologically-based approaches, with increases in information and decreases in non-renewable resource use (Francis 1990). Entomologists must aim toward the development of innovative agricultural practices that can address growing human population needs with rapidly dwindling natural resources. The impacts of pesticides and exotics on non-pest species, the development of more diversified crop systems, better management of forest systems, and the implementation of multiple land use strategies will be important areas of study.

Environmental education remains the most timely challenge in conservation. It is not well-appreciated that humans are not generally prepared to handle long-term and large-scale problems that now face agriculture and conservation. Although our large brains provide the capacity to think in the abstract and model complex problems, our nervous system was shaped by short-term reinforcement and punishment (Ehrlich 1988). It is because of this important shortcoming that Ehrlich & Wilson (1991) warn of hard choices ahead, suggesting that nations will have to make choices between saving their natural heritage and maintaining the economic well-being of their citizens. Assuming that in the long run the latter depends on the former, we must make great strides in education to prepare for coming changes.

A better understanding of the role of invertebrates in natural systems and increased public awareness and appreciation of this group are critical for future development and management strategies that can no longer depend on human emotional responses to a few cuddly critters. In order to educate the general public to what are often less than intuitive ecological concepts, we must rely on factually-based, locally accessible information. Experience-based lessons in local natural history and ecology can accomplish these goals most effectively by focusing on invertebrates.

In order to meet these challenges, we entomologists need to address our responsibility to the 99 percent of insect species, and 90 percent of all biological species, that are not considered pests (Wilson 1987). In order to maximize this possibility, which I'm advocating as a moral responsibility, we must 1) open our journals to conservation-oriented research, 2) encourage structured interactions with conservation biologists, 3) spend relatively more time studying the roles of insects in natural systems, 4) contribute to the development of ecologically-based agricultural management strategies, and to the selection, design and management of protected areas, 5) contribute to conservation policy development, and 6) educate the general public of the direct and indirect values of insects.

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