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Assessing effects of agriculture on terrestrial wildlife: developing ε hierarchical approach for the US EPA

Kathryn Freemark[1]

National Wildlife Research Centre, Environment Canada, Ottawa, Ont. K1A OH3, Canada

Abstract

Serious concerns exist about environmental and ecological degradation from modern agriculture. In respon: the US Environmental Protection Agency (EPA) and the US Department of Agriculture have established coc erative research programs in the midwestern USA to evaluate effects of different landscape structures and farmi practices on crop yield, movement of agrichemicals, water and soil quality, and biodiversity. This paper develo the hierarchical approach for those efforts particularly in relation to wild plants and animals (invertebrates, bir(small mammals) in terrestrial habitats. The importance of considering different levels of biological organizati and types of agricultural stressors over a hierarchy of spatial and temporal scales is developed and illustrated studies from North America and Europe. EPA studies of farmland wildlife in the Midwest are used to illustrate application of the hierarchical approach. Those efforts would be improved by more regionally specific informati on effects for a greater variety of taxa and over a broader range of biological organization. Metapopulation dynaı ics also need study. More detailed studies are required to evaluate specific, alternative within-field manageme practices, land set-aside schemes, and habitat restoration or enhancement options. Development and linkage GIS and spatially explicit population models would help develop, evaluate and communicate future scenarios. ≠ opportunity exists in the Midwest programs to compare biological patterns at population, community and lan scape levels with assessments of ecosystem processes over a hierarchy of spatio-temporal scales. The potential al exists to develop future scenarios which integrate across ecological, socio-political and economic perspectives. accomplish this, a more inclusive and consultative approach is required. Changes in existing institutional pr cesses and frameworks are likely required to promote the broad, integrated, transdisciplinary approaches need for more effective planning, research and management of agricultural landscapes.

Keywords: Agriculture; Landscape structure; Wildlife

1. Introduction

Since World War II, agriculture has become both more extensive and intensive in North America and Europe (O'Connor and Shrubb, 1986; Eijsackers and Quispel, 1988; Nation Research Council, 1989). Serious concerns ha been voiced about soil erosion, salinizatio ground and surface water pollution, habitat d struction, and ecological and human heal problems associated with modern agricultu (Crosson and Ostrov, 1990; Robinson, 1991; F mentel et al., 1991). In recent years, the abu: dance of game and nongame bird species ha

[1] Present address: US Environmental Protection Agency, Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333, USA.

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been declining in agricultural areas of North America (Potts, 1986; Herkert, 1991; Robbins et al., 1993) and Europe (Potts, 1986; O'Connor and Shrubb, 1986; Fuller et al., 1991). In North America, the impact of habitat loss and fragmentation has been the focus of attention for species, particularly birds, in remnants of native vegetation (reviewed by Faaborg et al., 1993). Invertebrates associated with biological control have been reasonably well studied (Altieri and Letourneau, 1982; Ali and Reagan, 1985; Rodenhouse et al., 1992). However, other wild animal and plant species in and adjacent to cropland have been much less studied (Rodenhouse et al., 1993). Consequently, our current understanding of wildlife associated with cropland is largely based on intensive studies in Europe (O'Connor and Shrubb, 1986; Eijsackers and Quispel, 1988; Jepson, 1989a; Paoletti et al., 1989; Bunce and Howard, 1990; Firbank et al., 1991; Spellerberg et al., 1991; Bunce et al., 1993).

In response to public concerns in the USA, a Midwest Water Quality Initiative was formulated in 1989 by federal agencies. The Management Systems Evaluation Area (MSEA) program was established by the US Department of Agriculture (USDA) to evaluate the effects of alternative farming practices and management systems on the fate and transport of agrichemicals, and on water quality in the Midwest (Fig. 1; Hatfield et al., 1993a). Subsequently, the Midwest Agricultural Surface/subsurface Transport and Effects Research (MASTER) program was established by the US Environmental Protection Agency (EPA) in cooperation with the USDA to further address these issues and to include consideration of biotic effects in terrestrial and aquatic ecosystems (Hatfield et al., 1993b).

The goals of the MASTER program are (1) to evaluate the impacts of current and emerging agricultural practices on the quality of ecological resources in the Western Corn Belt Plains ecoregion of the Midwest (Fig. 1) and, (2) to evaluate the effectiveness and viability of alternative landscape designs and agricultural management systems in preventing ecological degradation and contributing to ecosystem restoration while maintaining acceptable levels of agricultural production. The ecological risk assessment framework developed by the EPA (Norton et al., 1992) is being used to evaluate potential ecological effects caused by alteration of landscape structure, and by chemical, physical or biological stressors associated with agricultural activities in the Midwest. The ecological values that the MASTER program is trying to protect include biotic diversity and structure, habitat diversity and quality, soil quality, ground and surface water quality, and sustainable agricultural production. Current research efforts among the five EPA laboratories and one USDA laboratory in the MASTER program are centered around the Iowa MSEA watershed (Fig. 1) and include projects over a hierarchy of spatial and temporal scales (Table 1).

The objective of this paper is to develop and synthesize the conceptual and scientific basis for using a hierarchical approach, particularly in relation to assessing effects of agriculture on wild plants and animals (invertebrates, birds, small mammals) in terrestrial habitats. The importance of considering different levels of biological organization and types of agricultural stressors over a hierarchy of spatial and temporal scales is developed and illustrated by studies from North America and Europe. One limitation of many, previous studies of wildlife on farmland has been their focus on detailed studies of small plots with little regard to the context at larger spatial scales (Fry, 1991; Sherratt and Jepson, 1993). Application of the hierarchical approach is illustrated using studies of farmland wildlife initiated by EPA-Corvallis as part the MASTER program. While developed in relation to the Midwest, the approach is also relevant to research and management efforts in agricultural landscapes in other regions of the USA, Canada and Europe. Given the extent of agricultural activities in North America and Europe, there is a continued need to develop the conceptual and scientific basis for landscape design and management alternatives which promote sustainable farming practices that enhance conservation and restoration efforts on agricultural lands.

Table 1
Participating US Environmental Protection Agency (EPA) and US Department of Agriculture (USDA) laboratories, areas of responsibility and current research projects for the Midwest Agricultural Surface/subsurface Transport and Effects Research (MASTER) program in the Iowa Management Systems and Evaluation Area (MSEA) watershed and Western Corn Belt Plains (WCBP) ecoregion

EPA, Environmental Research Laboratory

Ada, OK / Groundwater, Subsurface ecology
(1) Database development and management for the Iowa MSEA watershed
(2) Hydrogeological assessment for Iowa MSEA watershed and WCBP ecoregion
(3) Analytic element modeling at local, watershed and regional scales
(4) Assimilative capacity of the subsurface for agrichemicals in Iowa and other Midwest MSEA sites
(5) Impacts of agriculture on subsurface ecology

Athens, GA / Ground and surface water modeling, Regionalization
(1) Adapt ground and surface water models to the Iowa MSEA watershed
(2) Test/demonstrate interactive graphics for existing ground/surface water models
(3) Develop methodology for extrapolation to regional scale

Corvallis, OR / Terrestrial ecology, Landscape ecology
(1) Effects of farming practices and habitat patterns on abundance, composition and diversity of birds and plants
(2) Effects of habitat patterns at different spatial scales on bird species abundance, composition, diversity and nest predation in the Iowa MSEA and other watersheds in Iowa
(3) Landcover retrospective for the Iowa MSEA watershed
(4) County-level model to assess agricultural impacts on upland game in Illinois and Iowa
(5) Subregionalization of the WCBP ecoregion
(6) Develop/evaluate alternative landscape design and management scenarios

Duluth, MN / Surface water, Aquatic ecology
(1) Develop computer-based system to identify and predict ecotoxicological effects of agrichemicals to aquatic organisms
(2) Assess bioavailability and toxicity of agrichemicals in runoff from Iowa and Missouri MSEA sites using laboratory tests on a fish, alga, zooplankton and vascular plant.
(3) Experimental determination of ecological fate and effects of agrichemicals in natural and restored wetlands of the WCBP ecoregion
(4) Assess effects of nonpoint-source pollution on biotic integrity of streams in the Iowa MSEA and other watersheds in WCBP ecoregion

EPA, Environmental Monitoring Systems Laboratory

Las Vegas, NV / WCBP ecoregion GIS, Spatial Decision Support System
(1) Develop geographical information system (GIS) for WCBP ecoregion
(2) Explore use of GIS to model hydrologic flow and agrichemical export
(3) Develop a spatially explicit decision support system for MASTER

USDA, National Soil Tilth Laboratory

Ames, IA / Crop Production, Socio-economics, Iowa MSEA GIS
(1) Evaluate effects of tillage, cropping system and agrichemical management on surface water quality
(2) Environmental and economic benefits of strip intercropping
(3) Effects of crop residue on soil water balance, and loss of pesticides and nitrogen
(4) Herbicide management to reduce offsite movement
(5) Effect of ridge tillage on soil water and agrichemical movement
(6) Evaluate processes controlling nitrogen cycling in conventional till and no-till cropping
(7) Interaction among tile drainage, runoff, surface and ground water in the Iowa MSEA subregion
(8) Groundwater flow and quality in geologic units under glacial till soils
(9) Effects of soil macropores and fractures on water and solute transport
(10) Effect of soil processes on fate and transport of agrichemicals
(11) Water quality profiling of atrazine and its degradates and metolachlor through the vadose zone of deep loess soil
(12) Degradation processes affecting pre- and post-emergence herbicides and implications for water quality
(13) Effects of changes in farming practices on ground and surface water quality at the landscape and watershed scale
(14) Water flow processes and related agrichemical loadings in the Iowa MSEA watershed
(15) Evaluate farmers' acceptance of alternative farming practices
(16) Agronomic evaluation of alternative farming practices
(17) Develop GIS and process models for water quality decision-making

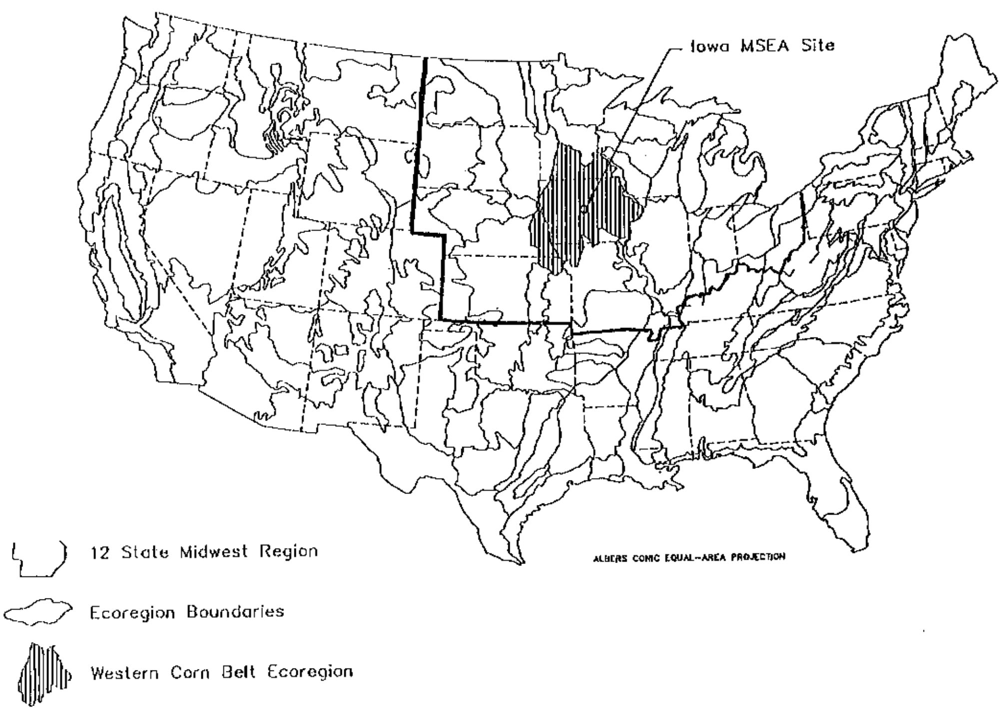

Fig. 1. Relation of 12 state Midwest Water Quality Initiative, Western Corn Belt Plains ecoregion (as delineated by Omern 1987) and the Iowa Management Systems Evaluation Area (MSEA) and Midwest Agricultural Surface/subsurface Transp and Effects Research (MASTER) watershed in the USA.

2. Levels of biological organization

Agriculture can affect terrestrial wildlife at different levels of biological organization from biosphere to cell (Fig. 2).

Levels are conventionally ordered hierarchically. Organisms are composed of cells. Populations (or the set of local populations forming the metapopulation) are composed of individual organisms. Communities are groups of populations that interact with other. Ecosystems are communities together with their physical and chemical environment. Landscapes are spatial groupings of ecosystems and so on to the biome and biosphere. Spatial and temporal scales are conceived as increasing up the hierarchy from cells to biosphere. Quantifying spatio-temporal scales (e.g. Suter, 1993, fig. 2.2) is problematical because levels such as populations, communities and landscapes are open systems with spatio-temporal domains that vary widely among species and processes (Turner, 1989; Wiens, 198 Pearson et al., 1995).

Allen and Hoekstra (1992) argue that diff ent levels of organization are better viewed as ternative, conceptual constructs which are n hierarchical per se (Fig. 2). They contend, f example, that ecosystem and community co ceptions can be compared across a landscape a given area as well as at larger and smaller sp tial scales. A given landscape can be seen to co tain smaller landscapes, while itself being a pa of a larger landscape. Lastly, community pa terns at a given scale may be related to the lar scape context at a larger scale. In practice, sp tio-temporal scaling is done by the observer su that, at the specified scale(s), the ecologic level(s) of interest appear(s) most cohesive, e plicable and predictable. For adequate unde standing, Allen and Hoekstra argue that it is ne essary to consider three levels and/or scales once: the one in question, the one below that giv

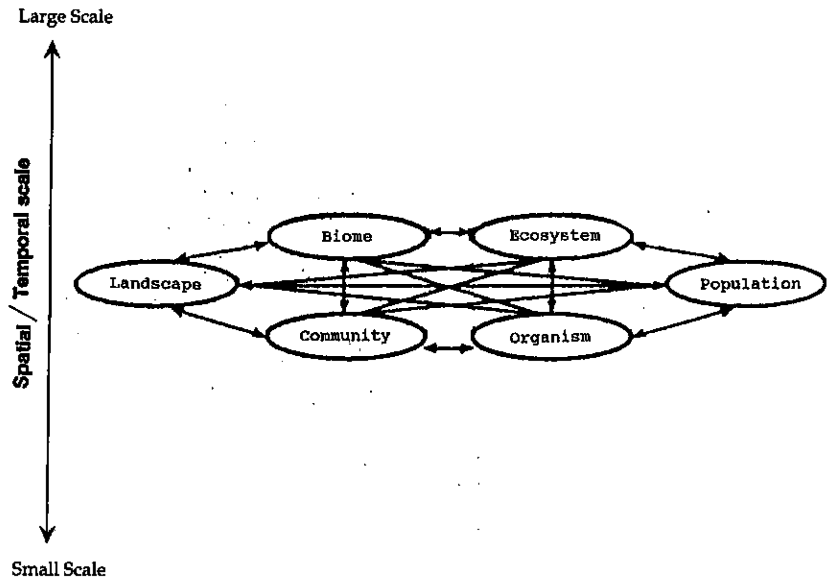

Fig. 2. Levels of biological organization potentially affected by agriculture over space and time. Cell and biosphere levels n shown. Adapted from Allen and Hoekstra (1992, fig. 1.13).

mechanisms, and the one above that gives context, role or significance.

In the USA, environmental protection, management and restoration is being advocated at the scale of watersheds (USEPA, 1991; Doppelt et al., 1993). While watershed is a spatially variable term, the watershed protection approach is generally being applied at spatial scales between landscapes (100 km^2) and regions (1000 km^2).

3. Ecological effects

At the level of cells, agricultural activities can alter biochemical functioning in wild plants and animals (Mineau, 1993; Freemark and Boutin, 1994). Growth, development and/or survival of individual organisms can be adversely affected by a variety of agricultural practices such as reduced crop diversity (Warner et al., 1984), mowing (Bollinger et al., 1990; Frawley and Best, 1991; Bollinger and Gavin, 1992) and pesticide use (Rands, 1986; Mineau, 1988; Freemark and Boutin, 1994).

Genetic diversity and extinction/recolonization probabilities of local populations within metapopulations can vary with changes in th structure and disturbance regime of agricultur landscapes (Merriam and Wegner, 1992; Man cacci et al., 1992; Villard et al., 1992; Jepso 1993; Fahrig and Freemark, 1994). At the com munity level, species diversity and compositio can also change in response to landscape struc ture and agricultural practices (Jennersten, 198 Bengtsson-Lindsjö et al., 1991; Freemark an Collins, 1992). Ecosystem processes such as nu trient cycling (Pimentel and Edwards, 1982) an water flow (Burel et al., 1993) are also affecte by agriculture.

Effects of agriculture within and among diffe ent levels of biological organization can occu over a hierarchy of spatial and temporal scale (Jepson, 1989a; Gilpin et al., 1992; Suter, 1993 For example, agriculture can affect alph (within-habitat), beta (between-habitat) an gamma (landscape) diversity at local, landscap and regional scales, respectively (Hudson, 199 Rice, 1992; Harrison, 1993). A better unde standing of these effects is important for ecolo ical, agronomic and conservation reasons (Fr 1991; Pimentel et al., 1992; Tilman and Dowr ing, 1994).

The temporal scale of agricultural effects may be within a season (Jepson, 1989b), between seasons (Vander Haegen et al., 1989), between years (Burn, 1989), over decades (O'Connor and Shrubb, 1986; Herkert, 1991; Sotherton, 1991; Jepson and Sherratt, 1991) or longer. To understand the present distribution of wild plants and animals on farmland, it may be essential to know the historic development of the landscape (Peterken, 1974; Burel, 1992; Kienast, 1993). Retrospective analyses may also provide insights into the range of possibilities for future landscape design and management scenarios in a given area.

4. Agricultural stressors

Wildlife at different levels of biological organization can be impacted by agriculture as a result of physical restructuring of the landscape, and physical, chemical and/or biological disturbance associated with agricultural practices (Fig. 3).

These stressors occur over a hierarchy of spatial and temporal scales against a backdrop of additional disturbance from natural variation (e.g. fire, disease, drought, floods) and from other anthropogenic sources such as ozone (USEPA, 1986, 1992) and climate change with increasing global CO_2 (Burke et al., 1991). To adequately understand effects, agricultural activities need to be viewed at multiple spatio-temporal scales. For example, a single application of pesticide or fertilizer on a field magnifies over both space and time with commercial-scale use among seasons and over years.

4.1. Alteration of landscape structure

Landscape structure can be altered by agriculture in terms of the composition and relative availability of habitat elements (e.g. patches, corridors), and/or their spatial configuration. When particular habitat elements become rare or absent as a result of agricultural activities, species that depend on them also become rare or absent (Erhardt, 1985; Herkert, 1991; Delphey and Dinsmore, 1993). While some wildlife species can use croplands, species richness and abundance is usually greatest in grasslands, pasture, shrubby habitats, and uncultivated edge vegetation such as grassed waterways, roadside verges

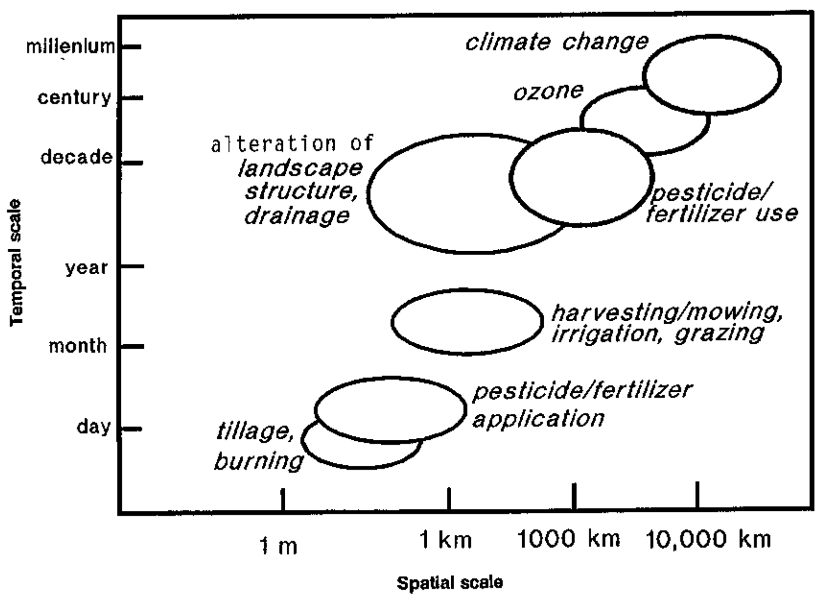

Fig. 3. Spatio-temporal hierarchy of potential stressors for wildlife in agricultural landscapes. The diagram is primarily intended to be illustrative.

and especially shelterbelts, hedgerows and wooded fencerows (O'Connor and Shrubb, 1986; Howe et al., 1985; Dennis and Fry, 1992; Johnsofn and Schwartz, 1993; Keddy et al., 1993; Rodenhouse et al., 1993). Because remnant woodlands, riparian areas and wetlands support a unique complement of species (Howe et al., 1985; Freemark et al., 1991), they are particularly important components of farmland structure for maintaining wildlife diversity. In addition to maintaining biodiversity, noncrop habitats such as hedgerows and grassed waterways are also important for controlling water runoff and soil erosion (Forman and Baudry, 1984; Barrett and Bohlen, 1991; Burel et al., 1993).

The impact of agriculture on the interspersion of different crops and noncrop habitat is important for both conservation and agronomic reasons. Agricultural landscapes with a greater diversity of noncrop habitats support a greater richness and abundance of wildlife species (Arnold, 1983; Robertson et al., 1990; Balent and Courtiade, 1992; Ryszkowski et al., 1993). A number of wildlife species require a combination of different crops (Warner, 1984; Warner et al., 1984; Smutz, 1987; Galbraith, 1988; Inglis et al., 1990) or of crop and noncrop habitats (Vander Haegen et al., 1989; Thomas et al., 1991). The removal of shelter, nesting and overwintering sites, and sources of alternate prey or hosts, pollen and nectar in noncrop areas can reduce biodiversity, pollination and biological pest control by adversely impacting the diversity, abundance and efficiency of insects and arthropods within crop fields (Altieri and Letourneau, 1982; Mader, 1988; Kevan et al., 1990; Wratten and Thomas, 1990; Dennis and Fry, 1992; Lagerlof et al., 1992; Rodenhouse et al., 1992; Ryszkowski et al., 1993; Kruess and Tscharntke 1994). Some authors argue that the loss of landscape heterogeneity associated with intensification of agriculture has contributed to higher incidences of pest attack for more prolonged periods (Pimentel and Perkins, 1980; Speight, 1983). The presence of certain weeds within and adjacent to crops can positively influence the insect fauna and lead to decreased pest damage compared with weed-free monocultures (Alti
1981 and references therein). Insect pest mo
ment into crops can often be attributed to the
sence, rather than the presence of wild plant s
cies in field margins (Van Emden and Willia
1974). Elimination or simplification of crop
tations also contributes to weed, insect and
ease problems (Ali and Reagan, 1985; Bezdi
and Granatstein, 1989). Within individual h
itat elements, the richness, composition a
abundance of species are affected by patch si
the quantity and quality of resources within
patch, and the amount and nature of the ed
For native habitats, the loss of general habi
types, specific microhabitats and habitat hete
geneity within a given patch can adversely aff
the presence and abundance of some spec
(Freemark and Merriam, 1986; Robbins et
1989; Van Apeldoorn et al., 1992).

However, habitat characteristics appear to
less important than area per se when patch s
is small. For native habitats, smaller patc
support fewer species than larger patches (F
4). In central and eastern North America, smal
patches support a depauperate subset of b
species characteristic of larger patches for gra
lands (Herkert, 1991), roadsides (Warn
1992), woodlots (Blake, 1991; Freemark a
Collins, 1992), wetlands (Brown and Dinsmo
1986; Gibbs et al., 1991) and riparian habi
(Stauffer and Best, 1980). In contrast, area-se

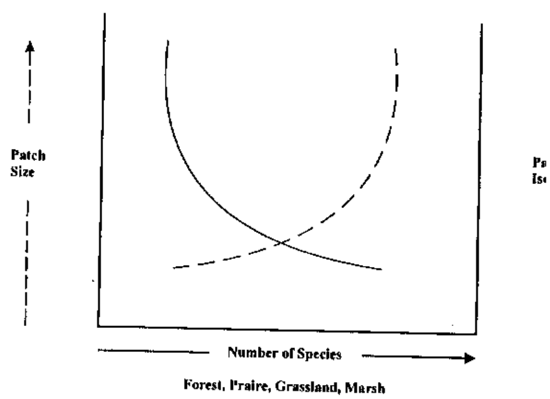

Fig. 4. Effects of patch size and isolation on the numbe
wildlife species in remnants of natural habitat in agricultu
landscapes. Data derived primarily from studies in east
North America (see text for details).

sitivity has been observed less often for forest birds or mammals of western North American (Freemark et al., 1993, 1995) or Europe (Rolstad, 1991). In France, (DeCamps et al., 1987) found that the structure of bird assemblages was negatively affected by smaller size in terrace woodlands but not in riparian woodlands because their linear shape facilitated movement of birds among patches. Jennersten (1988) found that meadow fragments had a lower diversity and abundance of both flowering plants and pollinating insects than an unfragmented meadow. Metapopulation dynamics within species is also significantly related to patch size (Verboom et al., 1991; Van Apeldoorn et al., 1992; Villard et al., 1992; Ouberg, 1993).

Even when present, reproductive success of some species, such as forest birds, may be lower in smaller patches than in larger patches (Gibbs and Faaborg, 1990; Porneluzi et al., 1993; Villard et al., 1993). Jennersten (1988) found that flowers of *Dianthus deltoides* had fewer visits, and produced fewer seeds in meadow fragments than in unfragmented meadows as a consequence of depauperization of the pollinator fauna following habitat fragmentation. Small noncrop patches and corridors can however, provide important habitat for species over winter (Sotherton, 1984; Chiverton, 1989), during dispersal or migration (Blake, 1986), and during the breeding season when suitable habitat is severely limited in the landscape (Blake and Karr, 1987; Freemark and Collins, 1992).

In contrast to native and other noncrop habitats, Best et al. (1990) contend that bird species richness and abundance in rowcrop fields decrease as field size increases because more birds and species use the perimeter of fields compared with the center. They predicted that narrower and/or more irregularly shaped rowcrop fields would support more birds because they have proportionately more perimeter. In Britain, O'Connor and Shrubb (1986) found that densities for 23 of the 57 most common farmland species decreased as field size increased.

The cropland matrix created by agriculture can increase the carrying capacity of generalist predators, competitors and nest parasites that interact negatively with species in remnants of native habitat (Temple and Cary, 1988; Johnson and Temple, 1990; Angelstam, 1992; Robinson et al., 1993). Large patches of native habitat with a high interior-edge ratio may 'buffer' against these adverse edge effects. Critical buffer distances depend on a variety of factors including the abundance and cruising radius of the matrix species (Rolstad, 1991). In agricultural landscapes, mitigation of adverse effects will likely require alternative management of the habitat matrix (cf. Robinson et al., 1993; Pearson et al., 1995). In addition, the nature of boundaries created by the juxtaposition of different habitats needs to be considered since they can significantly affect species richness, composition and abundance within habitat patches (Hansen and Di Castri, 1992).

Alteration of the spatial configuration of habitat elements by agriculture can also significantly affect wildlife (Fig. 4). For birds, less isolated habitat patches of native habitat support more species than more isolated patches (Brown and Dinsmore, 1986; Askins et al., 1987; Robbins et al., 1989; Gibbs et al., 1991; Freemark and Collins, 1992; McCollin, 1993). In Europe, the degree of isolation among patches has been related to the dispersion of plants with fleshy fruits (Van Ruremonde et al., 1991), and to metapopulation dynamics within species of plants (Ouborg, 1993) and birds (Verboom et al., 1991). The presence and management of corridors can enhance or inhibit inter-patch movement of plants (Verkaar, 1990; Burel and Baudry, 1990), small mammals (Fahrig and Merriam, 1985; Henderson et al., 1985; La Polla and Barrett, 1993) and invertebrates (Sherratt and Jepson, 1993). In Europe, hedgerow networks support more species and greater abundances of birds, invertebrates and plants than their extent alone would suggest (Lack, 1988; Burel and Baudry, 1990; Fry, 1991). The geographical orientation of patches can also influence their relative importance to migrating or dispersing organisms (Gutzwiller and Anderson, 1992).

4.2. Agricultural practices

In any given agricultural landscape mosaic, farming practices, such as mowing, grazing, and use of pesticides and chemical fertilizers, introduce additional stresses on wildlife (Fig. 3). Effects can be direct such as mortality from mowing (Warner and Etter, 1989; Bollinger et al., 1990; Gibson et al., 1993) or tilling (Basore et al., 1986; Rodenhouse et al., 1993). In this regard, conservation tillage benefits wildlife (House and Stinner, 1983; Basore et al., 1986). However, concerns exist in relation to the increased use of herbicides to control weeds (Castrale, 1985; see below). Greater use of commercial fertilizers in grasslands has led to a marked decrease in the number of plant species and an increasing dominance of nitrophiles in the UK (Marshall and Hopkins, 1990) and Sweden (Bengtsson-Lindsjö et al., 1991). Effects on wildlife can also be indirect via modification of food, nesting and protective cover (Geier and Best, 1980; Jepson, 1989a; O'Connor, 1992; Bock et al., 1993).

Effects on nontarget wildlife from use of agricultural pesticides have been of particular concern (Jepson, 1989a; Robinson, 1991; Freemark and Boutin, 1994). For example, certain granular insecticides are acutely toxic to birds when ingested (Mineau, 1988). Sublethal, but nonetheless significant effects have been observed in nontarget plants exposed to herbicides (Fletcher et al., 1993) and in a wide variety of vertebrates exposed to insecticides (Mineau, 1993). More intensive and extensive use of herbicides have contributed to population declines of plants, insects and birds in farmland (reviewed by Freemark and Boutin, 1994). For example, Sheehan et al. (1987) argued that the decline of ducks nesting in the prairie pothole region of North America was related, at least in part, to adverse alteration of food, nesting and protective cover in uplands, wetlands and wetland margins from repeated, broad scale use of herbicides. Kevan et al. (1990) argue that a lack of adequate numbers of managed and native insects for crop pollination is attributable to insecticide-based losses coupled with habitat destruction. In addition, they cite studies in Canada and elsewhere whi link declines in abundance and diversity of r tive pollinators to changes in forage plants frc weed control and alteration of drainage, ui formity of crop plants, increased amounts of ci tivation, and loss of nesting and overwinteri sites in field margins and noncrop areas. R duced pesticide inputs on field margins in the U have resulted in significant increases in abu dances of certain birds (Rands, 1986), sm mammals (Tew et al., 1992), rare plants (W son, 1991), butterflies (Rands and Sotherto 1986; Dover et al., 1990) and beneficial arthı pods (Chiverton and Sotherton, 1991).

5. Assessing agricultural effects in MASTER

Most laboratories participating in the Mi west Agricultural Surface/subsurface Transpc and Effects Research (MASTER) program ha initiated projects at local, watershed and ı gional scales (Table 1). This hierarchical a proach should provide a better understanding agricultural effects on soil quality, water qualit subsurface ecology and biodiversity by consi ering the watershed scale in relation to small spatial scales that give mechanisms and larg spatial scales that give context, constraints, rc or significance (Allen and Hoekstra, 1992; Fre mark et al., 1993). Resulting mitigative and re toration efforts may not only be necessary fı improving farmland for wildlife and people, b also for the long-term viability of Midwest are protected for nature conservation (Fry, 1991)

Application of the hierarchical approach c be illustrated using projects initiated by EP Corvallis. Current projects are evaluating effec on wildlife at population, community and lan scape levels over a hierarchy of spatial and ter poral scales (Fig. 5). In the Landuse Patter project, effects of local farming practices aı habitat at local and landscape scales are being a sessed by field studies of the abundance, cor position and diversity of bird and plant speci in agricultural areas similar to Iowa. Prelimina results show that the use of herbicides per se h a strong negative effect on the abundance of bir

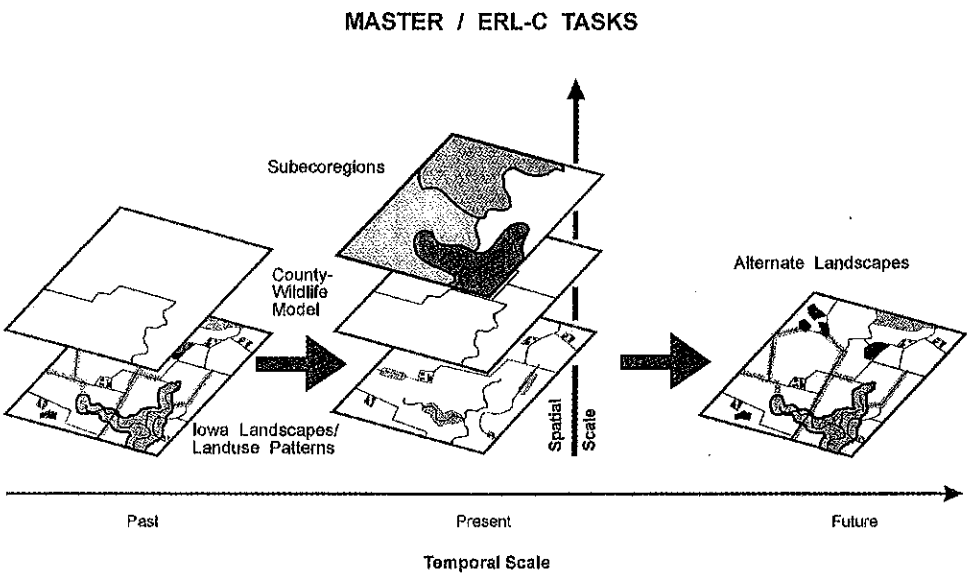

Fig. 5. Spatio-temporal hierarchy of MASTER projects at EPA-Corvallis to assess effects on terrestrial wildlife of landscape alteration and disturbance associated with agriculture, and to develop and evaluate alternative landscape design and management scenarios.

in and adjacent to cropland (Freemark and Csizy, 1993). The extent of woodlands locally, and wooded fencerows both locally and in the landscape were particularly important for maintaining a diverse avifauna (Freemark and Csizy, 1993). Woody fencerows, roadsides, pastures, grass fields and old fields supported a diverse, native flora (Keddy et al., 1993). Intensification of agriculture in these study areas in recent decades has reduced the diversity and extent of habitat types important to both birds and native flora (Moore et al., 1993).

In the Iowa Landscapes project, habitat use by birds in Iowa farmland has been quantified from previous field studies to evaluate the relative importance of different habitats and landscape mosaics (L.B. Best et al., unpublished data, 1994; cf. Howe et al., 1985). A field study is in progress to quantify relationships between bird species richness, abundance, composition, nest predation and landscape structure over a hierarchy of spatial scales within and among the Iowa MSEA and five other watersheds in Iowa. To understand historic development and potential futures, a retrospective analysis of landscape structure in the Iowa MSEA watershed is also underway based on interpretation of airphotos from 1939, 1965 and 1990. Preliminary results show that the Iowa MSEA watershed was already 89% cropland and pasture in 1939 (Freemark et al., 1994). Between 1939 and 1990, field size doubled, all remaining wetlands were drained, and riparian forest cover was reduced and fragmented.

The County-Wildlife Model project is developing a statistical model for Illinois of how land cover and farming practices at the county-scale and above have influenced the abundance of upland game between 1964 and 1987. Land cover and farming practice variables are being derived from agricultural statistics and include land-cover (extent of woodland, set-aside and acreage not in row-crops), soil condition (erodibility, extent of conservation tillage and soil-protecting crops), and farming disturbance (livestock density, acreages treated with fertilizers, herbicides or insecticides). The model will be used to evaluate likely effects on upland game from changes in land use patterns and agricultural practices in Iowa over a similar time period.

The Subecoregions project has conducted geographical information system (GIS) and statistical analyses of spatial patterns in low resolution datasets (e.g. soils, geology, AVHRR land cover) for the Western Corn Belt Plains ecoregion (Bernert et al., 1994). The main objective was to delineate ecologically similar subecoregions to put results at smaller spatial scales into larger spatial contexts. In the WCBP ecoregion, subecoregions were not clearly evident because environmental conditions and landcover are relatively homogeneous. The methodology developed represents a combination of qualitative and quantitative approaches that offers a promising alternative for regionalization (Huang and Ferng, 1990). It could also be used for quantifying and comparing landscape patterns among different spatial scales.

Lastly, the Alternate Landscapes project will combine results among different levels of biological organization and spatio-temporal scales to develop and evaluate alternative landscape design and management scenarios in relation to benefits for terrestrial wildlife. Methods for doing this are currently being investigated including the use of an interactive spatial decision support system (SDSS). An SDSS provides an interface which allows users to test different land use and management scenarios by linking GIS data, analytic models and visualization tools (Battista, 1994).

6. Future needs

Current efforts in MASTER for terrestrial wildlife would be improved by more regionally specific information on effects for a greater variety of taxa and over a broader range of biological organization including the level of cells, individual organisms and the biome. Investigation of metapopulation dynamics in the spatially structured populations characteristic of farmland is also needed (Opdam, 1991). More intensive studies are required to adequately evaluate potential benefits to terrestrial wildlife of specific, alternative within-field management practices (e.g. strip-intercropping, conservation or ridge tillage, alternative agrichemical management regimes), of land set-aside schemes (e.g. the USDA Conservation Reserve Program) or (alternative habitat restoration or enhancemei options (e.g. riparian buffer strips, conservatic headlands, corridors). Development and li kage of GIS and spatially explicit populatio models would also assist in developing, evalua ing and communicating alternative landscar design and management scenarios, particularl for larger spatial scales and over the long ter (cf. Hanson et al., 1990; Lankester et al., 199 Danielson, 1992; Pulliam et al., 1992; Sherra and Jepson, 1993; Battista, 1994).

An opportunity exists within the MASTE program to compare biological patterns at po ulation, community and landscape levels wit ecosystem-level assessments of nutrient cyclin water quality, and soil quality over a hierarch of spatio-temporal scales (Vitousek, 1990; Pac 1993). The potential also exists to develop fu ture scenarios which integrate across ecologica socio-political and economic perspective Methods for doing this need to be better deve oped in the MASTER program, as elsewhe (Doppelt et al., 1993; Bormann et al., 1994 More inclusive and consultative approaches wi be required to establish reasonable goals whic are acceptable to scientists, agronomists, farr ers, local interest groups and other stakeholde (Merriam, 1992; Olson and Poincelot, 199 Norton et al., 1992; Slocombe, 1993; Borman et al., 1994).

To date, the implementation and managemer of the MASTER program has been difficult b cause of bureaucratic processes and organiz tional structures within EPA and USDA. Inn vations in existing institutional processes an frameworks will likely be required to better pr mote the broad, integrated, transdisciplinary a proaches needed for more effective planning, r search and management of agricultur landscapes involving hierarchies of institution organizations, and individuals with varied goa and perceptions (Nassauer and Westmacot 1987; Dahlberg, 1992; Slocombe, 1993; Doppe et al., 1993; Bormann et al., 1994).

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