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Integrative methods to study landscape changes

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Abstract

In order to study landscape changes, an interdisciplinary approach that integrates landscape ecology and history is vital. This paper presents two methods to facilitate this integration. The first method aims at improving communication between the two disciplines by defining "interface categories" to talk more specifically about human impact on ecosystems. This procedure is illustrated with an example of forest changes in the Swiss lowlands. In the second method patterns of change in environmental features across regions are compared with regional differences in the importance of human activities with potential impact on the environmental feature under study. This method, referred to as double comparative study, is illustrated with an example of changes in forest composition in the northeastern United States. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Landscape change; Land use; History; Driving forces; Time lag; Methodology; Interdisciplinary

Introduction

Society and the environment are interconnected in space and time. The cultural landscape reflects changes in these interconnections (Birks et al., 1988; Russell, 1997, 1983). Thus, looking at the forces driving landscape changes is an important approach to study interconnections of society and nature in general. To take the holistic character of the landscape (Naveh, 1995) into consideration, Antrop (1998) suggests the use of the entropy as a measure of landscape structure that can be used to monitor landscape change over time. Whereas this approach broadens the understanding of landscape structures and functions within the field of landscape ecology, the methods proposed in this paper, attempt to integrate methods and knowledge from history as well as ecology to study landscape dynamics. We see this effort as a contribution to the construction of an intellectual framework to evaluate the interconnections of human activities and environmental changes sensu Crumley (1998).

Landscape ecology addresses how spatial relationships affect ecological patterns and processes, while history focuses on people and society. In landscape ecology, people are regarded as one factor among many that have an impact on the system under study. Similarly in history, the spatial setting of historical events is just one among many aspects considered. But real-world problems such as the loss of biodiversity or the decrease of regional water supply occur in both space and time. Thus, integrating landscape ecology and history is not merely of academic interest; an interdisciplinary approach has the potential to address practical problems society is facing.

The proposed methods address two problems in interdisciplinary studies of landscape change:

(1) A close cooperation between landscape ecologists and historians is still rare. As Meine (1999) puts it: "Natural scientists and historians may gaze upon the same landscape, but they see different things and draw different lessons from what they see". He points out the differences in the intellectual traditions and scientific languages used in the two fields. We suggest a way of bridging the disciplinary gap by talking more specifically about what is usually called in ecology "the human impact". Here, a historic approach is needed, as the main groups of actors shaping the landscape change over time. Moreover, changes in human activities are fostered by changing needs, demands, and interests — categories, not usually in the vocabulary of landscape ecologists but

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quite familiar to historians. Including such interface categories in studies of landscape ecology allows us to link changes in an environmental feature to changes in the needs and interests of society.

(2) There is a growing body of case studies of landscape changes, with differing aims, questions, and approaches. Comparing such studies helps us to understand further how society and non-human nature interact. The second method proposed develops a framework to compare changes in environmental features across regions with different histories of human activities, comparing results of several studies.

Scientists working in interdisciplinary projects are confronted with specific problems not only on the methodological level but maybe even more so by cultural and terminological differences between the disciplines involved. Even though this aspect of interdisciplinarity is not the focus of this paper, we consider the idea of defining interface categories a crucial one not only for gaining new insights into the temporal dynamics of the interconnections of society and the environment, but also for improving communication across different scientific cultures by removing terminological barriers.

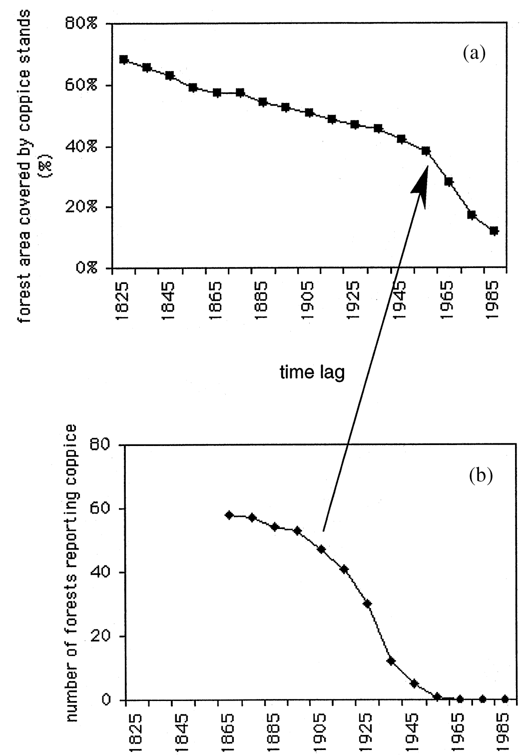

Fig. 1. (a) Percentage of forest area covered by coppice stands, and (b) number of forests reporting coppice management in the public forests of the northern part of the Canton of Zürich, 1825–1985.

Method 1: specification of human impact

In the northern part of the Canton of Zürich, located in the Swiss lowlands, the development of about 70 public forests mostly owned by communities were evaluated for the 19th and 20th centuries and the changes found were interpreted in their historic context (Bürgi, 1998a). The main source used in this study were 583 forest management plans. The characteristics of forest management plans and the procedure of building timelines based on data taken from these sources is described in Bürgi (1998a).

Generating timelines of changes in environmental features

Forest management plans contain information about various aspects of forests, e.g., total area of forests, stand structure, and species composition. In the descriptions of the forest stands different types of coppice and high forest stands are distinguished. Whereas coppice stands were cut with a rotation period of 5–30 years, regenerating by stump sprouts, high forests were cut every 60–100 years often followed by artificial regeneration. Thus, the two types of forests are very different in terms of habitats for plants and animals (Bürgi, 1998b). The timeline of percentage of the forest covered by coppice stands reveals a steady decline throughout the 19th and the first half of the 20th centuries followed by a much faster reduction since 1955 (Fig. 1a).

A timeline of the percentages of number of stems of the four most important species and taxa (spruce (Picea excelsa), pine (Pinus sylvestris), beech (Fagus sylvatica), and oak (Quercus robur, Quercus patraea)) reveals a strong decline in pine and an increase in beech whereas the portion of oak and spruce remained more of less stable (Fig. 2a).

Generating timelines of changing human activities

Forest management plans also contain information about human activities in the forests, e.g., type of forest management applied, uses of timber and wood, species composition in artificial regeneration, and use of non-timber forest products. The plans often mention the year in which coppice management ended in an individual forest. Thus, a timeline of the abandonment of coppice management was compiled (Fig. 1b). In some forests coppice management was already given up in the second half of the 19th century, but most coppices were abandoned between 1910 and 1930.

Changes in species composition of the forests are influenced by various factors, i.e., species specific regeneration, growth, and death, driven by natural and anthropogenic impacts. In the forests under study the choice of species used in artificial regeneration had a major impact on species composition. During the 19th

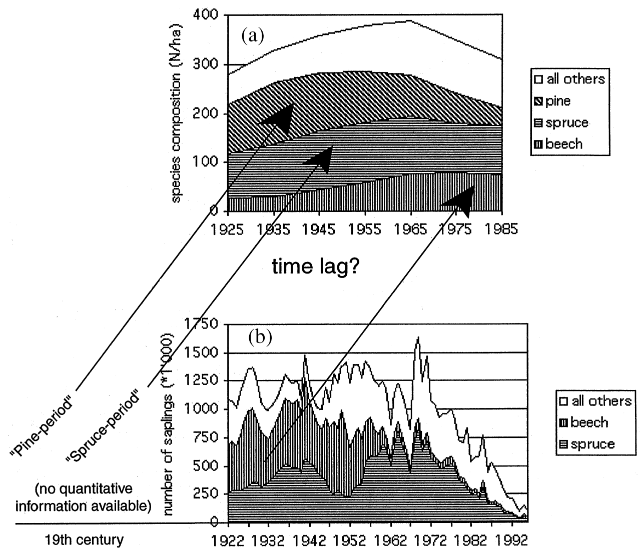

Fig. 2. (a) Composition in number of trees per area (N/ha) for the four most important species and taxa in the public forests of the northern part of the Canton of Zürich, and (b) number of saplings used in artificial regeneration in the public forests of the Canton of Zürich, 1922–1996.

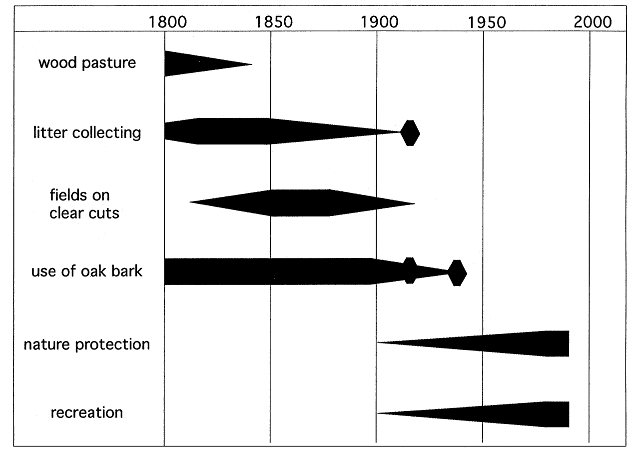

Fig. 3. Relative intensity of non-timber forests uses in the public forests of the northern part of the Canton of Zürich, 1825–1985. Copyright permission from Kluwer Academic Publisher.

century, artificial regeneration became important as clear-cutting and high-forests gained importance and coppice forests, which regenerate naturally, declined (Fig. 1a). Species used in artificial regeneration in the 19th century were mostly pine and later spruce (Fig. 2b), but hardly any quantitative information is available for this period (Bürgi, 1998a). Since 1922, the annual Swiss statistics about forests include data about species planted in the public and private forests of every canton. In the first half of the 20th century, beech and spruce were the dominant species used in the public forests of the canton of Zürich, and since the 1950 s spruce was preferred until there was a general decline in artificial regeneration activities (Fig. 2b). Still, the general trends are very likely the same in the study regions as in the whole canton.

Forest management plans also contain information about various non-timber forest uses. During the 19th century activities related to agriculture such as wood pasture (which was abandoned in the first half of the 19th century), litter collecting, and the agricultural use of clear cut high forests and coppice-stands that were cleared for conversion into high forests were common (Fig. 3). During the 20th century activities related to recreation and nature protection became increasingly popular (details in Bürgi, 1999).

Searching for the link between the two types of timelines

Due to the long history of human impacts on the forests in central Europe, they are part of the cultural landscape (e.g., Salbitano, 1988). Thus, it is a valid assumption that changes in human activities are the main driving forces of changes in forests as ecosystems. Comparing the timelines of changes in environmental features and changes in human activities reveals some important features of interactions between society and nature.

The example of coppice structures and coppice activities shows a strong link between the changes in human acitvity and the changes in ecosystem. In other words, it is an obvious effect of an obvious activity sensu Russell (1993), as coppice management is the only activity that leads to coppice stands. But even though the link between the two timelines is obvious, some time passes until the changes in the activity becomes visible in the environmental feature (arrow in Fig. 1). The decline in area covered by coppice stands happened about 30 years after the steepest decline in numbers of forests reporting coppice management. This time lag is well explained by the known forest development after the cessation of coppice management, as stands keep their coppice structure for several decades before being classified as high forests (e.g., Kriso, 1958).

Even though the example of changes in species composition of the forests and species composition in artificial regeneration could be interpreted as an example of an obvious activity with an obvious effect (sensu Russell, 1993) the story is more complicated. There are other activities (e.g., species-selective logging) and processes (e.g., selective disturbance events and competition between species) with a potential impact on species composition. A time lag of unknown length between planting certain species and their emergence as important components of the forest (indicated by arrows in Fig. 2) further complicates the interpretation of the link between the two timelines. This example illustrates the complexity of anticipating the consequences of changes in forest management.

The ecological effect of the documented changes in non-timber forest uses (Fig. 3) is also extremely difficult to assess on a regional level. Despite a very probable effect of some activities (e.g., litter collection) on the nutrient status of the forest (e.g., Glatzel, 1991) no available information about changes in the environment can yet be interpreted as a direct consequence of the changes in a specific non-timber forest use.

Defining interface categories between history and ecology

In order to interpret the changes in ecosystems in their historical context, terms have to be found that are meaningful and familiar for both ecologists and historians. We call these terms "interface categories" in order to stress their function for building bridges of communication between different disciplines. To better understand the interaction of society and nature in general, insights into the diversity of human impacts on ecosystems are crucial. Thus, we have to answer the question: "What are the interface categories that allow us to specify the diversity of human impacts on ecosystems in an ecological and historical context?" Firstly, it is important to acknowledge the changes in these impacts over time. In the example given, the timelines of changes in human activities reflect a complete change of the meaning and importance of forests for the society. Thus, an interface category is found with the term "periods".

Based on the timelines of changes in human activities, three overlapping periods of forest use and management can be defined (Fig. 4). The period of traditional multiple use lasted until the second half of the 19th century and was characterized by agricultural uses of the forests. This period was followed by the period of primacy of timber production, where the abandonment of the non-timber forest uses, a steady decline in coppice forests, and artificial regeneration of the clear-cuts with coniferous species gained importance. During the 20th century new demands such as recreation and nature protection became important and thus a period of modern multi-impact management can be distinguished.

Each period is characterized by a specific set of human activities and thus, main "actors" — the second interface category — can be defined. In Bürgi (1999) it is shown how asking questions such as "Who has an impact?", "What are their needs/demands/interests?", "How do they act?" for every period separately helps to define the most important groups of actors and their changing needs, demands, and interests over time and to interprete the changes found in a wider historical context. Consideration of these needs, demands, and interests is regarded as a critical link between landscape ecology and history and thus the terms also have the character of interface categories.

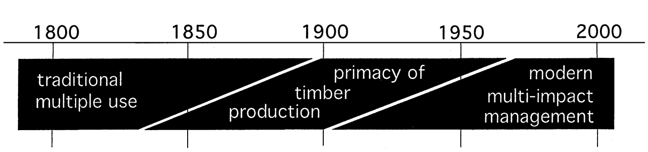

Fig. 4. Periods of forest use and management in the public forests of the northern part of the Canton of Zürich, 19th and 20th century. Copyright permission from Kluwer Academic Publisher.

Method 2: double comparative studies

In a recently published study, Foster et al. (1998) compared colonial and modern forest composition in Central Massachusetts, interpreting the changes found as resulting from human impacts. In a follow-up study, we applied the same approach to three additional regions in other parts of the Northeastern United States (Bürgi et al., in preparation). Here we compare results from two regions, Central Massachusetts and Pike County, PA. The two regions were similar in early colonial forest composition but have differed in human impacts since European settlement.

The aim of the study was to compare human impacts and forest ecosystem response across geographic regions. Such a comparison allows us to evaluate the relationship between regional changes in forest composition and regional patterns in human activities. As comparisons were conducted over time in both regions, and between the regions for two points in time, the approach is called a "double comparative study".

Classifying regional differences in environmental features

We compared forest composition from an early phase of European settlement, as revealed by early survey records (Bürgi and Russell, 2000), with modern forest composition taken from the Eastwide Forest Inventory Data Base (Hansen et al., 1992). Percentages of the major tree taxa were compiled for both periods and all study regions. The differences between colonial and modern forests were then classified. Maple increased very similarly in both regions whereas changes in oak and pine differed between the regions: oak decreased in Central Massachusetts and increased in Pike County, while pine increased in Central Massachusetts and decreased in Pike County (Fig. 5). In order to compare changes in forest composition across regions, we classified the changes in percentages according to a simple system (Table 1).

Classifying regional differences in human activities and natural disturbances

A crucial step in this method is to find and evaluate (Forman and Russell, 1983) information about human activities and natural disturbances with potential impact

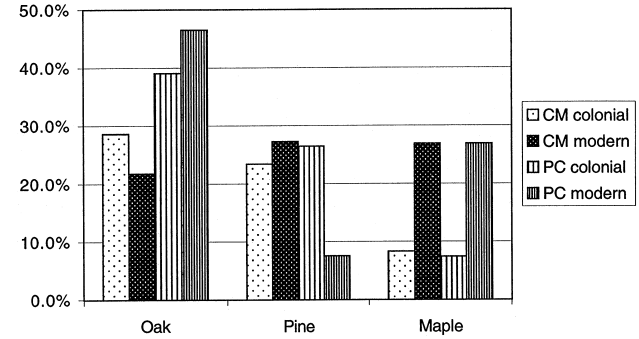

Fig. 5. Percentages of the three most abundant taxa in the colonial and modern periods in Central Massachusetts (CM) and Pike County (PC).

Table 1
Classification of changes in forest composition, human activities and natural impacts from the colonial to modern periods in the two study regions

	Central Massachusetts	Pike County
Oak	− −	+ +
Pine	+	− − −
Maple	+ + +	+ + +
Human activities		
Agricultural and abandonment	+ + +	+
Commercial logging	+ +	+ +
Natural impacts		
Fire	+	+ + +
Classification for change in taxa:		*for human activities/ natural impacts*:
$x < 2\%$	0	Negligible 0
$2\% \leqslant x < 5\%$	+/−	Less important +
$5\% \leqslant x < 10\%$	+ +/− −	Important + +
$10\% \leqslant x < 20\%$	+ + +/− − −	Very important + + +

on the same environmental feature for both regions. We compiled information from state and federal censuses, tax valuations, and local histories, and drew a timeline to structure the information. The timelines of human activities contain information about population density, land in forest, human activities, and transportation facilities, and indicate the time periods for which data about colonial and modern forest composition were available (Fig. 6).

Central Massachusetts was first settled in the middle of the 17th century, and after 1850 industrial towns grew as rural population decreased (Foster et al., 1998). Population density reached 87 people/km^2 in 1990. The first settlers had arrived in the area of Pike County by about 1725, but it remained mostly unsettled in the 18th century (Lehde, 1989). In 1920, < 5 people/km^2 were recorded. After 1960 a sharp increase in population occurred, reaching 20 people/km^2 in 1990.

According to maps and census data, in Central Massachusetts clearing for agriculture peaked in the first half of the 19th century, reducing forests to about 30% of the study area. Today, forests cover about 75% of the land, due to widespread farm abandonment. Pike County supported more than 85% forest cover throughout the time period investigated. As most of the land cleared from forests was used for agriculture in Central Massachusetts, modern forest composition there is much more influenced by agriculture and subsequent re-growth (Foster et al., 1998) than it is in Pike County, where agriculture was never very important. The commercial logging and tanning industries, mostly using the bark of hemlock, were equally important in both regions. Second growth white pine stands that became established as a consequence of farm abandonment throughout Central Massachusetts, were used heavily for producing wooden boxes and crates between the 1890 s and the 1920 s (Fedkiw and Stout, 1959; Irland, 1982).

In Central Massachusetts, an early network of overland trails was improved in the 18th century by a network of roads. However, the poor quality of many of these early roads limited market access (Parks, 1967). The construction of railroads starting in 1844 resulted in a significant improvement of overland transportation, and interregional automobile highway systems became widespread by the mid-1920 s (Connolly, 1985). The development of infrastructure in Pike was much slower, but by the 1980 s a popular movement to live in Pike and commute to New York or New Jersey (Fluhr, 1998) caused a sharp increase in second homes, commuters, and retired people living there.

Apart from human activities, regional differences in natural disturbances also have to be taken into consideration. In the northeastern US the importance of large-scale windstorms is highly variable. Central Massachusetts experiences severe hurricanes causing extensive blowdowns (F2 on the Fujita scale) about every 150 years, e.g., in 1815 and in 1938, when white pine was particularly susceptible to damage (Foster, 1988; Boose et al., in review). However, Pike County is out of the range of regular catastrophic wind damage by hurricanes (Boose et al., in review).

Another important abiotic disturbance (partly triggered by human activity) is fire. The extent, intensity, frequency, and source of ignition (i.e., human vs. lightning) of fires in the pre-colonial period remain a point of debate (Russell, 1993; Abrams, 1998; Ruffner and Abrams, 1998). In the 19th and 20th centuries, railroads and people (e.g., hunters, campers, and berry pickers starting incendiary fires to encourage the younger growth of blueberries and huckleberries) were probably the most frequent causes of the forest fires (Rothrock, 1894; Anonymous, 1906; Report, 1915). Pike was among the counties with the most extensive fires in Pennsylvania (Anonymous, 1896) but fires were also frequent in

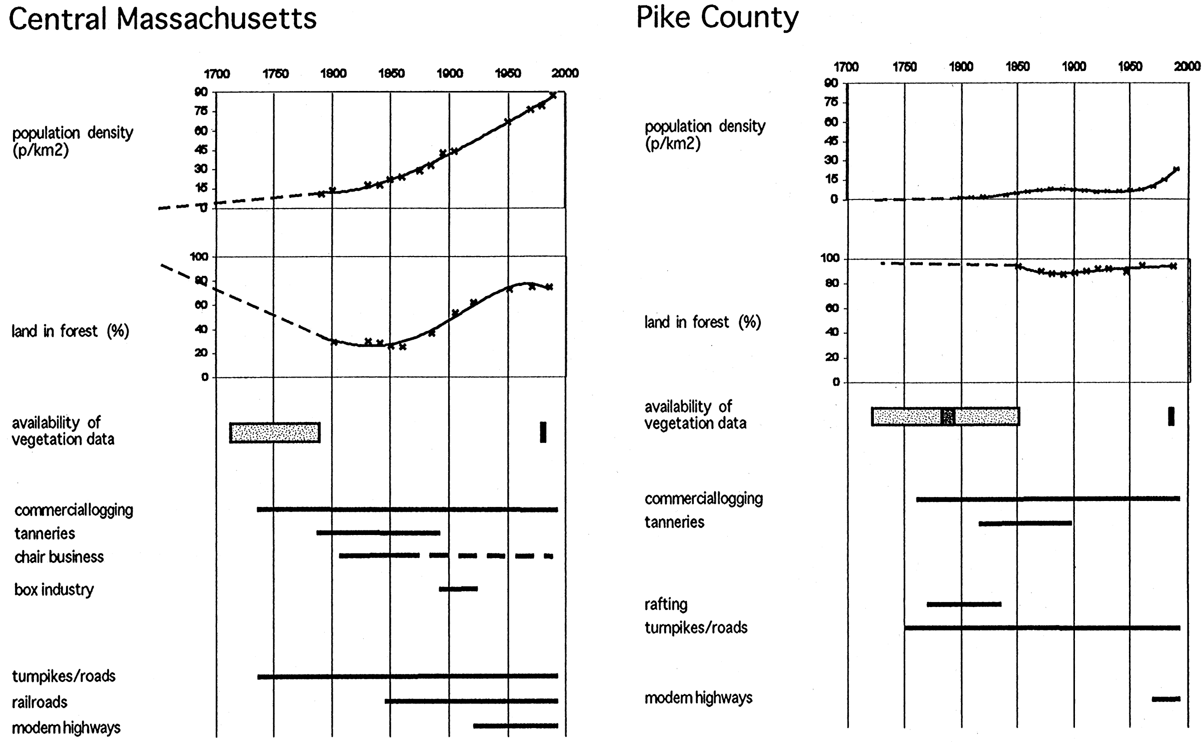

Fig. 6. Summary of historical information about human activities with impact on the forests in Central Massachusetts and Pike County.

Central Massachusetts. In the 20th century, improved fire detection and suppression resulted in a decline in the importance and size of fire (Pyne, 1982).

In order to compare the potential impacts on forest composition across regions, we summarized the human activities and natural disturbances since European colonization and classified the ones we considered to be most important (Table 1). In the example given, agriculture and its abandonment, commercial logging, and fire are considered to be the most important impacts.

Comparing the patterns of environmental features and human activities

Comparing classified regional changes in environmental features and classified regional differences in human activities and natural disturbances over time reveals interesting patterns (Table 1). Oak and pine were both intensively logged in the period under study. Whereas pine has the ability to colonize abandoned fields, it does not sprout after logging. Oak on the other hand does sprout, but it is not an important old-field species in the northeastern United States. Thus, the different changes in forest composition between the two regions can be well explained by the following process: After logging, oak was able to sprout in Pike County, whereas in Central Massachusetts the forest was not only logged but also cleared for agriculture. Pine colonized many of the fields abandoned there, whereas there were no such fields to colonize in Pike County, as agriculture never was of great importance in that region. The increase in maple is not only visible in the two regions under study, but is recognized as a widespread phenomenon (Abrams, 1998). It might be a result of the overall increase in forest disturbances (e.g., logging).

Thus, classified regional differences in human activities combined with information of the impacts of these activities on different taxa are consistent with the regional differences in classified changes in forest composition. We hypothesize that agriculture followed by its abandonment led to a decrease in oak and an increase in pine, whereas logging without subsequent clearing for agriculture is favorable for oak and triggers a decline in pine. This hypothesis has to be tested in other regions and its limitations may help to identify other human activities (e.g., dairy farms vs. crop protection) and differences between the regions (e.g., type of soil, climate) that have to be taken into account.

Discussion of the proposed methods

Whereas comparing timeline data (method 1) points out potential time lags between impacts on ecosystems — be it by human activities or by natural disturbances — no time lag can be taken into consideration in a comparative approach (method 2), where only two points in time are compared. Thus, double comparative studies are useful to study processes with time lags considerably shorter than the length of the period under study.

The aim of method 2 is to generate hypotheses that explain the patterns and are consistent with observations about potential impacts of the human activities under study (Russell, 1993). The stronger, more obvious, or more direct (e.g., showing a short time lag) the link between a given human activity and a change in an environmental feature is, the easier it is to formulate useful hypotheses. Such hypotheses can be tested in other studies, and contribute to more general hypotheses or theories about interactions between society and nature (Russell, 1993). Weak, subtle links that show long time lags are much more difficult to study.

For conducting double comparative studies it is crucial to compare changes in environmental features with changes in human activities on the same spatial scale. The method allows generalizations about the potential human impact on the temporal behavior of landscapes and therefore contributes to our knowledge of the interconnections of society and the environment.

Conclusions

The need for better integration of historical and landscape ecological perspectives does not primarily come from the disciplines involved, but from real world problems that need integrative solutions. Such an integration has to be based on closer cooperation between landscape ecologists and historians. We propose to improve the communication between these fields by defining "interface categories" of interests to both.

In general, time lags are a crucial feature of interactions between society and nature. This is not only true for the response of ecosystems to changes in environmental factors, such as climate change or natural disturbances (e.g., Davis, 1986; Magnuson, 1990), but also for impacts of changes in environmental features on human activities. One should note that time lags are important in both directions of the interconnection of society and the environment: it might take some time until the impact of human actions becomes visible in an environmental feature, but it also takes time until human actions are adjusted to avoid unintended and undesirable changes in the environment. This emphasizes the need to acknowledge and evaluate the interconnectedness of society and nature (Grossmann, 1993; Crumley, 1998). Such attemptss might be greatly facilitated by the integration of human impacts caused by human needs, demands, and interests into studies of landscape change, as suggested by method 1. The method of material flow analysis, which is a crucial element in the concept of social metabolism (Fischer-Kowalski, 1997), offers an approach where questions of time lags can be analyzed. However, new methods have to be found, where not only quantitative information (as in Figs. 1, 2, and 5), but also qualitative information (as in Figs. 3, and 6) can be included.

It will remain impossible to rigorously test hypotheses regarding the potential link between changes in environmental features and changes in human activities, but experimentation and modelling are valuable tools to gain additional insights into their plausibility and the dynamics of the interactions studied. In any case, landscape ecologists will have to incorporate circumstantial evidence and inferential reasoning in applying such integrative methods. The alternative of not including more historical information in landscape ecological studies frequently leads to misinterpretation of the observed change in environmental features (Pickett and McDonnell, 1993).

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