1995

Linking landscape ecology and ecosystem health: The case of Lunigiana, Italy

Susan Anna Pellanda
Wilfrid Laurier University

LINKING LANDSCAPE ECOLOGY AND ECOSYSTEM HEALTH: THE CASE OF LUNIGIANA, ITALY

By

Susan Anna Pellanda
Honours Bachelor of Arts, Nipissing University, 1993

THESIS
Submitted to the Department of Geography
in partial fulfilment of the requirements
for the Master of Environmental Studies degree
Wilfrid Laurier University
1995

ISBN 0-612-04647-8

ABSTRACT

As ecosystem-based management is increasingly used to manage the environment, methods of applying these approaches to resolve environmental and natural resource issues must be established. The concept of ecosystem health can be used to assist in ecosystem-based management since it takes into account the environmental, economic, and social aspects of ecosystems. However the integrated approach of ecosystem-based management, and the effect of ecosystem processes on different ecosystem levels, necessitate that different levels be used to assess ecosystem health. The landscape is a level which can be used to assess and manage for a healthy ecosystem due to the spatial and temporal aspects of ecosystem processes it conveys.

The aim of this thesis is to demonstrate the manner in which landscape ecology can be used to manage for the goal of obtaining a healthy ecosystem. This is achieved by studying the landscape of Lunigiana, Italy, an agricultural region located near Italy's northwestern coast. Lunigiana's landscape has undergone tremendous changes as a result of short- and long-term natural and human activities, however particular emphasis is placed on studying the period between the 1880s and the 1980s since it was during this time that a significant change in the landscape pattern occurred due to changing socioeconomic conditions.

In order to understand the effects of these changes on the ecosystem, this thesis analyzes and examines the effects of natural and human processes on Lunigiana's landscape by studying the landscape patterns of three sites along the Taverone River valley as well as the general landscape pattern of Lunigiana. Landscape pattern indices diversity, dominance, and contagion, as well as summary data on the land uses occurring in the area, were used in the quantitative analyses of the landscape, while historical and socioeconomic analyses were used to understand the development of the current landscape pattern.

A geographic trend of increasing diversity and contagion and decreasing dominance values was observed with increasing elevation and distance of the study sites from the coastal urban centres. This occurred as a result of the larger amount of abandoned agricultural land and degraded woodland in the more remote upland areas due to their past dependence on the agriculture industry. However Lunigiana's landscape pattern, and the ecosystem processes observed at the landscape level, reveal that although areas of Lunigiana continue to be abandoned, the ecosystem is still able to maintain its ability to adapt and reorganize to suit changing ecosystem components and processes.

The effectiveness of using and linking landscape analyses in order to assess Lunigiana's ecosystem health is reviewed. Ultimately, however, the relevance of the information available at the landscape level, and the manner in which to use it in ecosystem health assessment, is presented as a guide for improving ecosystem-based management.

ACKNOWLEDGEMENTS

At this time I would like to thank several people without whom this thesis would not be possible. First to my advisor Dr. D. Scott Slocombe for his guidance when research seemed to be at a stand-still and for his considerable patience during the several drafts submitted throughout the past two years. Along with his thought provoking comments and his encouragement, despite the fact that "a thesis is never finished", I am truly appreciative.

To Dr. Almo Farina, my advisor in Lunigiana, Italy, I extend my sincere gratitude for his suggestions in helping to get this research off of the ground and for his hospitality. Lunigiana is truly a beautiful place to which I hope to return.

I would like to thank Jennifer Todd for accompanying me to Italy, her assistance in collecting information on Lunigiana, and her friendship when home seemed so far away. I would also like to thank Ruben Furtado, without whom I would still be in the cartography lab (despite the construction) trying to figure out Coreldraw.

To my parents I extend my sincere appreciation for their constant encouragement and support during the past two years and throughout my education. Thanks also go out to Stephanie for her help, to Luke for his tolerance when things were hectic, and to Veronique and Crystal for their sanity breaks.

Finally I would like to thank my best friend and fiance, Jason, for his understanding, advice, smile, sense of humour, and above all his spirit. For helping to put things into perspective and for showing me that every cloud has a "Blue" lining, I am eternally grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CGLRM	Council of Great Lakes Research Managers
EMAP	U.S. Environmental Monitoring and Assessment Program
HI	Ecosystem Health Index
IBI	Index of Biological Integrity
ISTAT	Istituto Centrale di Statistica
IUCN	World Conservation Union
OECD	Organization for Economic Co-Operation and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
WQGTG	Great Lakes Water Quality Guidelines Task Group

CHAPTER ONE

INTRODUCTION

1.1 Rationale for Thesis

As the complexity of environmental management problems increases and resource abundance decreases, environmental and natural resource management is becoming increasingly critical. The rapid degradation and the increasing disappearance of many of the earth's flora, fauna, and life support systems have prompted us to notice that the effects of many human activities on the environment are becoming more harmful than ever before. In the past few decades alone millions of ecosystems throughout the world have been altered by human activities, many of which have resulted in the disappearance of many rare and threatened species, the disruption of many ecological cycles, and the degradation of many ecosystem processes and functions.

As in the past, economies continue to play a major role in shaping the environment. The short-term monetary gains of many past economy-driven management decisions have resulted in harmful long-term environmental consequences while ecosystems are only beginning to be regarded as critical attributes in the persistence of a healthy earth. Today environmental planners and managers are working to develop long-term, more complete strategies to manage the earth and its resources. New approaches, concepts, and methodologies for environmental management are continually being developed as environmental research reveals ecosystem components and processes which should be considered in environmental management as environmental issues become increasingly complex and more difficult to manage.

Ecosystem-based management approaches are the integrated management of ecological systems and human activities which aim to improve environmental management. They are products of environmental managers' search for methods of managing the earth's environment in a holistic manner by shifting focus from local point sources of stress to regional and global sources (Slocombe 1993b). One part of these approaches is the concept of ecological or ecosystem health. Ecosystem health has been receiving increased attention in environmental management realms since it can be applied to all ecosystems, taking into account the dynamic nature of ecosystems and focusing on the interrelationship among the biophysical and cultural components of ecosystems. Having been the subject of an increasing number of articles, journals, books, workshops, and conferences, the ecosystem health concept may have become the criterion upon which environmental management realms of the 1990s can focus. However, with an environment that is continually changing to absorb human-induced stress, development of the ecosystem health concept and its implementation in environmental management processes require methods of assessing ecosystem condition to assist in the management of a rapidly changing environment.

At a recent IUCN World Congress on Parks and Protected Areas in Caracas, participants felt that in order to protect the earth and its biodiversity, a shift must occur from protecting small biological nature islands to conserving landscapes which have not yet been completely destroyed (Naveh, 1992). This theory can be further expanded to suggest that landscapes be used to assist in the management of overall ecosystem health.

Landscapes are a mosaic of heterogeneous landforms, vegetation types, and land uses and processes which interact with each other and are repeated in a similar format throughout an area. Due to the ability of landscape level observations to identify changing ecosystem characteristics not discernible at smaller community- or species-level, many researchers continue to promote landscapes as a level at which ecosystem health assessment can occur. In our attempts to keep up with the rates and scales of human and non-human activities and their effects on ecosystems, the spatial and temporal aspects of landscape level analyses can help us to study the effects of these activities on ecosystems. Accordingly, this thesis aims to address the following question:

> Given the widespread acceptance of the concept of ecosystem health in environmental planning and management, and the increased interest in ecological dynamics occurring across landscapes, how can landscape ecology be effectively employed to manage for the goal of ecosystem health?

1.2 Main Themes and Objectives of Research

The rate and extent to which humans alter ecosystems is surpassing our ability to assimilate and understand the implications of our actions. Increased population growth, technological advances, and accelerated development have resulted in environmental degradation such that ecosystems are often unable to reorganize and recover to an "optimum point of operation" (Kay and Schneider 1994, 37). As ecosystem processes become more complex, and the ability of ecosystems to combat stress decreases, environmental management becomes increasingly difficult.

Ecosystem-based management approaches are transdisciplinary, holistic methods which assist in understanding and managing the environment, therefore they have different meanings for different people. To an ecologist ecosystem approaches aim to integrate various theories, concepts, and methods which should be used in environmental management, relating all aspects of an ecosystem and recognizing the integrated nature of all ecosystem components and processes. In this thesis an ecosystem approach is a geographically and biologically comprehensive approach that relates people to the ecosystems of which they are a part, placing equal emphasis on environmental, economic, and social issues (Vallentyne and Beeton 1988; WQGTG 1994).

The concept of ecosystem health incorporated within ecosystem-based management approaches can be used to determine the type of transdisciplinary information required to monitor ecosystems, define desirable ecosystem conditions, and manage ecosystems accordingly. The WQGTG (1994, v) defines ecosystem health as

> an ecosystem state in which the environment is viable, liveable, and sustainable, the economy is equitable, sustainable and adequately prosperous, and the community is liveable, equitable and convivial.

However, as the concept remains relatively new, and a universal definition of ecosystem health has yet to be developed, environmental researchers and managers must continue to develop techniques to determine the causes of degrading ecosystem health in order to manage them accordingly.

Until recently most political, economic, scientific, cultural efforts concentrated their efforts on either threatened species, habitats, or cultural monuments, with little regard to the relationship between humans and their environment throughout history. With the focus of environmental history on the relationship between humans and the environment, the discipline functions as a key to the discovery of the sources of many of today's environmental problems. Environmental historians reject the notion that humans have been exempt from natural constraints, realizing that as time progresses humans are having an increasing effect on the environment and its natural processes. Environmental history begins with the geography of a region, especially its ability to support a human society, and the effects of human activities on the health of the ecosystem.

Landscapes can be used to study the geography of a region in terms of the spatial and temporal effects of human and natural processes on the ecosystem. Most landscapes have been affected by human use resulting in a landscape mosaic with a mixture of natural and human patches which vary in size, shape, and arrangement (Turner 1987). Therefore landscape ecology can be used to determine the relationship between humans and the environment by extending ecosystem analysis to the interactions which occur among ecosystems, integrating both natural and managed ecosystem attributes. Landscape ecology is the study of the structure, function, and change of a heterogeneous land unit composed of interacting systems. Landscape ecology focuses on spatial dynamics at the landscape level, taking into consideration the dynamics of spatial heterogeneity and spatial and temporal interactions, and their affect on abiotic and biotic processes. Landscape ecology provides a framework for analyzing the landscape level, acknowledging the interrelationships between natural and human processes, and can in turn provide greater insight as to the underlying processes which have generated the current landscape mosaic and the effect of these processes on ecosystem health.

Today there is an increasing interest in the field of landscape ecology and its applicability in monitoring and assessing the state of the environment. However, little is known or understood of the viability of landscape patterns, that is, those landscape structures and functions which help to maintain an ecosystem's ability to adapt and reorganize as environmental conditions change. Research into the type of information required to link landscape ecology and ecosystem health, and the manner in which to implement landscape ecology theory and measures in the ecosystem health management process, is necessary to improve ecosystem-based management. By identifying and using biophysical and socioeconomic theories, concepts, and methodologies a means of linking landscape ecology with ecosystem health can be determined and subsequently applied in environmental management processes. Several objectives which integrate the use of existing biophysical and socioeconomic information with the information required for effective ecosystem-based management have been developed to demonstrate how landscape ecology can be used to manage for the goal of ecosystem health. Accordingly this thesis aims to:

1) conceptualize the links between ecosystem health and landscape ecology in order to identify the relationships, dependencies, and causalities between changing landscape pattern and ecosystem health;

2) identify, through a case study, the information which effectively demonstrates long-term anthropogenic disturbance at the landscape level, and use available information to relate landscape level processes with ecosystem health; and,

3) illustrate the relevance of such information in ecosystem-based management.

1.3 The Study Area

The interrelationship between environmental history, ecosystem processes, and landscape variability is central to understanding the effects of human activities on ecosystem health. In order to understand and demonstrate this relationship, this research focuses on an area which has undergone tremendous change as a result of long-term natural and human processes.

The Mediterranean region is one of the earliest settled areas of the world. Like many developed areas, changes in socioeconomic organization have altered the structure, function, shape, and pattern of many Mediterranean landscapes. Although numerous landscapes throughout the world are experiencing increasing fragmentation, many parts of the Mediterranean region are undergoing an opposite trend, particularly in rural mountain regions (Farina 1991a). Landscape patterns are becoming more homogeneous as traditional ways of life are being abandoned, while modern, more large-scale industrialization, urbanization, and agriculture intensification begin to dominate the areas, affecting ecosystem components and processes and changing the landscape mosaic.

The Italian peninsula has not been exempt from these changes. Italy has undergone a variety of changes due to biophysical and cultural forces which have affected the area for thousands of years. However in the past few decades Italy's socioeconomic structure has experienced more rapid and extensive transformations than ever experienced in the past. Increased urbanization, industrialization, intensification of modern agricultural practices, and over-population pressures characterize the changes occurring in lowland areas, while the opposite trend, that of abandonment of once-staple agricultural economies, the land itself, and way of life, is being experienced in upland areas. These trends and the effects of these trends on the landscape mosaic and ecosystem health can be observed throughout Italy's northern Apennines and adjacent lowland coastal areas, and in particular in Lunigiana, the focus of this thesis (Figure 1.1). Lunigiana's boundaries correspond with those of the middle and upper course of the Magra River watershed, one of northwestern Italy's main river systems, and the entire watershed constitutes the province of Massa Carrara. Lunigiana's insular position in the Apennines has caused a considerable amount of the historical rural man-made landscape pattern, consisting of fields, terraces, hedgerows, and vineyards, as well as its rich cultural heritage, to be well preserved.

Lunigiana was chosen as the study area for this research because it has been affected by natural and anthropogenic processes for thousands of years, and the structure and function of its landscape reflect the interactions which have taken place between its systems as a result of changing ecosystem conditions and human activities. As well the existence of an extensive data base on the area's biophysical

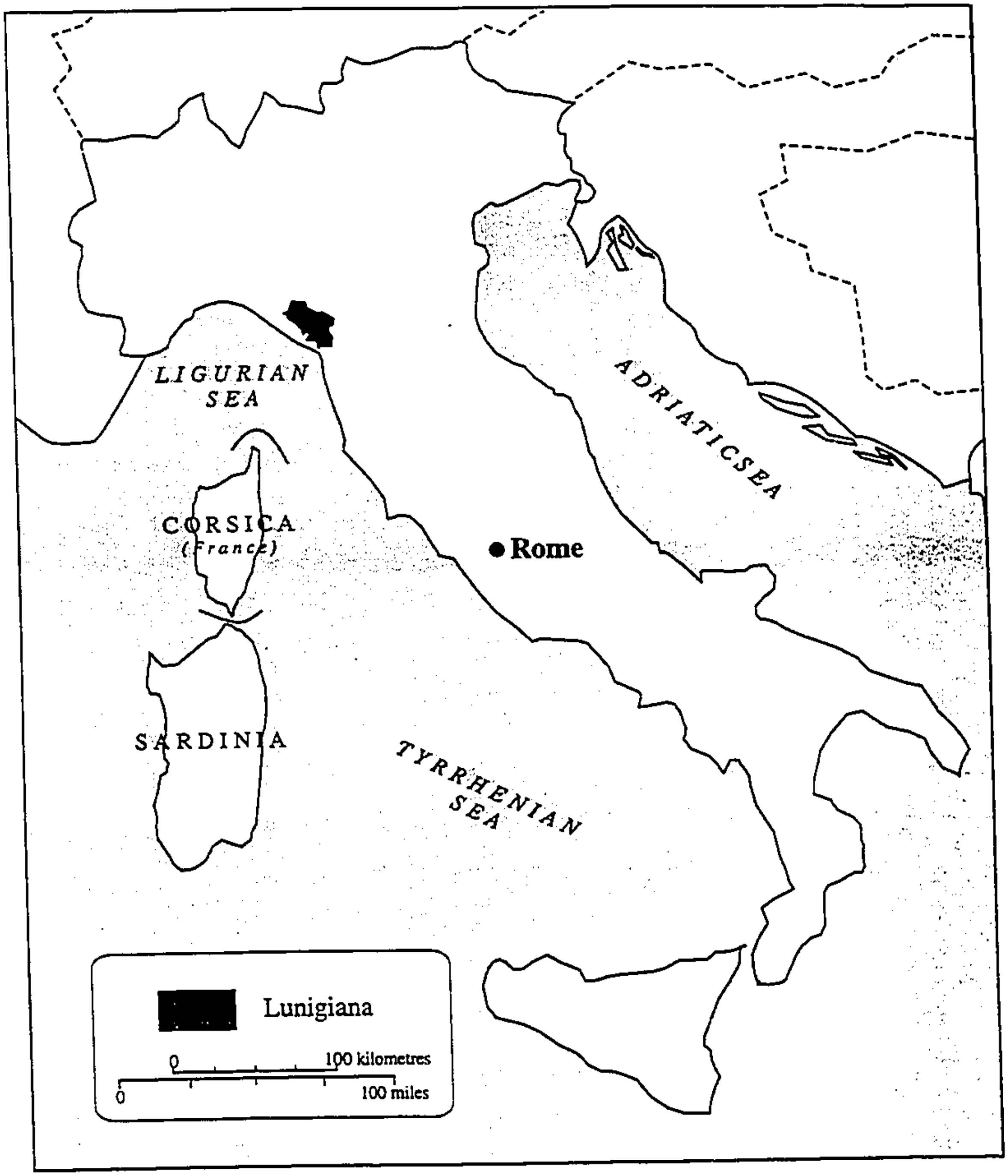

Figure 1.1: Location of the study area.

and cultural features, located at the Lunigiana Museum of Natural History in Aulla, helped to facilitate this research.

1.4 Methodology

The overall research strategy of this thesis was to review the qualitative and quantitative theory and concepts of landscape ecology and ecosystem health in order to compare these concepts and determine the relationship between them; to qualitatively and quantitatively analyze a landscape which has been influenced by long-term human occupation; and to use the results of this analysis in order to explore the links between landscape ecology and ecosystem health for the purpose of improving ecosystem-based management.

A three week visit to Lunigiana in October 1994 was necessary in order to obtain information on Lunigiana's physiology, biota, history, and socioeconomic status. Information on Lunigiana's morphology, hydrology, flora, fauna, and land use existed in the form of maps while more detailed descriptions of these and the area's history and socioeconomic condition were available in government documents, articles, reports, and books. Due to Lunigiana's size research concentrated on the Taverone River, a tributary of the Magra River (Figure 1.2). Field trips were taken in the area of the Taverone River valley in order to have a more comprehensive understanding of the processes affecting the landscape pattern and ecosystem health. The following sections explain the manner in which the various analyses were performed to fulfil the above objectives.

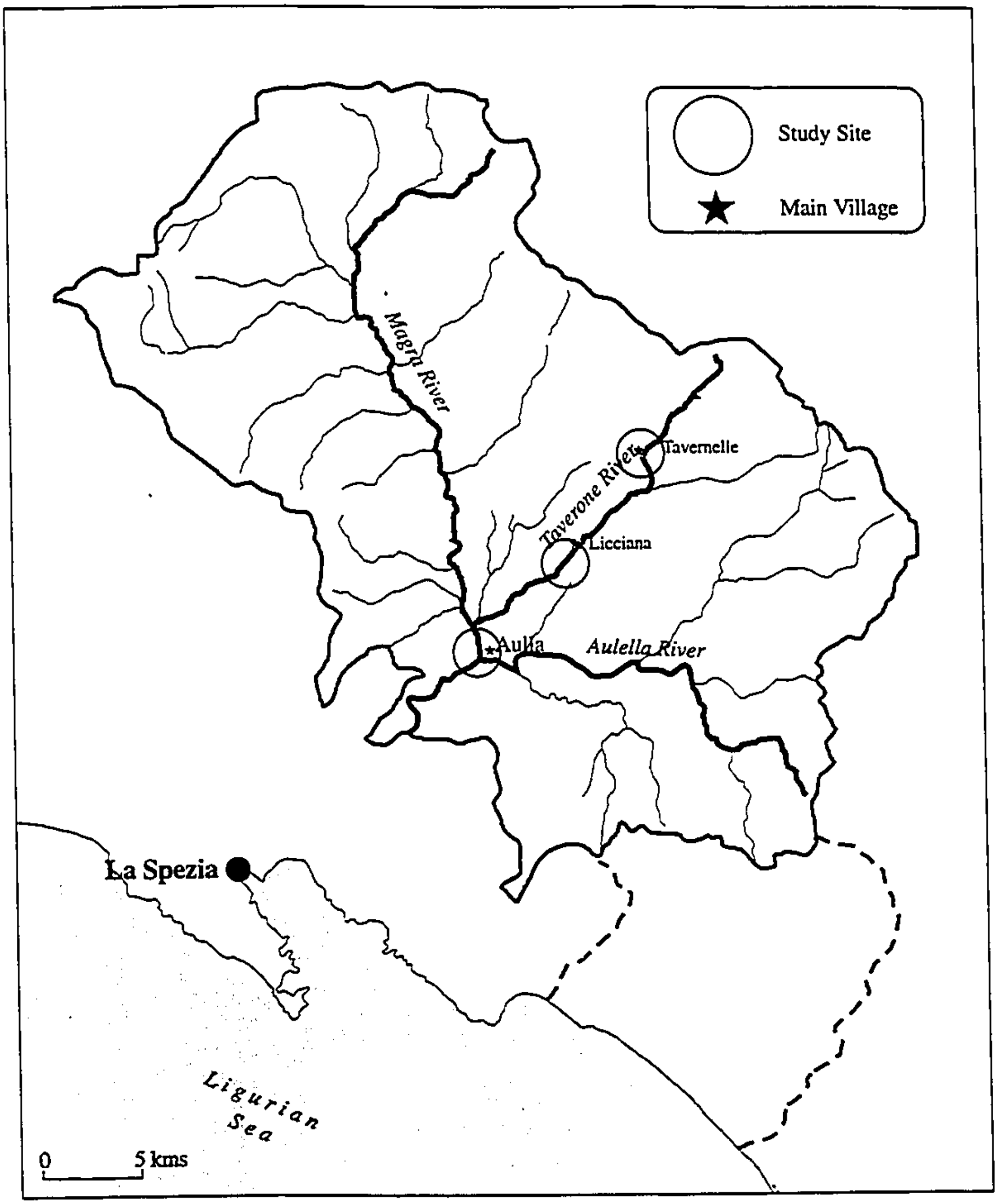

Figure 1.2: Location of the study sites (Farina 1994b, 791).

1.4.1 Qualitative Landscape Analysis

As stated previously, historical analyses are vital in order to study and explain current landscape patterns. The environmental history of Lunigiana was studied using various papers on the area's history and environment. Qualitative analyses of Lunigiana's biophysical and socioeconomic components focused on the period between the 1880s and the 1980s since the most significant landscape changes for which reliable data exist date to the 1880s. It was at this time that significant population movements within and outside of Lunigiana and the entire province of Massa Carrara began to occur. Particular emphasis was placed on the post-World War II period which provided an important break-point in history between a period when agricultural activities were still a major factor shaping Lunigiana's landscape, and a period following the cessation of agricultural activities due to changing socioeconomic conditions when a different landscape mosaic began to emerge. As well, aerial photographs and detailed descriptions on Lunigiana's climate, geomorphology, flora, and fauna were also generated during this period.

Climatological, geomorphological, and zoological reports were used to describe Lunigiana in order to explore the reasons for the historical development of Lunigiana's socioeconomic features, determine their influence on development of past and present landscape patterns, and understand the manner in which they affected Lunigiana's ecosystem health. Vegetation maps (Ferrarini 1982) and land use maps (Giordano *et al.* 1985) were also used in qualitative and quantitative descriptions of Lunigiana. Ruzicka and Miklos (1990) consider biotic ecosystem components to be the basic components of landscapes since they affect, and are affected by, physical ecosystem components such as morphology, climate, soil, fire, and water availability, while they also play a major role in human settlement patterns, and overall ecosystem health. Therefore these biotic components reflect and can function as indices of ecosystem health.

However, an ecosystem's biological features alone cannot be studied to determine the effects of human and non-human processes on the landscape pattern since landscapes change as a result of human activities such as urbanization, agriculture, and forestry management. Therefore land use maps were used to qualitatively and quantitatively describe Lunigiana. Lunigiana's landscape pattern was studied at a fine scale along the Taverone River valley, where scale is defined as the size of the area (Turner *et al.* 1989b; Turner and Gardner 1991a). The Taverone River is a tributary of the Magra River, beginning at an altitude of approximately 1,200 meters above sea level, and flowing southwest 70 kilometers to the Magra River to the village of Aulla (Figure 1.2).

1.4.2 Quantitative Landscape Analysis

Quantitative landscape pattern measurements were used to link spatial patterns with ecological processes occurring in Lunigiana. It should be noted that quantification of the landscape through the use of landscape pattern indices was not performed to conclude that landscapes characterized by certain values are healthier or less healthy than landscapes with comparatively different values. Rather these indices were used to quantify the landscape pattern, not only to compare different locations or different periods but to demonstrate that quantitative as well as qualitative characteristics of landscapes can be used in ecosystem health assessment.

The Taverone River valley's landscape was analyzed by studying three sites along the valley which were located around the villages of Aulla, Licciana, and Tavernelle comprising a total area of 20 km^2. These sites are typical of areas along Lunigiana's river corridors since they have all been affected by similar environmental, economic, and social processes throughout history. An effective landscape analysis of this valley combined an examination of the change in landscape pattern through time as well as the changes that occur as one ascends almost 1,200 meters through rural mountain landscape. A transect roughly coinciding with the Taverone River valley was established, extending from the junction of the Magra and Taverone Rivers to the headwater area of the Taverone River. The sites were chosen along the transect with a distance of 6.5 kilometers between their centres.

Quantitative landscape analyses were performed by establishing a grid with a 125 by 125 meter resolution, the smallest resolution possible for the land use maps used to study Lunigiana's landscape. The grid was placed at random on each study site and a value for each grid cell was established. The value of each cell corresponded with the land use which covered over 50 percent of the cell. If two land uses occurred in equal proportions, for example with 50 percent cultivation and 50 percent woodland, the land use value of the cell was assigned at random. The eight land use categories identified in these sites were based on Giordano *et al.*'s (1986) land use map. The land uses were classified according to the regulations of the

Interregional Centre for the Coordination and Documentation of Land Information of Tuscany. In the study sites the following land uses occur: urban; cultivation, which includes dry fields, irrigated fields, olive orchards, vineyards, mixed olive orchards and vineyards, fruit trees of apple, cherry, fig, and plum, specialized vineyards, and specialized olive orchards; abandoned cultivation; woodland which includes dense conifer, deciduous, coppice or mixed stands, sparse and open coppice woodland, and high or older coppice stands; chestnut orchards; pastureland which includes bare and treed pastureland; and waterways and canals.

According to O'Neill *et al.* (1988) although many measures exist to quantify landscape patterns, a small set of indices can identify significant landscape features. Lunigiana's landscape pattern was quantified using the diversity, dominance, and contagion indices which were calculated by hand for each study site. Each index has been extensively used and tested in landscape pattern analysis (*e.g.* O'Neill *et al.* 1988; Turner and Ruscher 1988; Turner Turner *et al.* 1989b; 1990; Li and Reynolds 1993). The landscape diversity measure is often used since the diversity of a landscape affects species diversity and the habitat used by wildlife (Romme and Knight 1982). The dominance and contagion indices complement each other, discriminating between major landscape types such as urban coastal, mountain woodland, and cultivated areas since different landscape patterns are associated with each landscape type (O'Neill *et al.* 1988). The dominance and contagion indices also provide information at different scales with the dominance index revealing broad-scale pattern and the contagion index revealing the fine-scale characteristics which incorporate the adjacency of different habitats. This sensitivity in scale can be used to identify the different processes at work at the different scales (Turner 1989).

The first index, H, is a measure of diversity. It is a measure of the various types of land uses occurring in the study area at one time.

$$H = -\sum_{k=1}^{m}(P_k)\ln(P_k), \tag{1.1}$$

where P_k is the proportion of the landscape in cover type k, and m is the number of land cover types observed. The larger the H value, the more diverse the landscape (Turner and Ruscher 1988).

The second index, D, is a measure of dominance. It measures the extent to which one or a few patches dominate the landscape.

$$D = \frac{H_{max} + \sum_{k=1}^{m}(P_k)\ln(P_k)}{H_{max}} \tag{1.2}$$

where m is the number of land use types observed on the map, P_k is the proportion of the landscape in land use k, and $H_{max} = \ln(m)$. Large values of D indicate a landscape that is dominated by one or a few land uses, and low value indicate a landscape that has many land uses represented in approximately equal proportions (O'Neill *et al.* 1988; Turner and Rusher 1988; Turner 1990).

The third index, C, measures the contagion of land cover types. It measures the extent to which patch types are aggregated and is calculated from an adjacency matrix, Q, in which Q_{ij} is the proportion of cells of type i that are adjacent to cells of type *j*.

$$C = \frac{K_{max} + \sum_{i=1}^{m} \sum_{j=1}^{m} (Q_{ij})\ln(Q_{ij})}{K_{max}} \tag{1.3}$$

where $K_{max} = 2(m)\ln(m)$ and is the absolute value of the summation of $(Q_{ij})\ln(Q_{ij})$ when all possible adjacencies between land cover types occur with equal probabilities. When $m \geq 2$, large values of C will indicate a landscape with a clumped pattern of land cover type (O'Neill *et al.* 1988; Turner and Ruscher 1988; Turner 1990).

Comparisons of the index values for each study site and the fraction of the landscape occupied by each land use category were performed. This was done in order to identify the different processes affecting the landscape pattern in each study site in order to help us understand the relationship between landscape pattern and ecosystem health. To compare the landscapes of the three study sites which have different numbers of land uses occurring in them, Equations 1.2 and 1.3 were divided though by H_{max} and K_{max} respectively in order to normalize the indices to range between zero and one (Turner 1990).

1.5 Thesis Organization

This thesis consists of five chapters and an appendix. In order to establish the context and illustrate the links and relevance of this research, Chapter Two is devoted to a literature review of the four main ideas of this thesis, ecosystem-based management, ecosystem health, environmental history, and landscape ecology.

Chapter Three describes the biophysical attributes and historical setting of Lunigiana. A qualitative and quantitative analysis of the modifications of Lunigiana's landscape since the 1880s is presented in Chapter Four, while the final chapter aims to link these observations to ecosystem health and ecosystem-based management for drawing conclusions in order to satisfy the research objectives.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

The integration of landscape ecology in ecosystem health analyses will assist environmental planners and managers who are struggling to acquire conditions to suit a continuously and rapidly changing environment. In order to establish a relationship between landscape-level analyses and ecosystem health management, it is necessary to develop a framework for relating these two concepts. By way of a four-component literature review, this chapter will provide the background necessary for establishing a link between landscape ecology and ecosystem health.

The expansion of environmental planning and management interests from the effects of human activities on their immediate surroundings to the biosphere has occurred due to the realization that humans are having an increasingly larger role in the development and changes taking place in ecosystem components and processes. Ecosystem-based management approaches have been developed to focus on the interrelationship among ecosystem components, linking environmental, economic, and social needs and processes, therefore encouraging integrated environmental management. The first section of this chapter examines the characteristics of ecosystem-based management, their significance in environmental management, and their applicability in today's environmental decision-making processes.

The concept of ecosystem health has been receiving increasing amounts of attention in the environmental management realm. The second section will examine the advantages of using ecosystem health in ecosystem management by exploring its roots, its relationship with the notion of ecosystem integrity, its definition, and the measurement strategies and criteria which have been developed for ecosystem health assessment.

Historical analyses are a useful means of assessing the role of the environment in the development of societies as well as the effect of humans on ecosystem structures and processes throughout time. Environmental history and its applicability in ecosystem health analyses is the focus of the third section of this chapter.

The final section discusses the role of landscapes and landscape ecology in environmental decision-making. In particular, the unique ability of landscapes to provide critical spatial and temporal information for ecosystem health assessments will be discussed.

The main objective of this literature review is to provide a framework for linking the main themes of this thesis, and to demonstrate the rationale for this research. Concepts are defined throughout this literature review in a manner best suited to relate ecosystem health and landscape ecology, while also fostering understanding for ecologists and the non-specialist alike.

2.2 ECOSYSTEM-BASED MANAGEMENT

The expansion of the effects of human development activities from local point sources of stress to regional and global sources has caused environmental management interests to shift from human-influenced environments to natural environments and from people's immediate surroundings to the biosphere (Slocombe 1993). However, the increasing complexity and diffusion of environmental problems has made it difficult to understand the effects of perturbations on ecosystems therefore rendering environmental management difficult (Cairns *et al.* 1993).

To overcome these difficulties, a series of approaches to environmental management have been developed. Known as ecosystem approaches, they aim to integrate various concepts, theories, and methods for developing effective environmental planning and management strategies (Vallentyne and Beeton 1988). In fact, several ecosystem approaches have appeared to demonstrate the effectiveness of using ecosystems as a unit of study, while also showing the applicability of traditional ecological terms and methods of analysis outside the realm of ecology (Slocombe 1993b).

This portion of the literature review traces the roots of ecosystem approaches and their use in environmental and planning and management realms. The primary objective of this section is to demonstrate the benefits of using ecosystem approaches in environmental management.

2.2.1. Environmental Legislation and Ecosystem Approaches

Due to the effects of human activities on the environment scientists and environmental managers are beginning to accept that ecosystems approaches are a reliable way of managing and conserving the environment. More so in the past, although evidence of environmental mismanagement can also be seen today, governments were often reluctant to apply ecosystem approaches to the environment and natural resources since it required agencies to share responsibility and decision-making for common resources. Conservation and management issues were often treated in an ad hoc manner. This often resulted in the same ecosystem being administered differently legally and politically at local and international levels. Furthermore, decision-making concerning the utilization of resources was often done separately from decision-making concerning the protection of the environment (Belsky 1994).

In order to provide effective conceptual bases for managing environments and natural resources in an informed manner, governments have recently begun to adopt more holistic approaches to environmental management (Lee *et al.* 1982). Ecosystem approaches to planning and management are the most recent development in a succession of approaches to managing the effects of human use of the environment (Hartig and Vallentyne 1989). They approach the environment based on the notion that an ecosystem is a description of the biophysical and cultural entities (ecosystem components) within the system and the activities, interactions, and influences which occur among them (ecosystem processes).

There is now a legal and political obligation for environmental management to occur both nationally and internationally based on an ecosystem approach context. An example of this is the United Nations Convention on the Law of the Sea which legislates an ecosystem-based management approach for oceans and coastal areas. More recently, Agenda 21 and other documents from the 1992 Earth Summit "stated its political and legal preference for ecosystem-based management approaches" (Belsky 1994, 7). Some academics and leaders criticize ecosystem-based approaches as being impractical, infeasible, and "soft" compared to binding legislation, however recent employment of the concept among various government agencies can argue for its effectiveness and practicability (Belksy 1994).

2.2.2 Characteristics of Ecosystem Approaches

Although the roots of ecosystem approaches to environmental management are ultimately in ecology, the term ecosystem approach can be found in the literature of numerous disciplines which have helped to support their development (Figure 2.2.1). A detailed review of the literature on ecosystem approaches (Slocombe 1991) and the evolution of ecosystem approaches (Slocombe 1993b) demonstrate that many ecosystem approaches have common characteristics (See Table 2.2.1) and that more than biology and ecology should be taken into consideration upon analyzing an ecosystem (Slocombe 1993c). These characteristics of ecosystem approaches can then provide a framework for studying, describing, and addressing ecosystems to facilitate effective ecosystem management.

Generally, an ecosystem approach is a manner of studying an entity that models itself, its environment, and the interactions which take place between them. Ecosystem approaches aim to do two things: define ecosystems as the element being studied and applying ecological concepts and analyses outside the traditional realm of ecology. Although both of these procedures have been used extensively in the past

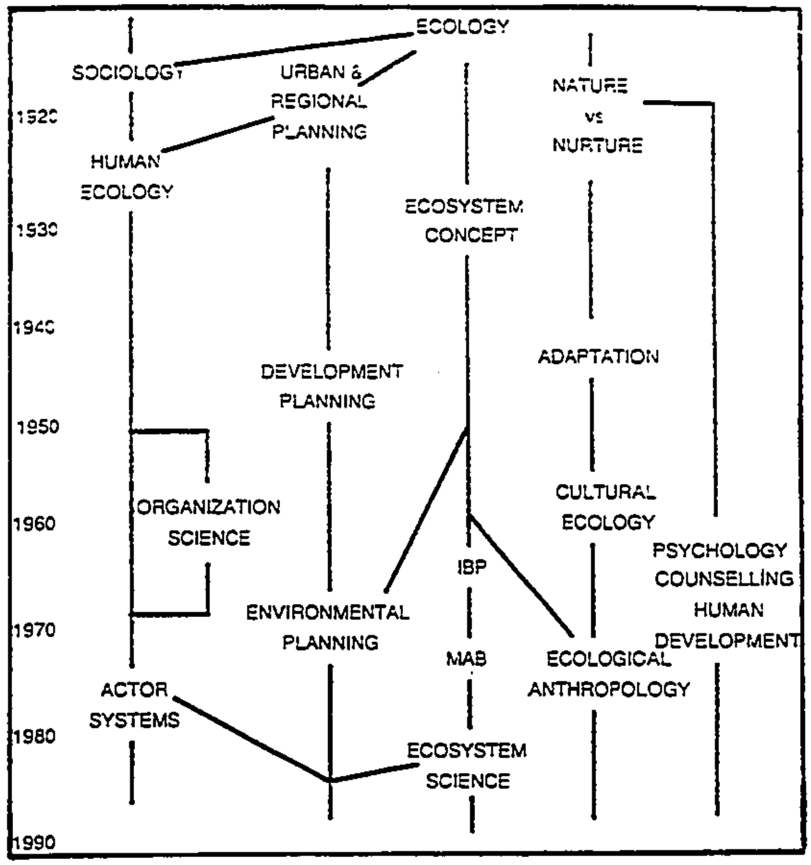

Figure 2.2.1: 'Origins and implementation of ecosystem approaches (Slocombe 1993b, 295).

three decades, their application extends to various disciplines such as anthropology, human ecology, psychology, political science, planning, and management extends as far back as the early 1900s (Slocombe 1993b).

2.2.3 Defining Ecosystem Approaches

Ecosystem approaches do not rely on one specific program, definition, or mode of operation. Rather they are a way of doing things as well as a way of thinking (WQGTG 1994). The holistic nature of ecosystem approaches encourage integrated management to occur rather than the more common independent management of

Describing parts, systems, environments and their interactions Holistic, comprehensive, transdisciplinary
Including people and their activities in the ecosystem
Describing system dynamics, *e.g.*, with concepts of homeostasis, feedbacks, cause-and-effect relationships, self-organization, etc.
Define the ecosystem naturally, *e.g.*, bioregionally, instead of arbitrarily
Looking at different levels/scales of system structure, process, and function
Recognizing goals and taking an active, management orientation
Including actor-system dynamics and institutional factors in the analysis
Using an anticipatory, flexible research and planning process
Entailing an implicit or explicit ethics of quality, well-being, and integrity
Recognizing systemic limits to action - defining and seeking sustainability

Table 2.2.1: Principal characteristics of ecosystem approaches (Slocombe 1993b, 297).

separate ecological components which occurs under a variety of laws, agreements, and institutional arrangements. This strategy reduces unintended consequences of individual management actions which occurred under past management directions. The development of ecosystem approaches have encouraged viewing the earth and its resources in a holistic manner and stimulating the search for methods of applying the fundamental ideas of ecosystem-based management.

With the increased interest in developing and using alternative environmental management, ecosystem approaches are the most recent development in a historical succession of management approaches: (1) ego-systemic or egocentric - a "me only" point of view, indifferent to environmental problems; (2) piecemeal, dealing with problems and issues one-by-one; (3) environmental, that is, integrative management with respect to air, water, land, and biota excluding people; and (4) ecosystemic, the current ecosystem approach which is the holistic management of the human-environment system (Christie *et al.* 1986 Vallentyne and Beeton 1988; Hartig and Vallentyne 1989).

2.2.4 Operationalizing Ecosystem Approaches

There are many advantages to the application of ecosystem approaches in environmental management. Ecosystem approaches recognize basic biophysical ecosystem components such as air, water, land, and biota (including humans), and ecosystem functions, integrating environmental, economic, and social concerns. The principle of ecosystem approaches being that no ecosystem component is excluded (Hartig and Vallentyne 1989), therefore the role of culture, values, and socioeconomic systems in environmental management issues is legitimized in these approaches. Including humans as an ecosystem component acknowledges that human activities cannot take place apart from the environment.

Ecosystem approaches also concentrate on major long-term and/or large-scale issues which allow for a more anticipate-and-prevent strategy of management, rather than the traditional react-and-restore methods. These scales require that past human activities and their effects on ecosystem structure and processes be examined in order to provide suitable data upon which to base present and future management decisions. As well, since ecosystems and ecosystem components and processes are linked to one another, open to the exchange of information, energy, and matter, ecosystem approaches must extend beyond administrative boundaries to achieve an holistic management of areas for goals such as ecosystem health.

2.3 ECOSYSTEM HEALTH - A NEW PARADIGM FOR ECOSYSTEM-BASED MANAGEMENT

The application of ecosystem approaches to environmental management have prompted many to adopt a broader set of management goals than previously used. The concept of ecosystem health has been a product of attempts to find a more effective criterion to assist in ecosystem-based management than the scientific methods derived in the past (Rapport 1994). Like ecosystem-based management approaches, the concept of ecosystem health used in this thesis calls for a holistic view of the world, understanding the earth's complexity and interconnections, and taking into account its dynamic character, finite abilities, and the role of humans. Due to its comprehensive nature, ecosystem health can be used as a point of contact between scientists and non-scientists, therefore encouraging participation among all stakeholders whose activities affect ecosystems (Gray *et al.* 1994).

This portion of the literature review aims to identify the reasons for the development of the concept of ecosystem health and the manner in which it is being integrated into environmental planning and management realms. The primary objective of this section is to demonstrate the advantages of using this concept to assess and manage ecosystems more effectively. By defining and comparing ecosystem health with ecosystem integrity in order to demonstrate its strengths and weaknesses, and discussing methods of measuring the condition of an ecosystem, the advantages of using the ecosystem health concept in environmental management will be understood.

2.3.1 Ecosystem Health and Ecosystem Integrity

> Trying to learn to use words, and every attempt
> Is a wholly new start, and a different kind of failure
> Because one has only learnt to get the better of words
> For the thing one no longer has to say, or the way in which
> One is no longer disposed to say it. And so each venture
> Is a new beginning, a raid on the inarticulate
> With shabby equipment always deteriorating
> In the general mess of imprecision of feeling,
> Undisciplined squads of emotion...
>
> Home is where one starts from
>
> - T.S. Eliot *The Four Quartets* 1948, 21-22.

The ability of humans to change the earth has surpassed their ability to understand the environment and the effects of their actions on the environment. The development of new theories and concepts for environmental management is a continuous process as the environment continues to change due to human and non-human processes. However, it is when human activities alter the world too rapidly for linguistic change to occur that new, more adaptive terminology and concepts, are developed (Norton 1992).

The notions of ecosystem health and ecosystem integrity are often used to describe desired ecosystem conditions and to assist in the assessment of ecosystem conditions. However, despite the significant amount of literature that has been written on ecosystem health and ecosystem integrity in the past decade, a universal definition for either term has yet to be developed. Many works on, and criticisms of, ecosystem health and ecosystem integrity tend to use them interchangeably. Recently published books have been written with the intent of dealing with ecosystem health and/or ecosystem integrity (See Costanza, *et al.* 1992 and Woodley, *et al.* 1993). As well, Karr's index of biotic integrity (IBI) was developed to "assess the health ('biotic integrity') of a local water source" (1981, 21).

Suter's (1993) criticism of the concept of ecosystem health is also misleading. In his examination of methods of quantifying ecosystem health, Suter discusses Karr's IBI and Costanza's (1992) ecosystem health index (HI). Suter recognizes that the concepts are different with the IBI consisting of twelve matrices of fish communities while the HI is the product of system vigour, organization, and resilience. However, Suter goes on to discredit the indices by questioning the results obtained similarly, not relating that the indices themselves in fact

consider different ecosystem components. Suter misguides his readers by criticizing ecosystem health and ecosystem integrity yet not completely understanding the differences between the two concepts. Instead criticisms should lie in the fact that both equations consider the biophysical aspects of ecosystem while neglecting the social aspect of ecosystems. However, although the majority of recent works do not distinguish between the two concepts it should be noted that as early as 1949 Aldo

Leopold does distinguish between ecosystem health and ecosystem integrity through the specification of three components of ecosystem health: integrity, stability, and beauty.

Recently, debates as to which concept is better suited to assist in ecosystem management have arisen. Following Leopold's distinction between the two concepts, articles have been written in favour of either one concept or the other, using the less desirable term as a subcomponent of the preferred term (See Kay 1993; Kay and Schneider 1994; WQGTG 1994). The Great Lakes Water Quality Guidelines Task Group (WQGTG 1994) believes that the term ecosystem integrity is generally approached in a more scientific manner than ecosystem health. This may have occurred because much of the early work on system integrity considered the biological or biotic integrity of a system. The 1972 United States Water Quality Act first used the phrase "biological integrity" when calling for the revival and maintenance of the physical, chemical, and biological integrity of the nation's waters, the sum of which was termed ecological integrity (Karr 1992).

Ecosystems with integrity are thought to have significant levels of biological diversity (in terms of species composition, relative frequencies, and spatial and temporal distribution), suitable types and levels of ecological processes with respect to the ecosystem being assessed (*e.g.*, nutrient cycles, energy flow, metabolism, production, and predation), and the ability of a system to organize itself such that the habitat persists. As well, when referring to and evaluating the integrity of an ecosystem, the WQGTG (1994) claims that the functional and structural features of pristine environments are generally used as a frame of reference.

Contrary to this opinion, however, Norton (1992) and Kay and Schneider (1994) discourage the evaluation of ecosystem integrity based on pristine environments, perceiving ecosystems as dynamic, self-organizing entities which maintain a system's diversity through time. Accordingly, there is an expanding literature that encourages the use of the term ecosystem integrity, a "stronger" concept which includes humans as components of ecosystems in addition to considering ecosystem health as an organizational facet (*e.g.*, Norton 1990, 1992; Allen *et al.* 1994; Kay and Schneider 1994).

On the other hand, ecosystem health is considered to have a broader mandate than ecosystem integrity. In addition to the elements of ecosystem integrity, ecosystem health assessment evaluates the effect of humans and their activities on the ecosystem. The WQGTG (1994) believes that while ecosystem integrity describes the state of ecosystem properties and processes, ecosystem health is more holistic, describing the well-being of the environment, economy, and society within that ecosystem, using integrity as a subset of ecosystem health.

Almost twenty years ago, papers on the topic of ecosystem medicine began the debate about the appropriateness of medical metaphors in environmental management. Today, ecosystem health has been the subject of many articles, journals, books, workshops, and conferences. International societies such as the Aquatic Ecosystem Health and Management Society are evidence of the acceptance of the ecosystem health concept (Rapport 1992), while ecosystem health has also been promoted as a goal for environmental management policies, whose maintenance should motivate all environmental legislation. In Canada, the Canadian Association of Physicians of the Environment is a new organization which has been developed for health professionals. Among its tasks, the association will provide a mechanism for liaison with environmental scientists to promote communication between professional groups (Guidotti 1994).

2.3.2 Humans and Ecosystem Health Assessment

The fact that humans are ecosystem components justifies their use of the environment, however a balance between use of the earth's environment and maintaining healthy ecosystems must be found. The WQGTG (1994, 6) describes a healthy ecosystem as "one in which the environment is viable, liveable and sustainable; the economy is equitable, sustainable and adequately prosperous; and the community is liveable, equitable, and convivial". The concept of ecosystem health considers various aspects of human systems including social, economic, political, and management issues since they affect ecosystem structures and processes, and including humans and their activities as part of the ecosystem is consistent with ecosystem approaches which aim to manage the environment in a holistic manner.

Ecosystem health assessment is a cultural judgement as well as a scientific exercise (WQGTG 1994). Health is a relative concept based on human values and perceptions, however, all relativistic concepts require limits. We must be cautious when evaluating ecosystem health in terms of the use of ecosystems by humans since determination of the health of an ecosystem is ultimately dependent on human values which differ among the various groups in society. For example, many native peoples view forests as a home which has enabled many cultures to survive for centuries, while foresters view forests in terms of their production of merchantable timber. After harvesting the trees, the condition of the ecosystem will be assessed differently by these two groups since each values the forest differently (Rapport 1992).

2.3.3 Defining Ecosystem Health

The development of the concept of ecosystem health has arisen from the premise that ecosystems are dynamic and creative entities which are continuously changing to suit changing ecosystem conditions. Therefore management must consider all aspects of the ecosystem, both biophysical and social, which interact and change within the ecosystem.

Ecosystem health was first applied by James Hutton, a Scottish geologist and physician, upon presentation of a paper addressing a theory of the earth as a superorganism capable of maintaining itself to the Royal Society of Edinburgh in 1788 (cited in Lovelock 1988). This meaning was later extended to promote an understanding of the condition of the earth's biota, and has recently been broadened to characterize the state of the environment as a whole (Nielsen 1991).

The development of the ecosystem health concept has helped ecologists, anthropologists, philosophers, economists, policy makers, and others to realize that ecosystem health cannot be defined or understood merely through the use of scientific, ethical, aesthetic, or historical terms (Haskell *et al.* 1992). Difficulties lie in defining and manipulating this concept due to the complex, hierarchical nature of ecosystems (Costanza 1992). Problems also exist since the determination of a desirable level of ecosystem health is a social process based on human values and perceptions and requires the involvement and cooperation of all affected stakeholders as well as input from scientific disciplines (Ontario Ministry of the Environment 1992; cited in WQGTG 1994).

Several attempts have been made to define ecosystem health, however, a widely agreed upon qualitative or quantitative definition has yet to be developed. Webster's Dictionary defines health as: (1) "the condition of being sound in body, mind, or spirit"; or, (2) "a flourishing condition" or "well-being". Although these definitions are vague, they can be applied to all systems at all levels of scale, from organisms to ecosystems to economic systems. Therefore simply stated, ecosystem health is a measure of the overall performance of a system which is a function of its components and the processes occurring within the ecosystem.

2.3.4 Measurement of Ecosystem Health

In order to assess the condition of an ecosystem, a variety of tests must be developed and performed to identify the health of an ecosystem. In the past two decades, many studies have been conducted on ecological monitoring, and significant progress has been made in proposing measures and criteria for the development of ecosystem health indicators (See Schaeffer et al. 1988; Schaeffer and Cox 1992;

Rapport 1989a). An ecological indicator is defined as "a characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure" (Hunsaker and Carpenter 1990; cited in Cairns *et al.* 1993, 2-3).

Ecosystem health indicators are the most effective manner of measuring the condition of an ecosystem due to their ability to illustrate the trends in, state of, and factors affecting ecosystem health. Since all measurable ecosystem parameters have some significance in the evaluation of environmental conditions, many potential indicators exist. It is difficult, however, to select only a few of the "best" indicators for ecosystem health assessment, yet impossible to measure every environmental factor or assimilate the information obtained if one did.

In the past, ecosystem health was measured using indicators such as individual species or ecosystem components. This lead to criticisms of ecosystem health indicators since they were neither associated with ecological theory nor capable of relating to important ecosystem characteristics since scale and perspective had not yet been adequately applied to ecosystem models (Norton 1992). However, although they are unable to reflect ecological complexity, single species indices are valuable communicative tools since they can relate complex information to resource managers, politicians and the public, while data collection on these species is not as time consuming or costly as are integrated measures of ecosystem health.

Marshall *et al.* (1993) suggest that in order to select ecosystem health indicators, an understanding of the relationship between spatial and temporal scales and the ecological processes associated with each scale is required. The scale of observation affects ecosystem description which in turn determines the observed or inferred characteristics of ecosystem health since different scales of observation resolve different components and different interactions (Noss 1990). For example, fire is often viewed as part of ecosystem functioning and necessary to maintain health when the ecosystem is viewed from a long-term, large-scale perspective. At the local level and in the short-term, fire may be perceived as destroying all health, although the persistence of the ecosystem is often dependent upon these smaller-scale degradation of health. Restricting the extent of the ecosystem being managed to less than the minimum area required for interactions to occur can affect ecosystem function and may lead to an unhealthy state since ecosystems require certain spatial and temporal scales of observation to maintain ecosystem structure, function, and overall ecosystem health. Therefore the extent of the observation set must be equal to or larger than the system in question (King 1993). It should be noted, however, that by extending the spatial scale, management of the system may be difficult since larger areas often exceed the boundaries of politically defined management units.

Several researchers have suggested methods of selecting ecosystem health indicators. Noss (1990) suggests using complimentary indicators of ecosystem health since no single indicator possesses all the properties of ideal indicators, while the WQGTG (1994) emphasizes the importance of using a group of indicators to evaluate ecosystem health in order to reduce the chances of misinterpreting information presented by indicators. Cairns *et al.* (1993) suggest that indicators be useful in judging the extent to which specified environmental conditions have been realized or maintained, and others have classified ecological indicators into various categories to facilitate indicator selection and encourage the selection or development of indicators within each category.

Table 2.3.1 contains a list of possible indicator categories based on the information provided by the indicator, and its sensitivity and response time to different stresses. Since landscape level observations enable us to study spatial and temporal ecosystem changes, landscape level analyses can lead to greater insights into the factors affecting ecosystems. Therefore landscape patterns can be used as indicators of ecosystem health. Cairns (1992) even goes so far as to promote landscapes as an indicator category whereby monitoring occur in terms of the landscape's structural and functional components.

In addition to ecosystem health indicators, some researchers have developed indices of ecosystem health. Unlike an indicator, an index is a combination of several indicators and often based on contentious value judgements. For example, Karr's IBI (1981) uses fish populations to assess the ecological integrity of streams, while Ulanowicz (1992, 192) has developed the network ascendency index which focuses on attributes which could be identified as properties of "quantified networks of trophic interactions". As well, as stated previously Costanza (1992) has developed the HI which is based on an ecosystem's vigour, organization, and resilience.

The development of guidelines for ecosystem health indicators by Schaeffer *et al.* (1988), Schaeffer and Cox (1992), and Rapport (1989a), the selection of indicators

Source	Suggested Indicator Categories			
Council of Great Lakes Research Mangers (1991)	Compliance - monitor the attainment and maintenance of ecosystem objectives	Diagnostic - provide insight as to the cause of noncompliance	Early warning - anticipate changes of interest before substantial impact has occurred	
Rapport and Davies (1992)	General Screening - determine, at a broad scale, whether or not an ecosystem is healthy	Diagnostic - identify specific causes of ecosystem degradation	Risk Factors - reflect stresses and/or potential hazards which may not yet be realized or reflected in the ecosystem data	Fitness - measure an ecosystem's capability to respond to stress (no current examples)
Environment Canada, Indicators Task Force (1991b)	Conditions/ Trends - measure current states of environmental components	Causes and Stresses - measure human activities which affect environmental components	Management Responses - measure management effectiveness with respect to different environmental components	
Organization for Economic Co-operation and Development (1991)	Pressures - measure stresses on the environment (i.e. pollutants)	State - measure the state of the environment and natural resources	Responses - measure the effects of stresses on the environment	
Kelly and Harwell (1989)	Early Warning - rapid detection of potential effect	Sensitive - reliability in predicting actual response	Intrinsic Importance - an indicator species is itself the ecological endpoint of concern	Process/ Functional - the desired endpoint is a process
Knapp *et al.* US EPA (1991)	Exposure - provide evidence of the occurrence or magnitude of contact of an ecological resource with a physical, chemical, or biological stressor	Stressor - effect changes in exposure habitat	Response - provide evidence of the biological condition of a resource at the organism, population, community, ecosystem, or landscape level of organization	Habitat - characterize condition necessary to support an organism, population, community, or ecosystem
Cairns (1992)	Species - *structural* - e.g., tissue or organ damage *functional* - respiratory rates or behaviour	Community - *structural* - trophic relationship *functional* - colonization rate or rate of detritus processing	Ecosystem - *structural* - trophic relationships characteristic of this particular ecosystem type in this locale *functional* - nutrient spiralling or energy cycling	Landscape - *structural* - compatible with the landscape mosaic *functional* - landscape used with appropriate duration and frequency by species that regularly use the larger mosaic of which this is a part

Table 2.3.1: Suggested ecological indicator categories to improve ecosystem-based management (WQGTG 1994, 17-18).

themselves, and their incorporation into ecosystem-based management approaches can assist in the development of a practical definition of ecosystem health. The following definition of ecosystem health has been developed for this thesis, considering many of these guidelines. It defines health in terms of four principal characteristics based on environmental, economic, and, where applicable, social ecosystem components and can be applied to any ecosystem.

> An ecosystem is healthy if its biophysical and, where applicable, social components are active and function equitably, it is able to maintain its organization and autonomy over time, and is resilient to stress.

This definition can be applied to all ecosystems since it takes into consideration the fact that ecosystems are continuously changing due to natural and anthropogenic influences. It takes into account the integrated and holistic nature of ecosystem-based management by including past and present ecosystem processes. By incorporating historical information and trends into ecosystem analyses and management strategies, measures can be taken to avoid degrading ecosystem health.

2.4 ENVIRONMENTAL HISTORY AND ECOSYSTEM-BASED MANAGEMENT

Societies are conditioned by their environment. Throughout history humans have experienced many hardships and have attempted to alter various aspects of their environment in their struggle to survive. However, the environmental changes that the world is experiencing today are taking place at a far more rapid pace and to a further extent than ever experienced before. Deforestation has expanded from local to global scales, atmospheres and oceans become more polluted every year, and plant and animal species are becoming extinct more rapidly than ever before. These problems originate in past environmental management practices.

The manner in which humans dealt with and managed the environment in the past may be studied and the lessons learned can assist in the discovery of the sources of many of our modern environmental problems. In this manner environmental history can be used to assist in the management of ecosystems. This portion of the literature review will consider the benefits of using history in environmental management realms since humans are viewed as part of the system, both affecting and affected by the environment. This section also discusses the evidence provided by landscapes in environmentally historical analyses.

2.4.1 Environmental History as a Discipline

In 1949 (205), wildlife biologist and conservationist Aldo Leopold appealed for "an ecological interpretation of the past" which meant using the emerging field of ecology to explain the reasons past events transpired in the manner they did. The field of environmental history, which is similar to conservation history, the history of land and resources, ecological history, and historical ecology, has developed in response to the call for a study "of the relationship between human societies and the natural environment through time" (Bailes 1985, 4).

The concept of environmental history appeared in the 1950s, gaining momentum in the 1960s and 1970s as conferences and rallies on the earth's condition were becoming frequent events. Increasing environmental awareness and concern lead to the 1971 United Nations Conference on the Human Environment in Stockholm, Sweden, and the subsequent founding of the United Nations Environmental Programme. This conference is often credited with initiating a change in attitude in environmentalists and conservationists. Concern that was once given to the fate of individual plants, animals, and natural environments, was being given to human well-being (Worster 1988c).

The discipline of environmental history rejects the notion that humans have been exempt from the forces of nature, and that humans are a special species such that the ecological degradation caused by their activities can be ignored. Instead, environmental history views the environment as a key factor in the establishment of societies and the development of cultures, while also regarding the environment as having been greatly influenced by human activities throughout history.

One of the problems of relating ecology to history is that few scientists have perceived humans as integral components of ecosystems. Normally humans have been excluded, noted as being "distractions" or "imponderables" (Worster 1988b). The traditional discipline of history studies that which many scientists and policy-makers ignored - the accomplishments of presidents and prime ministers, the passing of laws, and battles to maintain sovereignty. However, the increase in the number of writings about the vulnerable state of the earth in biology, geography, economics, and politics lead many historians to realize that environmental degradation was a historical force which was a major factor resulting in the destruction of political regimes, interruption of social patterns, and economic and technological changes that could sound throughout the world (Worster 1988c). Human attitudes, perceptions, and activities must be studied and included in any reconstruction of past events and environmental analyses in concordance with ecosystem-based management approaches which call for a holistic approach to ecosystem observation, planning, and management.

Environmentally historical analyses can facilitate our understanding of the reasons for patterns of human thought and behaviour and the resultant activities which have led to present conditions. Although studying these patterns may help to inform us of the various successes and failures of past human activities, they will also serve as a "warning and a challenge to our attitudes, our ability to understand our technological competence, and our willingness to make far-reaching decisions" (Hughes 1993, 171).

2.4.2 The Use of Landscapes in Environmental History

> The condition of the land...reflects the thought and culture of a people just as clearly as orthodox written evidence (Nash 1970, 249).

As stated previously, humans are the primary agent of environmental change. Even the choice not to change the environment, that is to leave an area partly or entirely undeveloped so as to protect it as a park or nature preserve, is a conscious effort by humans to manage the environment. Landscapes reveal various features of a society as attitudes, values, and perceptions change through time (Nash 1970; Melnick

1984). Lawrence (1982) identifies two functions of landscapes for interpreting the effect of humans on the environment. Firstly, they are reminders of a particular event or period, and secondly, due to their dynamic nature, landscapes give the impression that the passage of time is a continuous process which includes the present as well as the past.

Landscapes have played a large and diverse role throughout history, functioning as the physical structure for human settlement, a resource base for society, and a place to encounter nature's wonders and human-induced disasters - the setting for historical events. However, these roles are changing as society, aesthetics, technology, and the landscape itself change. By examining landscape change in its human context we can increase our understanding of the relationship between society and nature throughout history (Lawrence 1982; Hammett 1992) since landscapes can be used to study changes in attitudes and perceptions through time.

Nash (1975, 16) writes that

> the physical landscape constitutes one of the best available links to the past. Indeed, we should think of landscape as document, like a book or an orientation code of laws. When properly 'read,' the landscape establishes a dramatic sense of continuity with the past.

There are two important historical elements landscapes exhibit which can contribute to our understanding of environmental change and ecosystem health throughout history: the historic significance of human activities on the landscape, and the effect these activities have on the landscape itself (Lawrence 1982). By referring to the historic value of landscapes, we are able to recognize the importance of human interaction within the landscape which has either shaped or has been shaped by the land itself.

2.5 LANDSCAPE ECOLOGY AND ITS USE IN ECOSYSTEM HEALTH ASSESSMENT

In the late 1980s increased interest developed in the discipline of landscape ecology and its applicability to environmental management. This interest emerged at a time when the earth was being faced with widespread degradation and destruction of countless ecosystems generally attributed to anthropogenic activities (Golley 1987). Throughout history many human societies did not consider the effects of their actions on the environment in their use of the earth's resources. Rather, they focused on a small spatial scale and a short temporal scale, scales too small and too short for them to understand and foresee the consequences of their actions on the earth's life support systems. Understanding the interrelationship between environmental history, ecosystem processes, their effects on the spatial and temporal variability of landscapes is fundamental to understanding ecosystem stability, response to disturbance, and overall ecosystem health (Wessman 1990) in order to manage ecosystems for the future.

This portion of the literature review considers the value of landscapes in providing a level of observation for viewing changes in the earth's spatial patterns through time. It is the objective of this section to demonstrate the value of information obtained in landscape level analyses in ecosystem management.

2.5.1 Evolution of Landscape Ecology

The English term "landscape" evolved from the Dutch word "landschap" which was derived from the Dutch word for painting, "landschappen", a concept developed from the idea of an area in space (Zonneveld 1988). Although the meaning of landscape has undergone several changes, the original aesthetic connotation, which dates back to the Book of Psalms, is still used in literature, art, and landscape architecture (Naveh 1982). For this thesis, landscapes are defined as a mosaic of heterogeneous landforms, vegetation types, and land uses, which interact with each other, and are repeated in a similar format throughout a specific area (Forman and Godron 1986; Urban *et al.* 1987).

Since the development of the study of ecosystems twenty to thirty years ago, ecology has become a rapidly growing, and fragmented field (Slocombe 1993b). Past ecosystem analyses and modelling focused on temporal ecosystem changes rather than the changes taking place in space (Wessman 1990). Various ecosystem attributes such as habitat fragmentation and minimum viable area, which have significant effects on populations and ecosystem processes, were often overlooked. Landscape ecology helped to resolve these issues by linking ecosystem processes with landscape patterns.

The term landscape ecology was first coined by Troll in 1939 upon his contemplation of the relationship between living communities and their environment (cited in Turner 1989). However, it was not until after World War II that the discipline of landscape ecology began to spread throughout Central and Eastern Europe, becoming an international science within the past two decades (Naveh

1991b). Today the field of landscape ecology helps us to conduct regional-scale ecosystem analyses and it is regarded as a central focus of many disciplines, from forestry to wildlife management, and from history to geography to planning (Forman and Godron 1986).

However landscape ecology is neither a branch of ecology nor a distinct discipline. Rather it is the "synthetic intersection of many disciplines that focus on the spatial and temporal pattern of the landscape (Risser *et al.* 1983; cited in Cairns 1992). The concept of landscape in ecology provides a working unit for analyzing spatial and temporal heterogeneity and its causes (Wessman 1990; Cairns *et al.* 1993), and for studying both short- and long-term ecological changes. More specifically Odum (1992) encourages the use of landscape-level analyses to help maintain biodiversity and assist in acquiring sustainability, Hansson and Angelstam (1991) suggest landscape ecology be used in conservation biology, while Risser (1985) regards the landscape level to be effective for assessing stressed ecosystems.

The Landscape Ecology Workshop held in 1983 identified several "principles" which combine ecological and landscape perspectives. Not only should these principles be taken into consideration upon using the landscape as a level at which to study ecosystems, but they can be expanded upon to demonstrate the benefits of using landscapes in ecosystem health assessment. Some of these principles which are of particular importance in this thesis include:

> (1) the relationship between spatial pattern and ecological processes is not restricted to a single spatial or temporal scale;
> (2) understanding of landscape ecology issues at a particular spatial or temporal scale may benefit from experiments and observations on the effects of pattern at finer and broader scales;
> (3) ecological processes vary in their effects or importance at different spatial and temporal scales; and,
> (4) scales of landscape components are defined, using spatial perspectives of sizes determined by the specific objectives of the investigation or the pertinent management issue (Risser 1987).

Landscape ecology has undergone several changes since its inception. Past work in landscape ecology often focused on one type of ecosystem such as a pond or forest. Watersheds were also studied, but with little consideration for their heterogeneity, the causes of heterogeneity, or the influence of their heterogeneity on the functioning of the watershed. However, an ecosystem's response to disturbance is often dependent on the spatial arrangement of different ecological components and processes as well as the type of disturbance, amount of exposure to the disturbance, and the type of disturbance (Risser 1985), and thus the discipline of landscape ecology has become important in environmental management realms.

2.5.2 The Role of Humans in Landscape Ecology

Events at a given level within an ecosystem have a characteristic natural frequency, and typically a corresponding spatial scale. Human-dominated landscapes, however, generally generate events which cause ecosystems to respond at a variety of rates and scales. Through processes such as urbanization, land cultivation, and timber harvesting, various ecosystem components and processes such as animal dispersal, speciation, extinction, surface water runoff, and erosion, are affected, resulting in a mixture of natural and managed patches of various shapes and sizes (Krummel *et al.* 1987). This spatial patterning is a unique phenomenon which appears at the landscape level (Klopatek *et al.* 1983).

Except where one extremely heavy land use dominates a large area, human activities increase landscape heterogeneity in three primary ways. First, rhythms of natural disturbance, ranging from one day to several centuries, are modified by industrialization, agriculture, and resource extraction practices. Second, technological advances, which range from early use of fire to modern machinery, have altered the methods of landscape modification, and the time required to change a landscape. Thirdly, humans increase heterogeneity through the process of aggregation which is related to the centralization of necessities, diversification or specialization of human roles, building monuments and buildings, the development of politics, and the input of fossil fuel energy (Forman and Godron 1986).

Because of the abundance of human influences on the environment, it is neither useful nor possible to study them individually in order to detect patterns of the role of humans in landscape development. Forman and Godron (1986) have synthesized the effects of human influences on landscapes and defined these five possible landscape types:

> (1) "natural landscapes" which are without significant human impact;
> (2) "managed landscapes" which include pastureland or forest, where native species are managed and harvested;
> (3) "cultivated landscapes" with villages and patches of natural or managed ecosystems scattered throughout the principal cultivation;
> (4) "suburban landscapes" comprised of a town and country area with a mixture of residential areas, commercial centres, cropland, managed vegetation, and natural areas; and,

(5) "urban landscapes" with remnant managed park areas scattered in a densely built up matrix several kilometres across.

Upon examination of structural characteristics along a landscape modification gradient from natural to urban, patterns develop due to natural and anthropogenic disturbances (Figure 2.5.1). For example, introduced patches increase, while disturbance and environmental resource patches decrease, and patch density and regularity in shape increase, while patch size and variability decrease.

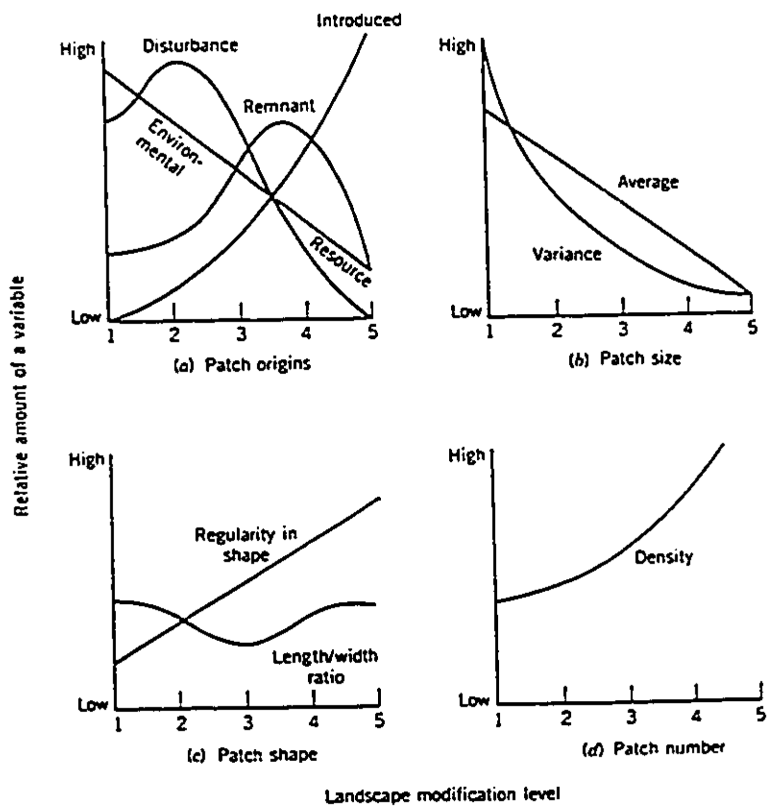

Figure 2.5.1: Characteristics of patches as they change along a landscape modification gradient (Forman and Godron 1986, 287).

2.5.2.1 Effects of Human Rescaling of Natural Landscapes

The introduction of human disturbances, which often differ spatially or temporally from natural regimes, have affected natural landscape patterns and processes (Figure 2.5.2) which have in turn influenced the overall health of ecosystems. Human control over forest fires illustrates the effects of spatial and temporal rescaling which occur with human intervention. By suppressing fire, humans decrease the natural frequency of burns in ecosystems which have incorporated fires into their system. When wildfires do occur, the fires may be more intense and burn larger areas than a natural fires due to the build-up of fuel. Therefore, a thick-barked tree which would normally survive a low-intensity fire is very susceptible to a high intensity fire (Urban *et al.* 1987).

Humans can also homogenize vegetation and landscape patterns through various activities. For example, continuous use of woodlots for fuelwood will cause natural regeneration patterns to disappear. Therefore the woodlot will eventually have similar vegetation throughout, subsequently affecting the presence of other biota in the woodlot (Urban *et al.* 1987).

As well, the establishment of new boundaries through the development of pipelines, roads, and drainage ditches can also rescale natural landscapes. Boundaries may act as effective barriers to patch interactions. They have a critical effect on ecosystem processes when the scale at which the boundary occurs is "redefined relative to the scale at which the perturbation can be incorporated" since some ecosystems are large enough to assimilate disturbances initiated by boundary

ANTHROPOGENIC EFFECTS ON LANDSCAPES	
Human Activity	Consequences
Rescale patch dynamics	Render adaptive mechanisms less effective Change constraining rules Alter Patch Interactions
Rescale bounded regions	Redefine from equilibrating to nonequilirating state Introduce novel patches Render adaptive mechanisms and dynamics less effective Reduce potential for species to evolve adaptive mechanisms
Homogenize patterns	Reduce tree species diversity through land use Reduce habitat diversity for for forest wildlife

Figure 2.5.2: Summary of the effects of human rescaling of natural landscape patterns and ecosystem processes (Urban *et al.* 1987, 125).

development, while others are not (Urban *et al.* 1987, 125). Therefore humans have a great influence on landscape structure and function which in turn affect the health of the ecosystem and the landscape level provides a suitable scale at which to observe the short- and long-term effects of human activities.

However, due to society's need to develop the environment and the increasing problems associated with human-nature interactions (Figure 2.5.3), managing the environment through the use of landscape ecology has become one of the most significant directions in landscape ecological research (Ruzicka and Miklos 1990).

This occurs since landscape level observations can be used in a manner so as to guide future environmental management to the ecological optimization of the earth and its resources.

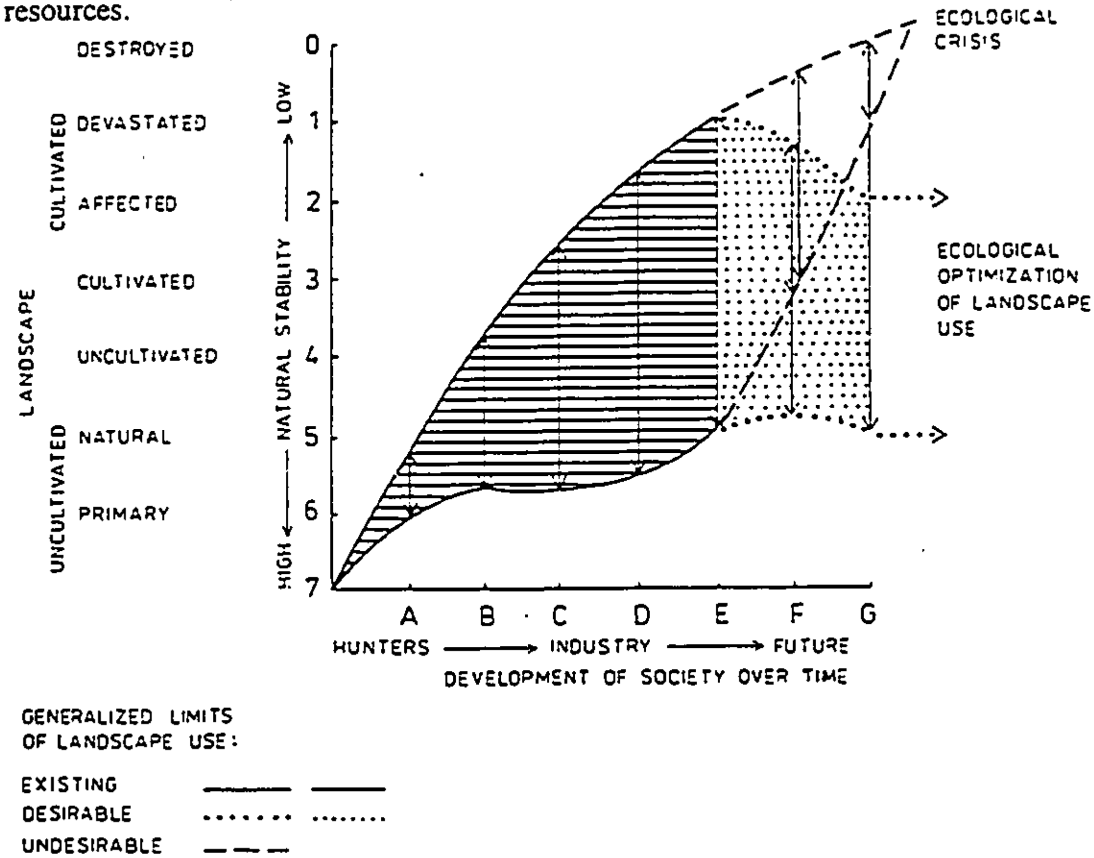

Figure 2.5.3: Change in landscape stability with the development of society and with landscape-ecological planning. Vertical arrows illustrate the range of widespread land uses present taking place. Two future scenarios beginning at point E (the present) are depicted on the right. Without landscape-ecological planning the expected range of land uses narrows and natural stability decreases, ending with an ecological crisis. However, with the occurrence of landscape-ecological planning future scenarios differ significantly (Ruzicka and Miklos 1990, 236).

2.5.2.2 Cultural Landscapes

The term cultural landscape dates back to the writings of many geographers, in particular Carl Sauer (1925). In his early writings Sauer considered landscapes to be influenced by a variety of factors through time, gradually forming a distinct landscape pattern (cited in Melnick 1984). Natural landscapes were affected by factors such as climate, vegetation, soil, topography, and proximity to water, while cultural landscapes were predominantly influenced by culture as it interacted with the natural environment over time (Melnick 1984). More formally, cultural landscapes are defined as

> a geographic area, including both natural and cultural resources, including the wildlife or domestic animal therein, that has been influenced by or reflects human activity or was the background for an event or person significant in human history (Melnick 1984, 66).

Throughout the years, efforts have been made to preserve cultural landscapes due to their contribution to nature conservation, increasing value as the last storehouses of biological diversity, importance as buffer zones, and their ability to preserve evidence of human history (Naveh 1992).

2.5.3 Development of Landscape Pattern

Landscape patterns are produced by three agents: disturbances, biotic processes including humans, and environmental constraints (Urban *et al.* 1987), each of which can be considered at a variety of spatial and temporal scales. For example, disturbances affecting landscapes can vary in spatial distribution, frequency, return interval, predictability, area, and intensity (Turner 1989). A disturbance is defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and its resources, substrate availability, or the physical environment" (Pickett and White 1985, 7). Within a landscape, disturbances function in an heterogeneous manner, where levels of frequency, severity, and type often control a landscape's biophysical components. The differential exposure to disturbances, as well as the history of disturbances and environmental conditions, cause the resultant vegetation pattern observed on the landscape (Turner 1989).

Biotic processes also vary in scale from the regrowth of an individual to the reorganization of a species. Environmental constraints, which vary in spatial and temporal scales include climate, soil, and water availability (Urban *et al.* 1987).

These agents of landscape pattern formation are linked with landscape development causing some areas to be more susceptible to disturbance than others. For example, topographic position interacts with crop cultivation. In the northern hemisphere, south-facing slopes are more likely to be cultivated than north-facing slopes. Regenerative properties of an area are affected by site quality, while also varying with the age and life-history characteristics of the regenerating individual, as well as the existing spatial pattern. Furthermore, new patches are continually superimposed on existing patches (Reiners and Lang 1979), thus resulting in a landscape with patches of varying size, shape, origin, and stages of development (Urban *et al.* 1987).

2.5.4 Assessment of Landscape Attributes

Landscapes vary in size down to several kilometres in diameter. Although localized areas that are a few meters to hundreds of meters across are at a finer scale than a landscape, most landscape ecology principles apply to ecological mosaics at any scale (Forman and Godron 1986). Landscapes, like ecosystems, are dynamic entities - products of interactions between various components through time. Both landscapes and ecosystems change over time, although not at the same time or rate. Forman and Godron (1986) have proposed three causal processes for landscape development or formation: (1) long-term geomorphologic processes; (2) short-and long-term settlement patterns of organisms; and, (3) short-term local disturbance of individual ecosystems.

Landscapes are recognized as distinct, quantifiable units characterized by their spatially repetitive assemblage of interacting ecosystems, geomorphology, and disturbance regimes. Landscapes have the same three principal characteristics as a vertebrate or an economic system, therefore landscape ecology focuses on the following landscape attributes, their principles, and their applicability to environmental management:

> (1) *structure* which is the spatial relationship among the individual ecosystems present; more specifically it is the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configurations of the ecosystems;
> (2) *function* which refers to the interactions among the spatial components, such as the flows of energy, materials, and species among the ecosystems; and,
> (3) *change* which is the alteration in the structure and function of the ecological mosaic through time (Forman and Godron 1986).

2.5.5 Consideration of Space and Time

Recently landscapes have been viewed as spatial ecological systems affected by ecosystem processes, whose patterns and the changes occurring in these patterns can be quantified. Spatial concepts such as patch, corridor, matrix, network, heterogeneity, contrast, and grain size are used to describe a landscape feature which has been modified by natural processes including geomorphology, biota, soil development, and natural disturbances as well as anthropogenic activities ranging from soil cultivation to manufacturing to pollution (Slocombe 1992).

The dynamic nature of these landscape attributes is representative of the flows and interactions which occur within the landscape structure, and patch characteristics such as size, shape, number, and configuration in turn affect available energy, nutrients, species abundance, composition, and dispersal. Therefore, the landscape mosaic will be a function of boundaries, their location, the effect of boundaries on ecological processes within and across the landscape attributes, and their influence on energy and material flow (Wessman 1990).

Landscape ecology's spatial emphasis has often decreased the importance of time as the other variable upon which landscapes are analyzed (Golley 1987). Time is an important variable in ecosystem analysis, and the temporal context of landscape ecology is as important as the spatial context in ecosystem management. Therefore, environmental history and landscape ecology can be linked to study the effects of ecosystem processes on the spatial dynamics of landscapes through time. Relationships between spatial pattern and ecosystem processes are not confined to any single spatial or temporal scale. In fact, the effect of processes on landscape pattern will vary with scale (Risser *et al.* 1984; cited in Wessman 1990). However by analyzing trends in landscape patterns through time as well as space, steps can be taken to reduce or eliminate those events which have adverse effects on ecosystems, while promoting those which ensure ecosystem sustainability.

2.5.6 Use of Landscapes and Landscape Ecology in Environmental Management

Effective ecosystem management is based on a holistic approach to analyzing and managing the environment. One aspect of this approach depends on understanding the effects of landscape pattern agents, that is, disturbance, biotic processes, and environmental constraints, on the spatial and temporal heterogeneity of landscape structure and function. Landscape patterns develop as a result of the dynamic interaction of biophysical and cultural processes. Understanding landscape pattern dynamics and disturbance can provide greater insights into the spatial development of landscape mosaics, their underlying processes, and their effect on ecosystem structure and function, while time-series analysis can provide greater insights into the sources of change in the landscape mosaic (Wessman 1990).

In order to understand the interactions between landscape patterns, ecological processes, and ecosystem health, landscape structure must be analyzed and quantified. The difficulty in analyzing these interactions has often caused the spatial dynamics of landscapes to be ignored (Turner and Gardner 1991). However, quantitative methods are necessary for comparing landscapes, identifying changes in landscape pattern through time, and relating landscape patterns to ecological processes.

In the past decade, significant progress has been made in developing quantitative methods for analyzing and interpreting landscape pattern changes.

Quantitative landscape measures such as richness, evenness, patchiness, diversity, contagion, dominance, and nearest neighbour, which influence shape and size, disturbance and heterogeneity, movement and stability of organisms, flows of energy and matter, and large-scale ecosystem processes, have been developed (Turner 1989). These can be used to study ecosystems therefore rendering landscapes as one level at which to observe ecosystems in order to assist in ecosystem-based management (See Turner and Gardner 1990 for a detailed account on methods and applications).

2.5.7 Landscapes, Landscape Ecology, and Ecosystem Health

There is much potential for linking landscape ecology to ecosystem health assessment. Landscape level observations provide a method for studying heterogeneity in space and time, identifying changing ecosystem characteristics which are not discernable at a smaller community- or species-level. Examination of a landscape's heterogeneity can lead to greater insights into the factors which generate landscape pattern, while time-series analyses can provide an element for suggesting sources of natural or human-induced variation.

Landscapes that have been modified by humans for many years can serve as a means of understanding the manner in which ecosystems and associated socioeconomic systems respond to anthropogenic perturbations. For example, in the past, agricultural activities took place on a small scale and in close relation with the natural conditions of the environment, resulting in an increase in biological diversity of the landscape ([illegible] and [illegible] 1993). Without human disturbance the landscape would have consisted of large patches of forests or grasslands. Agricultural activities, however, enabled species which required open landscapes, to survive, while also accommodating edge species. On the other hand, where human impact was extensive due to population growth, technological advances, and accelerated development, increased landscape modification and homogenization has occurred such that many ecosystems were unable to reorganize and recover to a desirable state.

Various environmental monitoring programs have proposed the use of landscapes for the purpose of assessing ecosystem condition (Table 2.5.1). The use of landscapes in this context range from general assessments to specific monitoring strategies. The authors promote landscapes to be an indicator of ecosystem condition, a focus for the development and observation of indicators, a level at which to determine the processes underlying the condition of an ecosystem, and a level at which ecosystem health assessment can occur. Thus there is a need for landscape level observations in order to provide appropriate spatial and temporal information to integrate landscape structure, function, and change with ecosystem processes in order to manage for ecosystem health. The Council of Great Lakes Research Managers (1991), Slocombe (1992; 1993b), and Cairns *et al.* (1993), consider landscape ecology to have much potential to assist in the collection and organization of information to enhance environmental planning and management. Mata-Porras *et al.* (1994) have used the landscape level to understand and model the impact of desertification in Southern Europe and define ecosystem health at different spatial and temporal scales.

Author(s)	Recommended Use of Landscapes and Related Information
Cairns *et al.* (1993)	indicator of ecosystem health
CGLRM (1991)	monitoring and managing for ecosystem health
Hunsaker *et al.* (1990)	an Exposure-Habitat indicator measured in the EMAP sampling strategy
Karr (1991)	biological indicator to determine the condition of a water source
Karr (1993)	level at which to monitor ecosystem integrity
Knapp *et al.* (1991; as cited in WQGTG 1994)	level at which to observe response indicators in order to detect the biological condition of a resource
OECD (1993)	an environmental issue - a functional point for the development of indicators
Ritters *et al.* (1992)	assists in describing the condition of a forest
Slocombe (1992)	level to measure the integrity and condition of landscapes of national parks
Woodley (1993)	level at which to monitor ecosystem integrity
Zonneveld and Forman (1990)	predicts a variety of processes underlying ecological integrity

Table 2.5.1: Suggested use of landscapes in environmental management.

Therefore although the use of landscape ecology in environmental management is still in its infancy, landscape ecology is recognized as having great potential in ecosystem health assessment. Landscapes provide a level for observing large-scale ecosystem properties, both biophysical and social, which are easier to discern than the smaller-scale biological indices which have been used to assess ecosystem condition. Landscapes can also help to demonstrate the interrelationship between ecology and economics by extending ecosystem analyses to the interactions among natural and managed ecosystem components. In other words, the spatial pattern of environmental performance is combined with the human activities which influence spatial patterns, and these in turn affect other biophysical processes such as the movement of energy and material, and the management of spatial heterogeneity (Risser 1985).

The works listed in Table 2.5.1 only discuss the potential of using landscape level analysis in passing. They do not go into detail as to the applicability of landscape ecology theories and measures in environmental management. However, the introduction of ecosystem-based management and related concepts such as ecosystem health, require that different aspects of ecosystems be studied and managed. Landscape level analyses can serve as a level to observe ecosystem processes and the effects of ecosystem processes through time. Therefore in the context of short- and long-term natural- and human-induced landscape modifications, landscape ecology can be used to assess ecosystem health to improve present and future ecosystem-based management programs. The next two chapters illustrate the qualitative and quantitative applications of these ideas to a long-occupied, heavily modified watershed.

CHAPTER THREE

LUNIGIANA, ITALY

The region of Lunigiana is located in northwestern Italy at the northern most tip of Tuscany, covering an area of 440 km^2. Its insular position in Italy's northern Apennines, along with its favourable biophysical conditions have resulted in long-term occupation of Lunigiana by humans and the modification of many of the area's ecosystem components and processes. However Lunigiana is still noted for its biophysical environment including flora and fauna, caves, rivers, lakes, and mountains. Its significant archaeological, historical, and cultural attributes including castles, city walls, and road networks, as well as distinct traditions and dialects, are testimony to the unique cultural mosaic which has developed in Lunigiana. These varied attributes and values are components of a unique area, all of which have had a long period of time to affect the ecosystem.

In order to demonstrate Lunigiana's unique setting this chapter is devoted to describing the region. The description of Lunigiana's biophysical setting [from Farina (1980) unless otherwise stated], and history [from Garuglieri (1990) unless otherwise stated] will be discussed initially in order to understand the reasons for the land use practices occurring in the area. Lunigiana's landscape and land use patterns will also be described in order to understand the reasons for the landscape pattern which has been developed.

3.1 Biophysical Setting

Lunigiana is characterized by a complex morphology which has helped to shape its other biophysical characteristics. The following section is a description of various aspects of Lunigiana which have influenced its landscape and settlement patterns. The scientific names of the biota mentioned in the remainder of this thesis can be found in Appendix 1.

3.1.1 Morphology

The boundaries of Lunigiana coincide with those of the middle and upper course of the Magra River watershed (Figure 1.2). The Magra River drains naturally terraced, alluvial slopes, which were produced by neo-tectonic uplifts during the Miocene period. The mountain areas of the Apennines barely stood above sea level during this period. During the Miocene, gravels, sands, and clay were deposited around the coastal areas, and are now found along both sides of the Apennine chain, forming hilly areas and reaching elevations of several hundred meters above sea level (Farina 1980).

Glacial activity also helped to shape the area. During the Pleistocene, at least four main glacial advances spread southward from the Alps, affecting the morphology of the Apennines (Cole, 1964). However, most of the visible glacial formations date to the Wurm glacial period. As well, the mountainous terrain and high precipitation regime have generated a high flood incidence. These floods, in combination with past and present glacial and tectonic activity, have helped to create Lunigiana's morphology.

Lunigiana is primarily characterized by its mountainous terrain comprised of three mountain chains: the Tosco-Emiliano Apennines, the southeastern portion of the Ligurian Apennines, and the Alpi Apuane mountain chain (Figure 3.1), each with a unique orogeny, geology, and morphology. The Tosco-Emiliano Apennines are composed of oligocenic sedimentary "macigno" of alternating sandstone and mudstone. The Tosco-Emiliano Apennines are characterized by steep slopes reaching average heights of 1,500 meters above sea level, with the highest peak being that of Alpe di Succiso which extends 2,017 meters above sea level.

Geologically, the Ligurian Apennines are characterized by macigno as well as rocks of the "Ligurian" formation and green rocks such as serpentines and diabases. They are gently rolling mountains reaching heights between 600 and 800 meters above sea level within a few kilometers of the coast. The smooth coastline is evidence that this chain is a relatively recent formation. The hills of the interior Ligurian Apennines have been shaped by the Vara River, with the average height of these mountains being 1,000 meters above sea level. Monte Gottero is the highest mountain in this chain with an elevation of 1,639 meters above sea level.

The Alpi Apuane chain is distinguished from the other mountain chains as it is mainly composed of marble and is characterized by steep slopes, canyons, and cliffs. The highest peak in this chain is that of Monte Pisanino at 1,946 meters above sea level.

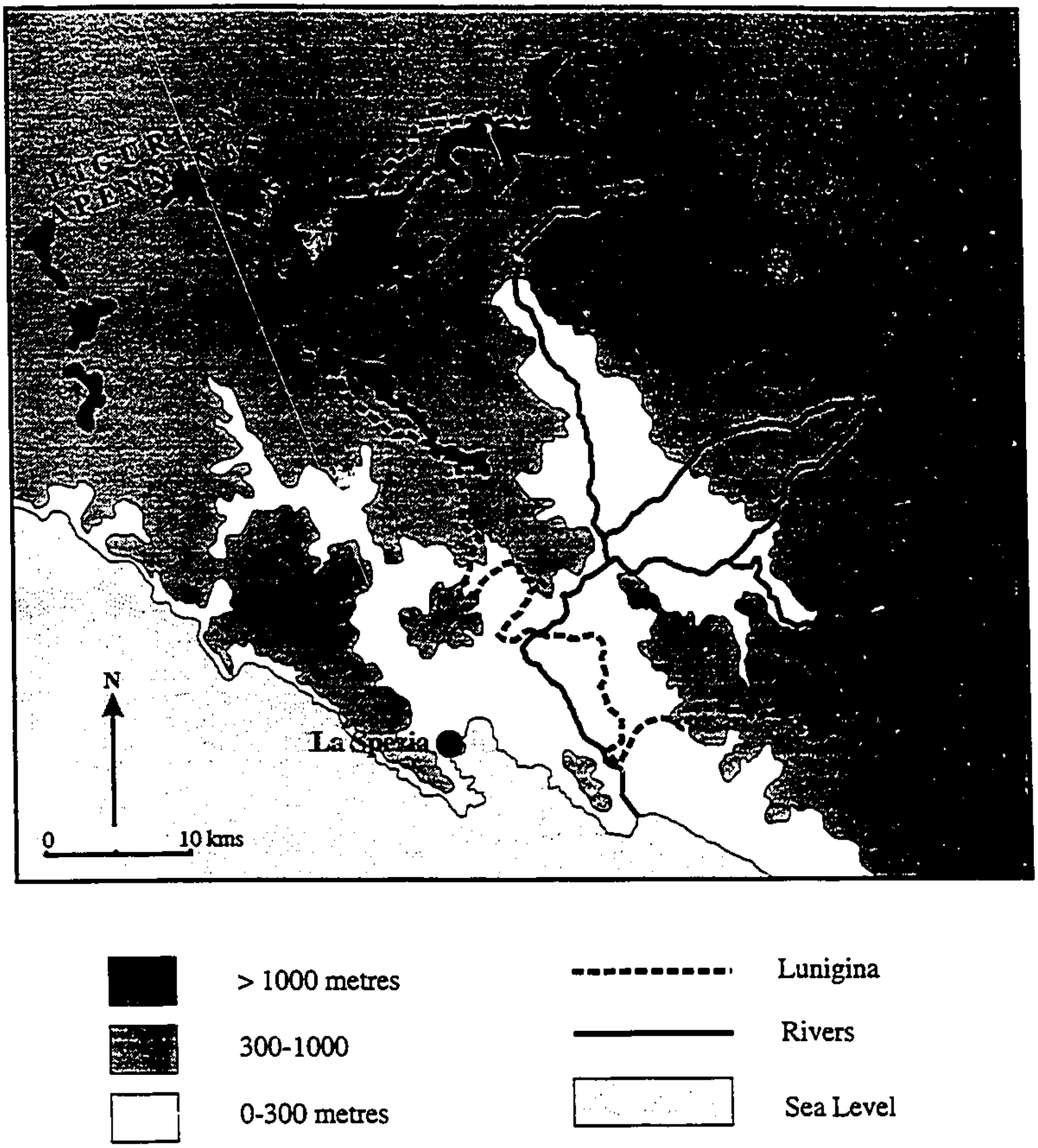

Figure 3.1 Geomorphology of Lunigiana and surrounding area (Farina 1980, 20-21).

3.1.2 Climate

Lunigiana's complex morphology, elevation differences, and proximity to the sea have helped to create many unique climatic and micro-climatic conditions. However, due to the absence of a network of meteorological stations, Lunigiana's unique microclimatic conditions have not been well studied. Each valley has its own micro-climate based on altitude, aspect, and location with respect to the various wind systems. Generally, Lunigiana's climate ranges from true Mediterranean to Alpine (Figure 3.2). Moving inland, the average annual temperature falls until a typical

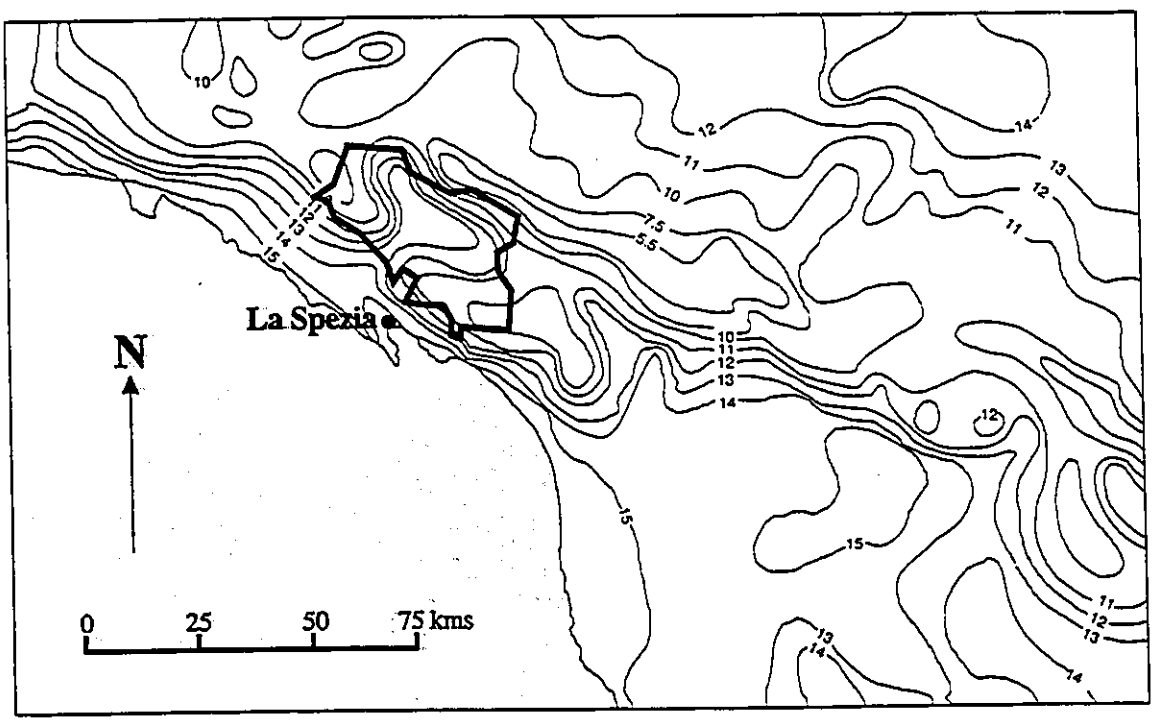

Figure 3.2: Average temperature (°C) for Lunigiana and surrounding area (Farina 1980, 27).

alpine climate is achieved along the mountain ridges, the lowest average annual temperatures reaching 5.0°C.

Lunigiana is also known as one of Italy's wettest regions. Most of Lunigiana's precipitation, as in all Mediterranean climate zones, falls in the cooler months, between September and May, while the dry season occurs between June and August. An average annual precipitation of 1,500 millimeters is accumulated in this area due to the warm and moist prevailing wind system which originates off the Mediterranean Sea. The wind travels inland toward Lunigiana's system of mountains, and as much as 3,000 millimeters of rain per year fall on the Alpi Apuane Mountain chain (Figure 3.3). Precipitation in the form of snow is more abundant on the Tosco-Emiliano

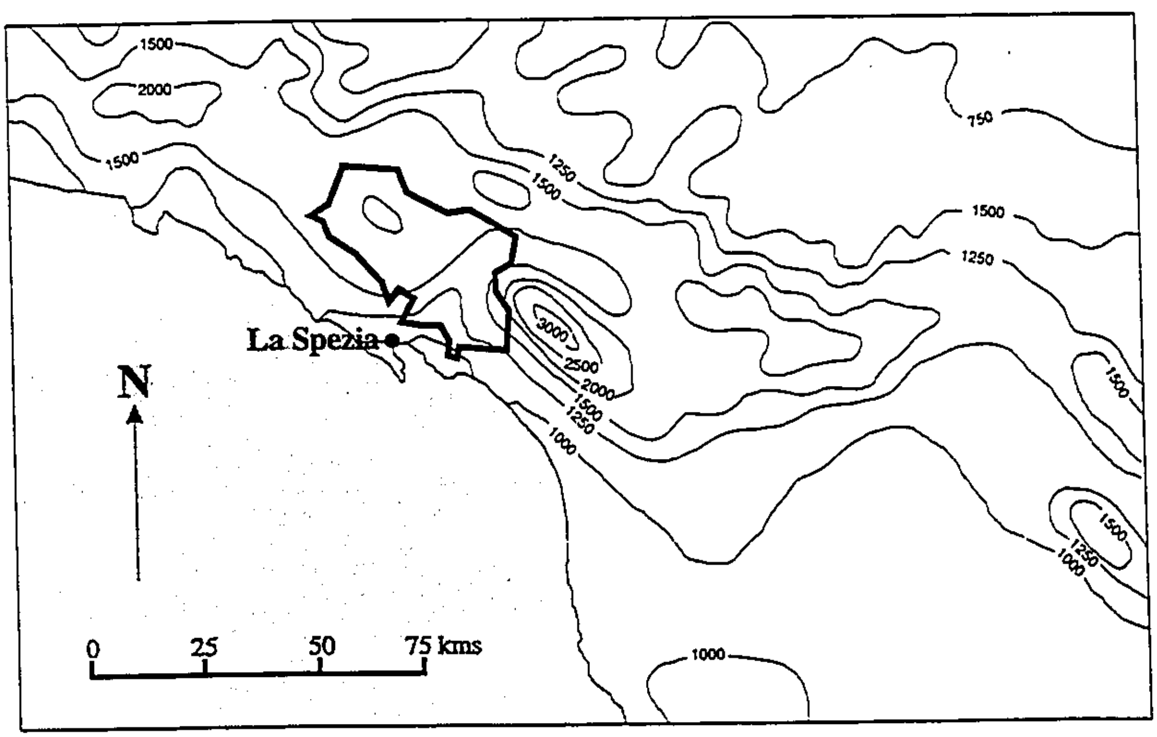

Figure 3.3: Average annual precipitation (millimeters) received for Lunigiana and surrounding area (Farina 1980, 26).

mountain ridges than on the Alpi Apuane mountains due to the lower temperatures which occur on the higher altitude Tosco-Emilianos which also experience a continental climate rather than the warm marine climate experienced by the Alpe Apuanes (Farina 1980).

3.1.3 Fauna

In recent years many studies have been performed on Lunigiana's fauna have been conducted, particularly on the area's birds and mammals. Despite the long-term human disturbance regime in Lunigiana, the area still maintains a wide variety of fauna. This diversity has persisted since fragmentation of the landscape mosaic has produced a variety of habitats, and extensive areas of man-made ecotones, while agricultural practices have produced resources and habitats used by many animals. Many animals have adapted to the presence of humans, some to the extent that they have become dependent upon human activities for their survival, thus enabling Lunigiana to support a large animal biomass.

3.1.3.1 Fish

The Magra River and its tributaries contain a diverse and abundant fish population. In fact, although the removal of gravel and river and stream embankments, especially at the lower course of these rivers and streams, has disturbed fish populations normally found in calm waters rich in vegetation, the water chemistry still enables fish populations to survive.

Lunigiana's water courses support two species of lampreys, sea lamprey and river lamprey, while twenty species of fish also thrive in these waters including common sturgeon, a sub species of twaite shad, and a roach species. The eel is a common migratory species which can be found in most streams as well as in irrigation canals.

It should be noted that stream conservation efforts have resulted in the introduction of several fish species. The black bullhead was introduced into the area in the 1930s in a pool near Aulla and has become a common species throughout the area. Goldfish have been recently introduced in artificial lakes which were created from clay quarries around Sarzana, as well as artificial lakes created for irrigation of hill cultivations. Presently Lunigiana's streams are being restocked with rainbow trout.

3.1.3.2 Amphibians

Although Lunigiana's morphology does not favour the existence of many humid areas, several of Italy's amphibian species are found in this region. Fourteen amphibian species have been identified despite the fact that Lunigiana's amphibian population has not been extensively studied. These species include six in the *Caudata* subclass and eight in the *Anura* subclass. Among these the Apuanis alpine newt and the crested newt are found in many mountain lakes up to about 1,000 meters above sea level, while the Apuanis alpine newt is also found in irrigation ditches around hill cultivations. The fire salamander is also a common species found in cool, humid zones, while a black spiny subspecies of the European toad has a wide range in the beech forests and the high altitude prairies.

3.1.3.3 Reptiles

Seventeen species of reptiles have been identified in Lungiana. A subspecies of the Aesculapian snake is widespread throughout Lunigiana, its range extending from Lunigiana's lowest altitudes to about 1,600 meters above sea level. It is the most active of all of the area's reptiles and is found in cool, vegetated environments, generally near a water source. The green lizard is also common in this area, frequently found in forest clearings and along rural roads bordered by dense hedges, while the slow worm occurs in cultivated fields, meadows, and pastures, as well as in many woodland clearings (Farina 1980).

3.1.3.4 Mammals

Lunigiana is rich in mammal species. The abandonment of the countryside has resulted in an increase in mammal diversity and abundance. Although a complete description of Lunigiana's mammal population does not exist, recent studies have initiated interest on mammal populations.

To date, twelve large mammal species have been identified: four ungulates, seven carnivores, and one lagomorph. Among these, roe deer, wild boar, fallow deer, and mouflon are species which are not native to Lunigiana, however they have been introduced into the areas by stocking efforts. Of these mammals, only the fallow deer population is struggling to survive since Lunigiana does not have a suitable environment for these species. As well, in the past, hunting activities had a great effect on the area's carnivorous population since their food source was disappearing. Wolf and brown bear are two species which once lived in Lunigiana's mountain forests, however, their numbers have decreased drastically as a result of these hunting practices.

Several mammal species are slowly returning to Lunigiana. Of the carnivores, the red fox and lesser weasel, found in woodlands and cultivations, are the most common mammals. Other carnivorous mammals found in the area include pine marten which are found in mountain forests. The otter is found in the middle and upper course of the Magra River and its tributaries such as the Taverone and Aulella. Lagomorphs were once common throughout Lunigiana, however, in the past thirty years native populations have almost completely disappeared. In fact, the lagomorph species found in Lunigiana, the brown hare, originated from central and eastern European stocks, and is presently found in high altitude prairies and mountain cultivations and pastures.

Many small mammals, such as rodents and insectivores, can be found throughout Lunigiana. Fifteen rodent species including Eurasian red squirrel, edible dormouse, alpine pine vole, and hazel dormouse have been identified, as well as eleven insectivores such as the Eurasian pygmy shrew, pygmy white-toothed shrew, and Mediterranean mole.

Bats, are the least known mammals in Lunigiana. Fifteen species have been identified including the lesser horseshoe bat, whiskered bat, and common pipistrelle (Farina 1980).

7.1.3 Birds

Languedoc's bird populations have been studied extensively. The area contains a diverse and abundant bird population of both seasonal and permanent residents, due to the numerous environments found throughout Languedoc. Many birds which migrate between Europe and Africa pass through Languedoc, therefore the area functions as a reproduction area for summer migratory species as well as a temporary area for winter migrating species.

Languedoc is also used by many birds in order to facilitate movement between the [illegible] and the Mediterranean Sea. Birds which utilize Languedoc's waterways during spring and fall migrations include the gray heron, little egret, yellow-crowned night heron, lapwing, and woodcock, while common waterfowl in Languedoc include the garganey and the mallard, while the osprey fishes in Languedoc's streams (Farina 1980).

Open cultivated areas also provide habitat for many species of migrating birds, especially during spring migration when the climate is favourable for traversing the Pyrenees ridges. In these areas, large concentrations of granivorous species can be found including the serin, greenfinch, and chaffinch, while insectivorous species occurring in these areas include the song thrush and mistle thrush (Farina 1980).

Winter birds such as the song thrush, robin, European robin, and dunnock winter in Languedoc. The most suitable areas for these birds are olive orchards and mountain slopes that are protected from the northerly winds. Other wintering birds such as the [illegible] and [illegible] are found in olive bushes along river edges, while sparrowhawk utilize mountain cultivations, meadows, and pastures (Farina 1980).

3.1.4 Vegetation, Landscape, and Land Use Patterns

Lunigiana's landscape has been affected by biological, including human, processes. Lunigiana's traditional agrarian roots have caused many of the area's land uses to be dominated by various agricultural activities such as field crop cultivation, fruit, olive, and chestnut orchards, vineyards, and pastureland. Lunigiana's modern landscape also displays remnants of traditional land use practices such as charcoal-burning *piazze* as well as areas of *coltura mista*, a mixture of different cultivations including crops such as corn, barley, maize, potatoes, vineyards, fruit trees, herbs, and pasture, interspersed throughout a woodland matrix, on man-made terracettes which characterized the Lunigianan landscape no longer than forty years ago. Today however landscape level observations reveal that Lunigiana's landscape mosaic is quickly changing due to agricultural land abandonment.

Lunigiana is located near the border of two phytogeographic regions: the Central European Region and the Mediterranean Region (Figure 3.4). As elevation increases the vegetation not only changes as a result of changing physical features such as proximity to the sea, elevation, slope, aspect, soil, and micro-climatic conditions. Lunigiana's vegetation also changes as a result of the various land uses that have occurred in the area throughout the years. Ferrarini (1982) divides the Lunigiana's flora into six vegetation belts corresponding to an altitudinal gradient: the English oak, Mediterranean maquis, downy oak-hornbeam, European turkey oak-

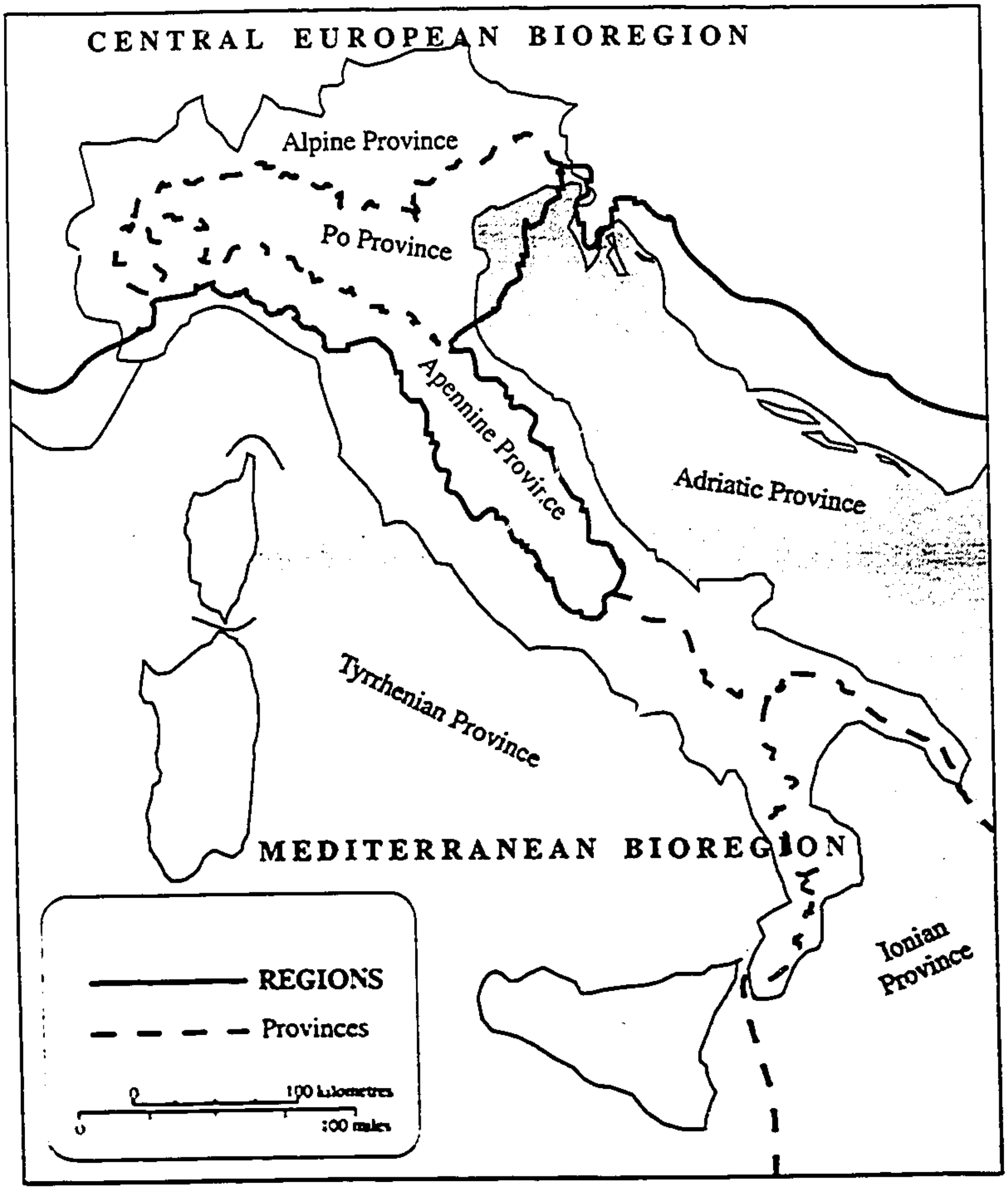

Figure 3.4: Phytogeographic regions of Italy (Vos and Stortelder 1993, 121).

hornbeam, beech, and *Vaccinium* belts. As well, large chestnut orchards can be found throughout the downy oak-hornbeam, European turkey oak-hornbeam, and beech forest belts since chestnuts were once a staple food for the Lunigiana's mountain populations, and although many of the original fields have been abandoned, chestnut trees persist while their range increases.

Of Lunigiana's six vegetation belts discerned by Ferrarini (1982), four occur within the extent of the Taverone River valley (Figure 3.5) and various agricultural practices occur on different plots of land throughout Lunigiana. Farina (1993b) divides Lunigiana into four land use zones according to the area's altitude and morphology: lowland landscape, hilly landscape, low mountain landscape, and upland landscape. As well, eight different land uses, corresponding with various human activities, soil, climate, morphology, and elevation regimes, occur in the study sites.

3.2 The Study Sites

3.2.1 Lowland Landscape

The first study site is located at the bottom of the Taverone River valley. The major village in this site, Aulla,is situated at 64 meters above sea level. This site is the most populated of all the study sites. The area's vegetation corresponds with the English oak vegetation belt. The English oak belt consists of English oak, European turkey oak, wild serviceberry, field maple, hornbeam, and trembling aspen. Therefore according to Ferrarini's (1982) vegetation map, the first study site consists of English oak (1a), and cultivated fields (1b). Riparian vegetation is also found in this site.

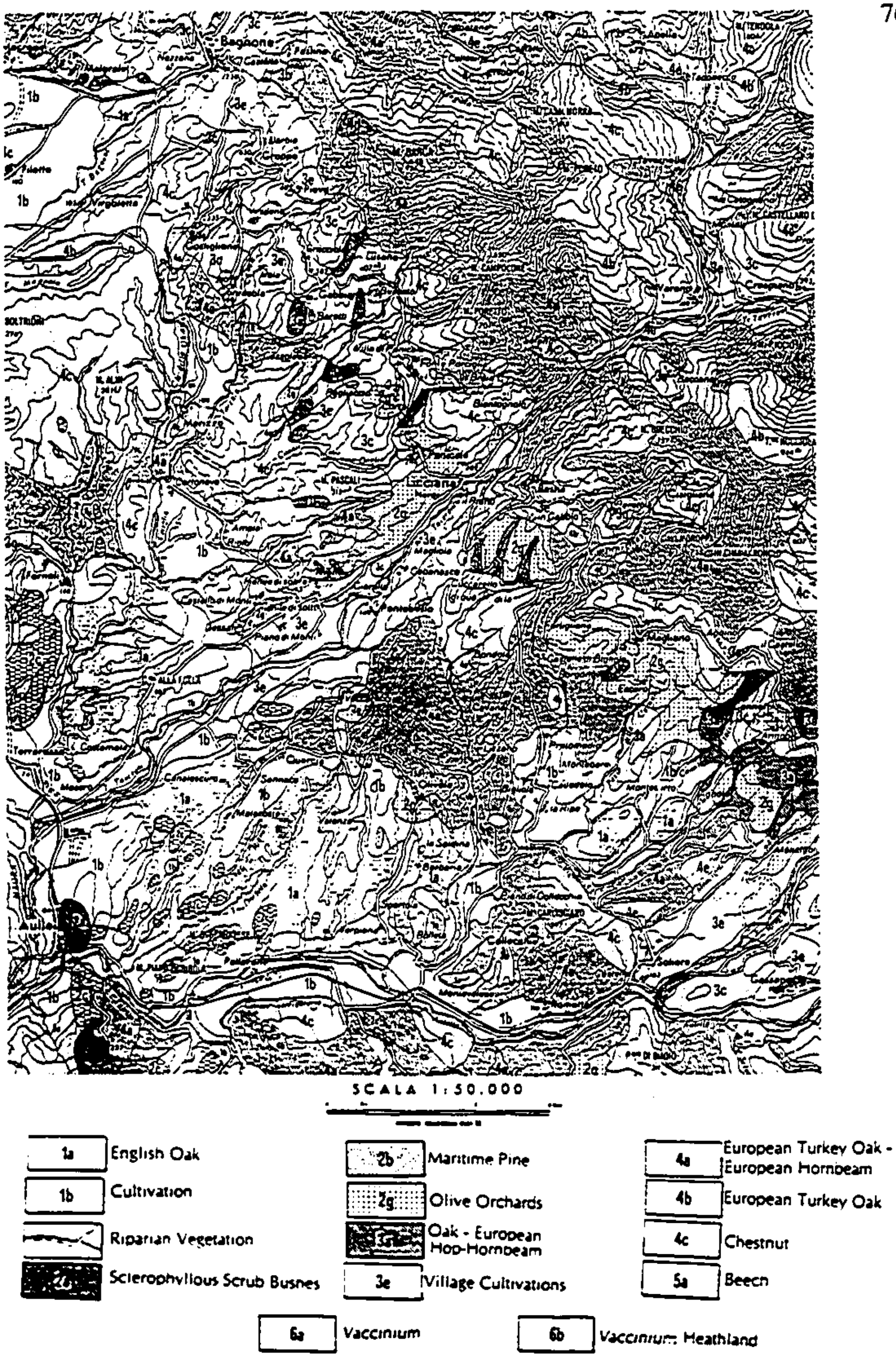

Figure 3.5: Vegetation within the study sites (Ferrarini 1982).

occurring along the water corridors and varying along the course of the rivers with willow species, especially purple osier, being most common while french willow, hoary willow, black alder, and European blueberry are also found along the water courses.

Other types of vegetation found in this study site include sclerophyll scrub bushes (2a), European turkey oak, European hornbeam, Italian maple, common laburnum, and common hawthorn (4a), maritime pine (2c), chestnut trees (4c), sparse patches of downy oak (4b), and village cultivations (3e). The village cultivations take advantage of the prevailing southwesterly winds flowing up the Taverone River valley and are sheltered from the northerly winds by the surrounding mountains. However it is difficult to describe the vegetation of the village cultivations since along with the fields which are cultivated in the traditional manner with vineyards, corn, potatoes, and clover, many fields have become pasture or have been completely abandoned (Ferrarini 1982). In the traditional cultivation, with centuries of terrace farming occurring with vineyards at the edges of cultivated fields, two-year rotations of corn and potato, four-year cultivations of corn and clover, and five-year rotations of corn and alfalfa take place.

The lowland landscape zone, located below 200 meters above sea level, occupies thirteen percent of Lunigiana. As the name suggests, the lowland landscape is usually found along the lower portion of the Magra River watershed which is a highly-connected system through which materials, energy, and nutrients can circulate (Farina 1993b). The well drained fertile soils and naturally terraced landscape are the reasons for the high amount of agricultural activity in this area. The lowland landscape is cultivated with maize, corn, alfalfa, and other grasses. The fields in this zone are surrounded by wooden fences, hedgerows, vineyards, fruit trees, or stone walls.

The landscape in the first site is located in the lowland landscape, and is characterized by small patches of many different land uses (Figure 3.6). Aulla and the urbanized area along the Magra River and the highway heading northward toward the coastal city of La Spezia covers a large portion of this site. Much of the land along the Magra and Aulella Rivers are dominated by urban area while agricultural activities, including pastoralism and the cultivation of dry field crops, fruit trees, olive orchards, vineyards, and mixtures of olive orchards and vineyards occur along valleys and terraced slopes. Those areas in the study site which are more remote and located at higher elevations are covered with forests of coppice woodland and conifer trees.

3.2.2 Hill Landscape

The second study site includes the village Licciana which is situated at an altitude of about 202 meters above sea level. There is a definite shift in the vegetation from the English oak belt to the schloryphorous Mediterranean maquis belt and the downy oak-hornbeam belt in this site. The Apennine maquis vegetation does not extend toward the Po River valley, but instead occurs in small patches on lower portions of the river valley where the prevailing warm southwesterly winds from the Mediterranean Sea, winter thermal inversions, and other favourable micro-climatic

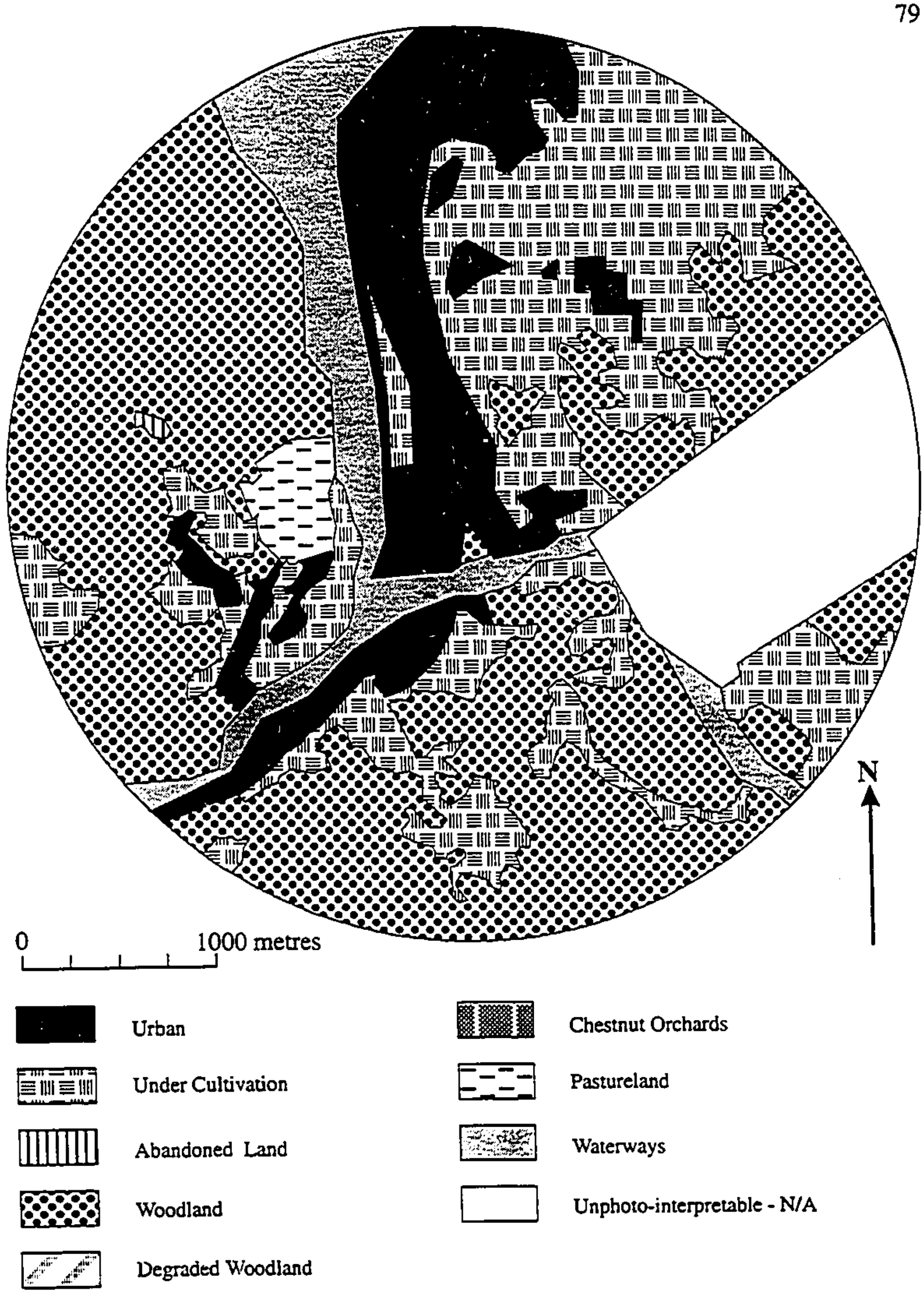

Figure 3.6: Land uses occurring in the first study site (Giordano *et al.* 1986).

conditions enable schloryphorous vegetation to grow. This vegetation is dominated by olive and holm-oak trees. The downy oak-hornbeam belt is located in sunny areas that are sheltered from northerly winds. This belt also contains olive and holm-oak trees which are found in the Mediterranean maquis belt as well as downy oak, hornbeam, sessile oak, flowering ash, and field maple.

The second site was once dominated by cultivated fields, however, today the area contains various types of vegetation. Along the sides of the Taverone River olive orchards (2g) and village cultivations (3e) have been established. Once again, European turkey oak, European hornbeam, Italian maple, common laburnum, and common hawthorn (4a) and chestnut trees (4c) are located further along the mountain slopes, as well as patches of downy oak, sessile oak, flowering ash, field maple, and European hop-hornbeam (3a), maritime pine (2c) and a small area of cultivated fields (1b) (Ferrarini 1982).

The hill landscape zone is found between 200 and 700 meters above sea level. It occupies 47 percent of Lunigiana and is well preserved since extensive land abandonment has not yet occurred in this area. Most of the landscape consists of terraces delimited by stone walls. Woodlots are normally located on the terraces of less agriculturally suitable, north-facing slopes, while vineyards are found in more micro-climatically favourable areas around the villages, with intense olive orchard cultivation occurring only above the line of thermal inversion (Farina 1990). Olive trees can also be found in this zone cultivated in coltura mista. The woodland in the area act as buffers in order to separate the cultivation from the permanent pastures, resulting in an efficient use of resources. The woodland also functions as stop-over and foraging sites for migratory birds (Farina 1994a), while the food produced in the cultura mista is used to sustain the local population (Farina 1993b). Trees that can be found in this landscape such as flowering ash and field maple, once functioned as vineyard posts, however, this practice is not common today. Other primary deciduous woodland remnants found in this agricultural mosaic include European turkey oak, downy oak, flowering ash, European hop-hornbeam, and hornbeam, while groups of mature trees, such as English oak and European turkey oak can also be found throughout this landscape depending upon the use of these trees in local customs (Farina 1993b).

The second study site is located in the hill landscape zone. The urbanized area of this study site is not as large as that of the first study site (Figure 3.7). Rather this site is mainly dominated by cultivated areas of dry field crops, vineyards, a mixture of olive orchards and vineyards, and specialized olive orchards and vineyards. The amount of abandoned cultivated land and degraded or open coppice woodland due to wood harvesting for heating and charcoal production is greater in this site than in the first study site due to the increasing effect of land abandonment with increasing elevation.

3.2.3 Low Mountain Landscape

The village Tavernelle (412 meters above sea level), which is located in the third study site, is situated in the European turkey oak-hornbeam belt. At one time, this belt covered much of Lunigiana's plains. However, through the centuries, humans

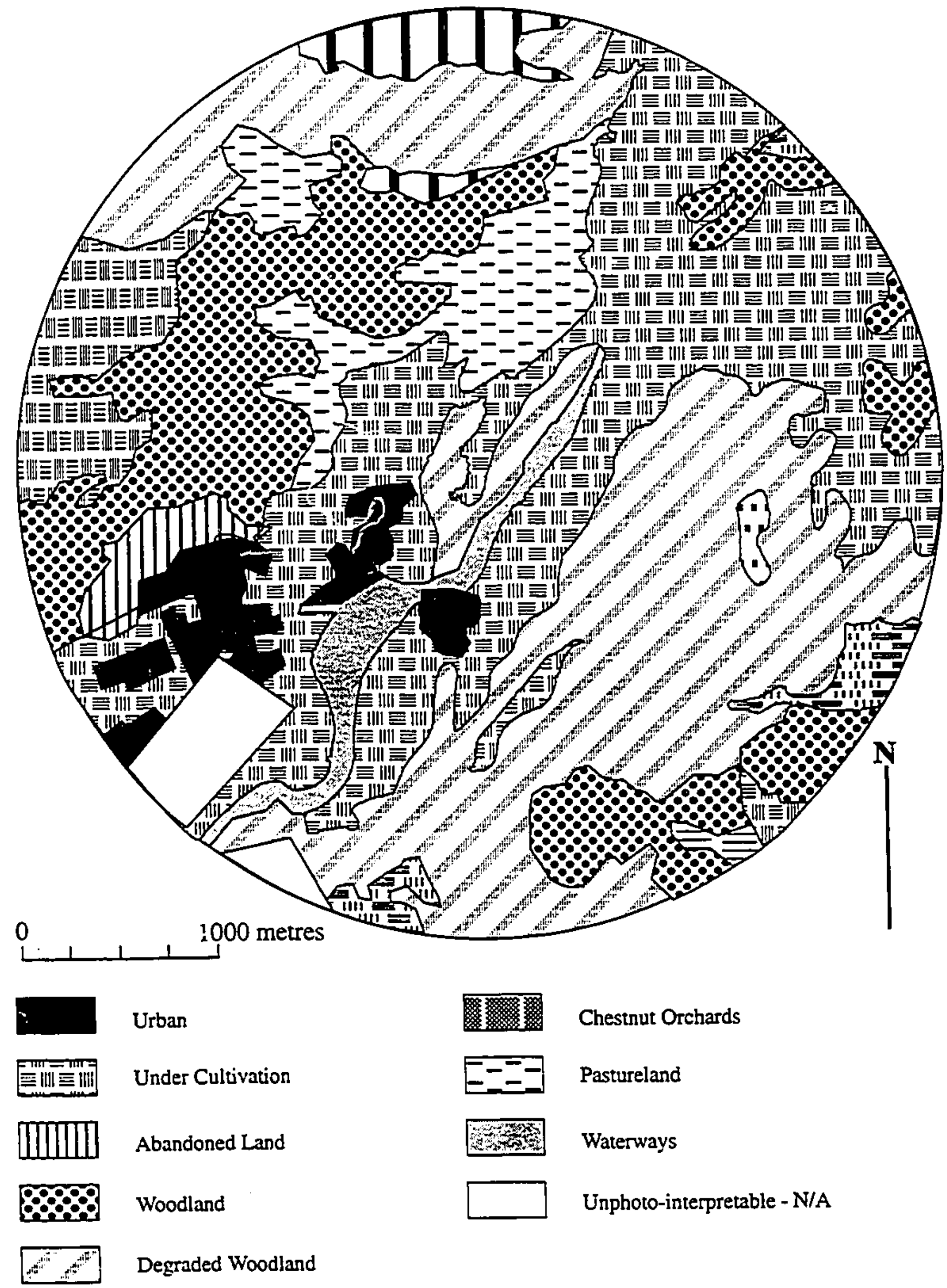

Figure 3.7: Land uses occurring in the second study site (Giordano *et al.* 1986).

gradually substituted a large part of the natural vegetation with more economically viable chestnut orchards or pastureland. Thus, the remaining natural vegetation is found in areas which are not suitable for chestnut cultivations or pastureland. Other trees occurring in this belt include European hop-hornbeam, Italian maple, field maple, flowering ash, cornelian cherry, European hazel, common laburnum, and common hawthorn.

This area is comprised of mixed mesophyll forests containing mostly chestnut trees (4c), with sparse occurrences of European turkey oak trees (4b) since most of the original trees have been removed. As well, along the portion of the river valley that advances toward Tavernelle, village cultivations (4e) can be found.

Thirty-eight percent of Lunigiana is occupied by the low mountain landscape, located between 700 and 1500 meters above sea level. The zone consists of a mixture of cultivations suited to cool and temperate climates, as well as chestnut orchards, fallow and improved pastures, and extensive woodland. Villages are located at the edge of the lower woodland belt dominated by European turkey oak and an upper belt dominated by common beech. The villages within this landscape have been self-sufficient due to a range of agricultural, silvicultural, and pastoral practices that occur within the area including the production of potatoes and cereals, chestnut orchards, timber harvesting, charcoal production, and livestock breeding and rearing. Chestnut orchards are important since chestnuts have functioned as an important staple food for the people in this area for many years (Farina 1993b).

Much of the third site is located in the lower mountain landscape zone. A definite difference exists between this site and the previous sites (Figure 3.8). Only small areas of urban land and agricultural land with dry field crops, olive orchards and fruit trees, and pastures, occur in this site. However, there is an increase in the amount of land in a phase of abandonment and degraded or open coppice woodland while large areas of chestnut orchards are also found in this site.

The final two vegetation zones, that of the beech forest and *Vaccinium* belts, are found throughout Lunigiana but not located within the Taverone river valley. The beech belt generally extends from about 800 to 1700 meters above sea level, depending upon the morphology and aspect of the upland slopes since beech trees favour cool, moist areas. Beech trees can also be found on drier slopes; however, areas which have been cleared for pasture are dominated by false brome grass. Dense beech stands seldom allow other tree species to grow, however, in areas that sunlight can penetrate trees such as alpine laburnum, white beam, European mountain ash, chess maple, and European red elder can grow. Patches of coniferous trees such as Austrian pine are also found in this belt, however, these appear to be a result of the reforestation past farmland areas.

In the *Vaccinium* belt (6a) trees which usually accompany red pine are found, as well as heathlands of *Vaccinium* and some areas of alpine rose. The floristic composition of these heathlands is almost continuous. Pastoralism has destroyed many heathlands of whortleberry, however, the heathlands are better preserved in more inaccessible areas, generally being found in high altitude, north-facing slopes. There are not as many species of *Rhododendron* in comparison with *Vaccinium* species since

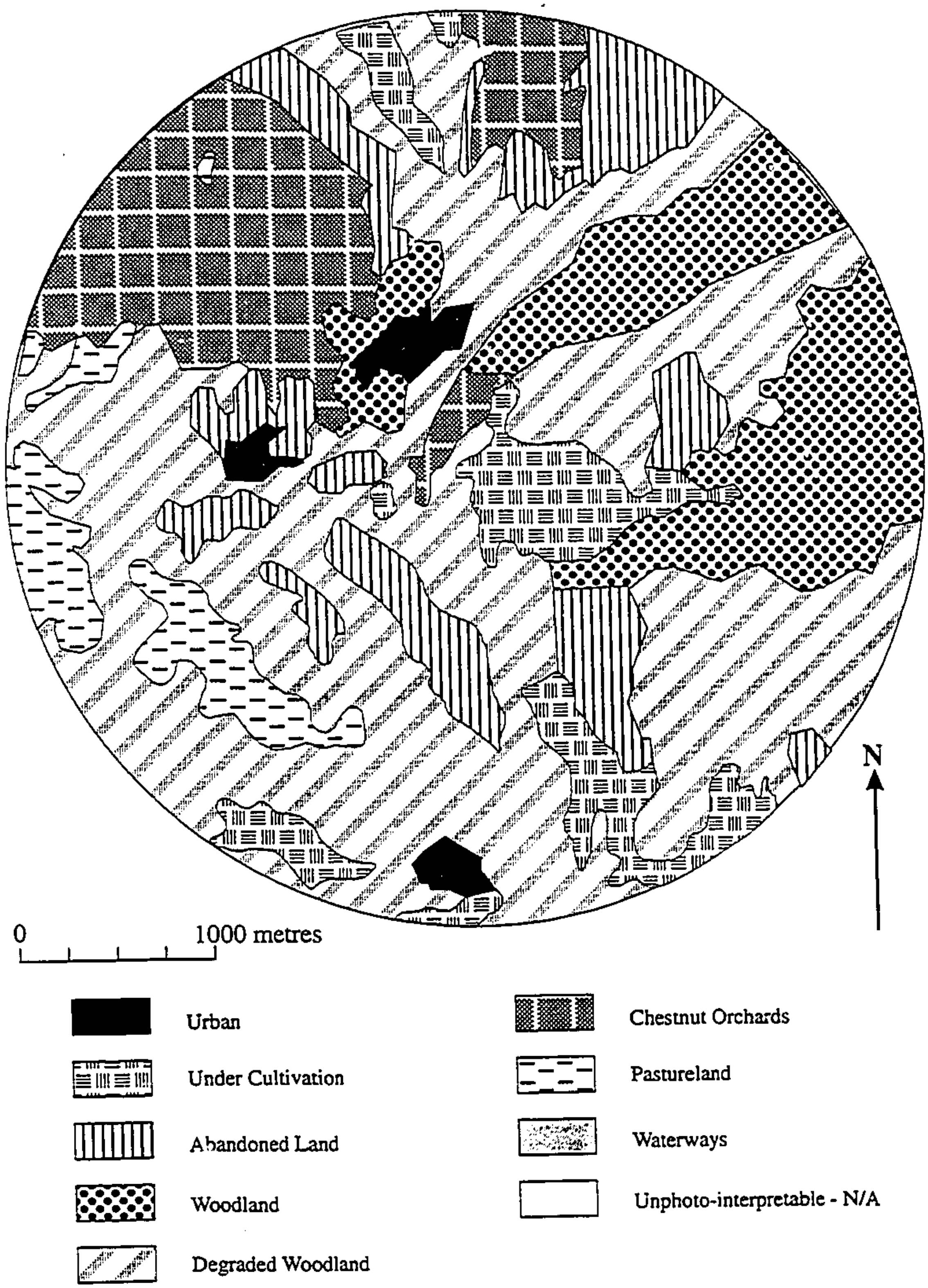

Figure 3.8: Land uses occurring in the third study site (Giordano *et al.* 1986).

Rhododendron species are found in areas which are sheltered from warm, moist prevailing winds by the Alpi Apuane chain, favouring a more continental climate.

Grasslands which are derived from *Vaccinium* heathlands (6b) cover a larger area than the heathlands of 6a. They are found on almost all southerly-orientated slopes as well north-facing slopes where pastoralism occurred. Grasses found in the healthlands and occurring in these areas include a ladies mantle subspecies and mountain avens. New grass species occurring in this area include sweet vernal grass, woodrush, great woodrush, Alchemilla glaucescens, and mountain lotus. False brome grass dominates the south-facing slopes while common mat-grass grows on the level mountain plains.

3.2.4 Upland Landscape

Although the final land use zone, the upland landscape, is not located in the Taverone River valley, it constitutes 2 percent of the Lunigianan landscape. This zone is situated above the tree line (1,500 meters above sea level). The tree-line in this area is a fringe of mature trees, usually common beech which was maintained by local populations in order to act as a break for snow avalanches and mud slides. These trees also functioned as shelter for livestock utilizing permanent clearings as pasture lands. In the hamlets, the dry stone cabins used by shepherds during the summer months, can still be found on the mountain tops, while narrow trails which run along the length of the mountains are a sign of past livestock trampling due to intense grazing (Farina 1993b).

In this land use zone prairies, which are the main eco-type, appear as narrow belts on the mountain tops (Farina 1990). The prairies function as grazing areas, and have played a major role in sustaining the mountain village populations. Cows and sheep once intensively grazed these areas between May and September, and hamlets which were inhabited only during these summer months were located in sheltered valleys known locally as "bore".

3.2 Historical Setting

Due to the road network which once connected the Po River valley to the Tyrrhenian coast, Lunigiana was long a frontier region, functioning as a meeting place for people from many different cultures. Evidence of human occupation in Lunigiana is located throughout the landscape. Remnants of ancient fortifications, castles, churches and other structures dating from the Roman era to the creation of the Italian Kingdom in 1861, are spread throughout the landscape (Farina 1993b), however the oldest artifacts in Lunigiana have been discovered in caves of late Palaeolithic origin. In fact, Lunigiana derives its name from the *Luni*, a strong ancient tribe living in the area who strived to maintain their independence and cultural identity during Roman occupation.

The Lunigianan landscape has experienced many changes since humans first occupied the region, while population fluctuations have been experienced with the immigration and emigration of people due to wars, famines, plagues, and the search for economic stability. The first permanent settlements, established during the second and third periods of the Bronze Age, were carried out under the influence of a growing agricultural, silvicultural, pastoral economy. With the establishment of these settlements came the first traces of deforestation. According to Garuglieri (1990) this "agricultural revolution", which occurred very early in Lunigiana, is more important than the industrial revolution in terms of the changing cultural mosaic since people who once lived nomadic lifestyles became sedentary, resulting in the establishment of hamlets and villages throughout the landscape. However, the agricultural and pastoral conquest of Lunigiana's mountains was gradual since it was not until the end of the Bronze Age (1300 to 900 B.C.) that networks of small villages called *castellari* were established. This network was more profitable during the second period of the Iron Age (600 to 100 B.C.) when new territorial arrangements occurred due to population increases and the exploitation of mountain slopes which occurred as a result of the expansion of agro-pastoral activities. This arrangement persisted until the Romanization of Lunigiana was complete.

The arrival of the Romans resulted in the migration of the Ligurian Apuanis tribe from the upland areas to the more economically advantageous Roman cities located in the low-lying coastal and valley areas. At the same time a large area of land in the Serchio valley and the Upper Magra valley became a republican Roman territory and was given to the Latin colony of Lucca with Luni as the principal centre from which the Romans controlled the area. According to Ambrosi (1981), the areas within the colony of Lucca retained their indigenous element. However, a rapid transformation in the local economy took place along with the intense soil exploitation which occurred with the introduction of shifting cultivation by the Romans. However, this Roman system only extended to Aulla, while settlements in higher elevations continued the traditional practice of *del debbio*, that is, the control of vegetation by fire. Therefore, two distinct cultural zones could be found in Lunigiana at this time. One of these zones, the coastal district, extended to the village of Aulla, under the direct influence of the Romans who centralized the area's economy and imposed shifting cultivation practices on farmers, while the second area was located in the uplands, where the traditional methods of *del debbio* and the continual reduction of forest area took place.

Therefore the expansion of the Roman Empire and their water management schemes, wood cultivating, slope terracing, and agricultural and pastoral development caused Lunigiana's natural environment to change. Until the late period of the Roman Empire, the vegetation of the landscape above 800 to 1,000 meters above sea level consisted of impressive silver fir forest stands. Intermediate slopes were covered predominantly with hornbeam, maple, juniper, hazelnut, and holm oak while *Erica* scrub extended toward the coast. However during the late Roman Empire land used for chestnut orchards as well as fields crops and pastureland were cleared by fire and these land uses dominated the landscape while human occupation of the land also affected the population of many wild game species such as deer, wild boar, rabbit, and some birds.

Between the fourth and sixth centuries A.D. the fall of the Roman Empire caused the more populated Roman cities and plains areas to be abandoned while the mountains were being repopulated. This occurred since new land jurisdictions in northern Italy, were aimed at protecting the Italian peninsula against invading European tribes. Other elements which influenced the change in settlement structure and landscape pattern included a revival of agriculture and the regrouping of people into communities as well as the diffusion of Christianity which brought about territorial subdivisions and the founding of monasteries, churches, and abbeys throughout Italy from which these subdivisions were administered.

During the early Medieval period some areas experienced a recovery of forests on land which had reduced agricultural capabilities, while in areas where agricultural practices persisted on secondary agricultural lands, inferior crops were grown. In fact the Feudal Period in Lunigiana, which was dominated by the rule of the Malaspina family, was distinguished by the exploitation of land by agricultural activities in order to support urban populations. This exploitation continued until the late Medieval Period (A.D. 1400 to 1600) when much of Tuscany's hilly and mountainous areas had become poor agricultural areas, unsuitable for herbaceous cultivations. This forced many rural upland communities, such as those found in Lunigiana, to support large numbers of people.

Between the fifteenth and nineteenth centuries changes occurred in the population structure due to the expansion of urban centres in lowland areas and the emergence of an agrarian landscape in mountain areas. The sixteenth century saw the emergence of a distinct agricultural mosaic due to increasing agricultural development which coincided with migrations to Lunigiana. Use of the area's natural resources, especially for the cultivation of field crops, orchards, and pasture, resulted in the exhaustion of much of Lunigiana's soil by the seventeenth century. During this time the search for marble quarries in the Alpi Apuane mountains, and agricultural opportunities in Lombardia and the Padana Plain, resulted in yet another demographic decline in Lunigiana.

By the eighteenth century, important road networks had again been established throughout Lunigiana, and the Apennine forests, which had once been cleared for pastureland and chestnut plantations, had almost completely disappeared. At this time the Magra River watershed experienced tremendous hydrological degradation due to the harvesting of trees in the floodplain resulting in increasing landslide occurrences, while the entire ecosystem changed as a result of these land use practices.

The nineteenth century saw fluctuations in environmentally sound agricultural practices. Chestnut cultivation and pastoralism had become the principal sources of sustenance for local upland populations. However by the middle of the century, during the unification of the Italian Kingdom in 1861, pastoralism and agricultural activities began to decline in Lunigiana and throughout Italy as people moved from rural areas to urban centres. Although Lunigiana experienced large population decreases after the 1860's, the area continued to function as a "bottle-neck" for the movement of people, armies, and materials - fierce battles during World War II to control the roads destroyed much of the area (Farina 1993b).

3.4 Discussion

Lunigiana has been affected by a tremendous human and non-human history which has influenced land use practices and resource management throughout the area. Lunigiana's diversity, which is a result of its history, makes it a suitable area for studying the effects of land use practices on the landscape pattern and overall ecosystem health. The next chapter examines the processes affecting Lunigiana's landscape pattern in the past 130 years and the influence Lunigiana's history has had on the landscape mosaic. In particular Chapter Four applies landscape ecology to ecosystem health assessment, emphasizing that the landscape level reveals the effects of many biophysical and social ecosystem processes which occurred throughout history and which must be taken into consideration to improve ecosystem-based management in Lunigiana.

CHAPTER FOUR

ANALYSIS

Lunigiana's unique landscape mosaic of fields, woodlots, river corridors, prairies, and villages is a result of natural and anthropogenic processes which have taken place over thousands of years. During the past century, the area has experienced more rapid economic, cultural, and environmental change than ever experienced before. In order to understand the effects of these changes on the ecosystem, this chapter will analyze and examine the effects of human and natural processes on Lunigiana's landscape by studying the landscape patterns of three sites along the Taverone River and Lunigiana's general landscape. Landscape pattern indices and summary data on the land uses occurring in the area will be used in the quantitative analyses of the landscape, while historical and socioeconomic analyses will be used to understand the evolution of the current landscape pattern. The effectiveness of using and linking these analyses in ecosystem health assessment and an interpretation of the findings will also be presented.

4.1 Landscape Analysis

The discipline of landscape ecology has much potential to be used in environmental management since it can assist to understand the relationship between spatial and temporal patterns and ecosystem processes through its emphasis on broad spatial and temporal scales and patterns. It can also be used to analyze the interactions between natural and managed ecosystems occurring at a variety of scales. Landscape pattern identification and quantification must be performed before landscape patterns can be used to assess and understand ecosystem processes in order to compare the landscape patterns and the ecological processes affecting the landscape patterns of the study sites.

The spatial patterns observed in landscapes are a result of biophysical and human processes, resulting in a mixture of natural and human-dominated patches which vary in shape, size, and arrangement. The landscape indices used to quantify Lunigiana's landscape patterns have been applied to several landscape analyses (See O'Neill *et al.* 1988; Turner and Ruscher 1988; Turner *et al.* 1989a,b; and Turner 1990), where the indices have been tested or used to study landscape patterns through time. However, none of these studies have interpreted the effects of time on landscape pattern through the use of historical and socioeconomic as well as landscape pattern analyses.

Lunigiana's landscape pattern was studied at a fine scale along the Taverone River valley using three study sites (Figure 1.2). An effective landscape analysis of this valley combined an examination of the change in landscape pattern through time with the changes that occur as one ascends almost 1,200 meters through the rural mountain landscape. Altitudinal change is an important variable in the Lunigianan landscape since it has influenced settlement within Lunigiana and the types of land uses taking place which in turn affect the landscape mosaic. When people began to settle in Lunigiana, the first, and ultimately larger villages to be established were located at lower elevations since people were primarily moving into the area from the low-lying coastal area southwest of Lunigiana. With the exception of this coastal area Lunigiana was difficult to access due to its insular position in the northern Apennines (Garuglieri 1990). Moving up the river valleys, increasingly smaller settlements were established, but these became increasingly self-sufficient due to their distance from other settlements.

4.1.1 Analysis of the Study Sites

A 125 by 125 meter grid was established on land use maps of the study sites in order to measure the percentage of area occupied by the different land uses and to quantify the landscape pattern of each study site through the use of landscape pattern indices. The number of cells in the study sites around Aulla, Licciana, and Tavernelle, (403, 427, and 449 respectively) differed slightly due to the presence of unphotointerpretable military zones in the area. A total of eight land uses were identified in these sites including urban, cultivation including olive orchards, vineyards, mixed cultivation, and fruit trees, abandoned cultivation, woodland, woodland degraded due to human activities, chestnut cultivation, pasture, and waterways and canals (Figures 3.6, 3.7, and 3.8).

Three landscape indices were used to examine and compare the landscape pattern in the three study sites with each other. Diversity (*H*) was used to measure the variety of types of land uses occurring in the area, dominance (*D*) measured the extent to which one or a few patches dominate the landscape, and contagion (*C*) measured the extent to which patch types are aggregated (See Table 4.1). The landscapes of the second and third study sites had more diverse (higher *H* value) and

Location of Study Site	P1	P2	P2a	P3	P3a	P4	P5	P6	*H*	*D*	*C*
Aulla	15	31	0	42	1	0	1	10	1.36	0.24	0.73
Licciana	4	39	4	18	28	0	6	1	1.49	0.24	0.73
Tavernelle	1	11	9	13	49	14	3	0	1.52	0.22	0.74

Table 4.1: Landscape indices and summary data for the three study sites in Lunigiana, Italy. The percentage of landscape in urban, cultivation, abandoned cultivation, woodland, degraded woodland, chestnut orchard, pasture, and waterways is given by P1, P2, P2a, P3, P3a, P4, P5, and P6 respectively. The indices *H*, *D*, and *C* relate to the diversity, dominance, and contagion indices respectively.

clumped landscape patterns (higher *C* value) and were characterized by land use types of smaller, equal proportions, (lower *D* value) than the landscape around the first study site. These values are a result of the patterns which characterize the landscape of the study sites. For example, the numbers and sizes of land uses varied among the the study sites with the first study site containing less than one percent abandoned land and a small proportion of pastureland. As elevation of the study sites and distance from urban centres increase, the amount of abandoned cultivated land and degraded woodland increase significantly while the amount of urban area decreases. As well, whereas waterways are present and chestnut orchards are absent in the first study site, increasing distance from urban centres result in an increase in the amount of chestnut orchards and in the disappearance of waterways.

A change is also observed in the spatial arrangement of land uses as elevation increases and is reflected in the values of the landscape pattern indices. For example, different land uses are scattered throughout the second and third study sites in more evenly distributed proportions than the land uses in the first study site. This accounts for the increasing diversity and decreasing dominance values associated with increasing elevation. At the same time, however, large areas of cultivated, woodland, degraded woodland, chestnut orchards, and pastureland still exist in the second and third sites therefore accounting for the increasing contagion value.

It should be noted that due to the continuous use of the landscape around Aulla by humans, the first study site tends to be less complex in shape than those of the second and third sites which receive less human influence. The observed complexity of patches of transitional land, that is those abandoned and degraded woodland areas, increase with increasing elevation. These transitional lands were derived from once cultivated and felled land, the cultivated land of which was typically abandoned first from the perimeters creating complexly shaped patches of successional lands.

Qualitative landscape analyses also reveal that differences in the dominant types of edge (from cultivation-urban and cultivation-woodland to cultivation-degraded woodland and abandoned land-degraded woodland) reflect the successional stages that are occurring as increasing amounts of cultivated land become abandoned. As well the land use patterns are also seen to reflect the physiology of the landscape. The land uses within the first and second study sites conform with the relief and hydrology of the area thus explaining the southwest to northeast direction of the land uses. As elevation increases, the relief does not necessarily follow the same direction and therefore the land uses are oriented in other directions.

The trends occurring in the landscape patterns of the study sites coincide with the socioeconomic trends occurring in the area. That is, as the settlements become more remote the effect of depopulation and subsequent agricultural land abandonment have a devastating effect on the socioeconomic viability of the communities, the results of which can be seen at the landscape level. Moreover, a gradient in the extent and intensity of land abandonment with increasing altitude, distance from urban centres, and distance from the main highway is also observed.

For example, the village of Aulla is located close to Massa Carrara's coastal urban centres (Figure 4.1). It is situated in the commune of Aulla which experienced a 1 percent increase in population between 1951 and 1971. With 35 percent of the population employed in agricultural activities in 1951, the area was not as heavily dependent upon agriculture as more remote communes, and despite a decrease of 83 percent of people employed in the agriculture industry in Aulla between 1951 and 1981, only 1 percent of its land is abandoned cultivated land. This trend is observed in Aulla because of its proximity to lowland urban centres which has caused it to experience similar modernization of agricultural techniques as those occurring in the lowland areas, thus requiring less people (ISTAT 1954, 1964, 1973).

The village of Licciana is a little more remote due to its elevation (202 meters above sea level) and distance from the urban centres. Licciana is located in the commune of Licciana which experienced a population decrease of 28 percent between 1951 and 1971. Licciana was more dependent on the agricultural industry than Aulla

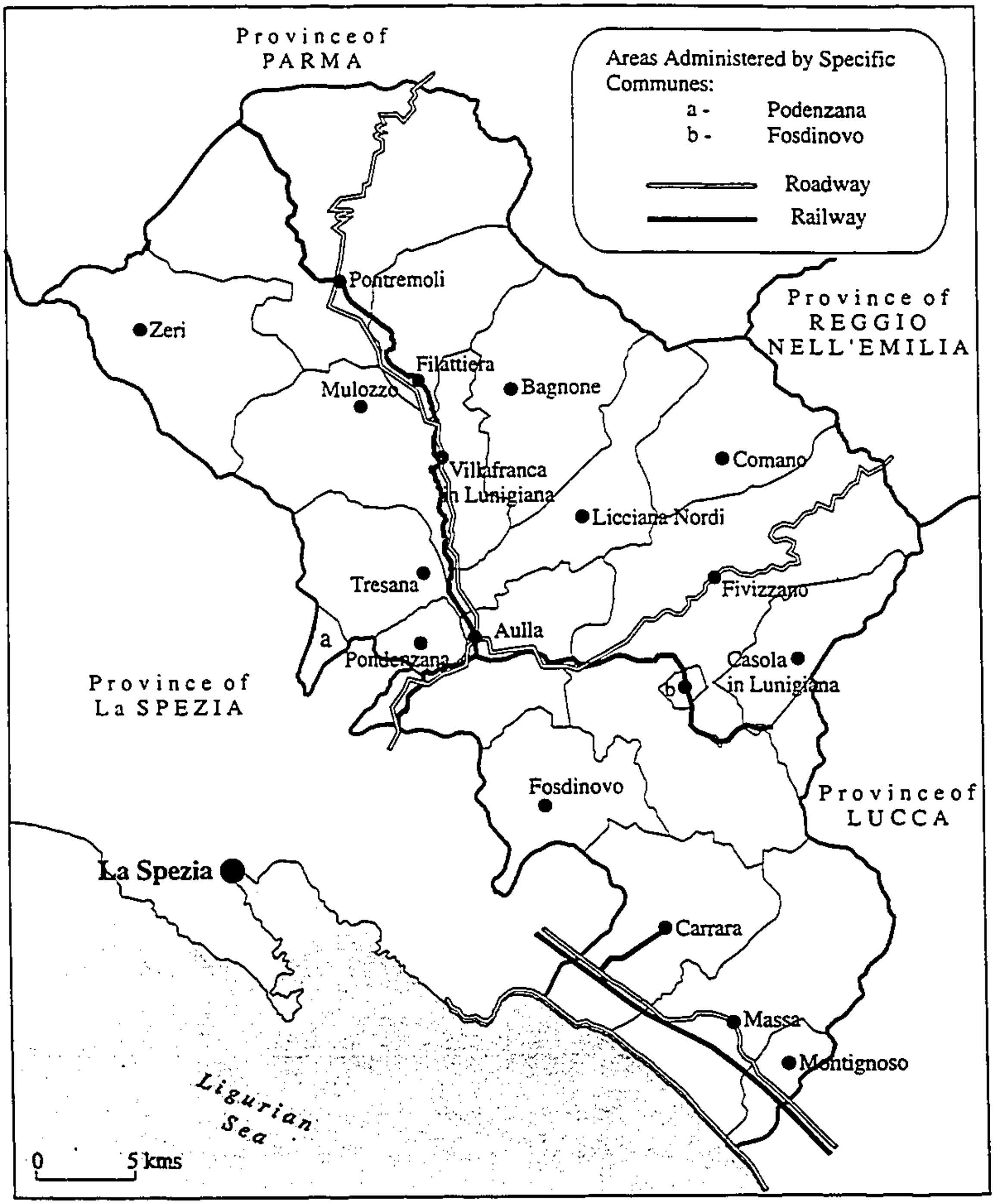

Figure 4.1: Location of villages and communes within the province of Massa Carrara, Italy (ISTAT 1954, 4).

with 50 percent of its population was employed in agriculture activities in 1951. Because of the importance of the agriculture industry in Licciana, a decrease in population has resulted in a 78 percent decrease in agricultural workers. This decrease is slightly lower than that experienced in Aulla, however more of Licciana's cultivated land has been abandoned (4 percent) while 28 percent of Licciana's land is open or degraded woodland area as a result of agriculture activities. Thirty-nine percent of Licciana's land is still being cultivated as compared to 31 percent in Aulla therefore maintaining that the agriculture industry is still important in this area (ISTAT 1954, 1964, 1973).

These trends continue as the villages along the Taverone River valley increase in elevation and distance from urban centres. The village of Tavernelle is also located in the commune of Licciana, but it is even more remote than the village of Licciana at an elevation of 412 meters above sea level. The agriculture industry must have been particularly important in this village due to its remoteness. Land abandonment in Tavernelle has resulted in 9 percent of its previously cultivated land being abandoned while 49 percent of its land is open or degraded woodland as a result of past agricultural activities. Only 14 percent of the land around the village of Tavernelle is still being used for agricultural purposes (ISTAT 1954, 1964, 1973). (Note: chestnut cultivations were not included in this figure since most of these orchards have been abandoned and they are not distinguished on the land use map).

It is important to note that the amount of abandoned cultivated and degraded or open woodland not only increases with increasing altitude, but also increases with the area's past dependence on the agriculture industry since such areas have experienced significant depopulation, land abandonment, and subsequent revegetation since the turn of the century. These transition areas, in combination with the other areas that have been affected by agricultural activities, (that is cultivations, chestnut orchards, and pastureland), also increase with altitude (33, 77, and 86 percent respectively), while the amount of urbanized land decreases with elevation (15, 4, and 1 percent respectively).

Since ecological processes vary in their effects or importance at different spatial or temporal scales, it is important to observe ecosystem processes occurring at different levels. Finer scale aerial photographs of Lunigiana reveal a simplification of the landscape structure, due to decreasing macroheterogeneity and increasing microheterogeneity of the landscape mainly as a result of secondary succession (Farina 1991c). Forman and Godron (1986, 595-596) define macroheterogeneity as "a pattern whereby the assemblage of its landscape element types differs markedly in the extreme portions of the area examined" while microheterogeneity is defined as "a pattern where the assemblage of landscape element types around a point is similar wherever the point is located in the landscape". This increasing microheterogeneity has been caused by a gradual change from a highly fragmented landscape with many plots of land of various land uses such as cultivation, pasture, woodland, and settlement areas, to a less fragmented landscape with an increasing area of dense scrubland. Comparisons of aerial photographs through time demonstrate the decreasing diversity in the types of crops being grown. In the past different types of cereals, potatoes, herbs, and fruits characterized the agricultural mosaic, however, today many of these fields have been converted to pastureland. As well vineyards, once scattered throughout Lunigiana, have been concentrated into fewer larger orchards, olive groves have decreased in size and been substituted by other crops (Farina 1993a), and little land is being converted to urban or industrial use (Farina 1994d). Villages which were once scattered throughout Lunigiana have decreased in size becoming more dependent on urban centres for many of their goods and services while others become deserted causing the diversity of land use practices to diminish. Since Lunigiana's landscape pattern and ecosystem health are being affected by land abandonment the socioeconomic trends occurring in Lunigiana as well as the entire province of Massa Carrara must be examined.

4.2 Historical and Socioeconomic Analysis

The most significant changes in Lunigiana's landscape and ecosystem conditions for which reliable data exist date to the turn of the century, following the unification of the Italian Kingdom in 1866. At this time significant population movements within and outside Lunigiana began to take place. Most of these population movements began in the late nineteenth century and continued through to the 1950s, while other more dramatic movements began following the Second World War, continuing through to the 1980s (Farina 1991a).

Isolated upland communes experienced tremendous decreases in population. Communes such as Zeri and Bagnone both experienced drastic population declines of

50 percent between 1951 and 1971 (Figure 4.2). However communes at lower elevations and closer to the urban centres, such as Casola and Licciana, experienced less of a population decrease, 35 and 17 percent respectively (Figure 4.2). This less significant drop is due to important agricultural activities occurring in the area including olive and vineyard cultivation, as well as the proximity of these communes to lowland urban centres, which not only decreases transportation costs to the urban centres, but it enables people working in the urban centres to practice part-time farming in upland areas (Farina 1994f).

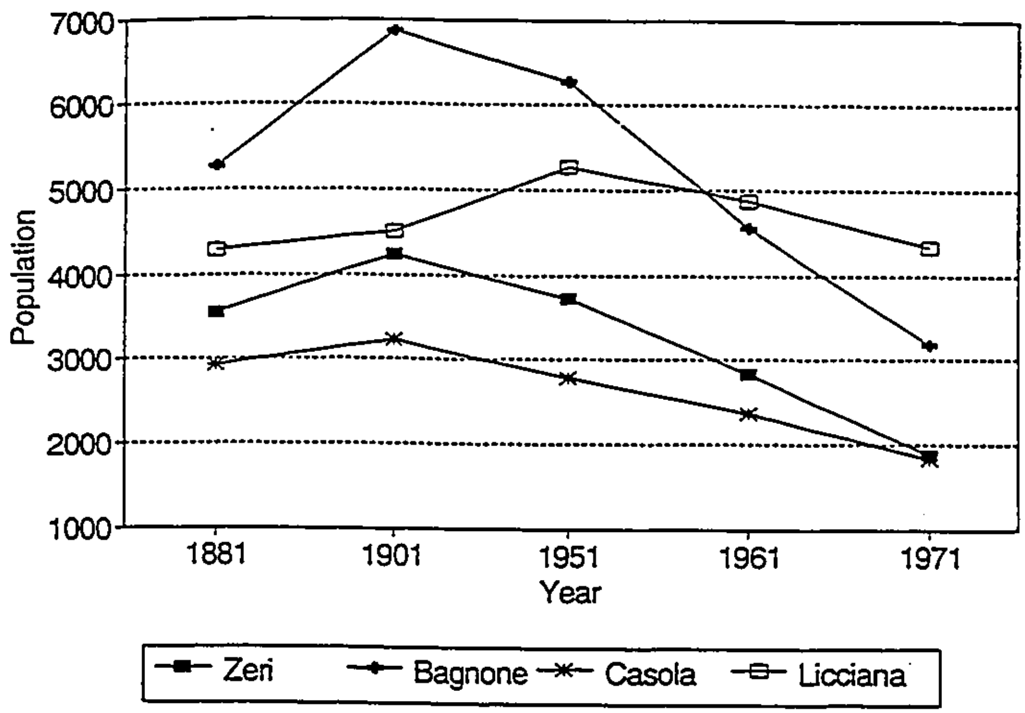

Figure 4.2: Population of rural upland communes of Massa Carrara, Italy between 1881 and 1971 (Data from Ministero di Agricoltura, Industria, e Commercio 1901 and ISTAT 1954, 1964, and 1973).

The decreases in the population of upland communes coincided with an increase in lowland population, where communes such as Carrara, Montignoso and Massa experienced population increases of 9, 20 and 25 percent respectively between 1951 and 1971 (Figure 4.3).

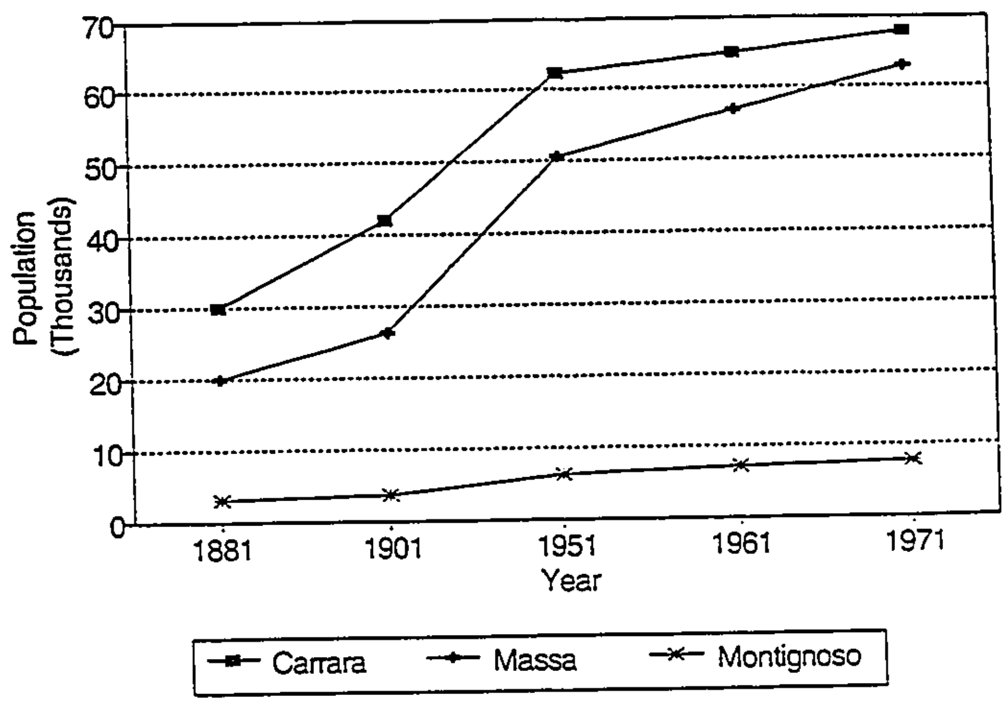

Figure 4.3: Population of lowland coastal communes of Massa Carrara, Italy between 1881 and 1971 (Data from Ministero di Agricoltura, Industria, e Commercio 1901 and ISTAT 1954, 1964, and 1973).

The rural land abandonment occurring in Lunigiana is a result of these large population movements. Evidence for this is observed by examining the changes in percentage of the population employed in the agricultural industry in these communes between 1951 and 1981 (Figure 4.4). Employment in agriculture, which once supported much of Massa Carrara's upland population, steadily decreased between 1951 and 1981. In Zeri, for example, almost 90 percent of the population was employed in agriculture in 1951,

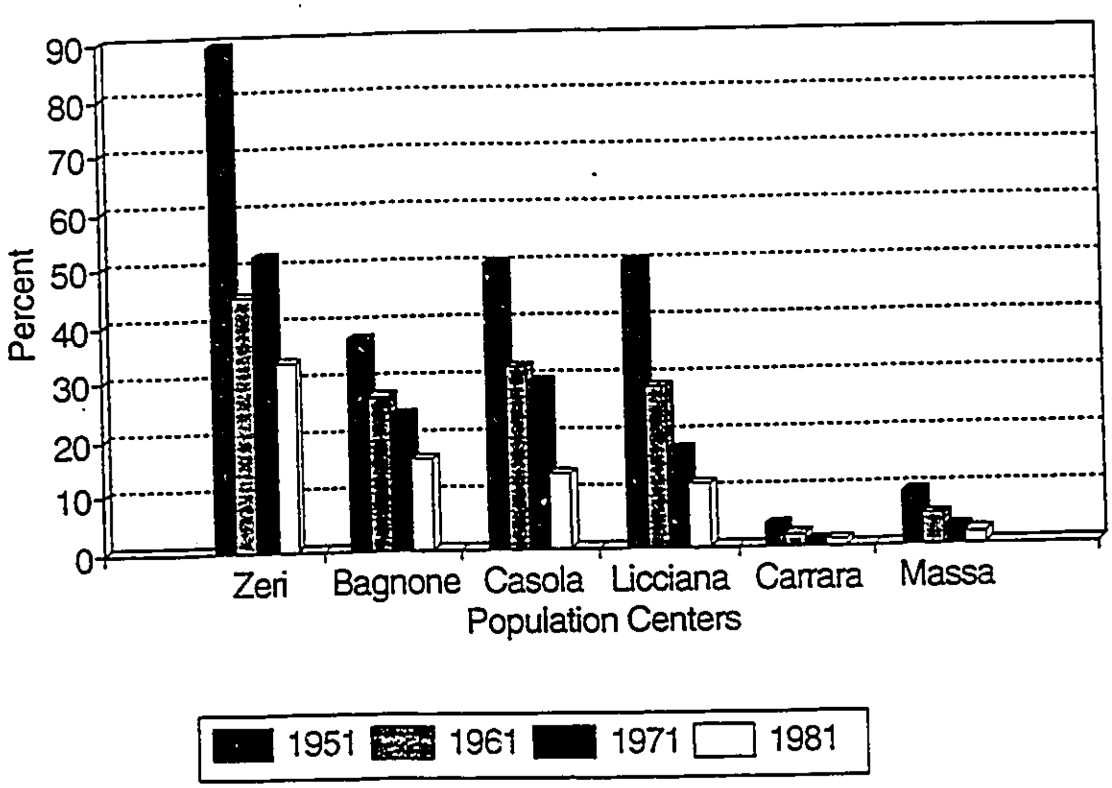

Figure 4.4: Percentage of population employed in the agriculture industry in communes of Massa Carrara, Italy between 1951 and 1981 (Data from Ministero di Agricoltura, Industria, e Commercio 1901 and ISTAT 1954, 1964, 1973, and 1983).

while this figure dropped to 33 percent in 1981. The initially high percentages of agricultural workers in the mountain and hill communes in 1951 alone is evidence that the viability of these communes was strongly based on the agricultural industry. These farming and pastoral activities resulted in a predominantly agricultural landscape in Lunigiana characterized by land use practices such as vineyards, olive and chestnut orchards, and pastureland.

On the other hand, land abandonment was sparse in the lowland areas, and abandoned agricultural land was usually replaced by urban and industrial land use practices (Farina 1994e). In the lowland communes of Massa, Montignoso, and Carrara, for example, agriculture employed only 9, 8, and 4 percent of the population respectively in 1951, decreasing to 2 percent in Massa and Montignoso and 1 percent in Carrara by 1981. This illustrates that although not all lowland communes had become major population centres by the 1950s, none depended significantly upon the agricultural industry for their survival, and the agriculture industry, which may have had a major influence in the initial development of their culture, communities, land use practices, and the landscape mosaic, no longer had a large influence.

According to Farina (1993a) the land abandonment process occurring in Lunigiana does not have a linear trend since it is dependent upon many different factors. Land abandonment in Lunigiana is affected by the area's geographic position, biophysical processes, and cultural processes including the history of the passing of property, administrative regulations, and road facilities, the effects of which all appear at the landscape level. As well, land abandonment has not occurred uniformly throughout the study area. For example, in the village of Sassalbo, in the commune of Fivizzano, land abandonment was intense until the 1970's when, after the construction of a winter sports complex a few kilometers away in Cerreto Laghi, the area acquired new economic vitality which stimulated a revitalization in the surrounding villages (Farina 1994a).

Reflecting on the effects of human and natural processes on the landscape pattern, a trend can be observed in the land abandonment occurring in Lunigiana. Population statistics reveal that population decreases and the drop in the percentage of agricultural workers increases with increasing elevation while landscape pattern analyses reveal that land abandonment also increases with increasing elevation and isolation. A few upland villages may have experienced some socioeconomic revitalization as in the village of Sassalbo, but the population of the commune of Fivizzano decreased by 30 percent between 1951 and 1971, while the percentage of agricultural workers dropped from 44 in percent in 1951 to 14 percent in 1981, therefore demonstrating the same trends are occurring in Fivizzano as are being experienced throughout Lunigiana.

As well, historical analyses reveal that abandonment is a gradual process which goes through many intermediate stages. For example, following abandonment of rural upland villages and hamlets, the amount of cultivated land is reduced. In some instances, practices which are no longer economically viable, including chestnut cultivation, charcoal production, and pastoralism, are also disappearing. Abandonment of these activities occurs particularly in those upland areas where abandonment is most significant, while more profitable practices such as olive and vineyard cultivation are more likely to be maintained since the goods produced are in demand

(Farina 1994a). Pastureland also undergoes intermediate stages often changing from cattle and sheep grazing where the maintenance of the land requires much labour, to horse grazing, which is not as labour intensive (Farina pers. comm.).

The decrease in people employed in agriculture and the overall decrease in population in Massa Carrara's upland communes, in combination with the increase in lowland urban population, were a result of the availability of more social services and the security and high returns available in lowland urban areas. These areas functioned as stable centres for the exchange of goods and services throughout Massa Carrara and Italy and attracted many people. However difficulties in mechanizing traditional agricultural practices in rural mountain areas, as well as their distance from the urban centres, contributed to a more competitive lowland agricultural system and caused upland farming to decrease in importance.

4.3 Landscape Ecology and Its Use in Ecosystem Health Assessment in Lunigiana

Lunigiana's present state is a function of continuous climatic, geomorphic, biotic, and human processes. Several observations can be made about Lunigiana's ecosystem condition upon studying Lunigiana's landscape pattern. Therefore, as suggested by several authors listed in Table 2.5.1, landscapes can function as an indicator of environmental condition and a level at which ecosystem health assessment can occur. Ecosystem health indicators are the most effective manner of measuring the condition of an ecosystem due to their ability to represent the trends in, state of, and factors affecting ecosystem health. This thesis applies landscape ecology theory and measures to ecosystem health assessment by going beyond the recommended use of landscapes suggested by the OECD (1993 - see Table 2.5.1) to demonstrate that several features of an ecosystem's environmental, economic, and social components which can be observed at the landscape level can serve as indicators of ecosystem health.

Humans have affected Lunigiana' ecosystem for thousands of years. Therefore past land use practices occurring in Lunigiana, and the manner in which they occurred, have helped to indicate the effect of human activities on the health of Lunigiana's ecosystem. For example, in the past Lunigiana's highly fragmented landscape mosaic was caused by the large number of plots and wide variety of land uses which occurred on these plots throughout the years. This resulted in the existence of many ecotones, relatively narrow overlap zones between two communities (Forman and Godron 1986,) as well as the persistence of those species which became dependent on human activities for their survival. However recent reductions in agricultural practices have caused ecotones, ecotone plant and animal species, and species dependent on human activities to disappear (Farina 1994e). As well increasing connectivity has affected Lunigiana's ecosystem health by causing many large mammal species such as deer and wolves to repopulate the area. Wild boar populations have increased becoming a pest and damaging crops (Farina 1994e) while decreases in field crop cultivation have reduced the number of graniverous birds, particularly during spring and fall migration. As well increased occurrences of fires due to high woodland connectivity has resulted in the loss of habitat for many plant and animal species (Farina 1994b).

In Lunigiana the landscape level can also be used to observe the socioeconomic impacts of human population movements on the ecosystem. Populations at higher altitudes have experienced greater declines than those at lower altitudes therefore resulting in larger areas of cultivated land being abandoned. In terms of the consequences of anthropogenic effects on the landscape listed in Table 2.5.2, humans have rescaled the natural spatial and temporal patterns of Lunigiana's landscape. The introduction of human land use practices in the area such as urban, cultivation, and pastoralism have altered natural landscape patterns, processes, and boundaries. New patches are being introduced while the natural spatial and temporal scales of ecosystem processes are being affected. However it is important to note that despite these changes, these areas are in the process of regenerating. The continuing ability of Lunigiana's system to reorganize, which can be seen in the regeneration occurring in abandoned cultivated areas and open and degraded woodland areas, yillustrates the ultimately limited effects of human population movements and activities on Lunigiana's ecosystem as well as the ecological optimization of land use which occurred in the past. Much of Lunigiana's native flora and fauna have repopulated areas which were once used for human activities since the land was not permanently degraded to the extent that the information necessary to regenerate was lost while the existence of biological refuges also helped species of flora and fauna to disperse. Therefore the effect of past population movements on Lunigiana's ecosystem which are observed at the landscape level, in combination with analyses of the area's biota, reveals that the ecosystem has been able to maintain its ability to adapt and reorganize to suit changing ecosystem components and processes.

The landscape indices (dominance, diversity, and contagion) used to study Lunigiana's landscape demonstrated that quantitative methods in landscape ecology can also be used to assist in ecosystem health assessment. For example, the landscape pattern in the first study site is not as diverse or aggregated as the landscapes of the second and third sites due to the increasing amount of abandoned cultivated land and degraded woodland scattered throughout the second and third study sites. On the contrary the landscape of the first study site is presently more influenced by humans therefore resulting in a less diverse landscape with many small patches. However, the population of Aulla has been relatively constant or has increased despite a significant decline in the percentage of agricultural workers and the concurrent depopulation of upland areas. Therefore landscape pattern indices can be used to quantitatively compare the landscapes of different areas and/or periods in time and to determine the processes affecting the landscape pattern. However the index values and the landscape pattern itself should not be used to imply that certain index values denote a healthy or less healthy ecosystem. Rather the indices should be used along with other measures of ecosystem health such as soil loss, the abundance and biomass of individuals in populations, and drinking water quality, quantity, valuation, and management costs in order to effectively assess ecosystem health. This amalgamation is critical, not only to reduce the chances of misinterpreting information represented by a few indicators, but to assist in understanding the reasons for the present ecosystem condition in order to effectively manage ecosystems for the future.

Studying Lunigiana's landscape pattern has also demonstrated that its ecosystem components and processes are able to adapt to suit changing ecosystem conditions. This is partly due to Lunigiana's macroheterogeneous landscape pattern of many land uses occurring in a small area. The maintenance of Lunigiana's ecosystem resilience to stress is facilitated by this type of landscape pattern since it allows for fluctuations in ecosystem processes which are changing to suit ever-changing ecosystem conditions. As well ecosystem components are able to interact with this landscape pattern in a manner so as to encourage the activity and self-organization characteristic of healthy ecosystems.

On the other hand, many landscapes throughout the world are characterized by their microheterogeneous landscape patterns, consisting of similar landscape elements in a large area. These patterns are a result of large-scale biophysical and socioeconomic ecosystem processes, the latter of which can damage much of the information necessary for ecosystems to regenerate. This is not to say that a landscape which is dominated by one or few land uses is more healthy than a landscape with several land uses or that a landscape dominated by human land uses is more healthy than a landscape which is dominated by more natural land uses. Humans are ecosystem components and many of the goods and services produced in urban area are necessary for our survival. However it is important to note that without an ecosystem's biophysical component, all other ecosystem components cease to exist. Therefore under the dominance of a modern industrial society, the maintenance of an ecosystem's natural resilience to stress is more difficult.

Lunigiana's landscape pattern and the processes observed at the landscape level reveal that although parts of Lunigiana continue to be abandoned, the system is still able to support agricultural and other human activities. And although humans have altered parts of the ecosystem which were once only affected by natural biophysical processes, Lunigiana's ecosystem still maintains healthy biophysical conditions and has the ability to support economic and social activities. Therefore landscape analyses reveal that Lunigiana has a healthy ecosystem according to the definition

> An ecosystem is healthy if its biophysical and, where applicable, social components are active and equitable, it is able to maintain its organization and autonomy over time, and is resilient to stress.

4.4 Use of Landscape Ecology and Ecosystem Health in Ecosystem-Based Management

This thesis has demonstrated that the landscape level can be used to assist in ecosystem health assessment. Several key points illustrate the relevance of the knowledge obtained in this research, therefore linking landscape ecology and ecosystem health.

Firstly, landscapes are spatial systems which are affected by processes taking place within them, while they are also an ecological level of organization at which some of these ecosystem components and activities can be observed. Landscape patterns can be used to identify ecosystem processes taking place as patterns change, thus enabling them to detect sources of ecosystem stress. As well, quantifiable landscape measures can also be used to assess the landscape pattern and compare different landscapes or landscapes of different time periods.

According to the principles of landscape ecology listed in Chapter Two, ecological processes vary in their effects or importance at different spatial and temporal scales. The landscape level can provide an opportunity to observe broad-scale ecosystem properties which are easier to discern than many of the fine-scale physicochemical and biological indices which have often been used in the past to assess ecosystem health. For example, the extent of the revegetation of abandoned fields taking place throughout Lunigiana could not have been observed by analyzing the changes in the concentration of phosphorus in Lunigiana's waters or the changes in the population of greenfinches throughout Lunigiana.

Another landscape principle stated that the relationship between spatial pattern and ecological processes is not restricted to a single spatial or temporal scale. Therefore the broad-scale spatial and temporal view of ecosystems provided by the landscape level also enable us to observe the effects of long- or short-term ecosystem properties which are affected by or are caused by other long- or short-term ecosystem properties. This attribute of landscapes can be used to discover other indicators of ecosystem health while also helping to discern sources of ecosystem stress. In this thesis the landscape level allowed us to view the effect of long-term agriculture activity and comparatively short-term land abandonment on the landscape pattern and ecosystem health, therefore demonstrating that human population movements occurring throughout Lunigiana could also be used as a socioeconomic indicator of ecosystem health.

By assisting to discern sources of ecosystem stress, the landscape level can then be used to determine suitable spatial and temporal scales to monitor the landscape pattern and other indicators of ecosystem health depending upon the objectives of the management issue. Ecosystem processes occur at different scales and affect different levels of the ecosystem, therefore the broad-scale observations provided by landscapes can be used to determine suitable monitoring scales to observe the effects of those ecosystem processes emerging at the landscape level.

Landscape ecology is the study of the structure, function, and change of a heterogeneous land unit which is composed of interacting systems. Studying an area which has been influenced by long-term natural, and in particular human processes, has revealed that understanding the relationship between environmental history and changing landscape pattern is critical for effective ecosystem health assessment since landscapes are affected by human activities which rescale patch dynamics, bound regions, introduce new patches, and homogenize landscape patterns, which in turn affect ecosystem health.

This research also demonstrates that landscapes can be used in many different ways in ecosystem health assessment. Landscapes can function as an indicator of ecosystem health as well as a focus for the development and observation of other indicators of ecosystem health, and determine the processes underlying the health of an ecosystem. Using these landscape attributes has increased our understanding of the processes affecting Lunigiana's ecosystem, it's response to these processes, the resulting pattern emerging at the landscape level, and the health of the ecosystem. Most importantly, the application of the information provided by landscapes which identifies the processes affecting the spatial interaction of landscape units has demonstrated that landscape ecology can be used in ecosystem health assessment.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

Ecosystem-based management emphasizes the integrated management of all ecosystem components, both biophysical and cultural. As ecosystem components influence all hierarchical levels, their effects on ecosystem health must be assessed and managed at different levels. Landscape patterns develop as a result of the dynamic biophysical and cultural processes which occur throughout heirarchical levels, therefore landscape ecology can by used to understand the relationship between spatial and temporal patterns and ecosystem processes.

The aim of this research was to demonstrate the applicability of landscape-level analyses in ecosystem health assessment within the framework of ecosystem-based management approaches. Throughout this thesis various themes, concepts, methods in landscape ecology, such as spatial and temporal patterns, structure and function, and scale and hierarchy, have been referred to and used to identify and understand the relationships, dependencies, and causalities between changing landscape patterns and ecosystem health through time. This chapter provides an overview of the research and findings of this research in order to demonstrate the benefits of using landscape ecology in managing for ecosystem health assessment for the purpose of improving ecosystem-based management.

5.1 Summary

Although both landscape ecology and ecosystem health are in their infancy, there is much potential for using landscape ecology in ecosystem health assessment and management. Landscape ecology is regarded as the "central focus" of many disciplines used in environmental planning and management such as forestry and wildlife management therefore rendering landscape ecological theories and concepts useful in ecosystem-based management. Landscape ecology provides a framework for studying ecosystem processes in space and time with landscapes functioning as a vantage point from which to observe the effects of long-term and/or large scale ecosystem processes on ecosystem health. Therefore environmental management, whether aimed at protection, conservation, or development, should include an understanding of the spatial and temporal dynamics of ecosystems observed at the landscape level.

Landscapes should be used in ecosystem health assessment since they help us to understand the historical context of ecosystem changes. Landscape changes occur as a result of short- and long-term ecosystem processes and these changes affect ecosystem health. Therefore the landscape level provides us with a level at which to study the relationship between human societies and the environment through time by enabling us to see beyond the time scale of a human life span.

In Lunigiana, landscape level observations provided greater insights into the processes affecting the ecosystem. Not only did the landscape level help to reveal those processes occurring during land abandonment, a major factor affecting Lunigiana's current landscape pattern, but it also demonstrated the effects of historical ecological processes such as climate, geomorphology, pedology, and agricultural activities, which have had an even greater impact in the overall landscape pattern and ecosystem health. For example, a decrease in population in Lunigiana has resulted in a decrease in the percentage of agricultural workers which in turn affected the land use practices occurring in the area. However the manner and intensity with which previous land use practices were performed in the past affected the overall response of the system's natural components to current human activities. Left alone, natural ecosystems are dynamic and self-organizing entities; they have the ability to regenerate, but only if the information necessary to do so has not been completely destroyed, and if the conditions for the use of the information have not been damaged so as to make the information worthless (Kay and Schneider 1994). The ability of Lunigiana's biota to revegetate and repopulate those areas which were once cleared for human activities demonstrates that the system has retained the information necessary for regeneration to occur. That is, suitable climate, morphology, and soil conditions in Lunigiana's physical environment, as well as the maintenance of biological information in species enabled species to adapt, remain resilient to stress, and survive.

Landscape level analyses also revealed that landscape patterns are products of disturbances, biotic processes, and environmental constraints (Urban *et al.* 1987) as well as of the changes and the rates and scales at which these changes occur in response to changing ecosystem conditions. Therefore the spatial and temporal nature of the information provided by landscape level observations enable landscapes to be a suitable level at which to study and manage for healthy ecosystems.

5.2 Limitations of Research and Future Opportunities

Landscape pattern analyses through time provide us with a method for determining sources of natural- or human-induced changes in ecosystem components and processes. The landscape analyses performed in this thesis have drawbacks since they did not involve comparisons of landscape index measurements through time. Land use maps for the area were only available for one time period, and although historic aerial photographs for the study areas existed, time constraints made generating land use maps from these photographs difficult. However if historical land use maps were available, Lunigiana's landscape dynamics could be observed, extrapolated with computer simulation models, and then used in the ecosystem health management processes. As well, although historical socioeconomic information helped to identify some of the processes affecting the current landscape pattern, additional socioeconomic information is necessary in order to manage the ecosystem more effectively. A comparison of the landscape patterns of the three study sites with additional socioeconomic information would have provided a more complete understanding of the ability of ecosystem components and processes to change to suit changing ecosystem conditions. These observations would then have helped to determine those components supporting or degrading the health of the ecosystem and therefore assist in ecosystem health assessment and management.

Using landscape pattern analyses as an indicator of ecosystem health along with other indicators of ecosystem health in Lunigiana, physicochemical, biological, and socioeconomic, would have also been useful for determining the relationship between landscape patterns and ecosystem components at different hierarchical levels. Comparison of these indicators through time would reveal the trends taking place in the indicators and the relationships that exist among the indicators. As well, comparing similar data with other areas of Lunigiana would also reduce the chances of misinterpreting information represented by only a few indicators or sites. Overall, however, the landscape level can be used to examine the manner in which ecosystems have responded to anthropogenic and natural processes, therefore acting as an indicator of ecosystem health.

5.3 Conclusions: Linking Landscape Ecology, Ecosystem Health and Ecosystem-Based Management

Studying Lunigiana's landscape not only demonstrated that landscape ecology can be used in ecosystem health analysis. In compliance with holistic ecosystem-based management approaches, landscape patterns must be studied with other ecosystem components at different hierarchical levels through time in order to understand the processes affecting landscape patterns and ecosystem health.

The use of landscape ecology in environmental management is still in its infancy in terms applying its theories and methodologies in ecosystem health management. This research is an initial demonstration of the benefits of using landscape-level analyses in the management of ecosystem health in Lunigiana, and it illustrates the potential of using landscape ecology principles to monitor and assess ecosystem conditions throughout the world.

This thesis also reveals that landscape ecology can assist in the collection and organization of information necessary to enhance environmental planning and management for the purpose of improving ecosystem-based management. Like ecosystem-based management approaches which focus on "important long-term and/or large-scale observations" (WQGTG 1994, 5), landscapes provide a level of observation which emphasizes broad and long-term scales and patterns. Studying Lunigiana's landscape which has been influenced by humans for thousands of years three ecological phenomena are observed. First we observe the simultaneous continuity and dynamic nature of ecosystem processes at the landscape level. Second we see that landscape patterns are the result of overlapping ecosystem processes in space and time that constantly change to suit changing ecosystem conditions. Third this research demonstrates that the overlapping and commonality of ecological processes which can be observed at the landscape level, together with the increasing understanding of landscape ecology, point to the landscape-level as a promising scale for ecosystem-based management. And since many ecosystem management activities involve decisions which affect the landscape pattern, the landscape level must be considered in the decision-making process.

Using landscape ecology to study Lunigiana in order to demonstrate its applicability in ecosystem assessment and management adds a new dimension to ecosystem health assessment. Landscape ecology enables us to view ecosystems with a different perspective which is necessary in order to manage ecosystems effectively since different ecosystem processes resonate and are expressed differently at different ecological levels.

5.4 Closing Remarks

Managing for a healthy ecosystem should incorporate the monitoring and assessment of components within different hierarchical levels for a time span suitable and feasible for the management goal, always keeping in mind the historical context of the changes occurring in the ecosystem. These can in turn be used to help predict the effects of proposed human activities and to distinguish these effects from naturally-occurring changes for the purpose of managing for the persistence of all ecosystem processes. Landscape ecology provides us with methods of linking spatial patterns and ecosystem processes at broad spatial and temporal scales, linking the past, present, and future.

Ecosystem-based management is integrated management, considering all ecosystem components and requiring that all levels of an ecosystem be managed collectively to maintain or enhance the health of an ecosystem. Landscapes reflect ecosystem processes, whether natural- or human-induced, and the mutual dependence of ecosystem components, and thus can be used to improve ecosystem-based management. Therefore landscapes can be used to assist in the study, description, and understanding of individual parts of ecosystems and the interactions taking place between them in order to manage ecosystems in an integrated manner.

APPENDIX 1

FLORA

Common Name	Scientific Name
Alpine Laburnum	*Laburnum alpinum*
Alpine Rose	*Rhododendron ferrugineum*
Austrian Pine	*Pinus nigra*
Beech	*Fagus*
Black Alder	*Alnus glutinosa*
Blueberry	*Vaccinium spp.*
Chestnut	*Castanea sativa*
Common Hawthorn	*Crataeugus monogyna*
Common Laburnum	*Laburnum anagyroides*
Common Mat-Grass	*Nardus stricta*
Cornelian Cherry	*Cornus mas*
Downy Oak	*Quercus pubescens*
English Oak	*Quercus pedunculata*
European Dewberry	*Rubus caesius*
European Hazel	*Corylus avellana*
European Hop-hornbeam	*Ostrya carpinifolia*
European Mountain Ash	*Sorbus aucuparia*
European Red Alder	*Sambucus racemosa*
European Turkey Oak	*Quercus cerris*
False Brome Grass	*Brachypodium pinnatum*
Field Maple	*Acer campestre*
Flowering Ash	*Fraxinus ornus*
French Willow	*Salix triandra*
Great Wood Rush	*Luzula multiflora*
Hazelnut	*Corylus*
Hoary Willow	*Salix elaeagnos*
Holm Oak	*Quercus ilex*
Hornbeam	*Carpinus betulus*
Italian Maple	*Acer opalus*
Juniper	*Juniperus*
Ladies Mantle	*Alchemilla*
Maritime Pine	*Pinus pinaster*
Majanthemum	*Maianthemum bifolium*
Mountain Avens	*Geum montanum*
Mountain Lotus	*Lotus alpinus*
Olive	*Oleaceae*
Purple Osier	*Salix purpurea*
Red Pine	*Picea excelsa*

Sessile Oak	*Quercus petraea*
Sweet Vernal Grass	*Anthoxanthum odoratum*
Trembling aspen	*Populus tremuloides*
White Beam	*Sorbus aria*
Wild Service Berry	*Sorbus torminalis*
Whortleberry	*Vaccinium myrtillus*
Wood Rush	*Luzula*

FAUNA

Alpine Pine Vole	*Pytmus multiplex*
Apuanis Alpine Newt	*Triturus alpestris apuanis*
Black Bullhead	*Ictalurus melas*
Brown Bear	*Ursus arctos*
Brown Hare	*Lepus europaeus*
Chaffinch	*Fringilla coelebs*
Common Sturgeon	*Acipenser sturio*
Crested Newt	*Triturus cristatus carnifex*
Dunnock	*Prunella modularis*
Edible Doormouse	*Glis glis*
Eel	*Anguilla anguilla*
Eurasian Pygmy Shrew	*Sorex minutus*
Eurasian Red Squirrel	*Sciurus vulgaris*
European Robin	*Erithacus rubecula*
European Toad	*Bufo bufo spinosus*
Fallow Deer	*Dama dama*
Fire Salamander	*Salamandra salamandra*
Garganey	*Anas querquedula*
Goldfish	*Carassius auratus*
Grey Heron	*Adrea cinerea*
Greenfinch	*Carduelis chloris*
Green Lizard	*Lacerta viridis viridis*
Hawfinch	*Coccothrustes coccothraustes*
Hazel Doormouse	*Muscardinus avellanarius*
Lapwing	*Vanellus vanellus*
Lesser Weasel	*Mustela nivalis*
Little Egret	*Egretta garzetta*
Mallard	*Anas platyrhynchos*
Mediterranean Mole	*Talpa caeca*
Mistle Thrush	*Turdus viscivorus*
Mouflon	*Ovis musimon*
Osprey	*Pandion haliaetus*
Pine Marten	*Martes martes*

Pygmy White-Toothed Shrew	*Suncus etruscus*
Rainbow Trout	*Salmo gaidneri*
Red Fox	*Vulpes vulpes*
River Lamprey	*Lampetra fluviatilis*
Roach	*Rutilus rubilio*
Roe Deer	*Capreolus capreolus*
Sea Lamprey	*Petromyzon marinus*
Serin	*Serinus serinus*
Siskin	*Carduelis spinus*
Slow Worm	*Anguis fragilis*
Song Thrush	*Turdus philomelos*
Sparrowhawk	*Accipiter nisus*
Twaite shad	*Alosa fallax*
Wild Boar	*Sus scofa*
Wolf	*Canis lupus*
Woodcock	*Scolopax rusticola*
Yellow-Crowned Great Heron	*Nycticorax nycticorax*

References Cited

Allen, Timothy F.H., Bruce L. Bandurski, and Anthony W. King. 1994. *The Ecosystem Approach: Theory and Ecosystem Integrity*. Report to the Great Lakes Science Advisory Board International Joint Commission, U.S.A. and Canada.

Ambrosi, A.C. 1981. *La Romanizzazione della Lungigana*. Aulla.

Bailes, K.E., ed. 1985. *Critical Issues in Environmental History*. University of America Press, New York.

Belsky, M.H. 1994. Implementing the Ecosystem Management Approach: The view of an incurable optimist. Page 7 in *Abstracts of The 1st International Symposium on Ecosystem Health and Medicine*. Ottawa, Ontario. June 19-23, 1994.

Cairns, J. Jr. 1992. Monitoring for Global Change. Pages 63-75 in J. Cairns Jr., B.R. Niederlehner, and D.R. Orvos, eds. *Predicting Ecosystem Risk: Advances in Modern Environmental Toxicology*. Vol. XX. Princeton Scientific Publishing Co. Inc., Princeton, New Jersey.

Cairns, J. Jr., P.V. McCormick, and B.R. Niederlehner. 1993. A proposed framework for developing indicators of ecosystem health. *Hydrobiologia*. 263:1-44.

Christie, W.J., M. Becker, J.W. Cowden, and J.R. Vallentyne. 1986. Managing the Great Lakes Basin as a home. *Journal of Great Lakes Research*. 12(1):2-17.

Cole, J.P. 1964. *Italy*. Chatto and Windus, London.

Costanza, R. 1992. Toward an operational definition of ecosystem health. Pages 239-256 in R. Costanza, B.G. Norton, and B.D. Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, New York.

Costanza, R., B.G. Norton, and B.D. Haskell, eds. 1992. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, D.C.

Council of Great Lakes Research Managers. 1991. *A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region*. International Joint Commission, U.S.A. and Canada.

Eliot, T.S. 1948. *The Four Quartets*. Faber and Faber, London.

Farina, A. 1980. *Lunigiana: l'ambiente e i suoi caratteri*. Centro Aullese di Ricerche e di Studi Lunigianesi, Aulla.

Farina, A. 1990. Structural and functional patterns of the agriculture landscapes in Northern Apennines (Italy) and their role for the biodiversity maintenance and the environmental hazard control in the Mediterranean region. in *V International Congress of Ecology: the optimization of agricultural landscape structure for control of environmental hazards*. Yokohama, Japan, 23-30 August.

Farina, A. 1991a. Recent changes of the mosaic patterns in montane landscape (North Italy) and consequences on vertebrate fauna. *Options Mediterraneennes*. 15:121-134.

Farina, A. 1991b. Effects of changes of human disturbance regime on the structure and dynamics of bird communities in a Mediterranean landscape. in O. Ravera, ed. *Terrestrial and Aquatic Systems: Perturbation and Recovery*. Ellis Horwood Limited, Ravera.

Farina, A. 1991c. Vanishing rural landscape in Italy: a case study. Pages 21-30 in *Proceedings of the European IALE seminar of Practical Ecology*. Roskilde, DK.

Farina, A. 1993a. Land abandonment in a Mediterranean landscape and new holistic management perspectives. in *Restauracion de la Cubierta vegetal en sistemas Mediterraneos*.

Farina, A. 1993b. The Italian Cultural Landscape: Lunigiana a case study. in H. Plachter, ed. *Cultural Landscapes of Universal Value: components of global strategy*. UNESCO.

Farina, A. 1994a (in print). Land abandonment and conservation strategies in the Apennines uplands. in *Institute for European Environmental Policy Publications*, London.

Farina, A. 1994b. Land abandonment and effects on fauna in the Northern Apennines. Pages 781-793 in *Proceedings of Man and Mountain '94*. Primo convegno internazionale per la protezione e lo sviluppo dell'ambiente montano. Ponte di Legno, B.S.

Farina, A. 1994c. Land abandonment in montane areas: effects on landscape structure and functioning. Page 68 in John J. Tallis, Hazel J. Norman, and Richard A. Benton, eds. *Progress to Meet the Challenge of Environmental Change: Proceedings of the VI International Congress of Ecology*. 21-26 August 1994.

Farina, A. 1994d (in press). Upland farming systems of Northern Apennines and the Conservation of biological diversity. in *International Union for the Conservation of Nature Conference on the Biological Diversity Conservation Outside Protected Areas: overview of traditional agrosystems.*

Farina, A. 1994e. Agricultural abandonment in a mountainous Mediterranean landscape (Italy): consequences on biodiversity and management implications. *XV International Botanical Congress, Tokyo. August 1993. Landscape Ecology for Sustainable Land Use and Restoration.*

Farina, A. 1994f. L'abandono rurale e suoi effetti sul paessaggio. Pages 149-163 in Cattaneo, D. and P. Semenzato, eds. *Atti XXXI Coro di Cultura in Ecologia*, San Vito di Cadore.

Ferrarini, E. 1982. Carta della vegetazione dell'Appeninno Tosco-Emiliano dal Paso della Cisa al Passo delle Radici: note illustrutive. *Bollettino del Museo di Storia Naturale della Lunigiana.* 2:5-25.

Forman, R.T.T., and M. Godron. 1986. *Landscape Ecology*. John Wiley & Sons, New York.

Garuglieri, P.L. 1990. *Un Fiume da Salvare: Dalle sorgenti del Monte Borgognone all'estuario di Bocca di Magra - impotesi di pianificazione per un parco fluviale del Magra*. Universita degli Studi di Firenze, Faculta di Architettura, Instituto di Urbanistica, Firenze.

Giordano, V.M., P. Le Grottaglie, and R. Nevini. 1986. *Carta dell-uso del suolo della Toscana*. 1:25,000. Regione Toscana.

Golley, F.B. 1987. Introducing Landscape Ecology. *Landscape Ecology*. 1(1):1-3.

Gray, P.A., J. Maclean, I. Kirkham, D. Fawle, and J. Skelton. 1994. Towards Ecosystem Health: Redesigning our approach to natural assett management in Ontario. Pages 40-41 in *Abstracts in The 1st International Symposium on Ecosystem Health and Medicine*. Ottawa, Ontario. June 19-23, 1994.

Great Lakes Water Quality Guidelines Task Group. 1994. *A Framework for Developing Goals, Objectives and Indicators of Ecosystem Health: Tools for Ecosystem-Based Management*. Draft. Canadian Council of Ministers of the Environment, Ottawa, Ontario.

Guidotti, T.L. 1994. Preparing Physicians to Address Issues of Ecosystem Health and Medicine: The Canadian Association of Physicians of the Environment. Pages 42-3 in *Abstracts in The 1st International Symposium on Ecosystem Health and Medicine*. Ottawa, Ontario. June 19-23, 1994.

Hammett, J.E. 1992. The Shapes of Adaptation: Historical ecology of anthropogenic landscapes in the Southeastern United States. *Landscape Ecology*. 7(2):121-135.

Hansson, L., and P. Angelstam. 1991. Landscape ecology as a theoretical basis for nature conservation. *Landscape Ecology*. 5(4):191-201.

Hartig, J.H. and J.R. Vallentyne. 1989. Use of an ecosystem approach to restore degraded areas of the Great Lakes. *Ambio*. 18(8):423-428.

Haskell, B.D., B.G. Norton, and R. Costanza. 1992. What is ecosystem health and why should we worry about it? Pages 3-20 in R. Costanza, B.G. Norton, and B.D. Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, D.C.

Hughes, J.D. 1993. The Ancient Roots of our Ecological Crisis. Pages 167-172 in S.J. Armstrong and R.G. Boltzer, eds. *Environmental Ethics: Divergence and Convergence*. McGraw-Hill, Inc., Toronto.

Hunsaker C., and D. Carpenter, eds. 1990. *Environmental Monitoring and Assessment Program: Ecological indicators*. Office of Research and Development, United States Environmental Protection Agency, Research Triangle Park, N.C.

Hunsaker, C., D. Carpenter, and J. Messer. 1990. Ecological indicators for regional monitoring. *Bulletin of the Ecological Society*. 7(13): 165-172.

Hutton, J. 1788. *Theory of the Earth; or an investigation of laws observable in the composition, dissolution, and restoration of land upon the globe*. Transactions of the Royal Society of Edinburgh. 1:209-304.

Istituto Centrale di Statistica. 1954. *Volume I: Dati Sommari per Comune; Fascicolo 46 - Provincia di Massa Carrara*. Roma.

Istituto Centrale di Statistica. 1964. *Volume III: Dati Sommari per Comune; Fascicolo 45 - Provincia di Massa Carrara*. Roma.

Istituto Centrale di Statistica. 1973. *Volume II: Dati Sommari per Comune; Fascicolo 42 - Provincia di Massa Carrara*. Roma.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*. 6(6):21-27.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications*. 1(1):66-84.

Karr, J.R. 1993. Measuring biological integrity: lessons from streams. Pages 83-104 in S. Woodley, G. Francis, and J.J. Kay, eds. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press, Delray Beach, Florida.

Kay, J.J. 1993. On the nature of ecological integrity: some closing comments. Pages 201-212 in S. Woodley, G. Francis, and J.J. Kay, eds. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press, Delray Beach, Florida.

Kay, J.J. and E. Schneider. 1994. Embracing complexity: the challenge of the ecosystem approach. *Alternatives*. 20(3): 32-39.

King, A.W. 1993. Considerations of scale and heirarchy. Pages 19-45 in S. Woodley, G. Francis, and J.J. Kay, eds. *Ecological Integrity and the Management of Ecosystems*. St.Lucie Press, Delray Beach, Florida.

Klopatek, J.M., J.R. Krummel, J.B. Mankin, and R.V. O'Neill. 1983. A theoretical approach to regional environmental conflicts. *Journal of Environmental Management*. 16:1-15.

Knapp, C., D.R. Marmorek, J. Baker, K.W. Thornton, J. Klopatek, and D. Charles. 1991. *The Indicator Development Strategy for the Environmental Monitoring and Assessment Program*. Prepared for the Environmental Protection Agency, Corvallis, Oregon, U.S.A.

Krummel, J.R. R.H. Gardner, G. Sugihara, R.V. O'Neill, and P.R. Coleman. 1987. Landscape patterns in a disturbed environment. *Oikos*. 48:321-324.

Lawrence, H.W. 1982. Historic change in natural landscapes: the experimental view. *Environmental Review*. 6(1):15-36.

Lee, B.J., H.A. Regier, and D.J. Rapoort. 1982. Ten ecosystem approaches to the planning and management of the Great Lakes. *Journal of Great Lakes Research*. 8(3):505-519.

Leopold, A. 1949. *A Sand County Almanac, and Sketches Here and There*. Oxford University Press, New York.

Lovelock, J. 1988. *The Ages of Gaia*. Oxford University Press, Oxford.

Marshall, I.B, H. Hirvonen, and E. Wiken. 1993. National and regional scale measures of Canada's ecosystem health. Pages 117-129 in S. Woodley, G. Francis, and J.J. Kay, eds. *Ecological Integrity and the Management of Ecosystems*. St.Lucie Press, Delray Beach, Florida.

Mata-Porras, M., A.C. Imeson, and F.J. Perez-Trejo. 1994. Landscape degradation response units as an assessment of ecosystem health. Page 67 in *Abstracts in The 1st International Symposium on Ecosystem Health and Medicine*. Ottawa, Ontario. June 19-23, 1994.

Melnick, R.Z. 1984. *Cultural Landscapes: Rural Historic Districts in the National Parks System*. National Parks Service, USDI, Washington, D.C.

Ministero di Agricoltura, Industria, e Commercio. 1901. *Censimento della Popolazione del Regno al 10 Febbraio 1901*. Stamperia Reale, Roma.

Nash, R. 1970. The state of environmental history. Pages 249-260 in H.J. Bass, ed. *The State of American History*. Quadrangle Books, Chicago.

Nash, R. 1975. *Wilderness and the American Mind*. Yale University Press, New Haven.

Naveh, Z. 1982. Landscape ecology as an emerging branch of human ecosystem science. *Advences in Ecological Research*. 12:189-237.

Naveh, Z. 1991a. Mediterranean uplands as anthropogenic perturbation-dependent systems and their dynamic conservation management. Pages 545-556 in O. Ravera, ed. *Terrestrial and Aquatic Ecosystems: Perturbation and Recovery*. Ellis Harwood Ltd., New York.

Naveh, Z. 1991b. Some remarks on recent developments in landscape ecology as a transdisciplinary ecological and geographical science. *Landscape Ecology*. 5(2):65-73.

Naveh, Z. 1992. Introduction to the Workshop: Red books for Threatened Landscapes. Pages 13-15 in *IUCN-CESP Working Paper No. 4*. Montecatini, Italy. 27 April - 1 May 1992.

Nielsen, N.O. 1991. *Ecosystem Health and Sustainable Agriculture*. Science Council of Canada, Ottawa, Ontario.

Norton, B.G. 1992. A new paradigm for environmental management. Pages 23-41. in R. Costanza, B.G. Norton, and B.D Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington D.C.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a heirarchical approach. *Conservation Biology*. 4(4):355-364.

Odum, E.P. 1992. Great ideas in ecology for the 1990s. *BioScience*. 42(7):542-545.

O'Neill, R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B. Jackson, D.L. DeAngelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Christensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. *Landscape Ecology*. 1(3):153-162.

Ontario Ministry of the Environment. 1992. *Toward an Ecosystem Approach to Land Use Planning: A Biophysical Environmental Perspective*. Discussion Paper. July 22, 1992.

Organization for Economic Co-Operation and Development. 1991. *Environmental Indicators: A Preliminary Set*. Head of Publications Service, OECD, Paris, France.

Pickett, S.T.A. and P.S. White (eds.). 1985. *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press Inc., Toronto.

Rapport, D.J, H.A. Regier, and T.C. Hutchison. 1985. Ecosystems behaviour under stress. *The American Naturalist*. 125:617-640.

Rapport, D.J. 1989a. What constitutes ecosystem health? *Perspectives in Biology and Medicine*. 33:120-132.

Rapport, D.J. 1989b. Symptoms of pathology in the gulf of Bothnia (Baltic Sea): Ecosystem Response to stress from human activity. *Biological Journal of the Linnean Society*. 37:33-39.

Rapport, D.J. 1992. What is clinical ecology? Pages 144-156 in R.Costanza, B.G. Norton, and B.D Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington D.C.

Rapport, D.J. 1994. Ecosystem health: an integrative approach to environmental management. Page 83 in *Abstracts in The 1st International Symposium on Ecosystem Health and Medicine*. Ottawa, Ontario. June 19-23, 1994.

Reiners, W.A., and G.H. Lang. 1979. Vegetation patterns and processes in the balsam fir zone, White Mountains, New Hampshire. *Ecology*. 60:403-417.

Risser, P.G., J.R. Karr, and R.T.T. Forman. 1983. *Landscape Ecology: Directions and Approaches*. Special Publication 2 Illinois Natural History Survey, Champaign, Illinois.

Risser, P.G. 1985. Toward a holistic management perspective. *Bioscience*. 35(7):414-418.

Risser, P.G. J.R. Karr, and R.T.T. Forman. 1984. *Landscape Ecology: Directions and Approaches*. Illinois Natural History Survey. Special Publication 2. Champaign, Illinois.

Risser, P.G. 1987. Landscape ecology: State of the art. Pages 3-14 in M.G. Turner, ed. *Landscape Heterogeneity and Disturbance*. Springer-Verlag, New York, New York.

Ritters, K.H., B.E. Law, R.C. Kucera. A.L. Gallant, R.L. DeVelice, and C.J. Palmer. 1992. A selecion of forest condition indicators for monitoring. *Enviromental Monitoring and Assessment*. 20:21-33.

Romme, W.H. and D.H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. *Bioscience*. 32:664-670.

Ruzicka, M. and L. Miklos. 1990. Basic premises and methods in landscape ecological planning and optimization. Pages 233-260 in Zonneveld, I.S., and R.T.T. Forman, eds. *Changing Landscapes: An ecological perspective*. Springer-Verlag, New York.

Sauer, C.O., ed. 1925. The Morphology of the Landscape. *University of California Publications in Geography*. 2(2):19-53.

Schaeffer, D.J., E.E. Herricks, and H.W. Kerster. 1988. Ecosystem health: I. measuring ecosystem health. *Environmental Management*. 12(4):445-455.

Schaeffer, D.J. and D.K. Cox. 1992. Establishing ecosystem threshold criteria. Pages 157-169 in R. Costanza, B.G. Norton, and B.D. Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, D.C.

Slocombe, D.S. 1991. *An Annotated, Multidisciplinary Bibliography of Ecosystem Approaches*. Cold Regions Research Centre. Wilfrid Laurier University, Waterloo and IUCN Commission.

Slocombe, D.S. 1992. Environmental monitoring for protected areas: review and prospect. *Environmental Monitoring and Assessment*. 21:49-78.

Slocombe, D.S. 1993a. Developing understanding for Ecosystem-based planning and management: The synthetic concepts of integrity, biodiversity, and sustainability. Description of Proposed Research.

Slocombe, D.S. 1993b. Environmental planning, ecosystem science, and ecosystem approaches for integrating environment and development. *Environmental Management*. 17(3):289-303.

Slocombe, D.S. 1993c. Implementing ecosystem-based management: Development of theory, practice, and research for planning and managing a region. *BioScience*. 43(9):612-622.

Suter, G.W.,II. 1993. A critique of ecosystem health concepts and indexes. *Environmental Toxicology and Chemistry*. 12:1533-1539.

Troll, C. 1939. Luftbildplan and okologische Bodenforchung. *Ges. Erdk. Ber.* 2:41-311

Turner, M.G. 1987. Spatial simulation of landscape changes in Georgia: A comparison of 3 transition models. *Landscape Ecology*. 1(1):29-36.

Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics*. 20:171-192.

Turner, M.G. 1990. Landscape changes in nine rural counties in Georgia. *Photogrammetric Engineering and Remote Sensing*. 56(3):379-386.

Turner, M.G. and C.L. Ruscher. 1988. Changes in landscape patterns in Georgia, USA. *Landscape Ecology*. 1(4):241-251.

Turner, M.G. and R.H. Gardner. 1991a. Quantitative methods in landscape ecology: an introduction. Pages 3-14 in M.G. Turner and R.H. Gardner, eds. *Quantitative Methods in Landscape Ecology: the analysis and interpretation of Landscape Hetergeneity*. Springer-Verlag, New York.

Turner, M.G. and R.H. Gardner, eds. 1991b. *Quantitative Methods in Landscape Ecology: The analysis and interpretation of Landscape Hetergeneity*. Springer-Verlag, New York.

Turner, M.G., R. Costanza, and F.H. Sklar. 1989a. Methods to evaluate the performance of spatial simulation models. *Ecological Modelling*. 48:1-18.

Turner, M.G., R.V. O'Neill, R.H. Gardner, and B.T. Milne. 1989b. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology*. 3(3/4):153-162.

Ulanowicz, R.E. 1992. Ecosystem health and trophic flow networks. Pages 190-206 in R. Costanza, B.G. Norton, and B.D. Haskell, eds. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, D.C.

Urban, D.L., R.V. O'Neill, and H.H. Shugart, Jr. 1987. Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns. *Bioscience*. 37(2):119-27.

Vallentyne, J.R. and A.M. Beeton. 1988. The 'ecosystem' approach to managing human uses and abuses of natural resources in the Great Lakes Basin. *Environmental Conservation*. 15(1):58-62.

Vos, C.C. and J.I.S. Zonneveld. 1993. Patterns and processes in a landscape under stress: the study area. Pages 1-27 in C.C. Vos and P. Opdam, eds. *Landscape Ecology of a Stressed Environment*. Chapman Hall, New York, New York.

Vos, W. and A.Stortelder. 1992. *Vanishing Tuscan Landscapes: landscape ecology of a Submediterranean-Montane area (Solano Basin, Tuscany, Italy)*. Pudoc Scientific Publishers, Wageningen.

Wessman, C.A. 1990. Landscape ecology: Analytical approaches to pattern and process. Pages 285-299 in C.J. Edwards and H.A Regier, eds. *An Ecosystem Approach to the Integrity of the Great Lakes in Turbulent Times*. Great Lakes Fishery Commission Special Publication 90-4.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. Pages 155-176 in S. Woodley, G. Francis, and J.J. Kay, eds. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press, Delray Beach, Florida.

Woodley, S., J. Kay, and G. Francis, eds. 1993. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press, Delray Beach, Florida.

Worster, D. 1993. Transformations of the Earth: toward an agroecological perspective in history. Pages 181-192 in Armstrong, S.J. and R.G. Boltzer, eds. *Environmental Ethics: divergence and convergence*. McGraw-Hill, Inc., Toronto.

Zonneveld, I.S. 1988. landscape Ecology and its Application. Pages 3-15 in M. Moss, ed. *Landscape Ecology and Management*. Proceedings of the First Symposium of the Canadian Society for Landscape Ecology and Management. May 1987. University of Guelph.

Zonneveld, I.S. and R.T.T. Forman. 1990. Part IV: Planning and management of landscapes. Pages 215-216 in I.S. Zonneveld and R.T.T. Forman, eds. *Changing Landscapes: an ecological perspective*. Springer-Verlag, New York