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ANALYSIS

# Aggregation and the matching of scales in spatial economics and landscape ecology: empirical evidence and prospects for integration

Jan E. Vermaat[a,*], Florian Eppink[a,b], Jeroen C.J.M. van den Bergh[a,b], Aat Barendregt[c], Jasper van Belle[c]

[a]*Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands*
[b]*Department of Spatial Economics, Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands*
[c]*Department of Environmental Sciences, Faculty of Geographical Sciences, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands*

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**Abstract**

Grain and extent of spatially explicit studies in landscape ecology and spatial economics have been reviewed in an assessment of differences between these two disciplines and possibilities for integration. In the latter field, (1) such papers were substantially less frequently found, and (2) median study area grains as well as extents were higher. We found no evidence of a different definition of spatial scale, but did find major differences between the two fields in embedding in theory (well-developed in spatial economy) and spatial realism (better in landscape ecology). Where studies integrated both fields, matching of the spatial scales was generally imposed by the data bases available and kept implicit in the derivation of research aims. In multidisciplinary environmental assessment, explicit matching of scales is often neglected. We evaluate three possible approaches to guide this matching exercise, and conclude that a local compromise for a specific landscape is probably the best achievable. We found no evidence for the existence of a limited set of convergent and globally overarching spatial scales that is of practical use.


*Keywords:* Grain and extent; Scale (dis)continuity; Integrated modelling

## 1. Introduction

Both in regional (or spatial) economics and landscape ecology, apparent spatial patterns are described, analysed, and modelled. However, the applied descriptive statistics as well as prevalent models are widely different in nature (cf. cf. Turner and Gardner, 1991; Bockstael, 1996; Lunney et al., 1997; Nijkamp, 1999), and so are approaches to aggregate heterogeneous data sets (cf. Atkinson and Tate, 2000). Remarkably similar conclusions were drawn for economics and geography (cf. Sjöberg and Sjöholm,

* Corresponding author. Tel.: +31 20 4449596; fax: +31 20 4449553.
*E-mail address:* jan.vermaat@ivm.vu.nl (J.E. Vermaat).

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2002). Integration of both disciplines, as in e.g. Van den Bergh et al. (2001) or Costanza et al. (2002) therefore requires a careful consideration of the issue of scale-matching and aggregation (see Dramstad et al., 2001). Both disciplines meet in attempts to value natural resources, ecosystem services or biodiversity (e.g. Costanza et al., 1997a, 2002; Edwards and P.J. Abivardi, 1998; NLWRA, 2002; Münier et al., 2004). Elicited by the opinions gathered in the survey of Gibson et al. (2000), and notably by their claim "that common definitions do not exist for scale", that is, common to natural and social sciences, we set out to review the background of this distinct difference and find possible solutions to bridge the gap.

"Scale" as a concept was the main focus of Gibson et al. (2000), justifying their tabulation of definitions and treatment of potential semantic confusion that we will not copy here. We have, however, attempted to first take their approach one step back, whilst limiting ourselves to spatial scales only. We review here the typical domains of applied and published spatial scales in regional economics and landscape ecology, in an attempt to let the published literature speak for itself through its empirical data. We use the modal definitions of spatial scale, extent and grain here (cf. Turner and Gardner, 1991; Gibson et al., 2000), whilst being aware of the caveats of a.o. Dungan et al. (2002), suggesting that (a) a change in scales of observation will lead to changes in descriptive statistics (means, variances, autocorrelation), and (b) the term "scale" per se has too many possible meanings and thus should be avoided.

This paper firstly charts differences in the typical domains of spatially explicit empirical studies in landscape ecology and regional economics, and then turns to concepts, hypotheses, research questions and approaches for the analysis of spatial pattern. We finally return to the question whether a common definition does exist.

## 2. Spatial scale in published literature—a review

### 2.1. Methodology

We obtained peer-reviewed publications from electronic literature data bases in both disciplines firstly by searching electronically using a wide array of key words, and secondly by closely scrutinizing tables of contents of selected key journals. We included papers in our data base from which we could extract quantitative and linearized (km) values for grain and extent. We excluded field experiments with exclosures, experimental plots or the like, because generally the spatial extent of these experiments beyond the limits of the plots remained unspecified. Still, our search resulted in a very large number of spatially explicit papers from landscape ecology "sensu lato", but much less so for spatial economics or integrated papers in the transition zone of these two fields. Since the latter two groups yielded a limited number of papers, we decided to merge them and label the combination as "integrated studies" (Table 1). We further decided to limit the number of landscape ecological cases in our database around 50, to maintain some degree of balance between the two sets of data. Whereas a decade ago King (1991) still had to conclude that landscape ecological papers often lacked explicit mention of spatial extent and grain, nowadays we have little difficulty in compiling a considerable literature base that does meet this criterion.

### 2.2. Spatial scales in the empirical data

Spatially explicit studies in both fields span wide spatial ranges in both grain and extent, and the two are

Table 1
Literature survey[a] summary statistics of spatial scale domains (km) of regional economics and landscape ecology

| Concept | Landscape ecology | Regional economics+ integrated studies | $p$($t$-test), assuming unequal variances |
|---|---|---|---|
| Extent | 88±34 (14, $n$=55) | 437±199 (59, $n$=24) | 0.10 |
| resolution or grain | 0.88±0.30 (0.03, $n$=55) | 2.76±1.22 (0.55, $n$=24) | 0.15 |

Presented are means±1 standard error (median, number of observations).

[a] Journals covered: Acta Bot. Neerl., Agric. Econ., Agric. Ecosyst. Environm., Aquat. Conserv.-Mar. Freshwat. Ecosys., Biodiv. Conserv., Biol. Conserv., Bioscience, Ecography, Ecol. Applic., Ecol. Econ., Ecol. Modell., Ecol. Monogr., Economica, Ecosystems, Env. Modell. Assessm., Env. Plann. A, Forest Ecol. Man., Hydrobiologia, J. Appl. Ecol., J. Biogeogr., Land. Econ., Landsc. Ecol., Landsc. Urb. Plann., Land Use Pol., Mar. Biol., Mar. Ecol. Progr. Ser., Math. Comp. Modell., Oecologia, Oikos, Regional Stud. References can be obtained form the author.

significantly correlated although scatter is considerable (Fig. 1). Several major points emerge from the scatterplot. Firstly, "integrated" studies only have grains higher than 30 m and extents beyond 10 km. The two "integrated" data sets with the largest extent deal with the whole contemporaneous USA or Australia (Konarska et al., 2002; NLWRA, 2002). No ecological paper in our data set covers such a large extent, whereas the grains of this category vary widely (from less than a meter to 10 km). Apparently, landscape ecologists may want to study their problems at considerably finer grains and extents than spatial economists, but also publish on issues of wide spatial extent. Summary statistics (Table 1) confirm this point: although mean grains and extents do not differ significantly among the two sets, medians do differ substantially.

A second observation is that the relation between grain and extent does not differ between the two samples: one common regression suffices to describe the variation observed. Thirdly, the span in extents studied does not change with increasing grains: for smaller and larger grains, the range of extents easily covers three orders of magnitude. Finally, a distinct clustering occurs around the grain size of 30 m, corresponding with the grain of images produced by the Landsat TM satellite. Clearly, available technology has been a major driving force here. We could easily have included more papers using the same remote sensing tool.

Our data base confirms the intuitive notion that regional and macroeconomics are more specifically oriented towards larger real-world spatial entities: actual provinces, states, regions, nations or the world. Very few economic or integrated studies have a grain less than these administrative units: these either used a remote sensing pixel (but for environmental data, see Geoghegan et al., 1997; Costanza et al., 2002), agricultural field or farm size (Skop and Schou, 1999; Groeneveld et al., 2001; Münier et al., 2004) as grain.

## 3. Concepts and models

Historically, an explicit treatment of space in economy has been mainly conceptual and wandered across the boundaries of geography and regional science (cf. Fujita et al., 1999). The well-known Von Thünen model, for example, allocated land-use as

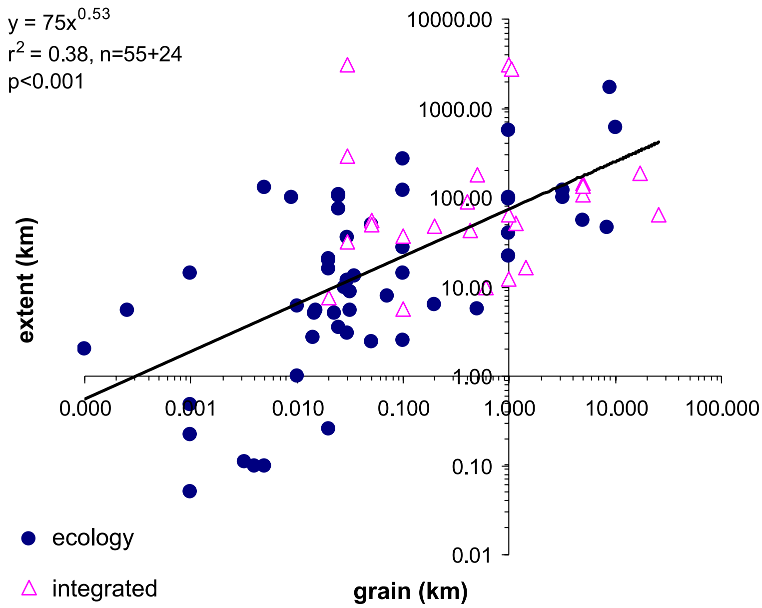


Fig. 1. Extent as a function of grain in published landscape ecological and spatial-economical or integrated (ecology+economy) studies. When necessary, both dimensions were approximated as the square root of the area given. See Table 1.

a function of the decline in land price when moving further away from a town. The representation of space, however, remained largely implicit in a qualitative distance zoning (Fujita et al., 1999). As an example, more recent models of commuting cost have difficulties in acquiring realistic travelling distance estimates because postal code areal units are used in the spatial data-base instead of travel networks (Thorsen and Ghitlesen, 2002). From within economics, spatial economics have provided space-oriented inputs to integrated modelling (Isard, 1969, 1972; Nijkamp, 1979a, 1979b; Hafkamp, 1984; Nijkamp et al., 1986; Lakshmanan and Bolton, 1986; Brouwer, 1987; Giaoutzi and Nijkamp, 1993; Van den Bergh, 1999). Spatial economics covers regional, urban and transport economics, which deal with location decisions of firms and households, land scarcitiy and allocation, spatial markets and inter-regional flows of products, capital and labour, inter-regional externalities, and spatially hierarchical planning problems. At a multi-regional level a distinction is usually made between bottom-up and top-down models. Bottom-up models start at the level of individual, "representative" agents or regions, and allow for feed-back from the lowest to the highest (macro-)level. Top-down models are steered by relationships among aggregate variables, and ultimately by exogenous macro-level developments. Multi-regional models following the bottom-up format are the most data-demanding (Rietveld, 1982).

Landscape ecology is probably similar to other branches of ecology in the comparative absence of unifying theory based on solidly tested hypotheses. Cherrett (1989), for example, published an inventory of the most "popular" concepts among members of the British Ecological Society (645 respondents or 15% of the members) and a total of 236 recognizably different concepts were suggested, ranging from "the ecosystem" (rank 1), via "stochastic processes" (rank 25) to "the guild" (rank 50). He cited McIntosh (1985) to conclude that "it is not easy to find consensus among ecologists about established theories, their basic postulates, sources or even their names or pseudonyms". Cherrett (1989) clustered his respondents into two distinct groups based on association of concepts mentioned: "practical holists" (432 cases, about half being "practical conservationists" and half "systems ecologists") versus "theoretical reductionists" (213 cases). Landscape ecologists would generally be ranked in the former group, which would probably limit their need for grand unifying theories. Being practitioners, self-proven rules-of-thumb may well be more popular among them. Landscape ecologists may have a theory in mind on the forces that shape their landscape, but the theory then remains implicit, may well be value-laden and locally case-specific, and the work done is not primarily intended to test this theory.

Also, landscape ecology is recent as a distinct branch of ecology: a dedicated journal entitled "Landscape Ecology", and comprehensive textbooks (Forman and Godron, 1986; Turner and Gardner, 1991) appeared less than two decades ago. The title of the latter monograph, "the analysis and interpretation of landscape heterogeneity", identifies the main focus of landscape ecology. Landscape ecologists investigate apparent variation in landscape pattern and both its causes and consequences. Thus, real-world, practically observable pattern generally is the starting point and not abstract theory. Furthermore, despite Levin's (1992) warning that "quite distinct underlying processes can give rise to identical sets of patterns", landscape ecology seeks to generate transferable, general answers from specific questions asked in local cases. Holling (1992), for example, demonstrated how the role of animals in the maintenance of landscape pattern can be predicted from body size and correlated home range. He argued that, over-and-above the gross dimensions dictated by climate and geology/topography, much of the observable landscape pattern is generated by animal–plant interactions. We will later return to Holling's point when we discuss the possibility of convergent natural spatial scales.

## 4. What underlies the difference?

Although we did find some similarity in methodology due to the wide availability of LANDSAT images dictating grain in many studies, we observed marked differences in the conceptual and practical treatment of spatial pattern between landscape ecology and spatial economy. We will now ask what has caused this twofold difference. We see that the starting points are principally different. Spatial economics has its roots soundly in mainstream economics theory. Furthermore, economists often seek to answer policy-related questions, which generally are asked at national scales. Landscape ecology, on the other hand has little theory but starts from equally sound real-world observations. The data of the latter, therefore, are also collected from real-world landscapes and may therefore, appear in a wide range of extents and scales. The data of the economist, however, are generally compiled by national bureaus of statistics. In the process, information is often aggregated to the level of administrative units, like municipalities, provinces or states, while individual household or firm level data associated with particular locations remain hidden for privacy reasons. This is unfortunate, because for a good understanding of landscape change, choices made by individual agents are crucial (Irwin and Geoghegan, 2001).

The remainder of this section considers possible responses to the problem of widely differing spatial scales between economic and ecological studies. These can contribute to effective integrated ecological-economic analysis and modelling.

## 5. Overcoming the difference in spatial scales: possible solutions

### *5.1. Selection of a measure of convergence: do natural scales exist?*

If one single, convergent and "natural" spatial scale would predominate in the scale spectrum of a given landscape, this would be an obvious baseline spatial resolution for integrated studies and hence a common meeting ground for both disciplines. Size distributions of landscape elements often are discontinuous, and have a limited number of modes as indicated by analysis of spatial pattern in fractal dimensions or semi-variance (e.g. Holling, 1992; Gustafson, 1998; Rietkerk et al., 2000). We briefly discuss the probability of such a convergent scale here. Holling (1992) observation of scale jumps in animal body size spectra of North American landscapes could be interpreted as an argument for scale convergence. His argument is that extended keystone species such as larger, grazing mammals predominantly affect the spatial pattern in a landscape by forcing the major patch dimensions in a large-scale mosaic such as that of forest and prairie. However, although mosaics of different spatial scale occur in several biomes (e.g. African savanna's, blanket and tundra bogs), this distinct spatial pattern is often far less obvious in others, particularly those dominated by trees (Walter, 1984), where smaller-scale patchiness is generally dominated by abiotic disturbances (such as treefall).

If any, landscape ecology has the catchment as a natural spatial unit that it shares with hydrology and geology. Spatial dimensions of catchments, however, are far from fixed (e.g. Petts and Foster, 1985). Spatial scale is considered to be hierarchical in ecology (Southwood, 1977; O'Neill et al., 1986; Holling, 1992), since processes as well as ecosystems fit together in a nested, though basically continuous fashion (O'Neill et al., 1986). Also when we focus on a particular type of ecosystem, e.g. natural wetlands, probably no distinct convergence exists for a particular radius or area that suffices for all or even the majority of populations of plants, birds or insects (e.g. King, 1991; Andelman and Fagan, 2000). Notably, Holling (1992) did not support his postulated impact of keystone species on landscape patterns with landscape element size distributions, in contrast with his two other, preceding, major points, i.e. the existence of distinct body size clumps and the correlation between territory and body size. We forward the opinion here that such strong herbivore–vegetation interactions only prevail and dictate landscape pattern in large, wider plains of gently sloping topography, i.e. where geomorphology allows, and where climate is not too favourable for tree growth. Hence the exercise of defining the scale where emergent properties of ecosystems are optimally aggregated is at best a compromise between the question at stake (for what purpose do we aggregate?), the larger geomorphological setting of a landscape, and the possibilities of the data base.

Human land-use, however, often has strongly shaped the patterns in a landscape. Across wide areas of Europe, for example, Iron Age settlement and reclamation patterns still prevail in the landscape and the lengths and widths of the fields (acres!) of medieval farmers predominate the shapes of the landscape elements that prevail (e.g. Holling, 1992; Tipping, 1995; Carcaillet, 1998; Odgaard and Rasmussen, 2000), of course all within broad, but locally variable, geomorphological settings. This strong shaping influence must have had a selective effect on the organisms that naturally populated these landscapes. Therefore, the spatial dimensions of human land use must be seen as a decisive filter for the spatial scales that can be occupied by such species.

In Dutch wetlands, for example, the extensive excavation of peat for fuel in the 16th and 17th century, for example, has created a landscape mosaic of narrow strips of land alternating with open water terrestrializing into fenland (e.g. Verhoeven, 1992). Both species inhabiting larger tracts of closed woodland as well as those of larger lakes will have a low probability of successful establishment and survival in this fragmented landscape. A second example derives from the number of unoccupied potential badger (*Meles meles*) territories in the Western part of the Netherlands (Schippers et al., 1996): increased habitat fragmentation by roads causes major mortality and prevents colonization of potential habitat. The badger is one of the last remaining larger wild mammals in increasingly human-dominated landscapes of Western Europe. This animal still survives mainly because of its flexibility in diet and tolerance or preference of woodland/field mosaics (Virgos, 2001; Revilla and Palomares, 2002; Johnson et al., 2002). Human occupation pattern as much as intensity of land use are major bottlenecks shaping biodiversity.

Hence we conclude that the occupation patterns and land use practices of man have shaped the size, form and availability of habitat already early in history. This must have had indirect effects on the natural abundance and distribution of plants and animals beyond the direct effects of exploitation and hunting (cf. Ponting, 1991). Therefore, we postulate that such long-term influences of man on the landscape must also have had profound influences on the spatial scales of the suite of species surviving in or adapted to many humanity-shaped landscapes across Europe and probably elsewhere. Spatial heterogeneity in older agricultural landscapes across Europe has a fine mesh. Inspection of topographic maps suggests that land units such as fields, plot meadows, and woodlots have dimensions in the order of 0.1–2 km (e.g. Clergeau and Burel, 1997; Odgaard and Rasmussen, 2000; less than the 3–4 km suggested by Holling, 1992, p. 483). For the analysis of spatial landscape pattern at a finer scale than the catchment, probably this order of magnitude comes closest to a natural spatial scale for landscapes that have been shaped by sedentary human agriculture. This also suggests that the plot or field scale would be the most useful grain for integrated studies of agricultural landscapes.

In regions where settled agriculture has left a less permanent imprint, as e.g. in the Eastern USA, finer-meshed landscape patterns are probably largely governed by geomorphology (Parker and Bendix, 1996; Stohlgren et al., 1997). Also in terrain where geology simply prevents large-scale human reclamation, such as alpine mountain valleys, geomorphological patterns dictate those of human occupation down to the smallest grain (e.g. Carcaillet, 1998). Finally, the apparently highly regular tiger bush landscapes of the Sahel (e.g. Rietkerk et al., 2002) serve to illustrate that a delicate balance between rainfall interception by vegetation and run-off over bare intermittent strips can be upset easily and dramatically by man-induced changes in grazing pressure. In these landscapes, where geological gradients are gradual, both form and size spectra of major landscape units are disrupted with the transition from savanna to steppe.

In short, we conclude that specific landscapes may show distinct convergence in landscape pattern and its predominant spatial scale. However, firstly, these cannot be extrapolated to other distant landscapes, and secondly, wherever man's occupation has been long-lasting, man's imprint on extant landscape pattern is of prime importance. Hence we cannot resolve our matching problem by identifying a single spatial resolution with a validity beyond regional scales.

### 5.2. A compromise: incorporate as much space into economics as possible

Costanza et al. (1997b, p. xxii) state that the integration of economics and ecology is hampered by the lack of space in economic theories and models. Although mainstream economics may have ignored space and spatial externalities between economic agents, the statement neglects the developing field of spatial economics, including regional, urban and transport economics with their links to environmental economics (see the various surveys in Van den Bergh, 1999, part V). Spatial economics is nowadays boosted by the wide availability of geographical information systems (see Scholten and Stillwell, 1990). In their comprehensive review, Fujita et al. (1999) propose that space has been largely absent until recently simply because it was beyond the computational capacity of equilibrium models to deal with spatial patterns explicitly, and because equilibrium has been too central to be sacrificed easily. Thus, we can conclude that the renaissance of space in economy is of recent date and fueled by the availability of computing power.

The difference in grain between economic and ecological databases will strongly constrain the spatial resolution of a study attempting to match ecological and economic data and their interaction. For example, recreation revenues will be reported per municipality, although the presence of clear hotspots (e.g. marina's, swimming beaches) within such a municipality have a major influence on the prevalence of distinct species and hence on the value of adjacent habitat as a carrier of biodiversity. This justifies a plea for economic data collection in the field at a sufficiently high spatial resolution to match with spatial distribution patterns of key species or habitat types. Indeed field surveys of economic value for example attributed by visitors to wetlands display considerable spatial heterogeneity in the distribution of such values (e.g. Costanza et al., 1989). Also, different habitats that are valued differently have a spatially heterogeneous distribution over the landscape.

Van den Bergh et al. (2001) use a polderwise spatial breakdown as a compromise of increased economic spatial resolution. This use of "polders" adds considerably finer spatial resolution below that of municipalities since these areal units have an average size of 200 ha. Also agricultural land use statistics are comparatively easy to obtain, since polders are often quite homogeneous in land use. However, two issues have to be resolved: (1) some data simply cannot be collected as truely variable replicates at this sub-municipality scale and hence may cause pseudo-replication (Hurlbert, 1984); and (2) at least for several plant or animal species of key interest, the spatial resolution of the "polder grid" is still too coarse. Particularly for species or habitat elements that have small-scale but distinct linear distributions along e.g. ditches or road verges, crucial spatial pattern will be lost at the polder resolution. Kleijn et al. (2001), for example, demonstrated for agricultural fields under environmentally friendly management schemes that 96% of the total species richness occurred along the outer margins (2 m wide for fields of $2.0 \pm 0.2$ ha). Practical solutions exist in the form of mosaic-type mixtures as compound land use types or in the inclusion of linear elements as a separate mapping layer.

### 5.3. Matching the scales before aggregation

Before aggregation, the smallest units should ideally match the spatial resolution needed to answer our questions. Aggregation, however, inevitably causes the loss of information (e.g. Van Beurden and Douven, 1999). Integration is needed to answer spatial-economic as well as ecological questions in concert. For the retention of spatial patterns, both for economics and biodiversity, aggregative integration can be accompanied by a suite of maps displaying such patterns.

An inherent problem of all mapped, spatial information, remains the fractal nature of the matter. Just as coastlines increase in length when they are mapped at a finer detail (cf. Milne, 1991), so are area's of for example valuable natural habitat. Indeed, Konarska et al. (2002) found that the aggregated value across the whole USA increased with increasing mapping resolution in a comparative valuation of ecosystem services using both NOAA and Landsat (1 km and 30 m grains, respectively).

## 6. Conclusion

We conclude that the treatment of space in spatial economy and landscape ecology has been different because of differences in conceptual background as well as approach towards data acquisition, not per se because of different definitions of spatial scale. Integration of these disciplines should be applauded, and this would benefit greatly from a systematic analysis of the relevant spatial scale and the approach towards aggregation of spatial data of such a different nature. No globally valid common spatial dimension exists that can be used in practice as study grain. Instead, a local compromise for a specific landscape should be searched for, and field size is a good candidate in landscapes that are predominantly agricultural. The renaissance of spatial economy based on GIS and sheer computing power is promising.

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## References

Andelman, S.J., Fagan, W.F., 2000. Umbrellas and flagships: efficient conservation surrogates or expensive mistakes? Proc. Natl. Acad. Sci. 97, 5954–5959.

Atkinson, P.M., Tate, N.J., 2000. Spatial scale problems and geostatistical solutions: a review. Prof. Geogr. 52, 607–623.

Bockstael, N.E., 1996. Modeling economics and ecology: the importance of a spatial perspective. Am. J. Agric. Econ. 78, 1168–1180.

Brouwer, F.M., 1987. Integrated Environmental Modelling: Design and Tools. Martinus Nijhoff, Dordrecht.

Carcaillet, C., 1998. A spatially precise study of Holocene fire history, climate and human impact within the Maurienne valley, North French Alps. J. Ecol. 86, 384–396.

Cherrett, J.M., 1989. Ecological concepts, the contribution of ecology to an understanding of the natural world. 29th BES Symposium. Blackwell, Oxford. 385 pp.

Clergeau, P., Burel, F., 1997. The role of spatio-temporal patch connectivity at the landscape level: an example of bird distribution. Landsc. Urban Plan. 38, 37–43.

Costanza, R., Farber, S.C., Maxwell, J., 1989. Valuation and management of wetland ecosystems. Ecol. Econ. 1, 335–361.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van den Belt, M., 1997a. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Costanza, R., Perrings, C., Cleveland, C.J. (Eds.), 1997b. The Development of Ecological Economics. Elgar, Cheltenham, UK.

Costanza, R., Voinov, A., Boumans, R., Maxwell, T., Villa, F., Wainger, L., Voinov, H., 2002. Integrated ecological economic modelling for the Patuxent river watershed, Maryland. Ecol. Monogr. 72, 203–231.

Dramstad, W.E., Fry, B., Fjellstad, W.J., Skar, B., Helliksen, W., Sollund, M.L.B., Tveit, M.S., Geelmuyden, A.K., Framstad, E., 2001. Integrating landscape-based values—Norwegian monitoring of agricultural landscapes. Landsc. Urban Plan. 57, 257–268.

Dungan, J.L., Perry, J.N., Dale, M.R.T., Legendre, P., Citron-Pousty, S., Fortin, M.J., Jakomulska, A., Miriti, M., Rosenberg, M.S., 2002. A balanced view of scale in spatial statistical analysis. Ecography 25, 626–640.

Edwards, P.J., Abivardi, C., 1998. The value of biodiversity: where ecology and economy blend. Biol. Conserv. 83, 239–246.

Forman, R.T.T., Gordon, M., 1986. Landscape Ecology. Wiley, New York. 640 pp.

Fujita, M., Krugman, P., Venables, A.J., 1999. The Spatial Economy: Cities, Regions, and International Trade. MIT Press, Cambridge MA, USA. 367 pp.

Geoghegan, J., Wainger, L.A., Bockstael, N.E., 1997. Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS. Ecol. Econ. 23, 251–264.

Giaoutzi, M., Nijkamp, P., 1993. Decisions Support Models for Regional Sustainable Development. Avebury, Aldershot.

Gibson, C.C., Ostrom, E., Ahn, T.K., 2000. The concept of scale and the human dimensions of global chance: a survey. Ecol. Econ. 32, 217–239.

Groeneveld, R., Bouwman, L., Kruitwagen, S., Van Ierland, E., 2001. Land cover changes as a result of environmental restrictions on nitrate leaching in dairy farming. Environ. Model. Assess. 6, 101–109.

Gustafson, E.J., 1998. Quantifying landscape spatial pattern: what is the state of the art? Ecosystems 1, 143–156.

Hafkamp, W.A., 1984. Triple Layer Model: A National–Regional Economic-Environmental Model for the Netherlands. North-Holland, Amsterdam.

Holling, C.S., 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecol. Monogr. 62, 447–502.

Hurlbert, S.H., 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54, 187–211.

Irwin, E.G., Geoghegan, J., 2001. Theory, data, methods: deveoping spatially explicit economic models of land use change. Agric. Ecosyst. Environ. 85, 7–23.

Isard, W., 1969. Some notes on the linkage of ecologic and economic systems. Pap. Reg. Sci. Assoc. 22, 85–96.

Isard, W., 1972. Ecologic-Economic Analysis for Regional Development. The Free Press, New York.

Johnson, D.D.P., Jetz, W., MacDonald, D.W., 2002. Environmental correlates of badger social spacing across Europe. J. Biogeogr. 29, 411–425.

King, A.W., 1991. Translating models across scales in the landscape. In: Turner, M.G., Gardner, R.H. (Eds.), Quantitative Methods in Landscape Ecology, The Analysis and Interpretation of Landscape Heterogeneity, Springer Ecological Studies, vol. 85, pp. 479–517.

Kleijn, D., Berendse, F., Smit, R., Gilissen, N., 2001. Agri-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. Nature 413,, 723–725.

Konarska, K.M., Sutton, P.C., Castellon, M., 2002. Evaluating scale dependence of ecosystem valuation: a comparison of NOAA-AVHRR and Landsat TM datasets. Ecol. Econ. 41, 491–507.

Lakshmanan, T.R., Bolton, R., 1986. Regional energy an environmental analysis. In: Nijkamp, P. (Ed.), Handbook of Regional and Urban Economics, vol. 1. North-Holland, Amsterdam.

Levin, S.A., 1992. The problem of pattern and scale in ecology. Ecology 73, 1943–1967.
Lunney, D., Pressey, B., Archer, M., Hand, S., Godthelp, H., Curtin, A., 1997. Integrating ecology and economics: illustrating the need to resolve the conflicts of space and time. Ecol. Econ. 23, 135–143.
McIntosh, R.P., 1985. The Background of Ecology, Concept and Theory. Cambridge University Press, Cambridge UK.
Milne, B.T., 1991. Lessons from applying fractal models to landscape patterns. In: Turner, M.G., Gardner, R.H. (Eds.), Quantitative Methods in Landscape Ecology, The Analysis and Interpretation of Landscape Heterogeneity, Springer Ecological Studies, vol. 85, pp. 199–236.
Münier, B., Birr-Pedersen, K., Schou, J.S., 2004. Combined ecological and economic modelling in agricultural land use scenarios. Ecol. Model. 174, 5–18.
National Land and Water Resources Audit, 2002. Australia's Natural Resources 1997–2002 and Beyond. Commonwealth of Australia.
Nijkamp, P., 1979a. Theory and Application of Environmental Economics. North-Holland, Amsterdam.
Nijkamp, P., 1979b. Environmental Policy Analysis. Wiley, Chichester.
Nijkamp, P., 1999. Environment and regional economics. In: Van den Bergh, J.C.J.M. (Ed.), Handbook of Environmental and Resource Economics. Elgar Publ. Cheltenham, United Kingdom, pp. 525–538.
Nijkamp, P., Rietveld, P., Snickars, F., 1986. Regional and multiregional economic models: a survey. In: Nijkamp, P. (Ed.), Handbook of Regional and Urban Economics, vol. 1. North-Holland, Amsterdam.
Odgaard, B.V., Rasmussen, P., 2000. Origin and temporal development of macro-scale vegetation patterns in the cultural landscape of Denmark. J. Ecol. 88, 733–748.
O'Neill, R.V., DeAngelis, D.L., Waide, J.B., Allen, T.F.H., 1986. A hierarchical concept of ecosystems. Monogr. Pop. Biol., vol. 23. Princeton University Press. 253 pp.
Parker, K.C., Bendix, J., 1996. Landscape-scale geomorphic influences on vegetation patterns in four environments. Phys. Geogr. 17, 113–141.
Petts, G.E., Foster, I.D.L., 1985. Rivers and Landscape. Arnold Publ., London.
Ponting, C., 1991. A Green History of the World. Sinclair-Stevenson, London. 469 pp.
Revilla, E., Palomares, F., 2002. Does local feeding specialization exist in Eurasian badgers? Can. J. Zool. 80, 83–93.
Rietkerk, M., Kettner, P., Burger, J., Hoorens, B., Olff, H., 2000. Multiscale soil and vegetation patchiness along a gradient of herbivore impact in a semi-arid grazing system in Western Africa. Plant Ecol. 148, 207–224.
Rietkerk, M., Boerlijst, M., Van Langevelde, F., Hille Ris-Lambers, R., Van de Koppel, J., Kumar, L., Prins, H.H.T., De Roos, A.M., 2002. Self-organization of vegetation in arid ecosystems. Am. Nat. 160, 524–530.
Rietveld, P., 1982. A general overview of multiregional economic models. In: Issaev, B., Nijkamp, P., Rietveld, P., Snickars, F. (Eds.), Multiregional Economic Modeling: Practice and Prospect. North-Holland, Amsterdam.
Schippers, P., Verboom, J., Knaapen, J.P., Van Apeldoorn, R.C., 1996. Dispersal and habitat connectivity in complex heterogeneous landscapes: an analysis with a GIS-based random walk model. Ecography 19, 97–106.
Scholten, H.J., Stillwell, J.C.H., 1990. Geographical Information Systems for Urban and Regional Planning. Kluwer, Dordrecht.
Sjöberg, O., Sjöholm, F., 2002. Common ground? Prospects for integrating the economic geography of geographers and economists. Environ. Plann. A 34, 467–486.
Skop, E., Schou, J.S., 1999. Modeling the effects of agricultural production. An integrated economic and environmental analysis using farm account statistics and GIS. Ecol. Econ. 29, 427–442.
Southwood, T.R.E., 1977. Habitat, the templet for ecological strategies? J. Anim. Ecol. 46, 337–365.
Stohlgren, T.J., Coughenor, M.B., Chong, G.W., Binkley, D., Kalkhan, M.A., Schell, L.D., Buckley, D.J., Berry, J.K., 1997. Landscape analysis of plant diversity. Landsc. Ecol. 12, 155–170.
Thorsen, I., Ghitlesen, J.P., 2002. A simulation approach to studying the sensitivity of commuting-flow predictions with respect to specific changes in spatial structure. Environ. Plann. A 34, 271–288.
Tipping, R., 1995. Holocene evolution of a lowland Scottish landscape—Kirkpatrick Fleming 2, Regional vegetation and land use change. Holocene 5, 8–96.
Turner, M.G., Gardner, R.H. (Eds.), 1991. Quantitative Methods in Landscape Ecology, The Analysis and Interpretation of Landscape Heterogeneity, Springer Ecological Studies, vol. 82. 536 pp.
Van Beurden, A.U.C.J., Douven, W.J.A.M., 1999. Aggregation issues of spatial information in environmental research. Int. J. Geogr. Inf. Sci. 13, 513–527.
Van den Bergh, J.C.J.M. (Ed.), 1999. Handbook of Environmental and Resource Economics. Edward Elgar Publ., Cheltenhm.
Van den Bergh, J.C.J.M., Barendregt, A., Gilbert, A., Van Herwijnen, M., Van Horssen, P., Kandelaars, P., Lorenz, C., 2001. Spatial economic-hydroecological modelling and evaluation of land use impacts in the Vecht wetlands area. Environ. Model. Assess. 6, 87–100.
Verhoeven, J.T.A. (Ed.), 1992. Fens and Bogs in The Netherlands, Vegetation, History, Nutrient Dynamics and Conservation, Geobotany, vol. 18. Kluwer, Dordrecht.
Virgos, E., 2001. Role of isolation and habitat quality in shaping species abundance: a test with badgers (*Meles meles* L.) in a gradient of forest fragmentation. J. Biogeogr. 28, 381–389.
Walter, H., 1984. Vegetation und Klimazonen. Ulmer Verlag, Stuttgart. 382 pp.