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Regional problems need integrated solutions: Pest management and conservation biology in agroecosystems

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ABSTRACT

Ecosystems produce goods and services that are essential for the wellbeing of humans and other organisms. The earth's expanding human population is altering both pattern and process in ecosystems, and hence is impacting the provision of ecosystem goods and services at a variety of scales. Food production and other ecosystem services, such as the many benefits provided by forests, are not exclusive of one another at a regional scale. Although it is becoming obvious that uncoordinated local management is inadequate to address regional ecosystem changes in the face of regional drivers of change, few regional governments have addressed the need for holistic landscape management of regional ecosystem services. We compare and contrast two regional programs, the agricultural agenda of integrated pest management (IPM) and an as-yet hypothetical, fragmentation-oriented conservation agenda that we term 'Regional Fragmentation Management' (RFM). IPM has a strong practical foundation but is weak on theory. RFM has a stronger theoretical base, but is weak on practice and has mainly focused on protected areas. Both programs address only a small subset of the larger question of how to effectively maintain regional production of regional ecosystem services. Some of the successes of IPM practitioners in building institutions and achieving societal acceptance for their program, particularly in relation to regionally coordinated ('areawide') pest management, suggest that regional ecosystem management is plausible. IPM offers some ingredients of an institutional role model for a broader, more ambitious program that seeks to manage regional ecosystem services and processes in a sustainable manner. As the looming crisis of global climate change brings a potential window of opportunity for the introduction of novel approaches for managing deforestation, closer synergies between conservation and agriculture at regional scales seem not only possible, but essential.

1. Introduction

Ecosystems provide humans with a range of goods and services that include such basic necessities as clean water, climate regulation, food production, and waste disposal (Daily et al., 1997). These goods and services are products of pattern–process interactions that occur across a range of different scales. As the human population expands, habitat loss

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and fragmentation are occurring at increasingly broader scales (e.g., Cane and Tepedino, 2001; Kearns et al., 1998; Ostfeld and LoGiudice, 2003; Ricketts, 2004) and pattern–process interactions in ecosystems are being increasingly disrupted (Brovkin et al., 2004; Chapin et al., 2000; Vitousek et al., 1997). In this time of change, local management actions are not sustaining regional ecosystem services. It is becoming more and more apparent that effective, long term management strategies at regional and global scales are needed to cope with broad-scale spatiotemporal variation in ecosystems and the environment (Bennett et al., 2003; Carpenter, 2002).

Available evidence suggests that a connected network of intact natural habitats is important for maintaining functional integrity and the resulting range of ecosystem services across a landscape (Crooks and Soule, 1999; Roland and Taylor, 1997). Ecosystem services often depend on processes that occur at larger scales than that of an individual protected area or smallholding. For example, control of elk populations is effectively undertaken by wolves, which need large areas (Beschta, 2003; Ripple and Beschta, 2004); and regional vegetation influences on climate (Foley et al., 2003; Heck et al., 2001) can alter fire and precipitation patterns, altering the viability of local cropping regimes (Shukla et al., 1990). Most farming systems rely heavily on ecosystem services such as soil fertilization, pollination, pest regulation, water filtration, and erosion control. Sustainable, low-input agriculture is only possible if essential ecosystem processes are maintained. Technology may substitute for some ecosystem services, but is often costly and less robust than a living, adapting system (Costanza et al., 1997; Heal, 2000). For example, soil stability and sufficient clean water for cattle ranching and irrigation purposes are cheaply and effectively ensured by maintaining forested upper catchments and riparian zones (Bruijnzeel, 2004).

In the long term, it makes good economic sense to maintain ecosystem goods and services in both natural areas and agroecosystems (Greiner, 1997; Kremen et al., 2002; Ricketts et al., 2004; With et al., 2002). Conservation biologists are increasingly recognizing that wise stewardship of agricultural lands can play a strong supporting role for networks of protected areas (Banks, 2004). The maintenance of regional ecosystem services is in the best interests of both conservation and agriculture. Conservation planning and agricultural activities, however, often occur in two different worlds that interact mainly when they come into conflict.

There are few good role models for truly integrated management approaches in either conservation or agriculture. One of the more successful regional programs in the United States has been integrated pest management (IPM). IPM in its most scale-conscious form ('areawide pest management', Knipling, 1980) includes regional management of a variety of agricultural activities, such as crop rotation sequences and the total areas of individual crops under cultivation at any one time. IPM emphasizes the maintenance of natural ecosystem processes, rather than pesticide use – a reflection of its origins during the backlash against organophosphates that was provoked by Rachel Carson's *Silent Spring* (1962). Despite the many successes of IPM in the USA, however, its overall impact is limited by its focus on the single ecosystem service of pest regulation. At the same time, conservation biologists have been developing conservation plans at national and regional scales (e.g., Poiani et al., 2001). Few such plans are directly concerned with fragmentation, but the evidence that fragmentation matters at regional scales (reviewed later in this paper) is compelling. We envisage a hypothetical agenda called 'Regional Fragmentation Management', or RFM. Some ingredients of RFM are already in place, but it currently lacks both an integrative methodology and a suitably high profile to appeal to people beyond the field of conservation.

Although RFM is well outside the scope of traditional IPM approaches, it is by no means independent of pest populations and their management. Pest outbreaks and habitat fragmentation are processes with strong links to landscape patterns and ecosystem services (With et al., 2002). The contrast between IPM and RFM reflects two very different approaches to the same basic issue. Habitat fragmentation and related ideas (such as island biogeography, metapopulation theory, and population viability analysis) have been of interest to ecologists, but relatively little attention has been payed to the more practical issue of how to manage fragmentation outside protected areas in a cohesive, strategic manner. By contrast, IPM has never had a particularly strong theoretical basis and has proceeded by trial and error on the basis of what works in practice (Kogan, 1998). The IPM paradigm would benefit from incorporating more ecological theory, particularly landscape ecology, into its foundations; while RFM has much to learn from the applied and institutional successes of IPM.

In this article we argue that the IPM paradigm in its strongest manifestations not only provides a potential role model for RFM, but also offers strong evidence for the plausibility of the regional management of ecosystem services through a combination of collaborative regional institutions, economic incentives, and individual initiatives. Since many readers will be familiar with either the habitat fragmentation literature or the IPM/pest outbreak literature, but not both, we offer a brief review of some of the central issues in each field and then elaborate further on their potential synergies.

2. Brief review of habitat fragmentation (RFM) literature

Ideas about fragmentation originate in a patch-matrix view of the world. Patches are nonlinear surface areas that differ from their surroundings; they are typically embedded in a permeable or semi-permeable matrix (Turner et al., 2001). Patches contain the majority of essential resources for a given study species, although organisms frequently move between patches (e.g., Cook et al., 2004). Habitat fragmentation occurs when formerly continuous patches of habitat are broken into smaller pieces (Fahrig, 2003), and is most commonly caused by habitat destruction. Its diagnostic features include a net reduction in the average size of habitat patches, increases in the distance between patches, reductions in the total distance that an animal can move without leaving its preferred habitat, increases in the relative proportion of edge habitats, and the introduction of other linear features (such as roads and power lines) that impede the movement of organisms (Fahrig, 2003). For example, forest animals that are vulnerable to predation in open habitats will often refuse to move out of the shelter of the canopy, even when the actual distance between patches is relatively short (Hayes and Sewlal, 2004; Laurance et al., 2004).

Although the patch-matrix paradigm has weaknesses (Brotons et al., 2003; Ricketts, 2001), it has been useful as a way of conceptualizing how animals perceive a landscape. Together with island biogeography (Gilpin and Hanski, 1991; Hubbell, 2001; MacArthur and Wilson, 1967), it offers a large body of empirical evidence that suggests that changes in the size, arrangement, and number of habitat patches in the landscape can have profound effects on organisms (e.g., Bender et al., 1998; Bowers and Matter, 1997; Fahrig and Merriam, 1994; McIntyre and Wiens, 1999; Nielsen and Ims, 2000; Summerville and Crist, 2001). Habitat arrangement assumes increasing importance when the total amount of habitat is low (Cumming, 2002; Fahrig, 1998; Flather and Bevers, 2002), with populations in isolated patches persisting only when habitat arrangement facilitates movement (Brown and Kodric-Brown, 1977; Major et al., 1999).

As patch size and shape are altered by fragmentation, changes occur in the relative influence of edge effects. Edge effects include changes in light penetration, temperature, and structure, and may affect species composition, competition, predation, and movement (Murcia, 1995). Ease of dispersal may increase or decrease with habitat fragmentation but will seldom stay the same. Animals that move along edges may benefit from an increased proportion of edge; for example, female voles have larger home ranges, larger body sizes, and faster reproductive rates along edges (Bowers et al., 1996). By contrast, animals such as understory birds that prefer to move below a forest canopy may find their movements impeded in fragmented forests (e.g., Laurance et al., 2004).

The configuration and composition of patches within a landscape can also affect food web dynamics. Spatial subsidies refer to flows of resources from one habitat type to a recipient in another habitat type, such that the recipient exists at a higher density than would otherwise be possible (Polis et al., 1997). Subsidies can influence trophic relationships and can buffer the negative effects of habitat fragmentation. For example, natural areas adjacent to agricultural fields may provide a larger input of prey items and increase in situ predator density (Jackson and Fisher, 1986; Polis and Hurd, 1995). Such interactions can initiate a trophic cascade in which spatially subsidized predators indirectly increase the productivity of the agricultural crop. Similarly, cross-habitat foraging by predators can increase their density, so that a landscape with a diversity of high quality habitat types can support more predators than a landscape of relatively homogeneous agricultural fields (Polis et al., 1997).

The impacts of fragmentation on population and community composition translate into changes in ecosystem function, the provision of ecosystem services, and the interactions of humans with ecosystems. Many ecosystem services, such as carbon fixation and climate regulation, are essentially area dependent and will decline as habitat is lost or converted to habitat types that perform similar functions less effectively. Other kinds of ecosystem service, such as erosion control and the regulation of nutrient loads to streams, are highly dependent on the specific location of habitat loss.

Large scale experimental studies are important for translating fragmentation theory into applied conservation science. For example, successional processes in an old field patch network in Kansas have been monitored since 1984 (Debinski and Holt, 2000; Holt et al., 1995a,b; Robinson et al., 1992). This study has found variable effects of fragmentation on plant, small mammal, and arthropod communities (Diffendorfer et al., 1995; Holt et al., 1995a,b; Robinson et al., 1992). Abiotic processes, such as nitrogen mineralization and water availability, have shown slight but mostly non-significant responses to fragmentation (Holt et al., 1995a,b; Robinson et al., 1992). Small mammal movement patterns have followed predictions that a lower proportion of individuals should move, and that dispersers should move further, when fragmentation was higher. However, no trend has been observed in source-sink movements (Diffendorfer et al., 1995); and although larger patch sizes have supported a greater number of butterfly species, the responses of small mammal and plant species richness to patch size have been variable (Holt et al., 1995a,b). The long duration of the Kansas fragmentation experiment has enabled the observation of processes that would not be seen in shorter studies. As Holt et al. (1995a,b) point out, "the ultimate drivers of key processes in arable ecosystems may, in the end, not be found within these ecosystems, but rather in the broader landscape of which they are a part".

A regional approach to managing fragmentation is essential if a full range of ecosystem services is to be sustained. Property boundaries are seldom aligned with ecological boundaries such as catchments or ecotones. Furthermore, the scales of human management activities and ecosystem processes are often mismatched (Cumming et al., 2006; Gibson et al., 2000; Saunders and Briggs, 2002). For example, in areas of Australia, the clearing of native vegetation for agriculture has allowed the saline water table to rise, drastically reducing agricultural productivity. Effective long-term solutions to the problem require revegetation on a regional, catchment-wide basis, creating a difficult management problem (Farrington and Salama, 1996; Saunders and Briggs, 2002).

With the possible exception of the few cases where broad-scale reserve networks have been implemented, there are relatively few examples of truly regional attempts at RFM. An interesting case study comes from northwestern Brazil, where a long tradition of sustainable extraction of non-timber forest products has been threatened by deforestation (Fearnside, 2003). The Brazilian government has set up a network of >3 million ha of extractive reserves in the state of Acre. Rubber tappers and other extractivists maintain the rights to harvest forest products within their family's established territory. The land within these reserves cannot be sold and only a small proportion (no more than 5 ha per family or 1–2% of a reserve) can be cleared for subsistence farming (Fearnside, 1989). This arrangement, if it can be made to work, should maintain the functional integrity of the forest ecosystem.

In summary, some of the key implementation issues for RFM are maintaining habitat amount and representation; maintaining a diversity of patch sizes and shapes; managing locations of edges; managing kinds of boundaries (i.e., which habitat types border on which); maintaining natural and important ecosystem processes, such as fire and water flows, in inhabited landscapes; maintaining a functional network of sites; maintaining keystone species and functional food webs; and achieving buy-in from a wide range of stakeholders, including organizations and individuals that have traditionally been opposed to conservation.

3. Brief review of integrated pest management (IPM) literature

The broad-scale nature of many ecosystem processes suggests that a landscape perspective on agriculture is essential for its long-term sustainability. Collapses of past agriculturally dependent civilizations, such as the Maya, highlight the importance of ecosystem services (Diamond, 2005). Agricultural landscapes are generally mosaics of croplands, rangelands, cities and towns, isolated houses and gardens, and natural areas such as grasslands and forests. The choices that people make about land use play a significant role in the continued provision of ecosystem services within the landscape (Summers et al., 2004). Although there are institutions and laws that exert limited control over the development of agricultural landscapes, there are relatively few programs that address the fundamental issues at an appropriate scale (Tilman et al., 2002).

Integrated pest management (IPM) is one of the few success stories of regional management in agroecosystems. IPM has been defined as 'a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment' (Kogan, 1998). As this definition implies, it is a multi-tiered approach to the management of pests and is applied across a range of different scales. For the purposes of this brief review we will focus primarily on the history of IPM, its broad-scale aspects, and some examples of successful IPM applications.

Modern IPM has its roots in the failures of single-solution control measures for pest species, particularly insects. Practitioners of IPM in the USA were motivated by the idea that adopting a range of alternative and more environmentally friendly strategies could reduce pesticide use and its harmful side effects. As Kogan (1998) explains in his review of the history of IPM in the USA, its adoption and subsequent success owed much to a fortuitous collusion of different factors, including the following: (1) public concerns about the broader environmental impacts of pesticide use; (2) outbreaks and/or expansion of the ranges of important disease vectors, including pink bollworm, equine encephalomyelitis, corn leaf blight, and the gypsy moth; (3) US congressional support for the IPM program through a bill passed in 1971, including a 5-year pilot program ('the Huffaker project') and subsequent IPM initiatives; and (4) a series of institutional reorganizations, which led to the formation or strengthening of integrative regional organizations such as the Pest Management Strategies Subcommittee of the Experiment Station Committee on Organization and Policy, the American Cooperative Extension Service (CES), and the United States Department of Agriculture (USDA). At about the same time that CES IPM programs were starting to develop a clear focus, the federal government began to make larger grants available for IPM research and testing. The timing of these different events was just right for the success of IPM, in the sense that the growing CES was able to take advantage of a window of social, political and economic opportunity and use it to develop and implement IPM approaches with considerable success. The innovations arising during this period, such as novel pesticide-free crop rotation programs, have since been adopted and communicated by global organizations such as the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP). For example, the FAO's Intercountry IPM-Rice program in southeast Asia has been successful in controlling outbreaks of the brown planthopper (Kogan, 1998; Schulten, 1991).

Considered in context, the pesticide crisis and the subsequent emergence of IPM provide an excellent example of the kind of system-wide cycling that is predicted by resilience theory (Gunderson and Holling, 2002). The standard use of pesticides was a typical 'command and control' approach (Holling and Meffe, 1996) that reduced natural variation in insect populations and disregarded the value of natural predators, while having increasing impacts on the broader environment. The linked social-ecological system gradually grew more and more constrained, implementing 'more of the same' when existing pesticides proved inadequate, rather than looking for new solutions. When a social crisis arose, triggered by the negative impacts of pesticides on the environment, pest control was thrown into a crisis. IPM emerged from the ensuing period of self-reflection and novelty as a reasonable alternative and became the new paradigm.

More recently, a growing awareness of the inadequacies of local control techniques for insects that have regional outbreak patterns (such as the army worm and the spruce budworm) has resulted in a drive to develop 'areawide pest management' (Knipling, 1980). The effectiveness of IPM depends on regional integration of pest control strategies and an understanding of the multiscale relationships between the control of pest outbreaks and the larger landscape. Areawide pest management involves forming cooperative partnerships in an attempt to manage pests at larger geographical scales across a network of fields. Proactive, coordinated management across a broad geographic region has the potential to reduce pest movement among fields in a cost-efficient manner that is simultaneously effective at reducing the pest population within the region (Beckler et al., 2005, 2004).

Following the failure of some traditional IPM techniques, a number of areawide programs have been initiated. The corn rootworm pest complex has caused great economic damage to maize crops across the US Corn Belt (Metcalf, 1986) and offers an instructive example. The effectiveness of IPM strategies involving a combination of insecticides and crop rotation was reduced when corn rootworms began to develop resistance to pesticide application and to adapt to crop rotation (Chandler, 2003). In 1995, the USDA Agriculture Research Service began an areawide program applying very low toxicity insecticide bait during periods of peak adult rootworm activity. The program has been successful in five trial locations and provided relatively large economic benefits (Chandler, 2003). Recent reports, however, indicate that corn rootworms may be evolving resistance to carbaryl, rendering the bait less effective in application areas (Siegfried et al., 2004; Zhu et al., 2001). Holt and Hochberg (1997) note that biological control, as opposed to chemical control, may be more evolutionarily stable. Broad-scale and inundative application of chemical pesticides can promote weak selective pressures that favor increased pest resistance. This research lends support to the notion that areawide and other forms of regional management plans (e.g., RFM) need to maintain the capacity to adapt in response to fundamental changes in the structure and function of the linked social–ecological system.

The benefits of a cooperative regional approach were also recognized in the management of a complex of viruses that were attacking tomatoes in the Del Fuerte Valley of Sinaloa, Mexico. Barnes et al. (1999) applied ideas from landscape ecology to map and control the spatiotemporal distribution of tomato virus disease vectors. Instead of relying on pesticides (this was, in fact, actively discouraged and reduced), the investigators used management strategies such as removing alternate hosts (for the virus and vector) near tomato fields, not planting in months associated with high virus incidence, avoidance of areas of historically high virus incidence, and the use of virus-free seed. Disease incidence has consistently dropped since the plan's inception, illustrating how understanding the temporal and spatial dynamics of pest populations and their relationship to landscape patterns can lead to low-impact, cost effective solutions (French et al., 2004).

In proposing IPM as a potential role model for practical conservation, it must be taken into consideration that IPM has not been universally adopted within the farming community (e.g., Czapar et al., 1995) and there has been debate over its general effectiveness (Barfield and Swisher, 1994). Barfield and Swisher (1994) make a distinction between 'strategic IPM' and 'tactical IPM'. Strategic IPM is founded on a general understanding of the entire agroecosystem and should thus integrate strongly with conservation efforts. Tactical IPM is more limited, representing primarily a responsible use of pesticides. According to Morse and Buhler (1997), strategic IPM is the ideal and tactical IPM is a relatively weak expression of the ideal. In many cases, unfortunately, tactical IPM is the norm (Morse and Buhler, 1997). Nor is the form of IPM that is most commonly practised in the US considered appropriate in every context, particularly in resource-poor areas where pesticide use has historically been low (Morse and Buhler, 1997). Some of the barriers to the adoption of strategic IPM that are discussed in the literature include a lack of pesticide regulation, aggressive marketing strategies by pesticide companies, economic instability, insufficient governmental funding and support, poverty, social inequity, inadequate training in IPM, short-term perspectives on agricultural production, a lack of understanding of the complexity of the agroecosystem, conflicting societal messages to farmers, and a failure to implement IPM in harmony with existing cultural practices (e.g., Holl et al., 1990; Smith, 1983; Trumble, 1998; Wearing, 1988). It is interesting to note that many similar problems have also dogged conservation attempts.

IPM programs have had some notable failures, partly as a consequence of becoming locked in to single, unvarying solutions (Holl et al., 1990). Hobbs (2001) illustrates the pitfalls of focusing management decisions on one aspect of a system, such as patch area. Unexpected events such as species invasions can alter ecosystem function and drive the extinction of native species. Assessment and control of the impact of invasive species on agroecosystems can be complicated by interactions among landscape structure, internal patch dynamics, and the history of landscape components (e.g., land use and invasion history, Hobbs, 2001). Given the constancy of environmental change, the wisest approach towards developing and implementing both IPM and RFM programs may well be that of 'stimulating the farmer to become an experimenter and a generator of technology', as proposed by Van Huis and Meerman (1997).

In general, IPM has proceeded through a trial and error approach with relatively little base in theory or landscape ecology. Some of the central research questions in the facilitation of IPM applications include understanding the role of the broader landscape in providing ecosystem services, such as pest control; the determination of regional habitat thresholds for minimum population viability of pests; better approaches to estimating the likely impacts of species introductions; and more effective solutions to the problem of pest adaptation, particularly where non-biological control measures are used.

4. Linking IPM and RFM

Despite coming from what may appear to be vastly different perspectives, pest management and fragmentation control are essentially two different aspects of the same problem: how can societies coordinate the regional management of regionally derived ecosystem services in a sustainable manner? Two relatively recent analyses of different aspects of the same question (Kogan, 1998; Poiani et al., 2000), each unaware of the other, have produced some remarkably similar depictions of the world (Fig. 1). As these diagrams show, both IPM and RFM will ultimately need to concern themselves with regional patterns of land use and land cover change. Both agendas require a perspective that links different elements of the landscape at multiple scales (Fig. 2). Although agriculture and conservation in the eastern USA have tended to focus on farm-sized areas, mechanisms that lead to landscape-wide change are often derived from either much smaller or much broader scales. For example, contaminant spills into streams typically occur from a single point source; national subsidies influence crop choice; and global market shifts and climate change may determine long-term sustainability. Fig. 1 illustrates the way in which practitioners in each area have tried to come to terms with the many influences that disrupt processes at the scales that we are generally most familiar with. The apparently independent convergence in perspectives is a strong indication of the need for interdisciplinary exchange and the formation of a more regional, integrated program for both IPM and conservation.

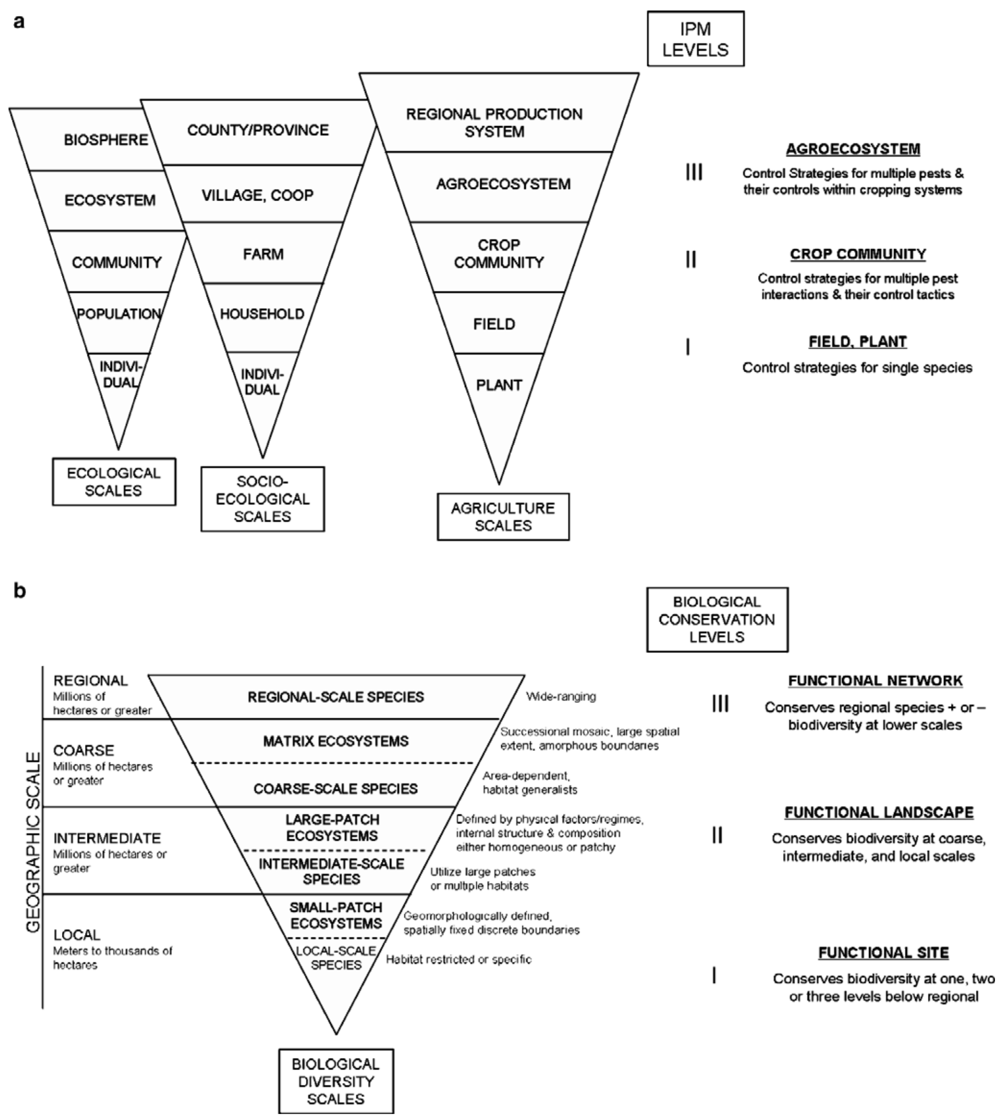

Fig. 1 – Kogan (1998) and Poiani et al. (2000) provide similar depictions of the relationship between scales of management for IPM and biological conservation, respectively. (a) Figure depicting the relationship between agricultural scales, which are derived from ecological and social/economic scales, and the levels of IPM management. Here Kogan illustrates the need for an approach to IPM that crosses scales from local to regional (adapted from Fig. 1 in Kogan, 1998). (b) Figure depicting the relationship between ecological spatial scale and the scale of biological conservation management (adapted from Figs. 1 and 2 in Poiani et al., 2000). As in (a), Poiani et al. advocate the need for an approach to conservation that considers cross scale management.

Strong, strategic, areawide IPM involves a number of key ingredients that are also essential for managing fragmentation. They include: (1) recognition of broad-scale nature of the problem; (2) an understanding of the fundamental ecological dynamics of relevant populations and ecosystems, and the impacts of different management strategies on these; (3) development of effective, multivariate (but not necessarily 'optimal') solutions to dealing with a variety of problems; (4) learning institutions, in the form of agencies that develop and transfer new approaches and technologies; (5) effective monitoring and the continual development of new approaches; (6) development of institutions at the appropriate scale (i.e., with appropriate power and political will) to achieve regional regulation; and (7) clear-cut cost effectiveness of solutions. Ultimately, the IPM program receives governmental and societal support because its benefits are clear to farmers and to society at large. The same cannot be said at present for regional fragmentation management.

The fact that IPM practitioners have in many cases been able to develop these seven ingredients and implement appropriate solutions suggests that in the US, existing institutional structures and regulations could, with some modification and the appropriate funding, be used to manage fragmentation at a regional scale. The reasons why this does not already occur are complex, and probably include: (1) lack of widespread recognition of the problems that result from fragmentation, which is less emotive than organophosphate poisoning; (2) science that has not clearly established the rel-

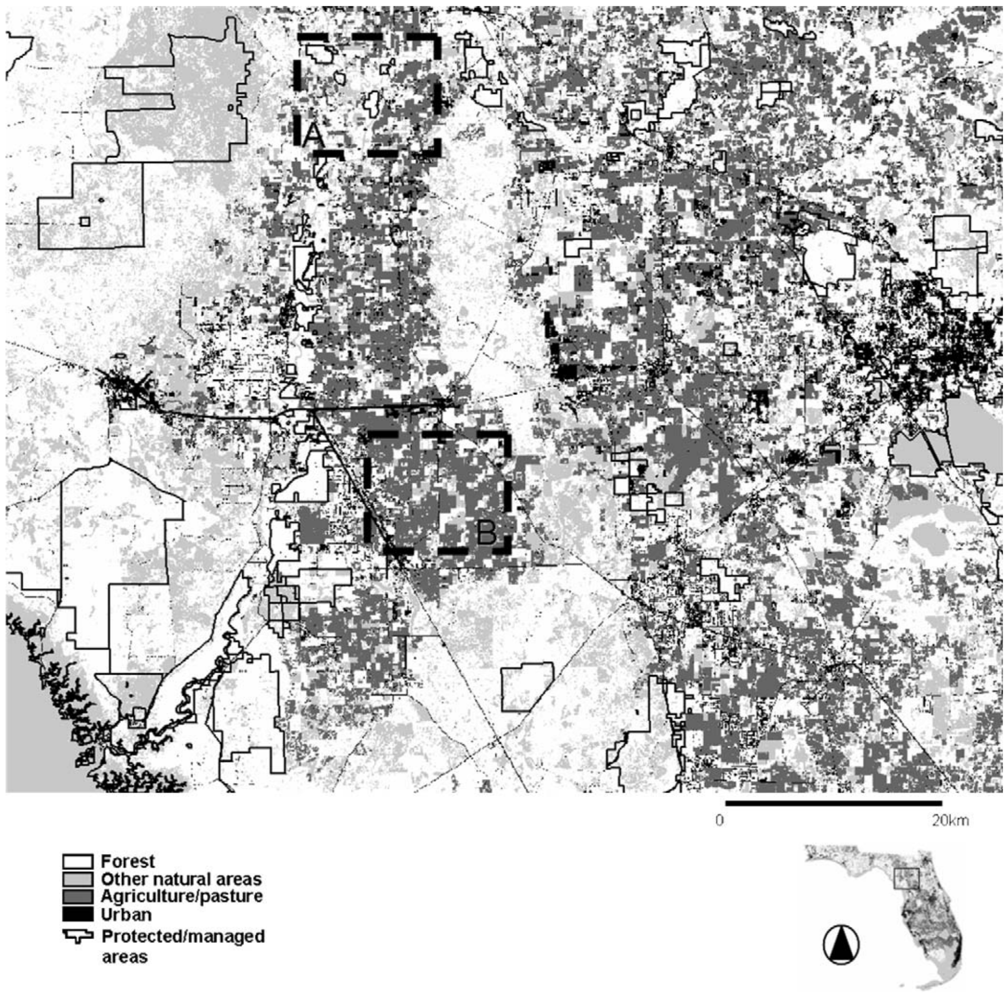

Fig. 2 – An agroecological region in northern Florida, USA (map derived from Stys et al., 2004). At intermediate scales local features such as forests, other natural areas, and protected areas can be well integrated into many agricultural landscapes (dashed box A). Agricultural lands can also dominate large portions of intermediate level landscapes, with a potentially negative effect for the long-term preservation of ecosystem services (dashed box B). Furthermore, individual management strategies in each of the protected areas in this figure may be an inefficient and ineffective approach for the protection of regional ecosystem services: a more integrated and multiscale strategy is needed. RFM would provide the means to help preserve a broad range of ecosystem services, including pest management and other services important for agricultural production, through developing a connected network of quality habitat on both public and private lands that maintains ecosystem integrity throughout the region.

evance of fragmentation to ecosystem function and ecosystem services, even though the link to biodiversity is clear (Debinski and Holt, 2000; Kinzig et al., 2001; Ostfeld and LoGiudice, 2003); (3) the current lack of regional institutions charged with the general maintenance of ecosystem services; (4) apparent conflicts between greater societal good and the desire of individuals to maximize short-term profits on their own land, regardless of the long-term implications of their actions; and (5) the broad-scale and long-term nature of fragmentation impacts, which can make them difficult to see until the situation is already irretrievable.

It is common for tradeoffs to occur between food production and other kinds of ecosystem service (e.g., Lu et al., 2003). While such tradeoffs are to some extent inevitable, there will come a point in any landscape at which trading food production for other services (such as water quality and quantity, pest regulation, or erosion control) is not the best long-term economic decision. The maintenance of ecosystem services is not always expensive, even in the short term. For example, contour ploughing (Paningbatan et al., 1995), protecting riparian zones from cattle (Krueper et al., 2003), leaving hedgerows and small patches of woodland intact (Ricketts, 2004; Van Buskirk and Willi, 2004), and reducing domestic and feral cat populations (Nogales et al., 2004) can all have significant benefits for biodiversity and ecosystem services. Maintaining greater ecological diversity in agricultural areas also offers a more secure long-term future for farmers. If the market for a particular product collapses, uncultivated land often has the potential for use in alternative ways. For example, farmers in southern Africa were able to turn to wildlife tourism to generate income following a severe drought in the early 1990s that resulted in the mortality of large numbers of cattle. As the threats of BSE and foot and mouth disease loom over ranchers in the USA, activities such as bird watching and tourism-oriented ranches offer alternative land uses that often make both economic and ecological sense.

IPM and RFM should be complementary to one another, in the sense that maintaining a more complete range of ecological functions and ecosystem services in a given landscape should also result in the enhancement of pest regulation by birds, insects, spiders, rodents, and bats. The current status of bat populations is a case in point. The impacts of bats on populations of volant pest insects, such as gypsy moths, are potentially enormous (Vaughan, 1997). This ecosystem service is provided free of charge. However, populations of insectivorous bats are declining in many parts of the world, with the two most likely causes of the decline being pesticide use and habitat destruction (Sedgeley and O'Donnell, 1999; Wickramasinghe et al., 2004). Broad-spectrum pesticide applications will substantially reduce insect abundance; and bats that feed on many individual insects that have each come into contact with a small amount of pesticide may concentrate toxins in their tissues, much as piscivorous fish concentrate mercury from their prey.

It is possible that IPM and RFM may pull in opposite directions under certain circumstances, for instance if pest species of concern spread more rapidly through a less fragmented landscape or are dependent on a critical density of a particular resource, such as dead wood. Farmers often worry that maintaining natural areas close to fields will increase numbers of crop pests. However, most of the research that has specifically addressed this assumption has found that the converse is true. For example, Deschenes et al. (2003) found that diversified riparian strips can contribute to the preservation of avian diversity without providing significant breeding habitats for birds harmful to agriculture; and Maisonneuve and Rioux (2001) concluded that structurally diversified riparian areas adjacent to fields enhanced insectivore diversity and reduced the proportion and abundance of pest species. Although we would expect pest outbreaks to be most severe in depauperate (species-poor) systems, some recent research has indicated that intraguild predation may dampen trophic cascades, reducing the potential benefit of greater predator diversity (Finke and Denno, 2004). Lastly, some ecologically beneficial actions, such as the control of feral cat populations through baits and disease (Calver et al., 1998), can be difficult to implement because they elicit strong public reactions.

Although RFM comes from a more theoretical background than IPM, it would still benefit from a more solid scientific understanding of the regional relationships between land cover/land use change and ecosystem services. There at least four areas in which further research in RFM is needed: (1) The regional and longer-term impacts of fragmentation. This is particularly important for understanding the spread of disturbance, food web interactions, regional extinction patterns (Hobbs, 2001; Holt et al., 1999; Suarez and Case, 2002), and global impacts (Jackson et al., 2001; Pringle, 2001). (2) The effects of fragmentation on process, rather than just on pattern (Kremen et al., 2004; Ricketts, 2004). (3) Regional restoration and recovery processes, such as plant succession in abandoned agricultural areas and the role of landscape history in determining how subsequent successional pathways vary (Stover and Marks, 1998; Zedler, 2003). The most cost-effective means of improving the integrity of ecosystems may sometimes be to simply improve the quality of the habitat (Franken and Hik, 2004). (4) The relationships between habitat fragments, pests, invasive species, and regional land use-patterns.

5. Conclusions

In this article, we have argued that it is essential that problems of a regional nature are tackled at the appropriate scales to achieve effective regulation and management. Furthermore, it is important that the whole problem is recognized and that management efforts do not focus on only a small piece of it. Perfecting IPM while losing a whole suite of ecosystem services makes no sense; nor does conserving forests while losing the capacity to produce food. The example of IPM illustrates the plausibility of achieving regional management of regional ecosystem services, and suggests that both fragmentation and pests could be managed on a regional basis in the United States by expanding and revising the roles and the powers of existing institutions and regulations. Regional Fragmentation Management is not yet an active program, but probably should be. RFM faces many of the same problems as IPM and can benefit from incorporating aspects of the IPM approach, particularly in terms of institutional and social sustainability. At the same time, while areawide IPM is to be applauded for broadening its scope to an appreciation of regional problems, it still represents only a partial solution to pest management and a small part of the solution to the broader problem of maintaining a full set of complementary ecosystem goods and services in agricultural landscapes.

Recognition of the need for RFM may the first step towards achieving it. It seems likely that a window of opportunity for developing better approaches to regional landscape management is approaching. In the same way that IPM was instigated in response to public awareness of excessive pesticide use, we are currently in a time of increased concern about the problem of deforestation and its potential consequences for ecosystem services, particularly in relation to high-profile problems like freshwater quality and quantity, flood control, and climate change. Awareness of the need for integrated, broad-scale management approaches to ecosystem problems is higher at present than it has been for many years. Perhaps it is time for the conservation community to make regulatory and governmental agencies more aware of the broad-scale problems that are associated with habitat destruction and fragmentation, to advocate more strongly the value of developing and applying regional habitat management plans, and to work with policy makers, managers, and private land owners to achieve effective, win-win solutions to the maintenance of ecosystem services in agricultural landscapes.

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