AN ABSTRACT OF THE DISSERTATION OF

Kikombo Ilunga Ngoy for the degree of Doctor of Philosophy in Geography presented on February 21, 1997. Title: Spatial and Temporal Patterns of Forest Cover in the Central Western Cascades of Oregon and Southeast Zaire: A Test of Distance Decay and Deforestation Models.

Abstract approved: Julia Allen Jones

Julia Allen Jones

The Central Western Cascades and southeast Zaire were selected to test the distance decay and deforestation models on forest environments. Distance gradients included away from cities, and away from highways/roads. Two forest definitions were used in each study site. The "extended-forest" definition included areas with at least 30 percent canopy cover in the central western Cascades, and with at least 10 percent canopy cover in southeast Zaire. The "restricted-forest" definition included at least 80 years old conifer forests in the central western Cascades, and forested areas least affected by human activities in southeast Zaire. Additional variables included land ownership, population growth rates, per capita gross national products/money income.

The distance decay model assumed increasing forest cover with distance. Extended-forest cover was predicted to increase more rapidly than restricted-forest cover. Forest cover was also hypothesized to increase more rapidly with distance away from highways/roads than away from cities, and more rapidly in southeast Zaire than in

the central Western Cascades. Furthermore, it was hypothesized that forest loss rates were higher in southeast Zaire than in the Central Western Cascades.

Resulting distance decay curves varied with study sites, land ownership, and forest types. The impact of distance was more identifiable in the restricted than the extended forest definition in the central western Cascades. Forests with at least 30 percent canopy cover increased more rapidly than unmanaged forests. Slope values in the away-from-highways gradient were also higher than in the away-from-cities gradient. There was no significant difference between forest types, and distance gradients in southeast Zaire. The distance was a constraint in private non-industrial lands in the central western Cascades and in all lands in southeast Zaire. This was not always the case with lands owned by United States Forest Service, Bureau of Land Management, and private industrial.

The deforestation model was not validated in the central western Cascades. The average forest loss rate was 0.5 percent per year (1972-1988), and it was 1.3 in southeast Zaire (1973-1989).

Differences in results were due to natural variability of forest environments, external demands, forest cut policy, socio economic reasons, and population density.

Spatial and Temporal Patterns of Forest Cover in the Central Western Cascades of Oregon and Southeast Zaire: A Test of Distance Decay and Deforestation Models.

By

Kikombo Ilunga Ngoy

A DISSERTATION

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APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Kikombo Ilunga

Kikombo Ilunga Ngoy, Author

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Spatial and Temporal Patterns of Forest Cover in the Central Western Cascades of Oregon and Southeast Zaire: A Test of Distance Decay and Deforestation Models.

Chapter I. Description of conceptual models

1.1. Introduction

The impact of humans on forest environments has a long history. Detailed information related to the evolution of historical human-environment relationship has been documented by Perlin (1993), Mather (1990), Richards and Tucker (1988), and others. Ancient civilizations in Europe, China, and North Africa evolved within a spatial setting where access to water was guaranteed, where the soil was relatively fertile and the access to forest resources was insured. Forests were cleared to provide land for agriculture, fuel for cooking, copper smelting, pottery making, and construction and shipbuilding materials. The resulting relative socio-economic prosperity supported population increases. As areas developed demographically and economically, the demand for soil and forest resources also increased (Perlin 1993). In Europe, it accelerated as wood demand increased during the early years of the industrial Revolution. Industries required access to large quantities of wood (FAO 1993a).

Economic growth and industrialization gradually eased the pressure on forest resources by expanding available options. The use of gas and electricity decreased the amount of wood needed in cooking and heating, for example. As a result of wood scarcity European governments passed laws allocating, protecting, and expanding the remaining forest resources. By the early years of the present century, the total area of the European forests had more or less stabilized, and a new reforestation program has led to an actual relative increase in extent of forested lands (Perlin 1993).

In the United States, a similar process took place. Forests were cleared in the last two centuries as the population grew and the country was being industrialized (Williams 1989). Westward migration left abandoned towns surrounded by cleared forest areas. But, as in Europe, the clearing process was reversed in the second quarter of the twentieth century (FAO 1993b; Perlin 1993; Mather 1990; Richards and Tucker 1988).

The transition from rapidly diminishing to stable forest areas in the Europe and North America is attributable to several factors. Most important were the major demographic and economic changes that took place as industrialization and economic growth proceeded, leading to the use of alternative energy sources (coal, electricity, and oil) instead of fuelwood. Rural populations relying solely on forest lands fell drastically with urbanization. Today, in Europe and the United States the rural population is about 25 percent of the total (FAO 1993b). National population growth rates have also dropped to around replacement level in most of the industrialized countries. Changes also took place in agricultural production. Subsistence farming gave way to an agriculture relying on mechanization and high inputs of fertilizers and pesticides. Agriculture productivity has increased so that additional agricultural lands are less and less needed.

Deforestation patterns experienced by developed countries in the nineteenth and early twentieth century are now emerging in developing countries. Several studies evaluated the scale, rates, and causes of tropical forest losses (Myers 1980; Lanly and Rao 1982; Allen and Barnes 1985; Postel 1988; Sader et al. 1990; Amelung and Diehl 1992; and Grainger 1993). These studies found that the main causes of deforestation were demographic and socio-economic changes.

Changes in socio-economic environment positively affected the population growth rate in developing countries. Big cities and towns emerged as a result of these changes. But the rate of socio-economic improvement did not keep pace with the rate of population growth. In most developing countries, low agricultural productivity and stagnating economies offer few opportunities for those wishing to look for alternatives (Anderson 1987; Mather 1990). More lands for agriculture and fuel woods are needed to sustain the ever increasing population. In addition to national wood and land needs, other countries clear forest lands to export forest products in exchange for industrialization.

1.2 Conceptual models and approaches

At every scale, whether global, national or local, causes of forest clearing show identifiable and even predictable patterns. Studies by Myers (1980), Allen and Barnes (1985), Sader et al. (1990), and Grainger (1993), for example, were undertaken to identify underlying processes and develop models to predict the pattern of deforestation. To understand patterns of forest cutting in the central western Cascades of Oregon and southeastern Zaire, two models were identified--a distance decay model and a deforestation model.

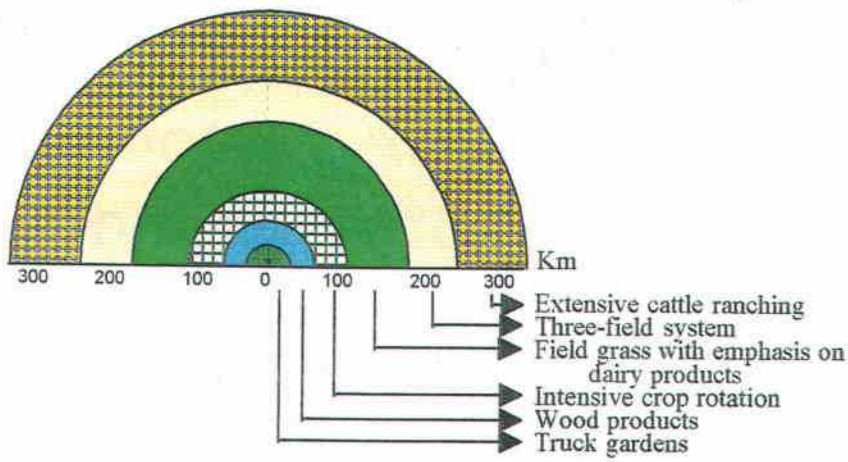
1.2.1 Distance decay model

The distance decay model is based on the Von Thunen (Johan Heinrich von Thunen 1783-1850) land use zoning model and has mostly been applied to smaller spatial scale studies. Additional descriptions of the model are found in Abler et al. (1971), Haggett et al. (1977), and Haggett (1983). Von Thunen's notions assume an island type of land completely isolated from the rest of the world with a single city surrounded with an endless and uniformly fertile plain. Farmers' profits at any location will be a function of two variables: how much people in the city are willing to pay for their products, and how much the transport will cost to bring crops to the city. With increasing distance from the city or town the land will progressively be given up to products cheaper to transport in relation to their value. Regular patterns of agricultural activities will appear around the city. A series of concentric zones will be created around the city ranging from narrow bands of intensive farming to a broad band of extensive agriculture and ranching to the furthermost outer area (Figure 1.1).

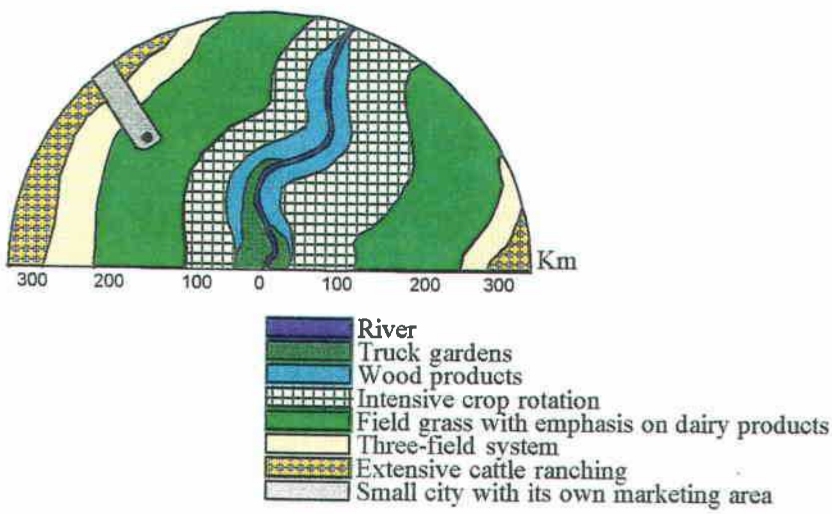
Von Thunen's model departs from reality in several respects. Few cities are as isolated as he described. They are surrounded by a variety of smaller towns and villages complicating the hinterland spatial structure. No region is as homogeneous as the hypothetical uniform plain. The natural resources of real landscapes are clustered in patterns that inevitably distort the theoretical zones. The quality and type of

Figure 1.1 Von Thunen model (Haggett 1983)

a. Ideal Von Thunen model



b. Distorted Von thunen model

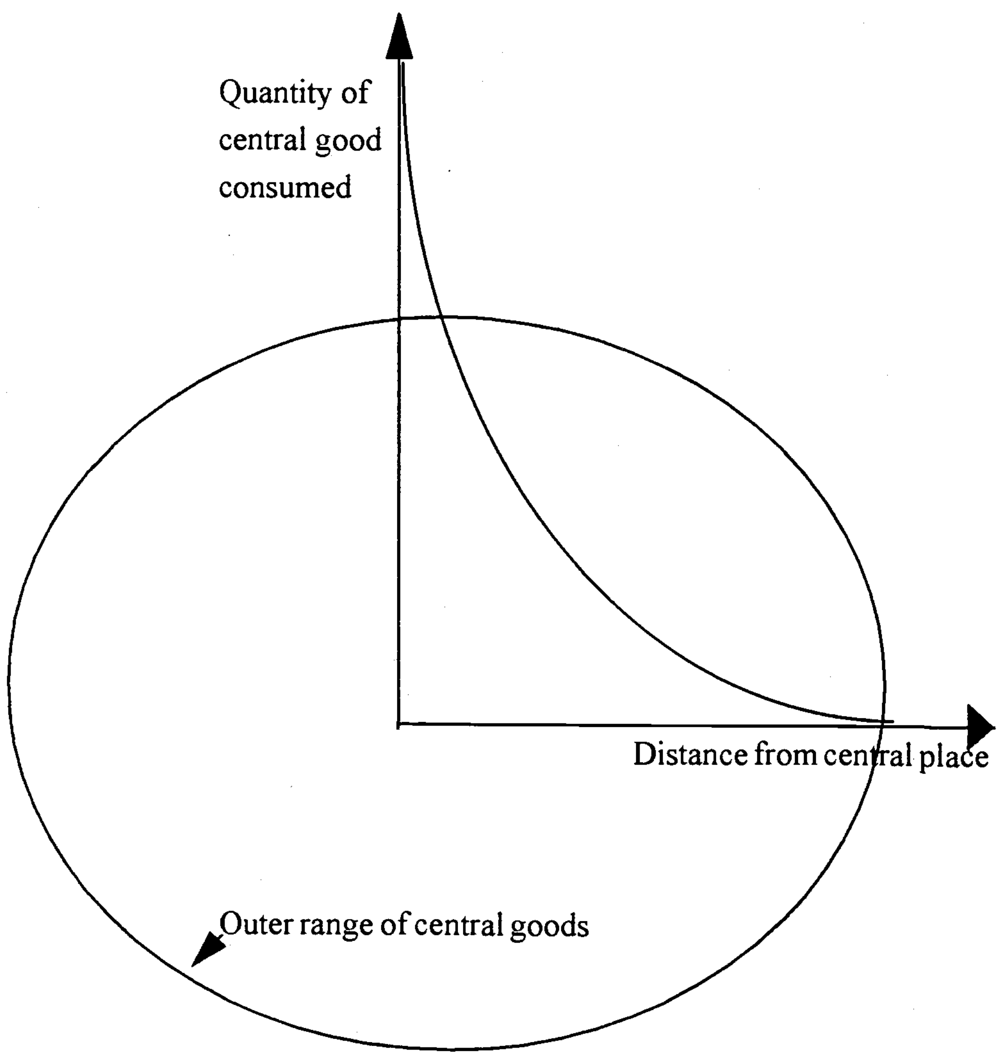


transportation networks, such as rivers and roads, also introduce distortions to the model. However, none of these "distortions" undermines Von Thunen's underlying principles. People value the products of the soil, and there are costs to get them to markets. These factors together shape the landscape in a spatially predictable fashion.

Von Thunen simplified his landscape to demonstrate what modern central place theorists have confirmed with formal mathematics. Christaller's Central Places as broadly defined by Haggett (1983) are towns serving as centers for regional communities by providing them with central goods. They are places where farmers come together with their agricultural products to be sold and in return buy non-farm goods. Central places vary in importance depending upon the size of the market area and the transportation network quality and cost (Figure 1.2).

Christaller's model requires the same underlying assumptions as Von Thunen's (Haggett 1983)--a uniform, and economically isolated area where change occurs as a result of rural productivity increase in the lowest settlement leading to a more complex hierarchical and higher-order centers. The Vance Mercantile Model, on the other hand, supplements Christaller's theory by bringing in a historical and dynamic perspective. Vance's theory is based upon the path in which actual world settlements have evolved-particularly the mercantile cities of America's east coast and Australia. There city growth began as a point to connect with the area to be colonized, indeed from the top down (the reverse of the Christaller model) from which the central-place development later emerged (Cronon 1991). The city's historical background has a strong imprint on the actual landscape pattern.

Figure 1.2 Christaller Central place model (Haggett 1983)



Christaller's, Vance's, and Von Thunen's models are supply-demand based models where the transportation (cost and/or quality) is a linkage between the supplier and the consumer. Agricultural and forest products are goods supplied. There is a positive relationship between goods supplied and the size of the population. The demand increases as the number of people increases. Hence, the supply also increases. Demand increases can be related to the increased population in the nearby central place and/or in central places located several thousands of kilometers away within the same country or outside the country's boundaries (higher order ranks according to Christaller's central place model).

A forest or agricultural product supplier will locate somewhere between the location of goods and the demand (central place) to maximize his profits and minimize transportation costs. If, for example, a city is surrounded by a forest with no existing restriction governing its use, the supplier will be likely to locate as near as possible to the city. Therefore, the most likely place to be cleared whether for agricultural or forest product sale purposes will be located near the city and the eventual existing transportation network. As one moves away from the city and roads, the area cleared will likely decrease. An increase or decrease of an observed pattern as the distance increases can be explained by the distance-decay model.

One way of characterizing the relationship between observed patterns (flow of goods or people) and distance is by the use of the concept of the gravity model (Fotheringham 1981; Haggett 1983):

$$F_{ij} = am_j d_{ij}^{-bi} \qquad (1.1)$$

Where F_{ij} is the interaction between origin i and destination j; m_j is the attractiveness of j (potential buyers or total population in j), d_{ij} is the distance between i and j; a a constant; and b_i is the origin-specific distance-decay parameter. The estimate of b_i helps to evaluate the strength of the relationship between observed spatial structures and the distance, when all other factors are assumed constant. Highly negative parameter estimates indicate that distance is a strong deterrent to interaction, while slightly negative estimates are indicative of a distance perceived to be a weak deterrent.

The Von Thunen and the distance decay models have been applied in studies of both agricultural land distribution and spatial location of business and industrial activities. For example, Moindrot (1992) overviews analyses of Von Thunen and the distance decay model's applicability to field systems and rural settlements in Argentina, Ethiopia and Spain. Contrasts were made against agricultural land distribution in the American Middle West, the Soviet Union, and Netherlands. Bein's study (1992) used the Von Thunen's model in a desert-like environment of Sudan and showed that land use zones observed around Khartoum are the result of historic and interacting socio-economic forces structuring the landscape. Cronon (1991), on the other hand, analyzed the pattern in a developed countries. He examined Chicago's growth by relating it to the evolution of its hinterland and the transportation systems linked to the metropolis. He found that as one moved away from Chicago the spatial pattern of agricultural lands is close to the Von Thunen model.

Although Cronon (1991), Bein (1992), and Moindrot (1992) examined city hinterlands from an agricultural land distribution point of view, others look at these cultivated lands as forest cut areas. Their studies are indirect studies of patterns of removed forests. Lands likely to be cleared, whether for forest product or agricultural purposes, are indeed those located near a city. There are however, some more straightforward studies of forest fragmentation. A case in point is a recent study by Medley et al. (1995) dealing with the analysis of forest-landscape structure around New York. This study analyzes the relationship between socio-economic factors such as population density and transportation, and the pattern of forest fragmentation. It was found that forest fragmentation decreased as the distance away from New York increased.

1.2.2 Approach to testing the distance-decay model

The distance-decay concept can be extrapolated to the understanding of the pattern of forest cuts, since forest removal is generally associated with populated areas, and since the likely places to be cut are those surrounding the city as forest product suppliers maximize their profits. A general deduction from this is that non-forested areas will decrease as one moves away from inhabited areas. Such a pattern fits within the distance decay model framework.

For the purpose of this research equation 1.1 will be replaced by a linear equation from a fitted line relating observed forest cover to distance. This new equation together with conceptual models will be referred to in the analysis of forest cut or forest cover patterns in the Western Cascades of Oregon and southeastern Zaire urban-rural gradients.

Spatial forest cut patterns are affected by local to international socio-economic environments in addition to local physical spatial heterogeneity. Depending upon its socio-economic makeup, a study area from a developing country will have a pattern different from that of an industrialized country. In the case of the southeastern Zaire, the percentage of urban population depending on forest primary resources is relatively high and the degree of industrialization is relatively low. Because of transport difficulties, distance, is a major constraint so that the slope of the fitted line (Equation 1.1) is expected to be very high. More cleared areas are likely to be found around inhabited areas. However, in the case of Oregon, because of advanced transportation systems and relatively high socio-economic well being, local population dependence on local forest as a source of energy or agricultural lands is relatively low. The slope value is expected to be low as the distance is a weaker deterrent in Oregon than in southeastern Zaire.

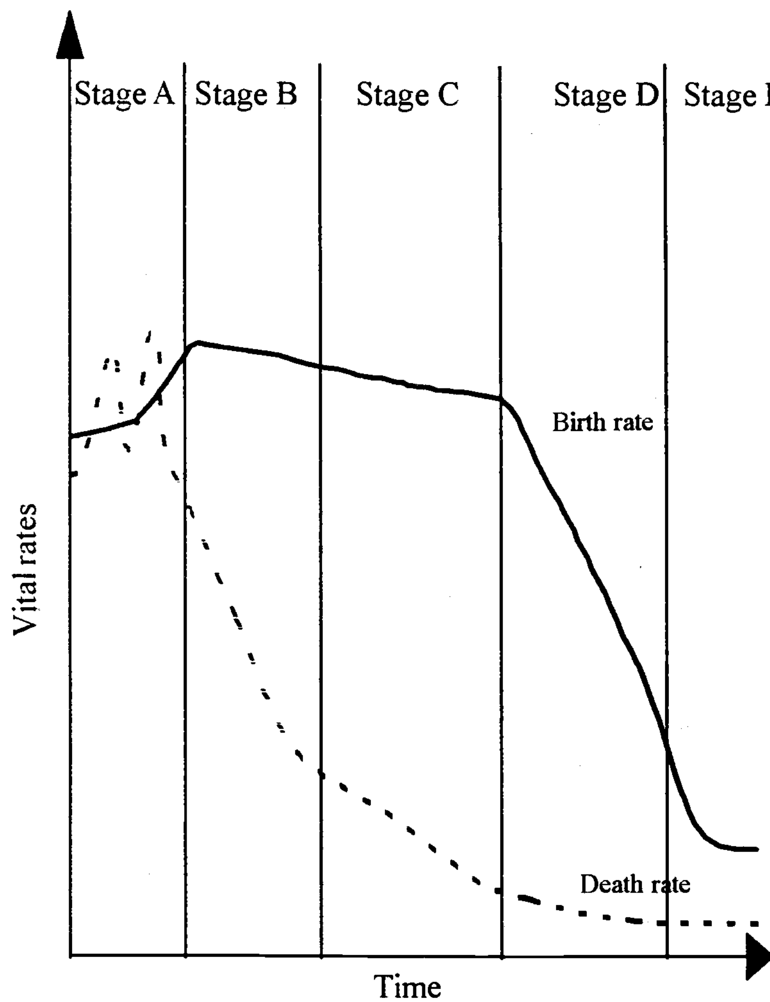
A general observation from above literature is that historical and socio-economic factors, in addition to physical variability have a major impact on actual forest/non-forest cover patterns. This is why an additional conceptual model related to socio-economic factors is needed to provide additional explanations of forest fragmentation processes. The basis of the model is the demographic transition.

1.2.3 Demographic transition model

A look at past trends throughout the world has led to the identification of a relationship between economic development, population growth, and deforestation as demonstrated by Perlin (1983). First, the presence of a forest resource helps the population and the economy to grow. This growth leads to more forest clearing. Later, economic development helps people seek out and afford alternative resources. The socio-economic well being stabilizes population growth, and subsequently forest clearing. People's perception of forest resources changes, and protective laws are implemented. This trend mirrors processes and patterns which took place in most industrialized countries and are assumed to be a likely trend for most developing countries. A demographic transition model (Peters and Larkin 1989) has been developed to classify each country according to its birth and death rates. The pattern of this model is used later to characterize the deforestation model.

Five stages, represented in Figure 1.3, are identified in the demographic transition model as described by Peters and Larkin (1989). Stage A includes countries or areas of high birth and death rates (The World Resources Institute 1990). This stage prevailed during the preindustrial era and may not be associated with any country nowadays. Stage B represents countries with a declining death rate but where the birth rate is still high. Many African nations including Angola, Chad, Ethiopia and Mali are now in this stage. Some Asian countries such as Laos, Afghanistan, and Yemen may also fit into this category. Stage C includes nations with high birth and low death rates, and the highest population growth rates. Most tropical Latin American and some other

Figure 1.3 Demographic transition model (Peter and Larkin 1989)



African countries are within this category. Kenya, Zimbabwe, Tanzania, and Zaire are among these countries. Stage D includes countries with a declining birth rate and a low death rate. Countries related to this stage include temperate Latin American countries such as Argentina and Uruguay, as well as Asian countries such as China, Taiwan, and South Korea. The final category, stage E, characterizes a country with low birth and death rates, and consists of Western European countries including the United States of America and Japan.

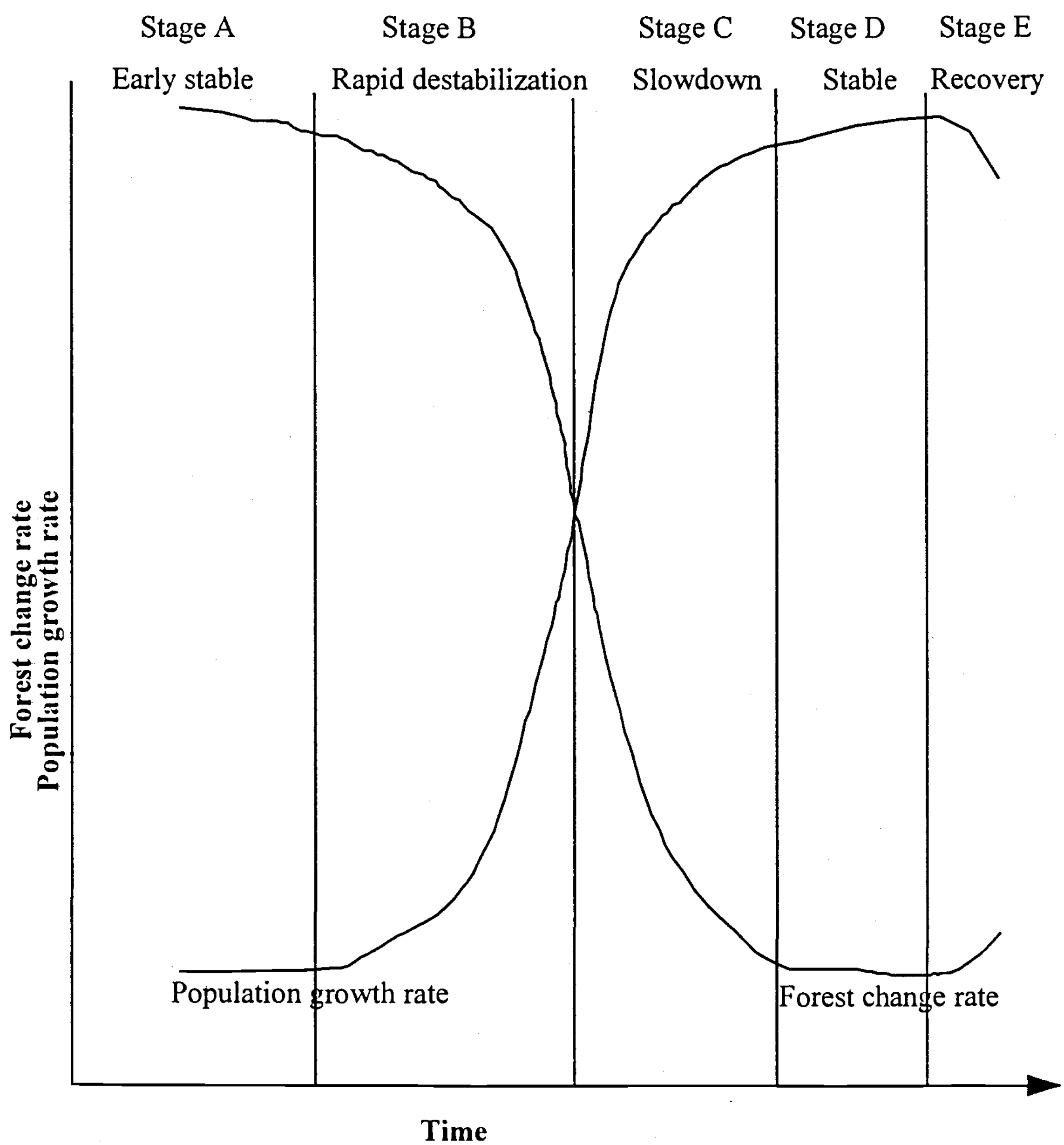
A clear outcome of the demographic transition model is the demonstrated relationship between the socio-economic development of one country and its population growth rates. This general trend has led to an assumption that today's developing countries may pass through the same population growth rate pattern as experienced by industrialized countries to reach a relatively stable population growth (Stage E). The assumption for such a trend is that conditions in today's developing countries are similar to those that prevailed in the Western nations as they were moving through the demographic transition. However, questions still need be answered. As a country moves through this demographic transition model, how is the forest environment being affected? How is the spatial configuration of affected forest areas? Can a pattern from an area within a country such as the central western Cascades in Oregon and the southeastern Zaire be a representative of a national trend?

1.2.4 Deforestation model

Forest clearing, population growth, and economic development are related. This relationship is dynamic (Turner II and Meyer 1993). A five stage deforestation model is been proposed in this study, based on Grainger's model (1993). The five stages of the demographic transition model are used together with Rostow's (1971) stages of economic growth (traditional society (stage A), preconditions for take-off (Stage B), take-off (Stage C), drive to maturity (Stage D), and age of high mass-consumption (Stage E)) to produce the five stages of the deforestation model. In Figure 1.4, Grainger's (1993) and FAO's (1993b) models were used to delineate the proposed five deforestation stages and to show the pattern of forest cover as it relates to population growth rate.

The Early Stable stage (stage A) in Figure 1.4 consists of stages A of the demographic transition model, and economic growth. This class in both cases relates to traditional societies which, because of the limitation on productivity, devote a very high proportion of their resources to food collection and a rudimentary form of agriculture. The population growth rate is fluctuating due to death rates sometimes higher than birth rates associated with inadequate sanitary conditions within these societies. The impact of these societies' activities on forest environments is almost non-existent so that the rate of deforestation is relatively stable. No country is actually in this stage even though some very spatially localized societies of this stage are likely to be found within some countries.

Figure 1.4 Deforestation model
Source: adapted from FAO (1993b) and Grainger (1993)



The Rapid destabilization stage (Stage B) includes stages B and C of the demographic transition and the preconditions for take-off stage of economic growth model. This stage followed the intrusion by relatively advanced societies. Traditional and modern economic activities coexist within these countries. These countries are characterized by traditional low productivity methods and a stagnant to low level of economic development. The population growth rate increases because of diets, sanitary condition, and medical improvements. The death rate has decreased and the birth rate increased. Population growth pressure leads to an increased pressure on land to clear more forests for more food production.

This pattern illustrates processes taking place in developing countries, including most African countries including Zaire. Sub-Saharan African countries are characterized by a low soil fertility due to the impacts of climatic conditions (Higgins and Kassam 1984; Lal 1984; United Nations Environment Programme 1992; Stock 1995). The inability to afford fertilizers due to the level of the country's economic development and low per capita income lead most people to practice subsistence agriculture (Grainger 1993; Kalapula 1989; Nations and Komer 1982; Bailey 1982). As a result, more forested areas are likely to be cut to supply agricultural lands and fuel wood for the increasing needy population. The shifting cultivation and fuelwood harvest practices are motivated and maintained in part by the *de facto* open access resource lands policy in most of these countries (Mather 1990). A further forest clearing cause, found mainly in countries with a relatively large forest resource is wood export (Lanly 1982; Laarman 1988; Rudel 1989) to compensate for the lack of hard currencies to support development projects and promote industrialization.

The Slowdown stage (Stage C) corresponds to countries where the deforestation rate starts to level off. Such a pattern is a result of several factors including increased agricultural productivity and a stabilizing population growth. This process is taking place in some rapidly industrializing countries of the developing world. South Korea is one example where the rural population has been falling sharply and agricultural production increasing. The country has reached the point where forested areas are likely to expand again but at a relatively smaller pace. In other developing countries, such as Thailand and Malaysia, the forest removal rate is decreasing and economic and demographic conditions for stabilization of the remaining areas of forest are beginning to emerge (FAO 1993a).

The Stable stage (Stage D) shows the deforestation rate in Industrialized countries where a relatively high percentage of the country's forest cover have already been removed. Countries have reached a high economic development level, a high per capita income and a high purchasing power to allow people afford alternative energy sources—electricity and oil, and related appliances. Agriculture productivity has improved because of the use of fertilizer and improved crop species so that the pressure to search for new agricultural lands decreases. Even though the forest cutting rate is still relatively high the government policy requires and encourages people to replant trees so that in the long run the impact of clearcutting is minimized. Public environmental awareness has increased and public perceptions of forest cutting also have changed. Most people see forested areas as recreational sites and wildlife habitats. This is also stimulated and enforced by the government policy to set aside national parks, natural forests, and wilderness areas. To supplement local wood needs, wood imports increase (Cox 1988). This is happening in Industrialized countries including the United States of America.

The Recovery stage (Stage E) is found in some countries where a certain decline in population growth rate has been taking place. This is the case of some Western European countries where, because of the aging population, a stable to a declining population growth rate combined with economic well being and government forest policy, have led to an increase of forest cover. In the United States of America for example, the forest recovery trend has been noticed in New England (Foster 1993).

This study examines a region within the United States of America and compares it with a region in Zaire. The deforestation model used in this study is derived from the demographic transition model. According to the demographic transition model Zaire is in stage C and the US in stage E (Figure 1.3). Peters and Larkin (1989) used nationwide data to illustrate the demographic transition model. The deforestation model is also expected to be applicable at the same national level. Therefore, the national deforestation model can be applied to distinct regions of countries. In this study the regions examined were the central western Cascades of Oregon and southeast Zaire.

According to recent global-regional assessments, causes of national patterns and their impacts might be poorly illustrated at the sub-national scale (Turner II and

Meyer 1993). Some regions within a country might fit the national model while others might depart from it depending upon factors including the size of the country and its spatial economic development variability, environmental characteristics, and local population size and structure. In the case of Zaire, the southeastern part is assumed to represent the demographic and deforestation trends taking place at the national level because the local socio-economic structure and environmental perception is similar in several respects to most parts of the country (Laclaviere 1979). Thus, it is expected to be in stage B in the deforestation model (Figure 1.4).

The United States of America on the other hand, has experienced a different spatial and temporal population growth and deforestation rate trend (Williams 1989, Vogelmann 1995, and Burgess and Sharpe 1981). The Western Cascades of Oregon may have a pattern somewhat different from the general United States trend. The Pacific Northwest is indeed the last frontier of economic development with environmental settings distinguishable from the rest of the country (Cronon 1991). Population has been increasing in the Western Cascades of Oregon especially through the immigration process (Cronon 1991, Leonard 1983). Therefore, the Western Oregon is expected to be classified in two stages at the same time (Figure 1.4). On the one hand, it is in stage B, characterized by high forest cuts for wood export to other states and abroad, and by an increasing population in-migration from surrounding neighboring states. On the other hand, it is in stage E where the government forest policy and public awareness favor protection and forest regrowth in previous clearcut forest areas.

1.3 Objectives

Objectives of this study were to: (1) evaluate satellite imagery as a tool for monitoring and characterizing forest cover and forest loss in the central western Cascades of Oregon and southeast Zaire; (2) characterize rates of forest loss for the 16-year period between 1972 and 1988 in the central western Cascades of Oregon, and between 1973 and 1989 in southeast Zaire; (3) relate patterns of forest cover and forest loss to distance decay and deforestation models.

Chapter II. Materials and Methods

2.1 Study Areas

This chapter reviews general characteristics of each study site including topographic settings, climatic conditions, and vegetation characteristics. It also describes the types of satellite image data used and steps undertaken to classify these images. In addition, it lays out the sampling design used in the analysis of forest cover and forest loss patterns.

2.1.1 Southeastern Zaire: vegetation and physical characteristics

2.1.1.1 Physical and climatic characteristics

The southeastern part of Zaire has distinct topographic features. The southeastern Zaire study area is located between about 10°30' and 12° 30' South latitude, and 26° 30' and 28° East longitude. The topography is a relatively flat plateau with a mean altitude of 1200 m. Additional topographic characteristics include isolated landforms: inselbergs with 150 m height, and giant termite mounds with a density varying between 1 and 5 per ha (Bruneau and Pain 1990, Castiaux et al. 1991, Robert 1950). The major river drainage basins are the upper Lufira and Kafubu rivers. The transition between the river bottom and the top of the plateau is very smooth. The overall study area covers about 4,141,500 ha.

The climate is tropical with two seasons and a mild mean annual temperature (Mbenza 1990, Robert 1950). The dry season lasts from April to October with less than 10% of the mean annual precipitation (MAP) and the remainder of the year is the rainy season. The MAP is about 1300 mm. The mean annual temperature is about 20° C. July is the coldest month with a mean temperature of about 15.6° C. October and November are the hottest months with mean temperatures of 22.5 and 23.5° C. The absolute maximum temperature recorded is 37.8° C.

2.1.1.2 Vegetation characteristics

Thirteen vegetation types were identified within the southeastern Zaire study area (Malaisse 1990). For the purpose of this study they have been classified in two major groups: grass and forest-dominated vegetation types. Forest classes include deciduous forests, evergreen dry forests, and evergreen riverine forests (Malaisse 1990). The evergreen dry forest, Muhulu, the late successional vegetation stage in this area, has been considerably reduced and now covers a very restricted area. Detailed analyses of the ecoclimatic and phenological characteristics of Muhulu are given by Dikumbwa (1990). Deciduous forest (Zambezian Miombo) is the most dominant forest type. Miombo is an open woodland dominated by trees of *Brachystegia, Julbernadia,* and *Isoberlinia* species (Campbell 1996, Malaisse 1978).

Duvigneaud (1958) and Malaisse (1978) characterized the Zambezian Miombo in southeast Zaire as an ecosystem where trees of 15 to 20 m height provide 60 percent canopy cover with a mixture of a sparse gramineous (grass and herb) layer beneath, and few intermediate shrubs between the forest and the herbaceous layer. Trees have interlocking or nearly interlocking crowns, with light foliage, and branches extending like an umbrella. The density of Miombo trees measured at 1.3 m above ground level varies from 12 to 25 m^2/ha of basal area. The overall Zambezian Miombo structure varies with micro soil characteristics including structure, texture, and the degree of laterization of the area (Bruneau and Pain 1990, Malaisse 1978).

2.1.2 The central western Cascades of Oregon: Vegetation and physical characteristics

2.1.2.1 Physical and climatic characteristics

Topographic features in the central western Cascades are different from that of southeast Zaire. The topography is generally steep and dissected with sharp ridges dividing the larger sub-drainages (Jackson and Kimerling 1993; Loy 1976). The study area is located in west-central Oregon between the Willamette Valley and the crest of the Cascades Range. It extends from about 43.5° to 45° north latitude and about 122° to 123° west longitude. The total area is about 12,240 km^2 with elevation varying from 244 to 1706 m.

The climate is characterized by wet, mild winters and dry, warm summers. The mean monthly high temperatures range from the low 80's (26.7° C) in the summer to about 40° F (4.4° C) in the coldest months. The monthly average lows are generally in the lows 50's (10° C) in summer and lows 30's (-1.1° C) in winter (Taylor and Bartlett 1993). Mean annual temperature varies with elevation, from 9.5° C at 450 m to 5.5° C at 1300 m. The MAP varies from 2390 mm at 450 m elevation to 4000 mm at 1300 m (Waring et al. 1978). Seventy five percent of the precipitation occurs between November and March. Snowfall varies with elevation, and a relatively large snow pack accumulates above 1200 m and persists long after the winter season.

2.1.2.2 Vegetation characteristics

Three vegetation series are identified in the central western Cascades study site: the western hemlock (*Tsuga heterophylla*), Pacific silver fir (*Abies amabilis*) and "Interior Valley" zones (Franklin and Dyrness 1988). Altitudinal air temperature and moisture content variation determine their spatial distribution. *Tsuga heterophylla* zone is widely distributed in the lowlands from about 300 to between 1250 m. The *Abies amabilis* zone ranges upward from 1050 m. Dominant species within the western hemlock zone are western hemlock, Douglas-fir, grand fir (*A. grandis*), western red cedar (*Thuja plicata*), and incense cedar (*Calocedrus decurrens*). Dominant trees within the Silver fir zone are Pacific silver fir (*Abies amibilis*), red fir (*A. magnifica*), Douglas-fir (*Pseudotsuga menziesii*), noble fir (*A. procera*), western hemlock (*Tsuga heterophylla*), subalpine fir (*A. lasiocarpa*), and western pine (*Pinus monticola*) (Agee 1993; Franklin and Dyrness 1988).

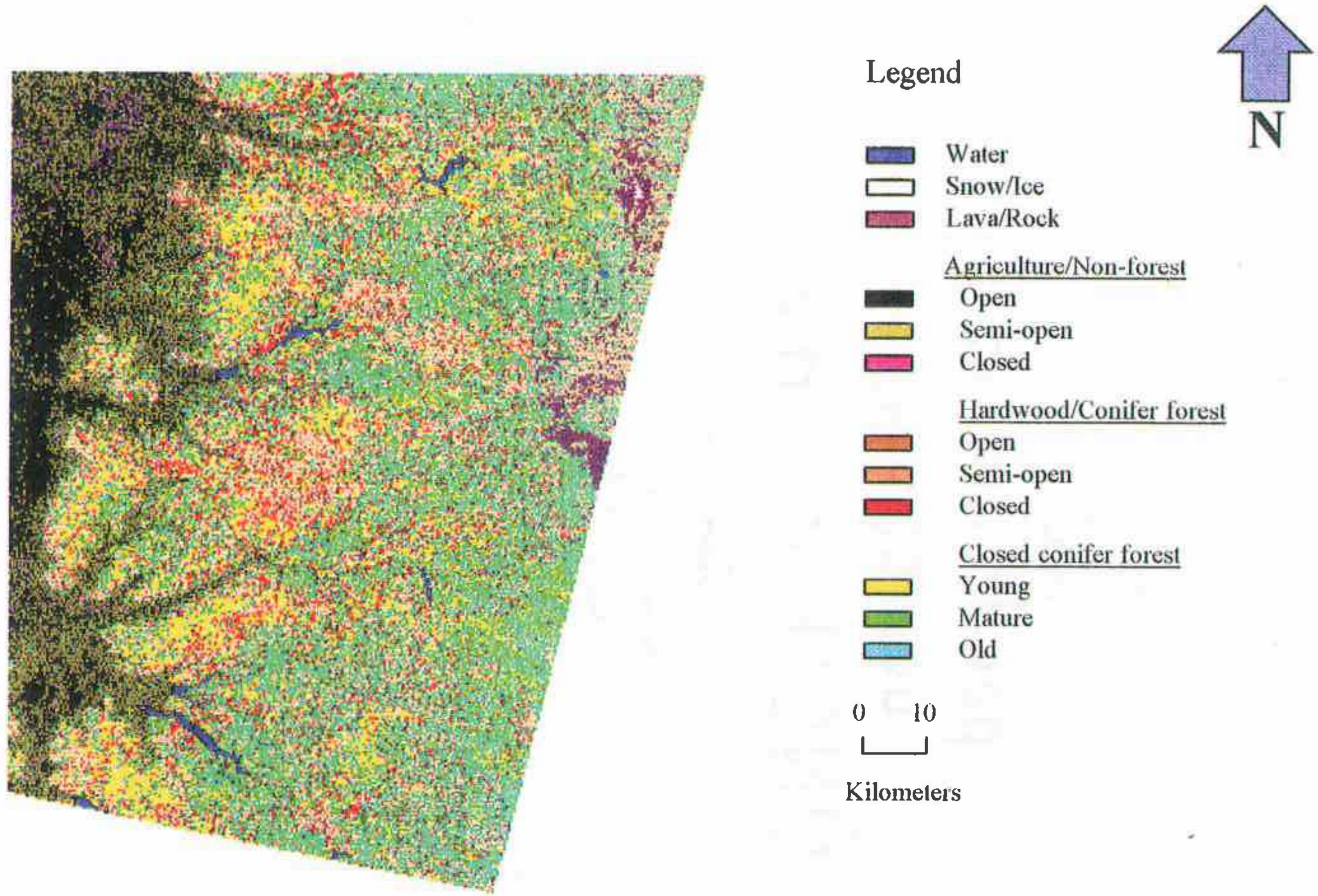
The "Interior Valley" zone refers to vegetation types of valley bottoms and lowlands. It is a typological unit rather than a climax community-based type. The vegetation cover is dominated by *Quercus* woodlands, grasslands, sclerophyllous shrub communities, and riparian forests. This vegetational mosaic is considered seminatural because of human activities. The “Interior Valley” zone was settled during the middle of the 19^{th} century and has been subjected to extensive human disturbances. Pre-settlement Native American burning also influenced this environment (Franklin and Dyrness 1988).

Using unsupervised classification Cohen et al. (1995) identified twelve classes including water, snow/ice, lava/rock, agriculture/non-forest (open, semi-open, closed), hardwood/conifer forest (open, semi-open, closed), and closed conifer forest (young, mature, old) (Figure 2.1). Percent vegetation canopy cover was used to define hardwood/conifer forest classes: open (0-30 percent cover), semi-open (30-85 percent cover), closed mix (>85 percent and at least 10 percent of non-conifer cover), and closed conifer (>85 per cent and less than 10 per cent of non-conifer cover). Open and semi-open areas are forest stands that have been recently severely disturbed or are growing on poor and rocky sites. Closed conifer forests were divided into three age classes—young (less than 80 years), mature (80 to 199 years), and old-growth (200 and more years) (Cohen et al. 1995).

2.1.3 Specific terminology clarification

This section explains specific expressions used to characterize spatial and temporal patterns of forest cover in both study sites. Since this study compares the central western Cascades of Oregon with southeast Zaire, terminologies in some cases were simplified to facilitate and clarify comparisons of forest environments and conditions , as well as land ownerships within and between study sites.

Figure 2.1 Vegetation of the central western Cascades of Oregon



Source: Cohen et al. 1995

Two definitions have been proposed to characterize forest cover in each study site. The "extended-forest" definition terminology has been applied to two forest types. In the central western Cascades of Oregon it includes forests classified as hardwood/conifer forest (open, semi-open and closed) and closed conifer forest (young, mature and old) (Cohen et al. 1995). This terminology has been used interchangeably with forest defined as areas with at least 30 percent canopy cover terminology. In southeast Zaire, forest defined as areas with at least 10 percent canopy cover terminology has been used indistinguishably with the "extended-forest" definition terminology.

The restricted-forest definition terminology has also been applied to two forest types. In the central western Cascades of Oregon it includes forest classified as mature and old-growth conifer forests (Cohen et al. 1995). This terminology also is being referred to as unmanaged forest cover. The use of unmanaged forest cover terminology is due to the fact that, even though stands of mature conifer forests included in this category consist of managed forest older than 80 years, the majority of trees were not planted. In southeast Zaire, restricted-forest-definition and unmanaged terminologies also are applied to forest less affected by human activities. The use of unmanaged-forest terminology might not yield the same meaning as in the central western Cascades of Oregon because, as will be explained later, it is not an age-related classification. Since this forest type is relatively far away from human settlements, the less-affected-by-human-activities terminology may be more fitted to this case. Nonetheless, the use of unmanaged-forest terminology in this study was necessitated by the need to apply the same terminology as in the central western Cascades.

The forest-loss terminology was adopted in the analysis of temporal variation of forest cover. This terminology includes forest lost through cutting and forest conversion to other types of land uses from 1972 to 1988 in the central western Cascades of Oregon, and from 1973 to 1989 in southeast Zaire. While this classification may fit with the central western Cascades study site because of the availability of background information (Cohen et al. 1996), it may not always the case with southeast Zaire where such information was lacking. The selection of forest-loss terminology instead of forest-change terminology was due to the fact that the latter terminology may include not only forest losses, but also non-forests which became forests during the same period.

Terminologies also were applied to land ownership types. In the central western Cascades of Oregon terminologies used by Cohen et al. (1995) in the characterization of land ownership types were also used in this study. They include United States Forest Service (USFS), Bureau of Land Management (BLM), State lands, private non-industrial (PNI), private industrial (PI), no data class, miscellaneous (MISC), and Wilderness lands. The difference between PNI and PI is based on the minimum size of lands owned, the number of employees, and the purpose of the forest by each individual owner. The USFS manages public lands both in Wilderness and for other land use designations where some cutting may be permitted. Wilderness was put in a separate category because it is the most restricted. USFS lands in this study refer to USFS non-

Wilderness. In southeast Zaire, Urban and Rural land-ownership terminologies were proposed. Section 2.3.5 deals with the concept behind their use.

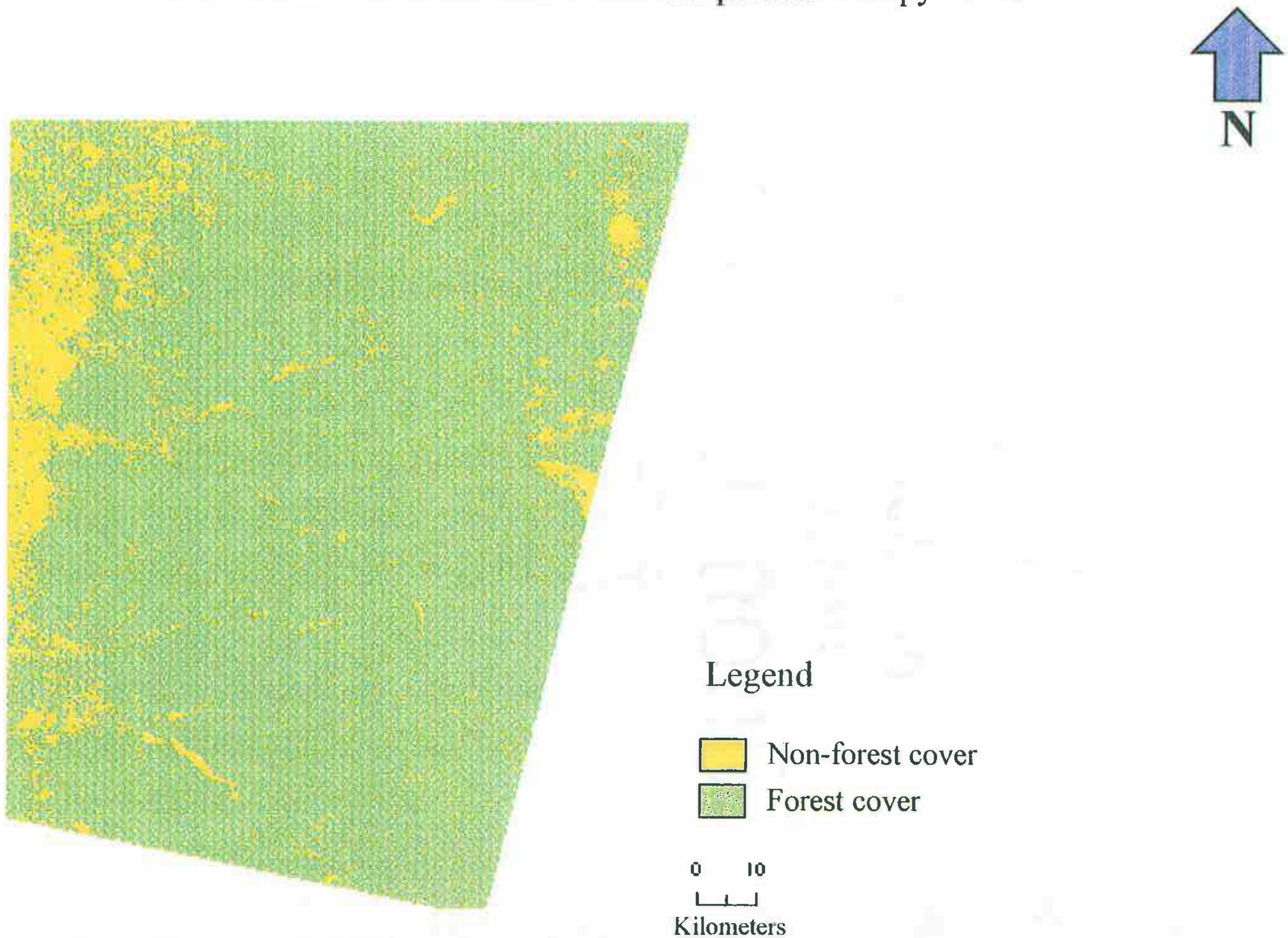
2.2 Remote sensing data

2.2.1 Central western Cascades data set

Satellite imagery data have been selected for use in this analysis of forest cover patterns. In Oregon, the 1988 central western Cascades data set is a TM (Thematic Mapper) satellite image already classified in twelve classes by Cohen et al. (1995). For the purpose of this study, Cohen et al.'s (1995) classes were combined into two classes: forest and non-forest, using two methods. In the first method, hardwood/conifer forests (semi-open and closed) were combined with closed conifer forests (young, mature, and old) to create the forest class. The remaining classes (water, snow/ice, lava/rock, agriculture/non-forests (open, semi-open, and closed), and hardwood/conifer forest (open forest)) were grouped to form the non-forest class (Figure 2.2). The threshold used to delineate forest and non-forest classes was based on the definition of temperate forest established by the FAO (1992). The FAO (1992) defines temperate forests as areas with at least 20 percent canopy cover. The open vegetation class with 0 to 30 per cent of canopy cover was classified as non-forest even though some areas might have more than 20 per cent canopy cover.

A second method consisted of reclassifying mature (80-200 years) and old-growth (>200 years) conifer forests to create a class of forest conditions little affected

Figure 2.2 Forest of the central western Cascades of Oregon (1988)
Forest defined as areas with at least 30 percent canopy cover

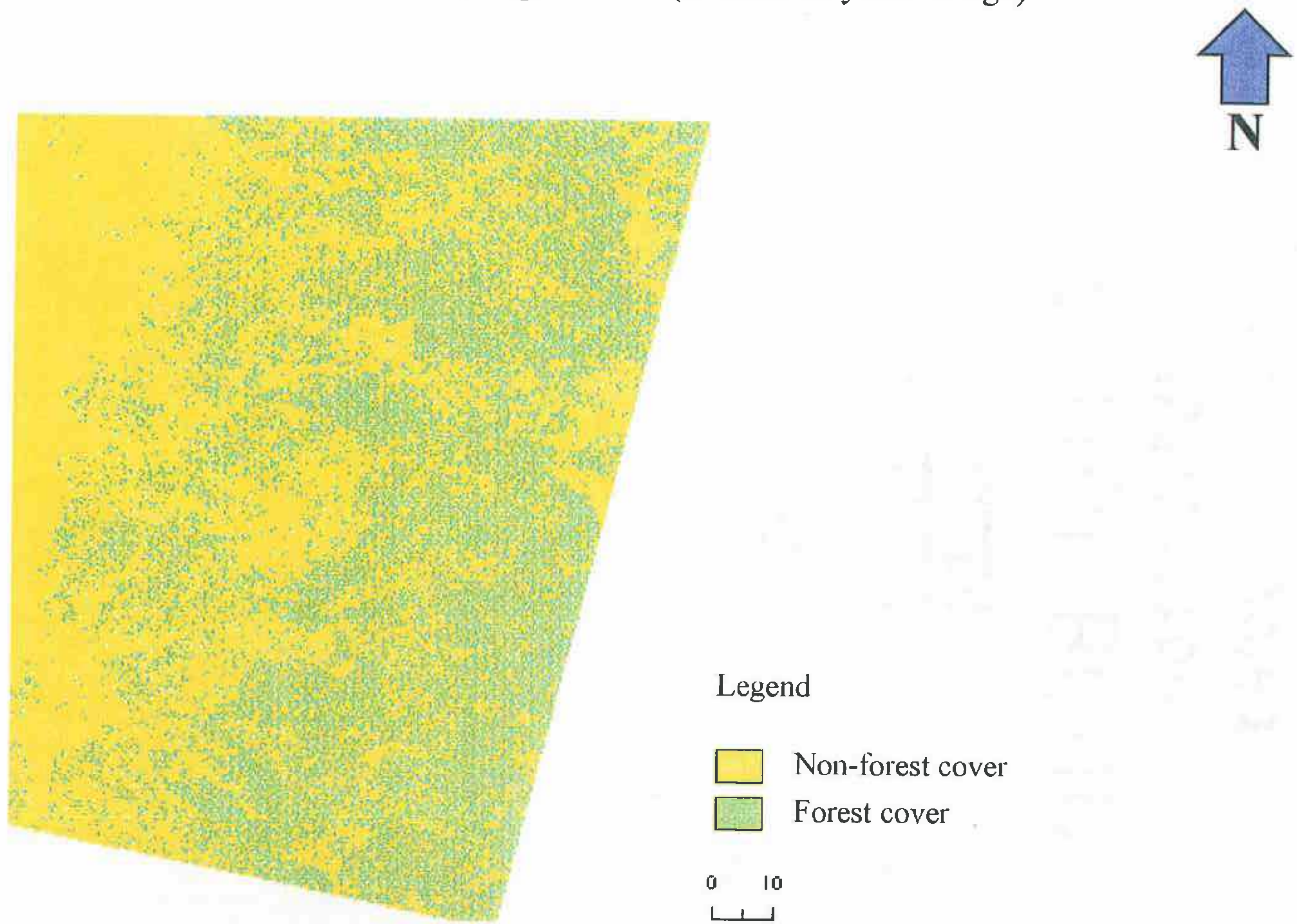


Source: adapted from Cohen et al. 1995

by human activities since Europeans arrived in Oregon about 150 years ago (Figure 2.3). This forest type is also referred to in this study as unmanaged forest. Mature and old-growth conifer forests were grouped together to create this class. The remaining classes were reclassified as non-forest. Some forest stands less than 80 years in age have been previously cut and are managed on cutting rotations less than 80 years, and some others may have originated after wildfire. The age-related classification highlighted and helped analyze forest cover distribution and pattern of a relatively pristine environment distinct from the previous classification.

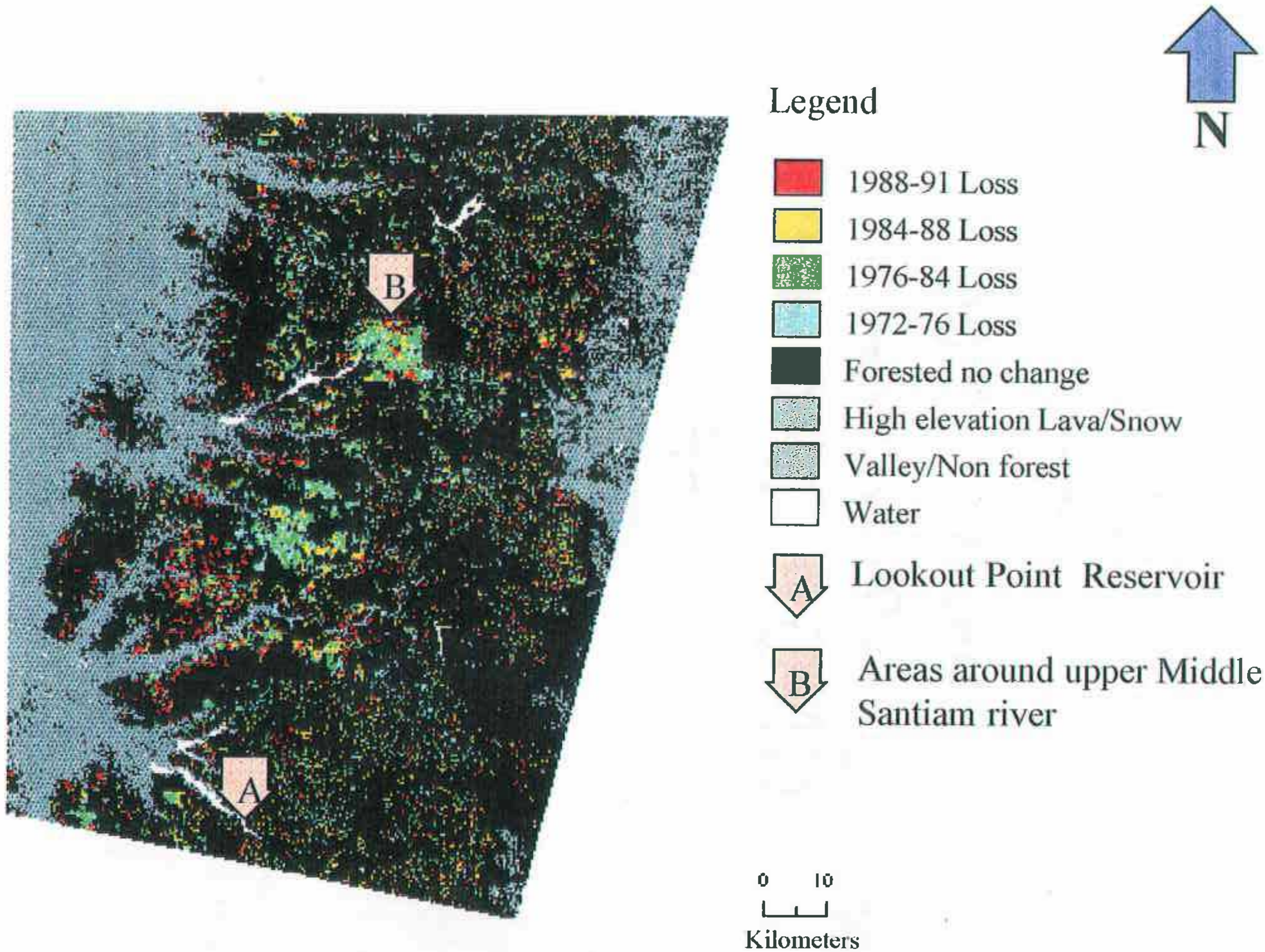
Satellite imagery data were also used in the analysis of forest loss. The 1972 image was compared to the 1988 satellite imagery. In the case of the central western Cascades of Oregon, a 1972-1991 forest change image had been produced and classified by Cohen et al. (1996) (Figure 2.4). The eight classes include losses occurring in four periods: 1972-1976, 1976-1984, 1984-1988, and 1988-1991, and four other classes including forested areas which did not change, high elevation lava/snow, valley/non forest, and water (Cohen et al. 1996). For comparative purpose with the Zairian study area, these classes were reclassified in two classes--Forest losses and Others (Figure 2.5). The class identified as 'Forest losses' for this study includes forest cover lost between 1972 and 1988, based on Cohen et al. (1996). The rest of classes constitute the class called 'Others'.

Figure 2.3 Forest of the central western Cascades of Oregon (1988)
Forest defined as unmanaged forest (at least 80 years in age)



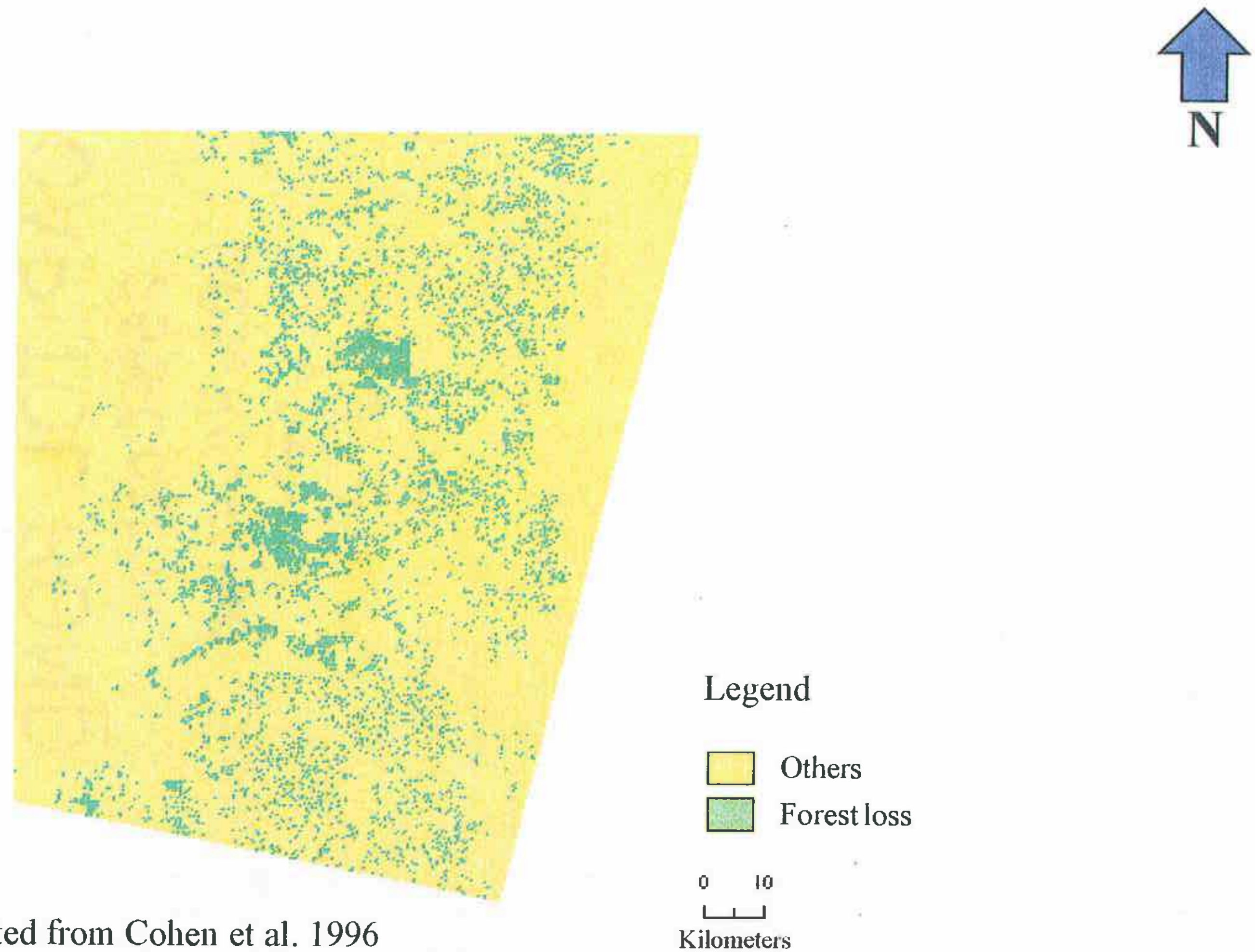
Source: adapted from Cohen et al. 1995

Figure 2.4 Forest loss in the Central Western Cascades of Oregon between 1972 and 1991



Source: Cohen et al. 1996

Figure 2.5 Forest loss in the central western Cascades of Oregon between 1972 and 1988



Source: adapted from Cohen et al. 1996

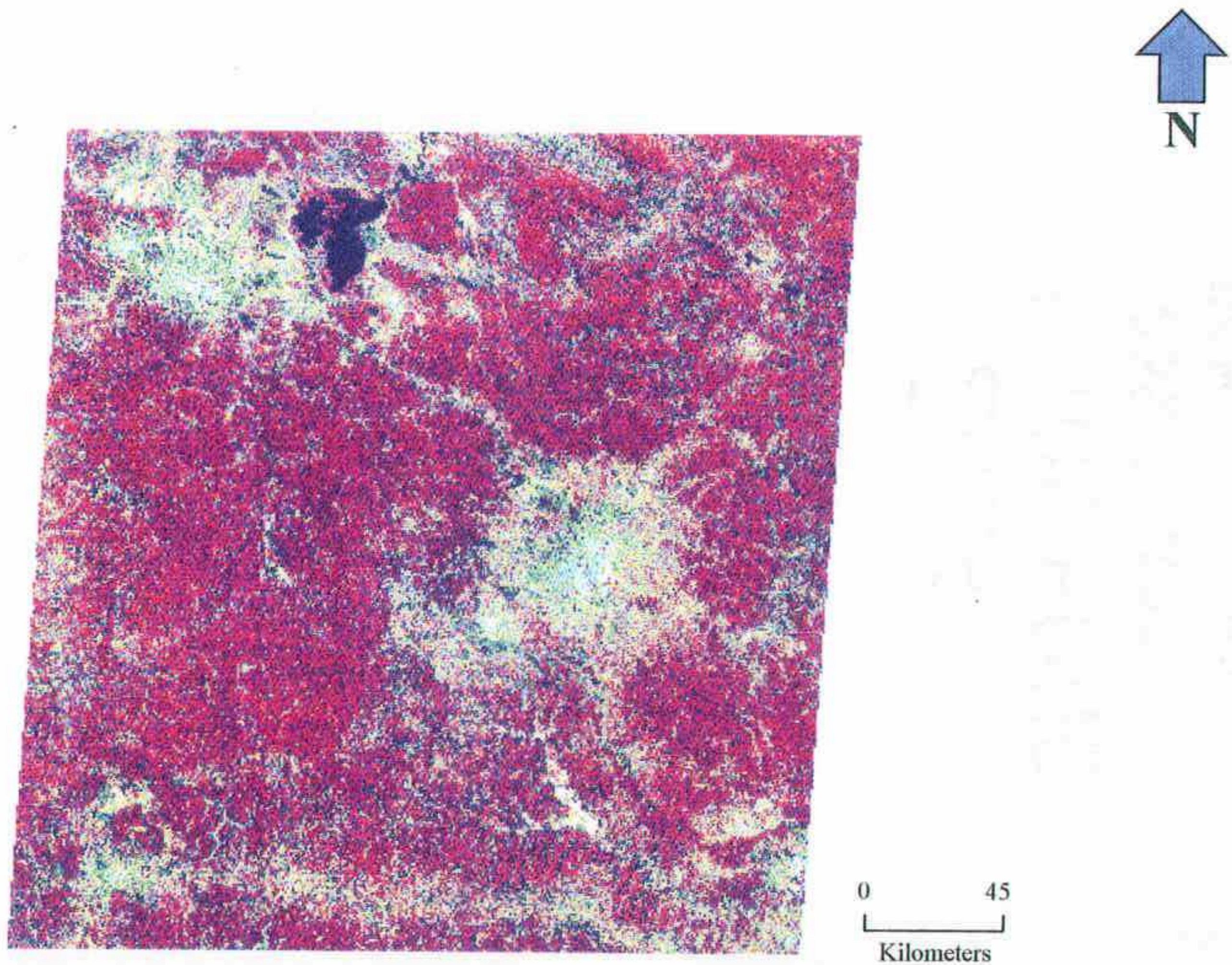
2.2.2 Southeastern Zaire data set

A 1989 Landsat MSS (Multispectral scanner) data set was used to analyze forest cover patterns in southeastern Zaire (Figure 2.6). These Landsat scenes could not be registered to any known ground geographic coordinates because of lack of ground control points (GCP) and reliable reference maps. Given the lack of GCP, and assuming MSS data have about 80 by 80 m ground resolution representing a pixel on the image (Lillesand and Kiefer 1987), pixel values were used to calculate related areas and distances in this study.

An unsupervised classification of vegetation was performed on southeastern Zaire data. Two techniques were used in this classification procedure. First, a Tasseled Cap brightness image was generated using the ERDAS software. The method consisted of using the ALGEBRA subroutine to input raw MSS data and select the appropriate equation generated from rotation matrix coefficients to create a brightness and greenness MSS image. Then, the CLUSTR subroutine was executed on this MSS brightness and greenness image to create 27 initial classes (Kauth and Thomas 1976; Richards 1993). Maps from Bruneau and Pain (1990) and personal field knowledge were used to identify a threshold so that two classes--forest and non-forest--could be distinguished.

Two classified forest types were derived based on this thresholding technique. In the first classification effort, the RECODE subroutine was applied to the Tasseled Cap image to obtain forest areas which are believed to conform to the FAO (1991)

Figure 2.6 Unclassified MSS satelllite image data of southeast Zaire (1989)



definition of tropical forest as areas where canopy cover occupy at least 10 percent (Figure 2.7).

In the second classification effort, the Tasseled Cap image was also used together with vegetation classes from Malaisse (1990) to identify unmanaged forest cover (forest areas less affected by human activities). Malaisse (1990) identified 13 vegetation classes outlining the degree of human impacts on forest environment (Figure 2.8). These classes may be categorized in four major types including short grasses (three classes), savanna (five classes), wooded savanna (two classes), open forest, and closed forest (two classes). Wooded savanna was defined as a forested area with a less advanced degradation process. Wooded savanna is in fact a transition zone between grass and forest dominated vegetation types.

To identify the unmanaged forest (forest less affected by human activities) class, four training sites were selected from the wooded savanna class. Three training sites are located in the northern part and one in the southern part of Lubumbashi (Figure 2.8). By classifying the wooded savanna into the non-forested class the remaining forest cover from the Tasseled Cap image was considered as unmanaged forest (Figure 2.9). This classification believed to be similar to the age-related unmanaged forest in the central western Cascades of Oregon was necessary in comparative analyses with the other Zairian forest type and with the central western Cascades forest types.

Satellite images were also used in the southeast Zaire study area for the 1973-1989 forest loss analysis. They were taken in June of each year. The 1973-1989 study

Figure 2.7 Forest of southeast Zaire. Forest defined as areas with at least 10 percent canopy cover.

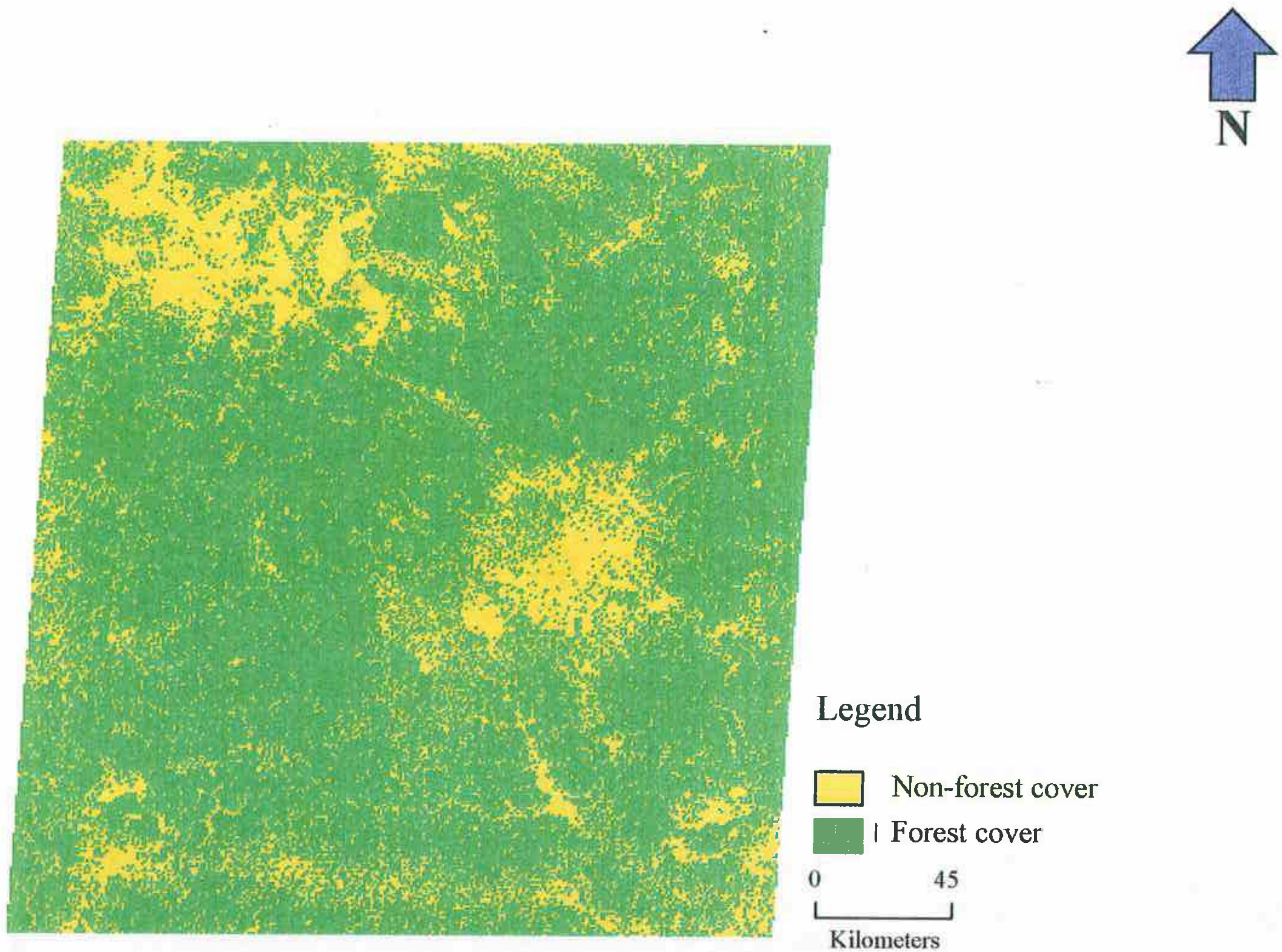
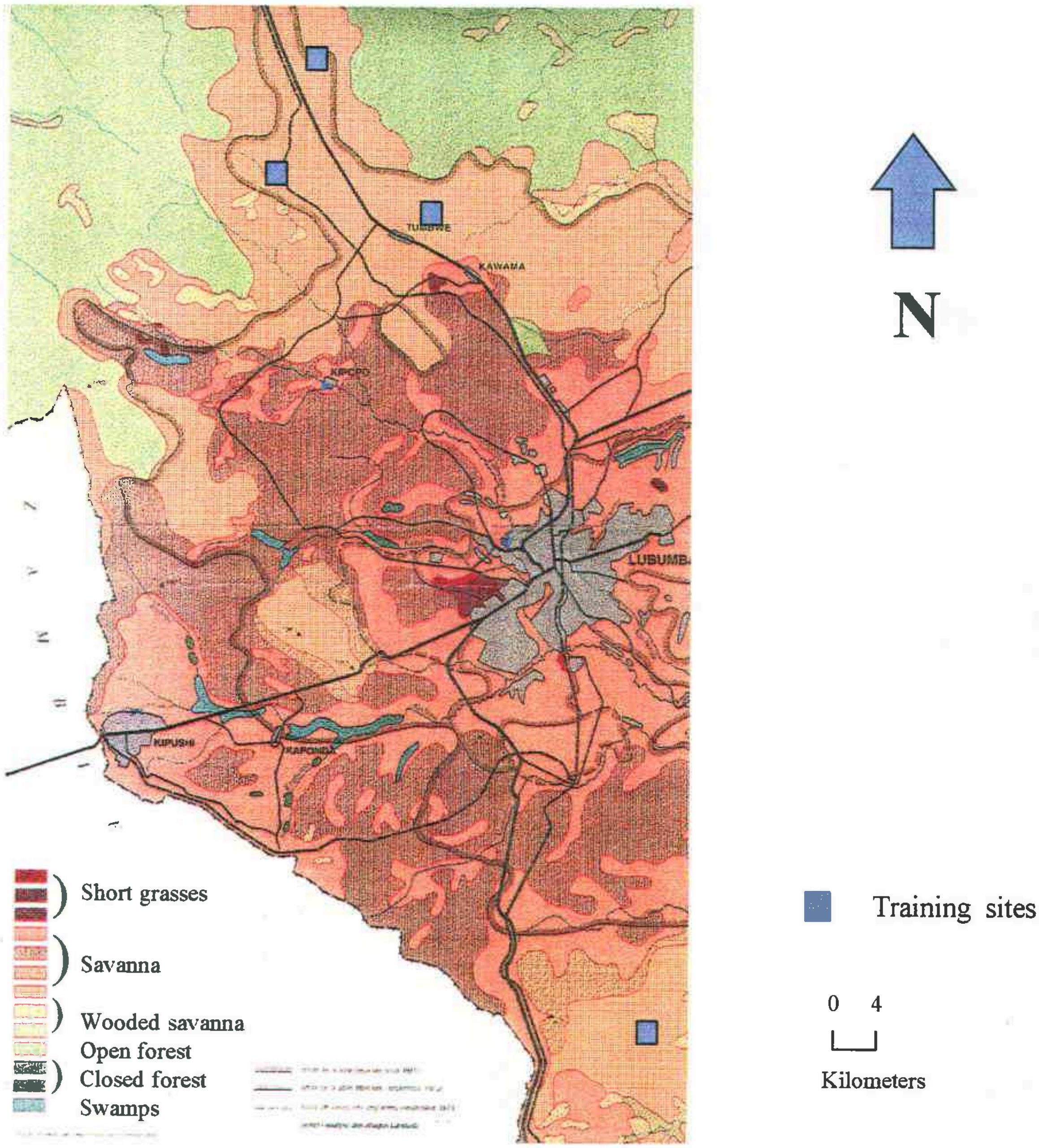
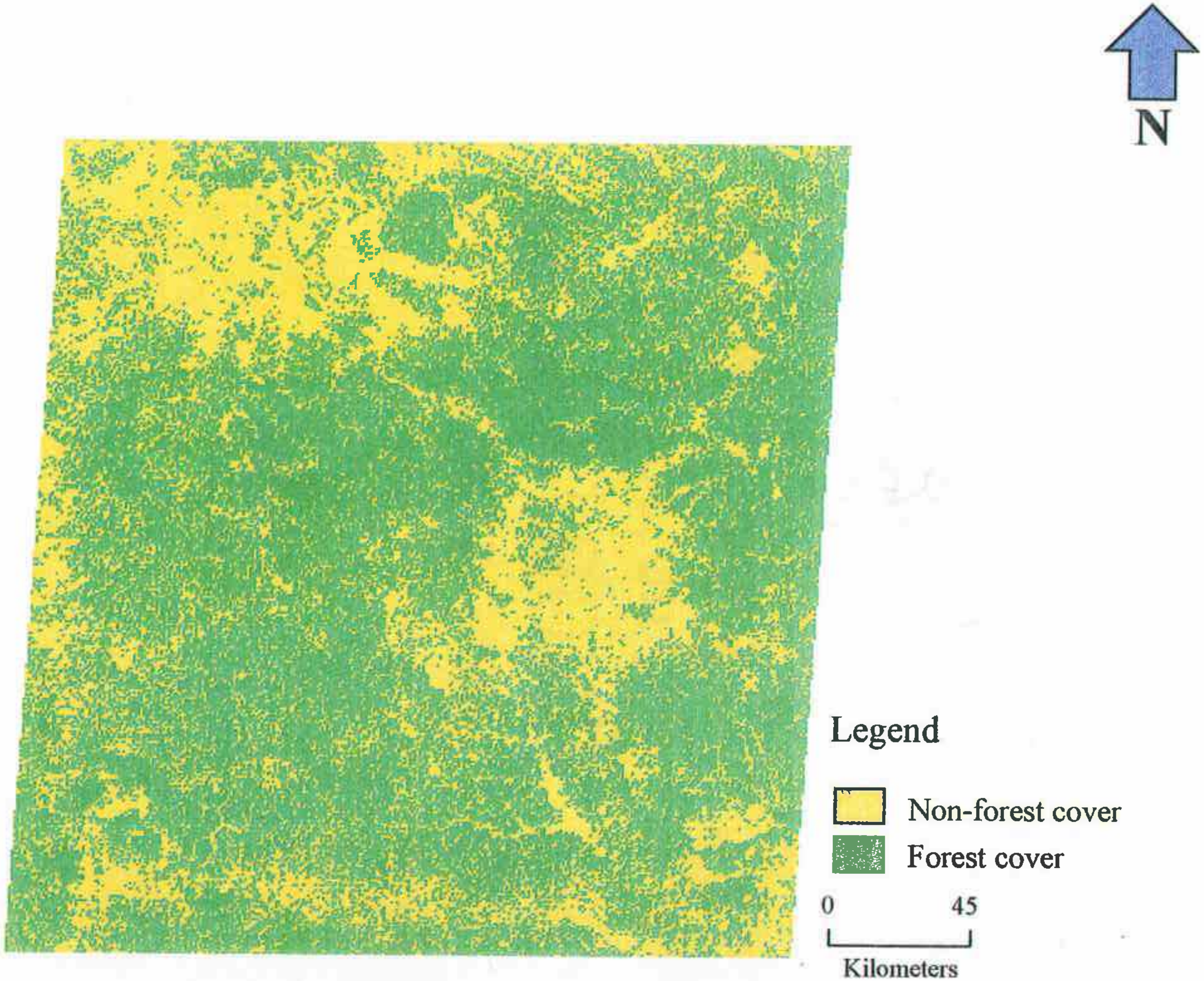


Figure 2.8 Vegetation distribution around the city of Lubumbashi



Source: Bruneau and Pain, 1990

Figure 2.9 Forest of southeast Zaire. Forest defined as unmanaged forest.



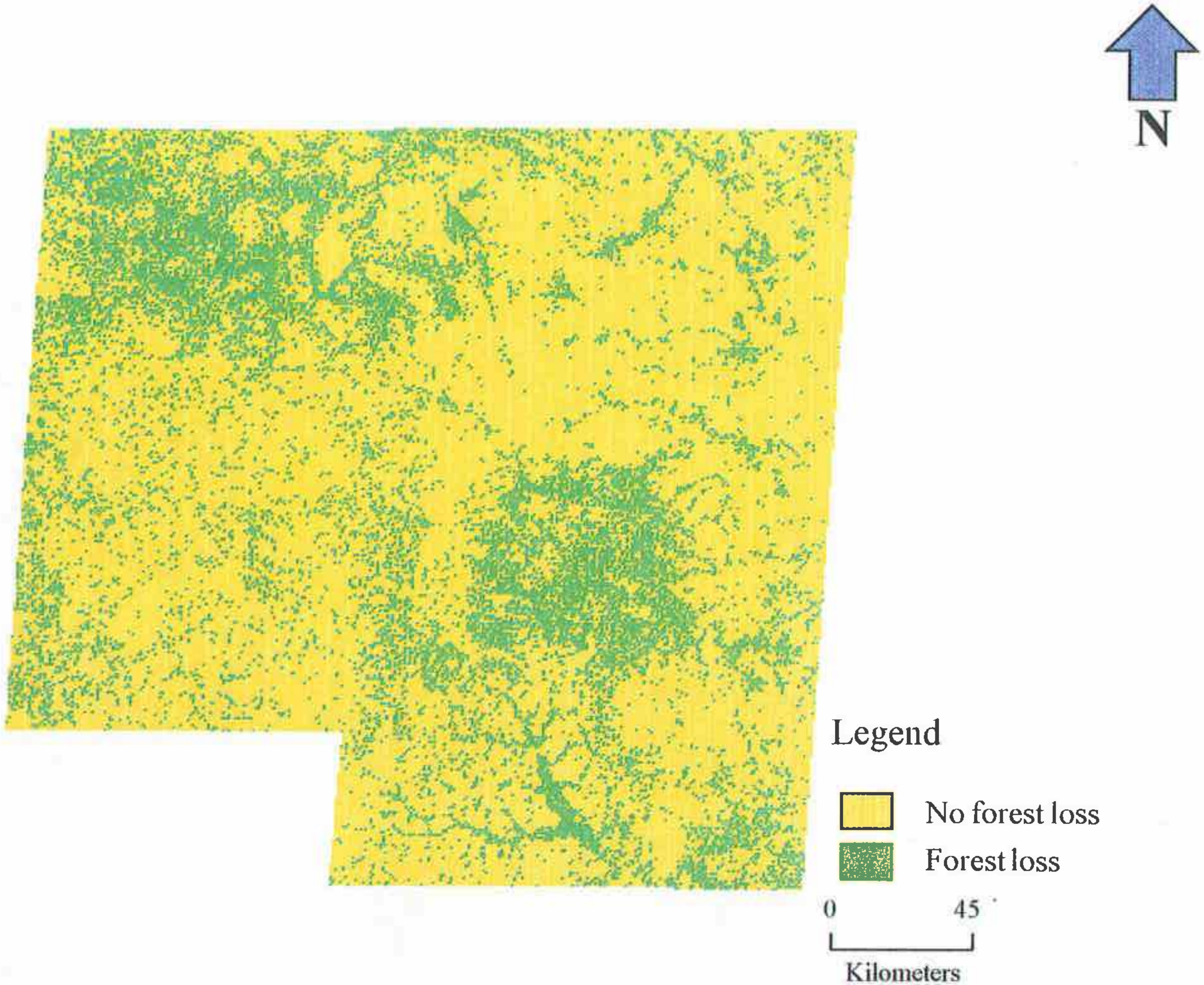
period was selected due mainly to data availability. Tasseled Cap difference images were used to perform forest loss analysis. Therefore, in addition to the existing 1989 Tasseled Cap brightness image, the Tasseled Cap transformation procedure as described earlier was also performed on the 1973 image. The ALGEBRA subroutine was used to input these two Tasseled Cap images and generate the vegetation change image (Kauth and Thomas 1976). The CLUSTR subroutine was also applied to this vegetation change image to create 27 initial classes. As in the classification of previous Tasseled Cap images, maps from Bruneau and Pain (1990) and field knowledge were used to define brightness and greenness threshold values to distinguish two classes which included areas which lost forest cover and areas of no changes (Figure 2.10).

2.3 Sampling Design

2.3.1 General description

The selection of southeastern Zaire and the central western Cascades of Oregon as study sites is attributable to several factors. First, the two areas are located in somewhat similar environments in the sense that both are dominated by forest, agriculture, and related activities. Second, the two areas are similar in the spatial distribution of their populations, with high demographic concentration in urban centers and overall low population density in the hinterland with clear transportation paths. There are, however, large differences between the two sites, such as in their stages of economic development, physical and topographic characteristics, and land ownership

Figure 2.10 Forest loss in southeast Zaire between 1973 and 1989.

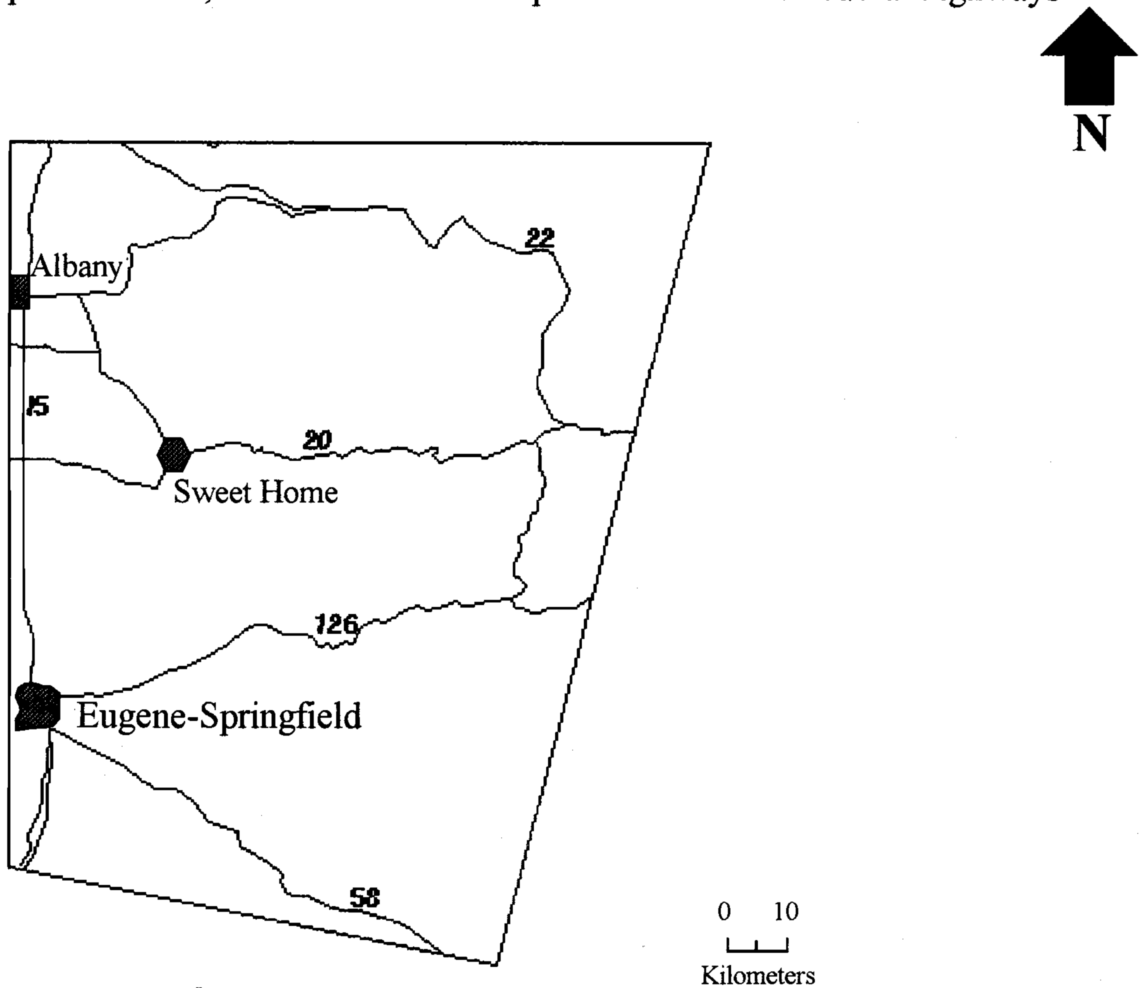


types. Because of these similarities and differences it was relevant to examine different models of forest change under conditions of high harvest technologies represented by the central western Cascades of Oregon and low forest harvest technologies represented by southeast Zaire.

Two socio-economic variables were identified to characterize the socio-economic impact on the forest ecosystem, to answer questions related to different spatial patterns of forest between and within southeastern Zaire and the central western Cascades of Oregon, and their suitability to theoretical models. Socio-economic data included the population growth rate and the per capita gross income or per capita money income. For the central western Cascades of Oregon these data were collected from the Census Bureau database (US Department of Commerce Bureau of the Census of Population, 1981 and 1991) and include the result of every recorded town and city within the study area. For southeastern Zaire, the only published census data available were for the city of Lubumbashi (Bruneau and Pain 1990, The World Resources Institute 1990, and The World Bank 1975). An argument for using population data from Lubumbashi only is based on the belief that the city is one of the most important driving forces in southeastern Zaire forest cut patterns.

In addition to these socio-economic parameters, infrastructure, such as roads and urban centers, were also considered. The quality of the transportation system was used to explain the pattern of forest cover distribution when analyzing within-and between-study site variations. In this study, roads were defined as all existing highways in the central western Cascades in Oregon (Figure 2.11), whereas in southeast Zaire all

Figure 2.11 The Central Western Cascades of Oregon: highways and cities
Shaded areas represent cities, lines and numbers represent State and Federal highways



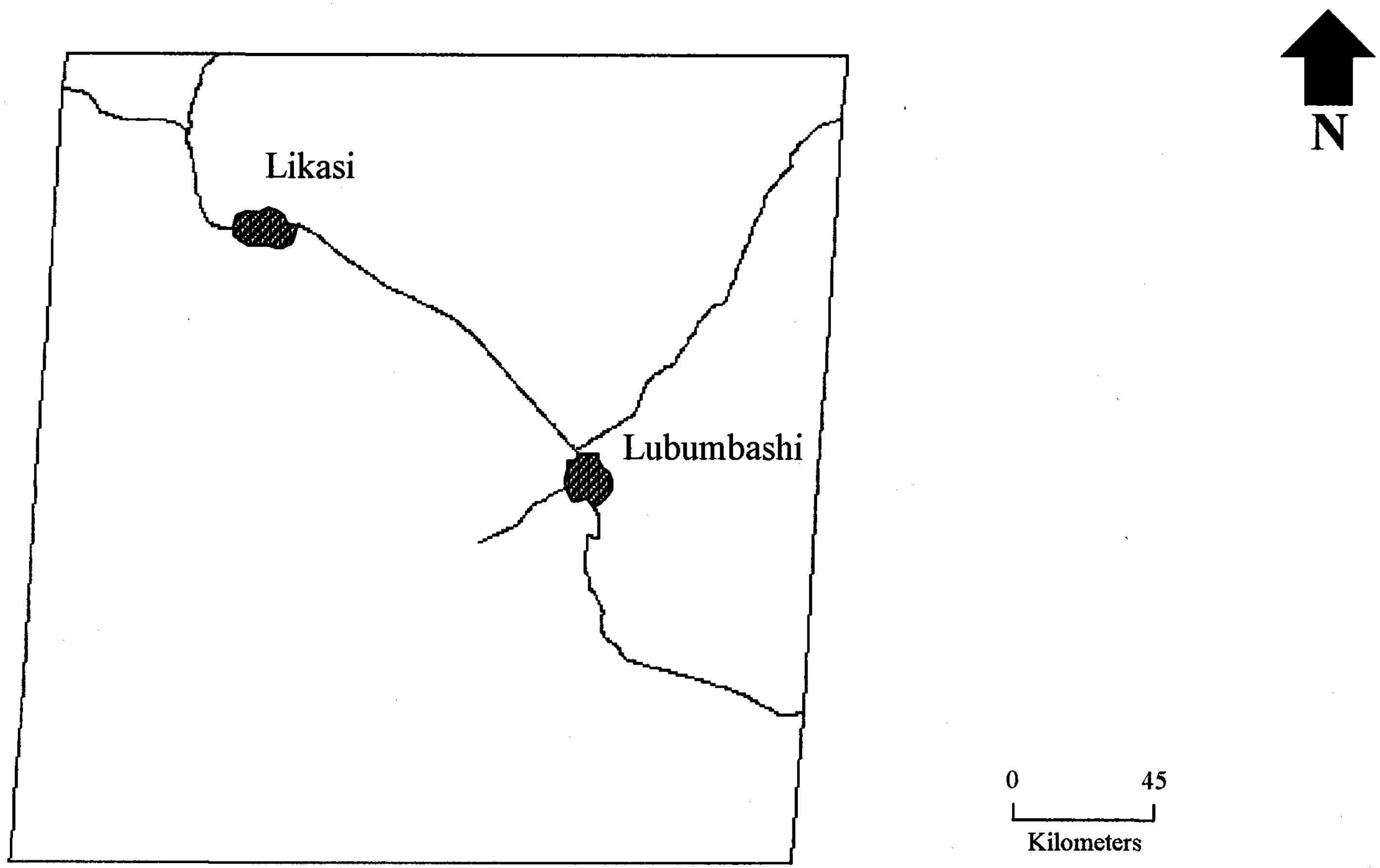
"roads of general interest" were considered (Figure 2.12) (Bureau d'Études d'Aménagements Urbains 1982).

The purpose of the sampling design was to attempt to separate the impact of distance from highways/roads versus distance from cities and urban centers on forest cover patterns. The design was based in part on Medley et al. (1995), who investigated human activities and forest-landscape structure along a 20-km wide and 140-km long transect from New York City to northwestern Connecticut. Two sampling designs were used: (1) the transect was divided into 20 km by 5 km transect sections for a coarse resolution study, and (2) circular landscape units of about 75 km^2 were centered on each of 9 forest study sites for fine resolution analyses. Medley et al. (1995) investigated the relationship between variables such as land use, population growth, and urban land development versus forest stand distribution, size and shape. They found that forest area increases as one moves away from urban environments.

Two scales of analysis were also used in the present study. In this study each study site was divided into 1600 m by 1600 m cells. This grid cell division of the 12,241-km^2 of the central western Cascades study site produced 4782 cells of which 2391 were selected, while the subdivision of the 41,415 km^2 southeast Zaire study site produced 16178 cells of which 8089 were selected.

Two gradients were considered for analysis at this coarse resolution: away from cities and away from highways/roads. The away-from-cities gradient consisted of 71 buffers each 1600-m wide extending from the urban corridor along the Willamette Valley to the crest of the Cascades in the central western Cascades of Oregon. In

Figure 2.12 Southeast Zaire: roads and cities
Shaded areas represent cities, lines represent major roads



southeast Zaire, the away-from-cities gradient consisted of 54 1600-m wide buffers extending from the city of Lubumbashi along the northeast road to the east. The away-from-highways/roads gradient consisted of 19 1600-m buffers extending from all highways within the central western Cascades of Oregon study site, and 38 1600-m buffers extending from major roads in southeast Zaire.

This study also included detailed analyses as in Medley et al. (1995). Four sub-samples of about 300 km^2 were taken from selected sites within each study area, and within each the away-from-roads forest cover and forest loss patterns were examined. Fifty to sixty out of 100 to 120 cells were selected from each detailed study site. Results from this small-scale study were compared between sub-samples and to the overall gradient away-from-roads of each study site to test the effect of ownership patterns on gradients.

Several comparative analyses of these two gradients and two sites were undertaken. First, the away-from-cities pattern was compared to the away-from-roads pattern in each study site. Then, the away-from-cities pattern in the central western Cascades was compared to the away-from-cities pattern in southeastern Zaire. Further, the away-from-roads pattern in the central western Cascades was compared to the away-from-roads pattern in southeastern Zaire.

2.3.2 Overall sampling design

This section describes steps taken and techniques used prior to the analysis of results in order to divide each study site into cells, to select subsamples, and to delineate buffer zones away from cities and urban centers, and away from highways/roads.

Study sites were first divided in 1600 m by 1600 m cells. A net fitting the lower left and upper right limits of each study site was generated using GENERATE subroutine in the ARC/INFO software with 1600 m by 1600 m (256 ha) cell size. This grain size was selected based on the fact that it was large enough to encompass more than one patch, but small enough to produce at least seven distance classes to display the gradient, and also could evenly be divided by the pixel size of the two study sites (25 m for the central western Cascades of Oregon, and 80 m for southeast Zaire).

A systematic subsampling of every other cell in the created net was used. To select half of cells covering each study site the TABLES subroutine in the ARC/INFO software was used. Cells whose centers fell within the study site were selected as samples for analysis. However, some samples had a size less than 1600 by 1600 m because of the non-rectangular shape of study sites (Figures 2.13 and 2.14). This sampling design was believed to give a fair representation of patterns of forest cover and forest loss rates.

2.3.3 Distance-gradients sampling design

Two types of distance gradients were used to classify the selected cells. First, cells were classified as a function of distance away from cities and urban centers. Two different methods were used to categorize cells in the investigation of away-from-cities forest cover/loss patterns. In the case of the central western Cascades of Oregon, 1600-

Figure 2.13 Central western Cascades of Oregon sampling design
(Each cell size is 1600 by 1600 m)

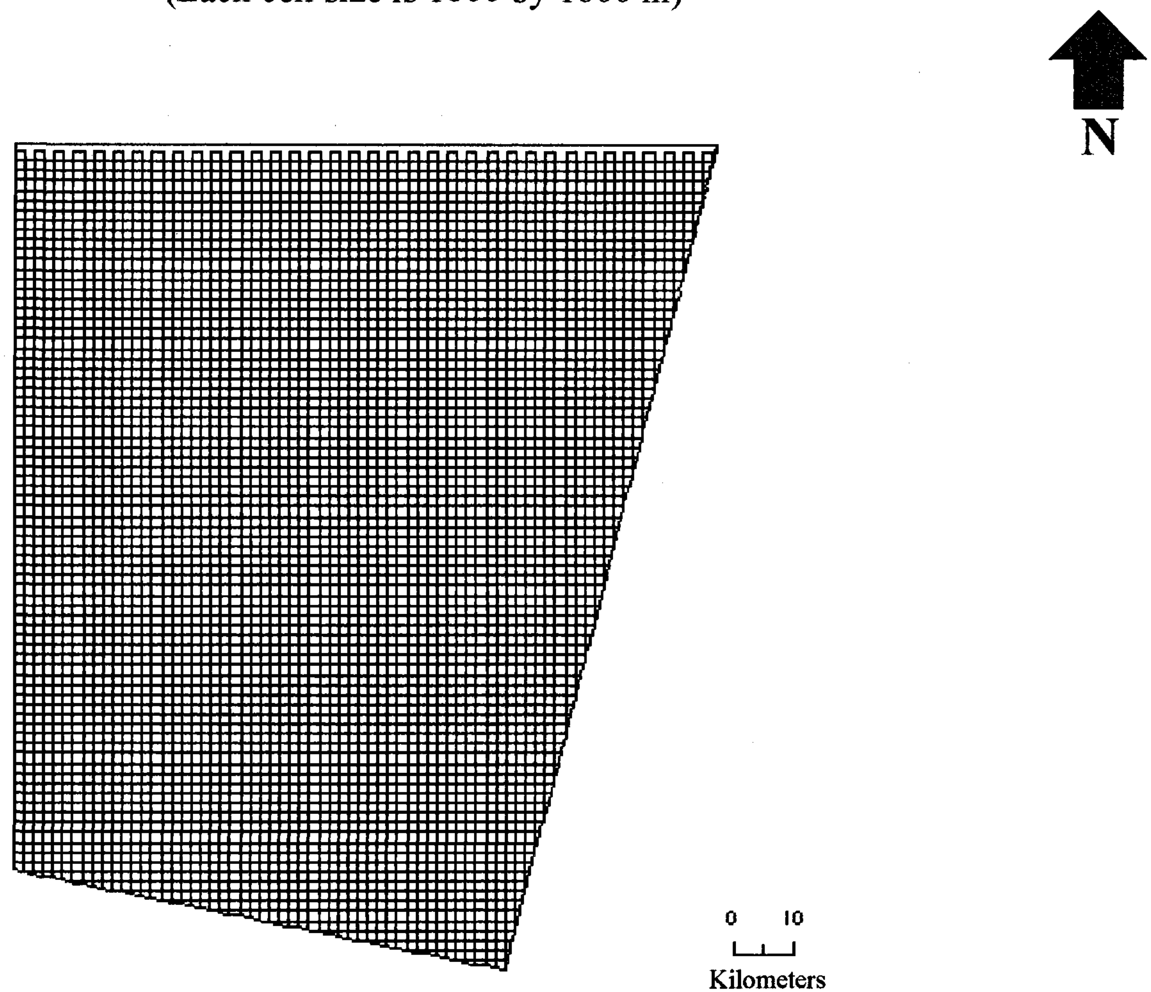
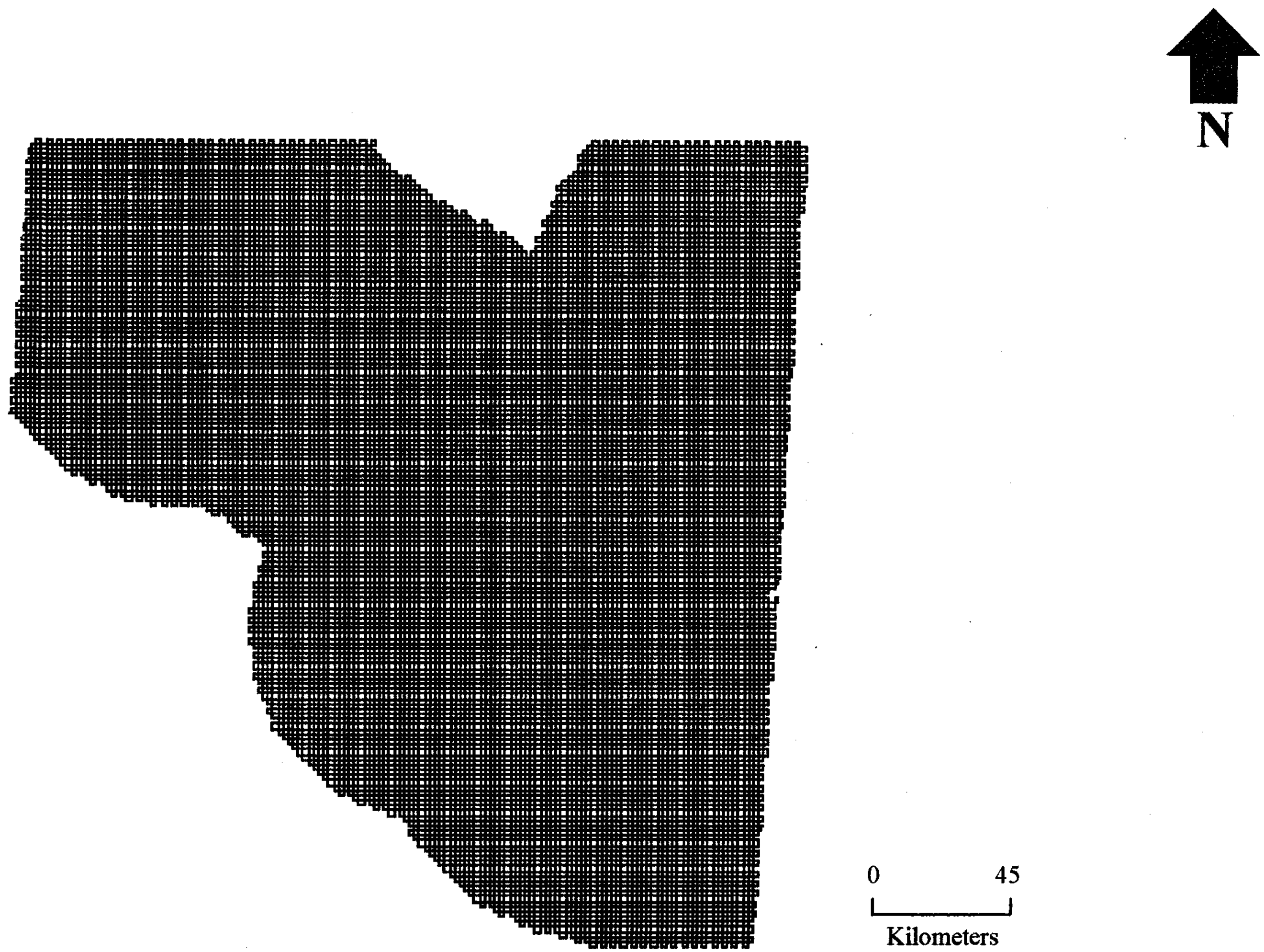


Figure 2.14 Southeast Zaire sampling design

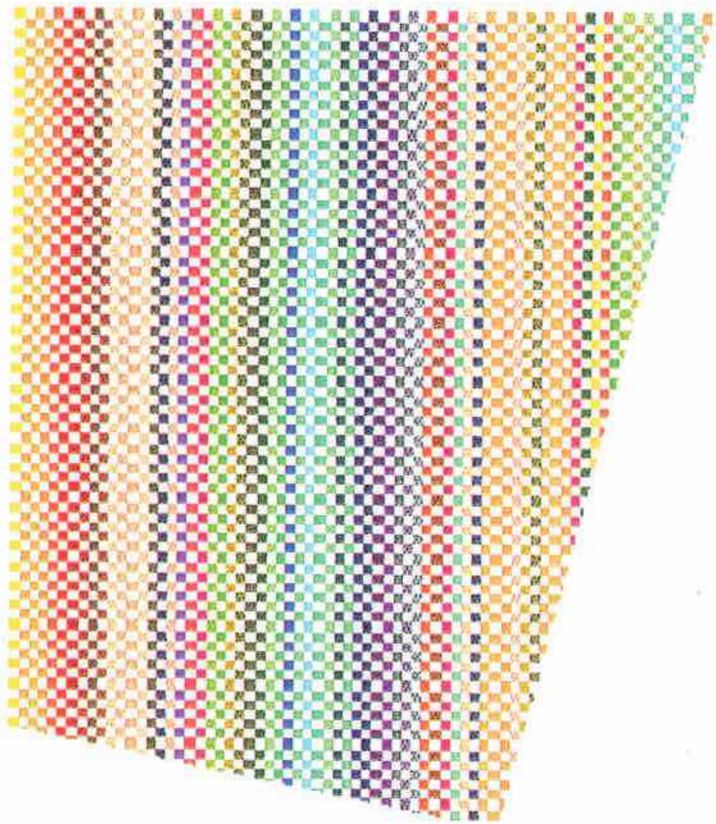


m buffers were delineated from the western boundary of the study site (from the Willamette Valley eastward to the crest of the Cascades). This buffer zone design was preferred because most highways in the study area were oriented east-west, and also, most towns and urban centers are located along the western border. As a result of this classification, seventy-one distance classes were identified (Figure 2.15).

In the case of southeastern Zaire the away-from-cities sampling design was different. For the gradient to represent an area which included a road network, and a city-to-rural forest cover pattern, a buffer of about 11 km was delineated along the northeastern road from the city of Lubumbashi. A total of 558 cells were selected within the delineated buffer zone. Then, all cells within the delineated area aligned perpendicular to the northeast road were grouped to create a same class distance (Figure 2.16). The closest distance class to the city was identified as distance class 1. The next set of perpendicular cells were classified as distance class 2, and so forth. Distance class numbers increase outward from the city each by 1600 m following the northeastern road from Lubumbashi. Thus, fifty-four class distances were created (Figure 2.16). Hence, the away-from-cities analysis in southeast Zaire examined only a portion of the image.

Cells were also classified as a function of distance away from highways/roads. Using the ARC/INFO software, a set of buffers of 1600 m width were created from highways and road coverages of the central western Cascades in Oregon and southeastern Zaire study sites, respectively. The cell center was also used to assign each cell to a specific buffer zone. Each cell buffer constituted a class distance buffer.

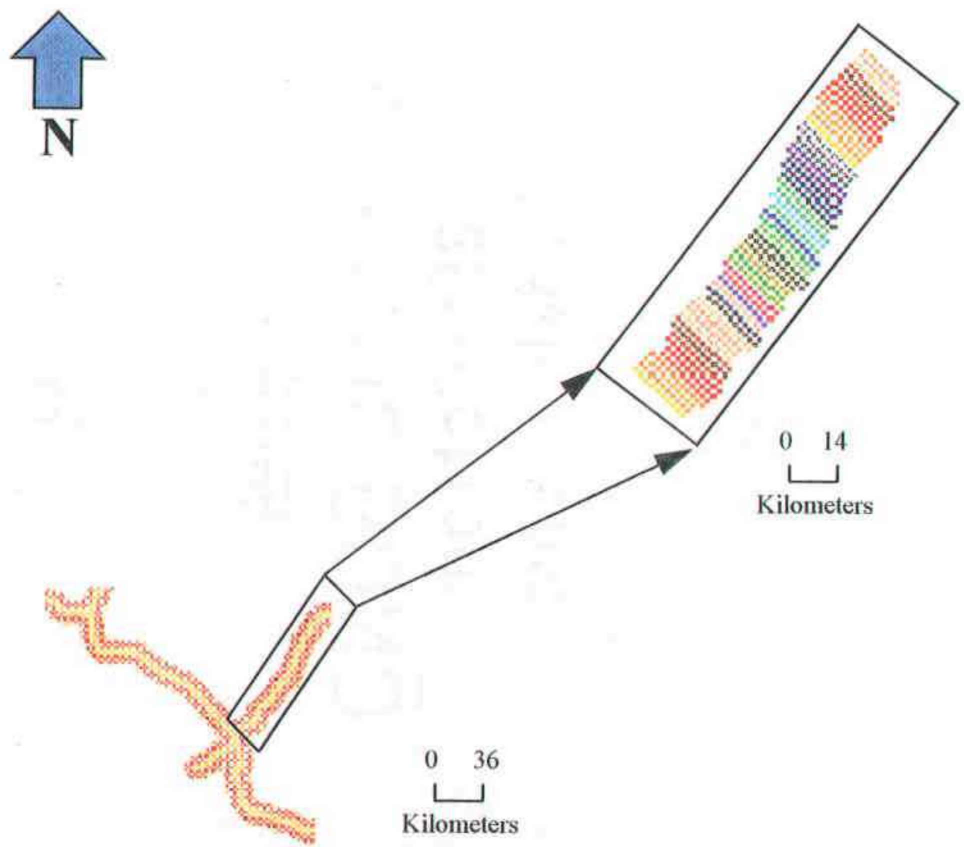
Figure 2.15 Away-from-cities distance classes in the central western Cascades of Oregon
(Each cell size is 1600 by 1600 m)



Legend

Each distance class away from the western boundary is 1600 m wide.
There are 71 distance classes
The closest to the western boundary is distance class 1

Figure 2.16 Away-from-cities distance classes in southeast Zaire
(Each cell size is 1600 m by 1600 m)



Legend

Each distance class away from Lubumbashi along the northeast road is 1600 m wide.
There are 54 distance classes
The closest to Lubumbashi is distance class 1 (yellow)

Distance class 1 corresponded to cells located within the first 1600 m buffer away from highways/roads. Distance classes increased away from the transportation system. For example, distance class 2 was the buffer zone between 1600 and 3200 m away from highways or roads. Nineteen distance classes were defined in the central western Cascades of Oregon and thirty-eight in southeastern Zaire (Figures 2.17 and 2.18).

The resulting coverages from ARC/INFO software were transformed into grid coverages using POLYGRID and GRIDIMAGE sub-routines, then exported to the ERDAS software. In ERDAS, images with different buffer classes were overlaid using the MATRIX subroutine with images related to forest/non-forest and land ownership classes of the central western Cascades of Oregon (Sollins 1995) (Figure 2.19), and southeast Zaire (Figure 2.20).

2.3.4 Land-ownership sampling design

Cells were also classified as a function of land ownership. Eight land ownership types were identified in the central western Cascades of Oregon (Sollins 1995) They include United States Forest Service (USFS), Bureau of Land Management (BLM), State lands, private non-industrial (PNI), private industrial (PI), no data class, miscellaneous (MISC), and Wilderness lands (Figure 2.19).

Southeastern Zaire has two land ownership types including Urban and Rural lands (Figure 2.20). Land ownership delineation in Zaire was based on existing land tenure systems (Salacuse 1985) with reference to maps from Bruneau and Kakese (1989) and Bruneau and Pain (1990). Areas of traditional ownership system, and under

Figure 2.17 Away-from-highways distance classes in the central western Cascades of Oregon (Each cell size is 1600 by 1600 m)

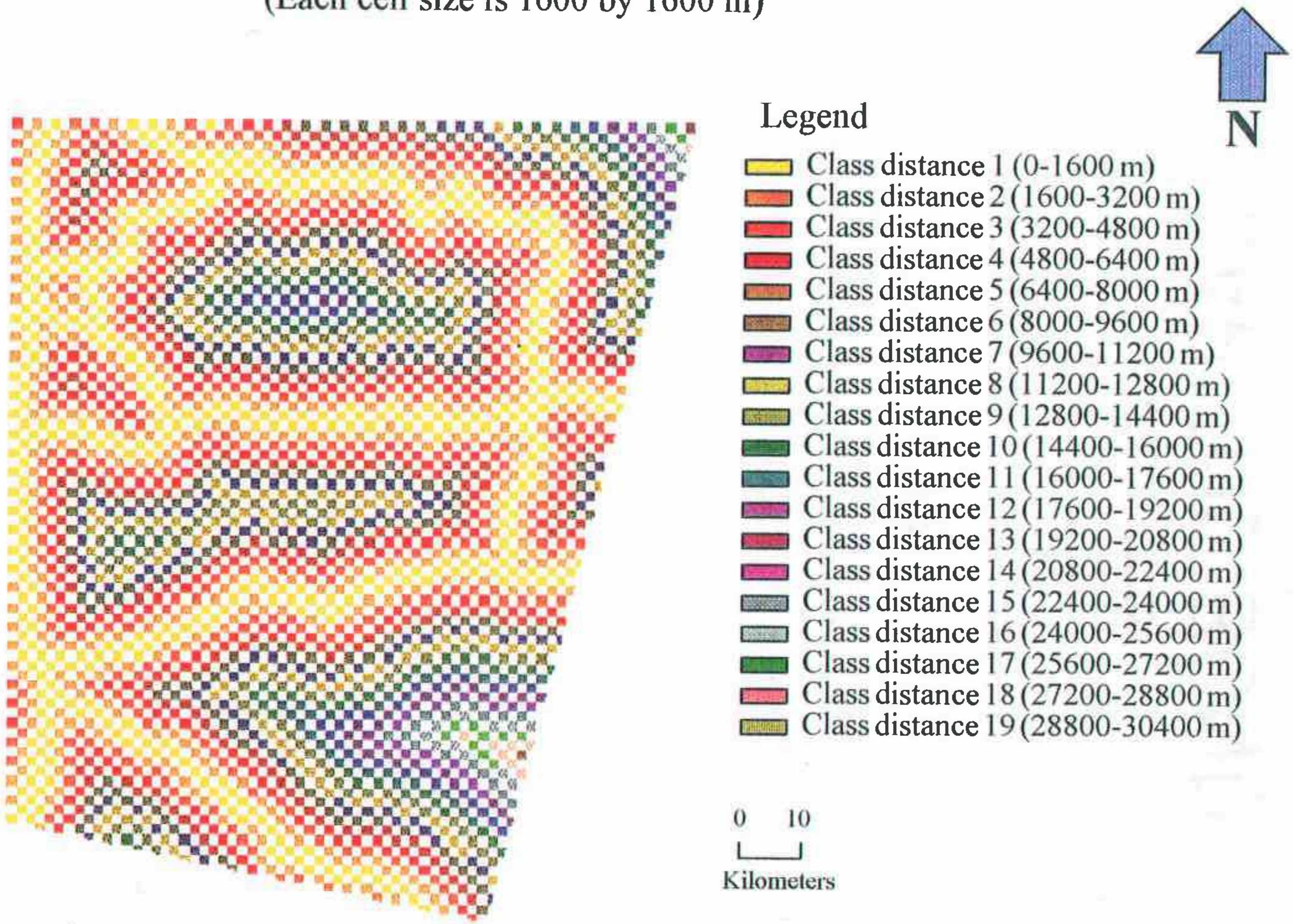
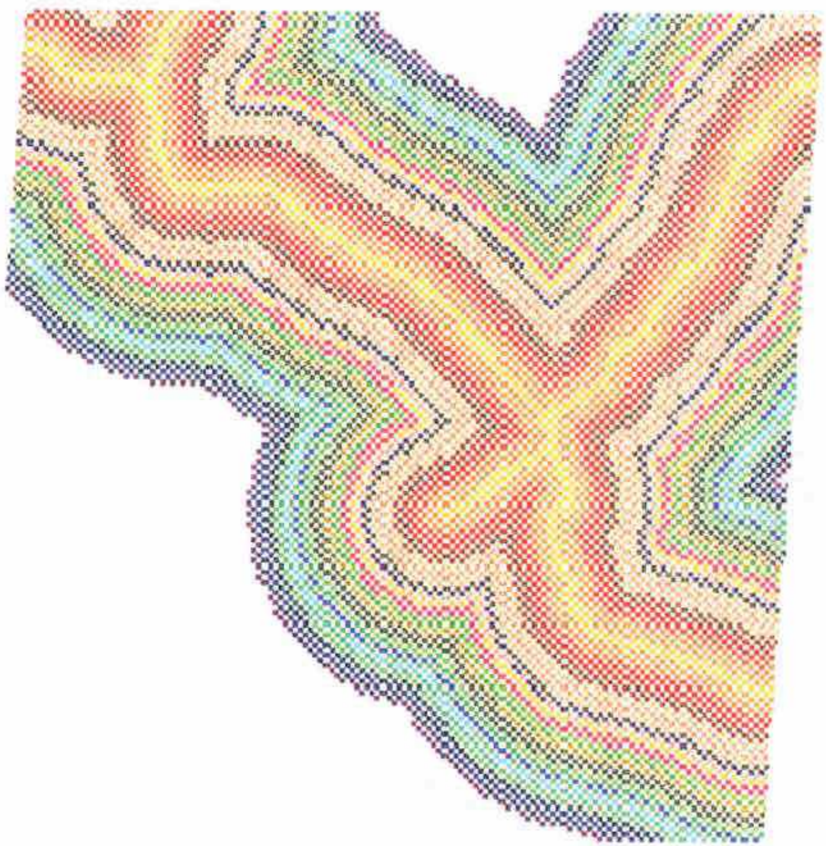


Figure 2.18 Away-from-roads distance classes in southeast Zaire
(Each cell size is 1600 by 1600 m)

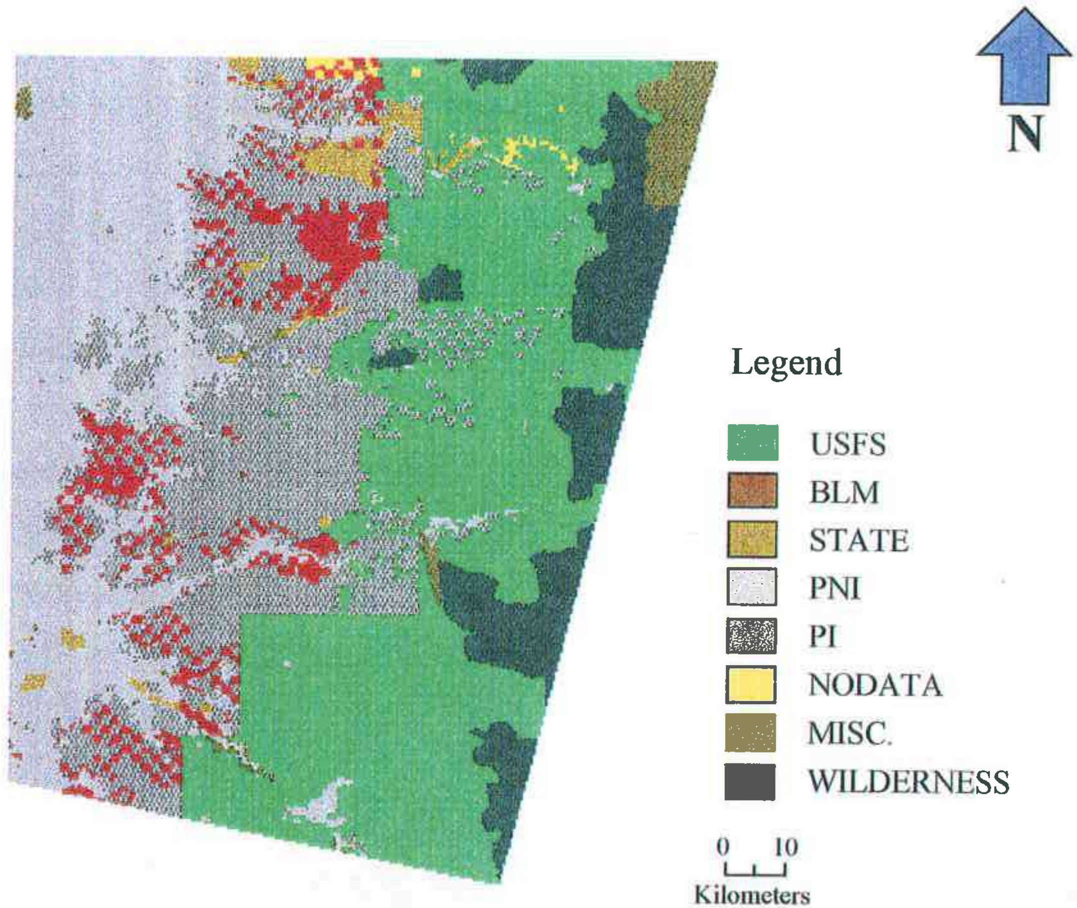


Legend

Each distance class away from roads is 1600 m wide.
There are 38 distance classes.
The closest distance class (yellow) to roads is distance class 1

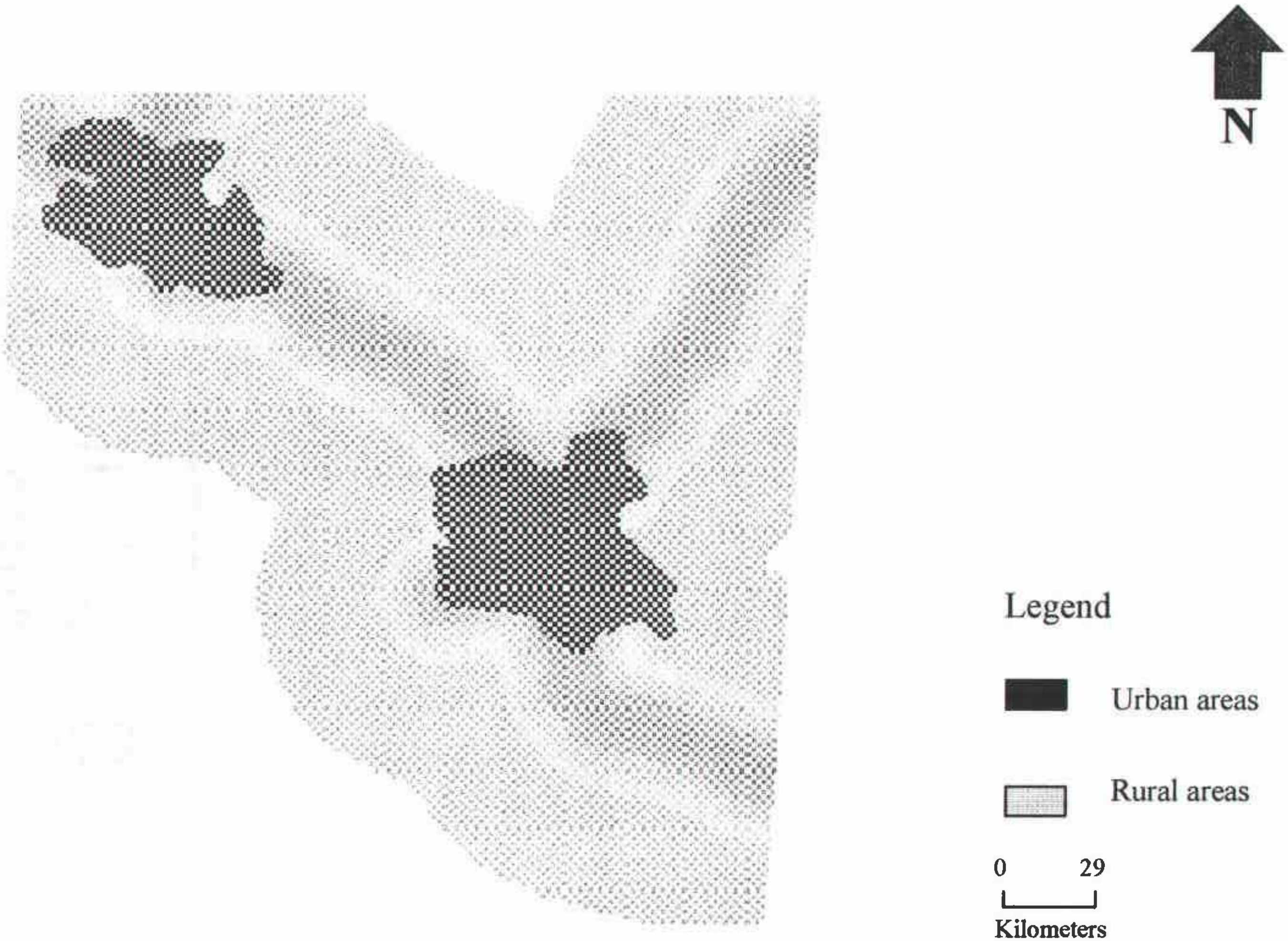
0 45
Kilometers

Figure 2.19 Land ownership distribution in the central western Cascades of Oregon



Source: Sollins 1995

Figure 2.20 Urban/rural land distribution in southeast Zaire



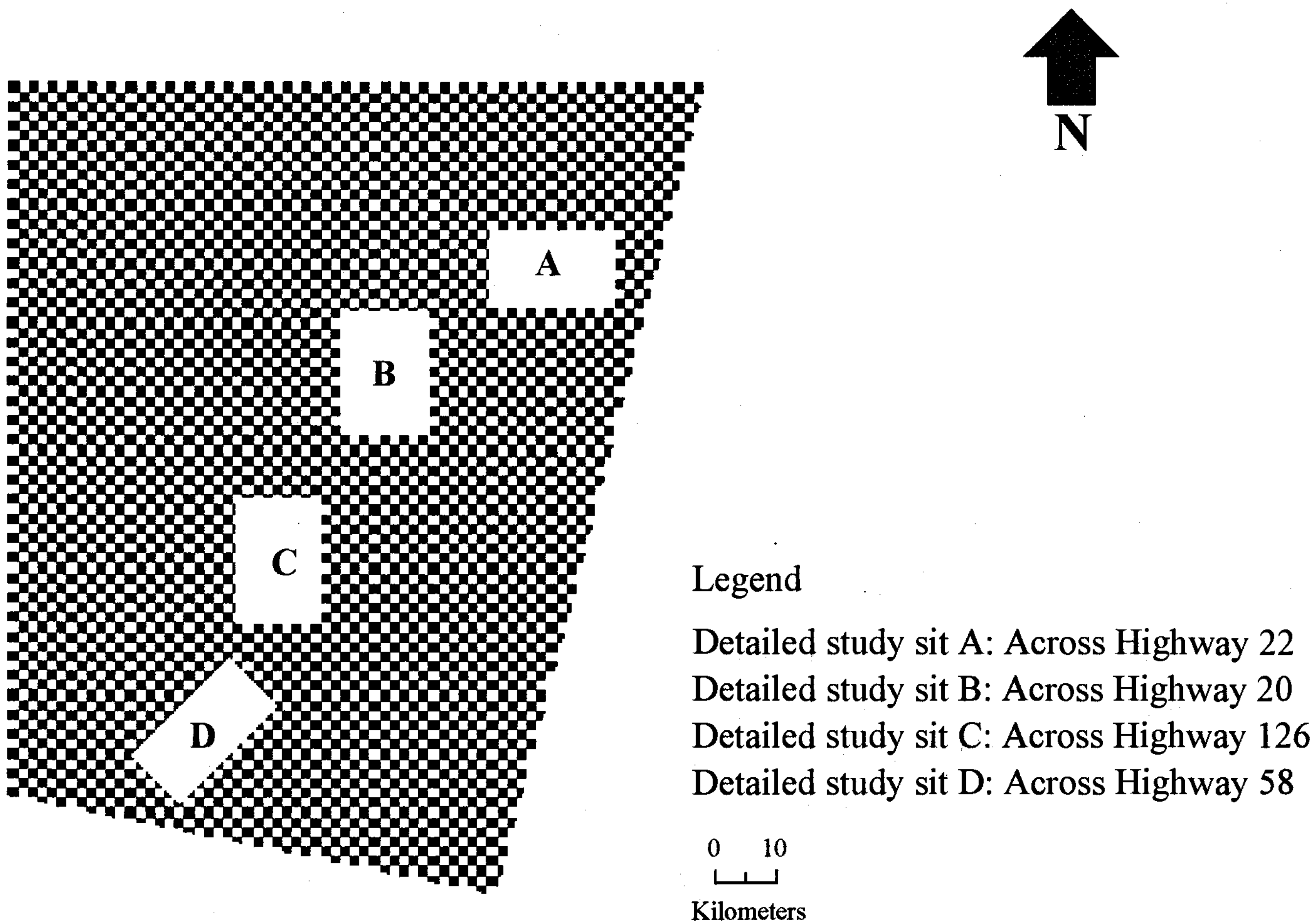
the traditional chief supervision were classified as Rural lands. Land uses including agriculture and fuel wood harvest within Rural lands are generally administered on the basis of first come first served (Salacuse 1985). Lands within delineated urban boundaries were identified as Urban lands. They are managed according to the modern type of administration. Individuals are expected to buy their lots and meet urban land use requirements before any exploitation.

2.3.5 Central western Cascades sampling design

In the case of the central western Cascades of Oregon the side bounded by interstate highway I-5 was used as the starting axis because important urban centers such as Eugene and Springfield are located along this corridor. From this western boundary corridor, the entire study area from the valley bottom to the crest of the Cascades was subdivided into 1600 m by 1600 m cells (Figure 2.15). Then, the same cell size and distance were used in selecting cells away from Highways 22, 20, 126, and 58 in detailed study sites. These highways follow North Santiam, South Santiam, McKenzie, and Middle Fork of the Willamette rivers, respectively (Figure 2.17).

Sub-study sites for detailed analyses (Figure 2.21) were selected in such a way that they crossed highways so that the lateral pattern away from a highway could be analyzed. One of them (area A) was positioned along Highway 22 in USFS- and Wilderness-dominated areas (UTM zone 10 coordinates: upper left 591375; 4916375 and lower right 612075; 4903425). This sub-study site was expected to detect forest cover patterns in an environment with mostly publicly owned lands. Indeed, on one side

Figure 2.21 Detailed study sites in the central western Cascades of Oregon



of the highway were USFS managed lands and on the other side was mostly Wilderness areas. A second sub-study site (area B) was along Highway 20 in an environment where private and public lands were arranged in a checkerboard pattern near the highway and mostly public lands away from it (UTM zone 10 coordinates: upper left 567375; 4903275 and lower right 581625; 4882575). A third sub-study site (area C) was located along Highway 126 with a mixture of public and private lands next to the highway and mostly private lands away (UTM zone 10 coordinates: upper left 549825; 4872825 and lower right 564075; 4852125). The fourth sub-study site (area D) crosses Highway 58 and was also in an environment with a mixture of land ownership distribution pattern but public lands dominated away from the highway (UTM zone 10 coordinates: upper left 548925; 4846575 and lower right 540900; 4822500).

2.3.6 Southeastern Zaire sampling design

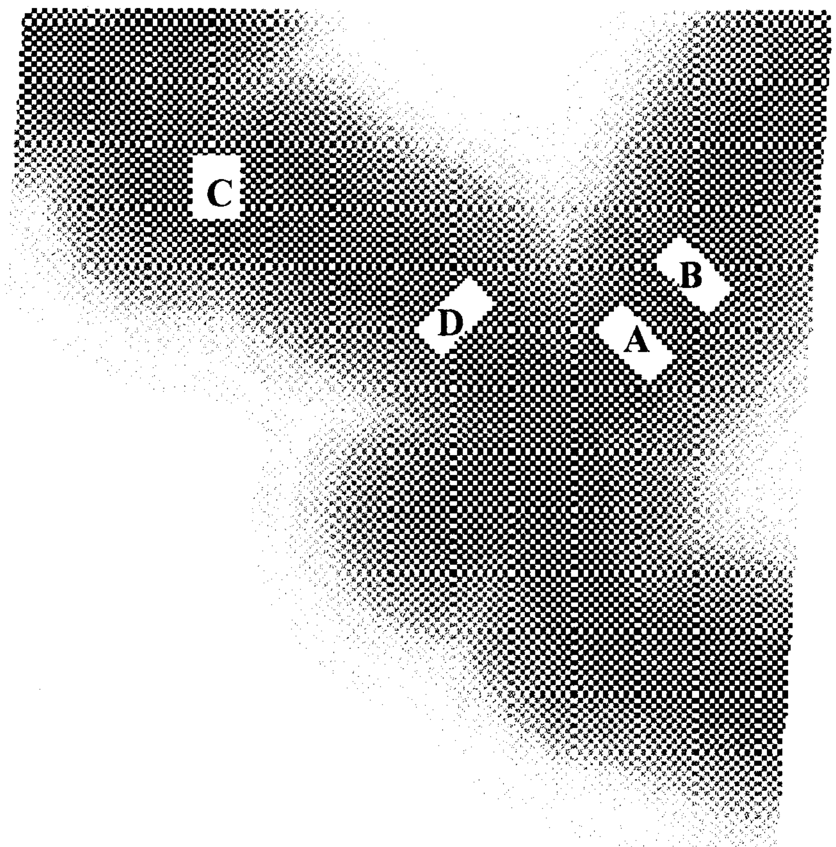
The sampling area in the away-from-roads analysis was different in size and shape from that of the away-from-cities. In the away-from-roads analysis buffer zones were delineated from roads defined as roads of general interest (Bureau d'Études d'Aménagements Urbains, 1982). Three major roads originating from Lubumbashi city were identified--northwest, northeast, and south roads (Figure 2.12). As previously explained, thirty eight buffers were delineated from these roads (Figure 2.18).

The sampling area in the away-from-cities analysis was smaller than that used in the away-from-roads. The difference in the sampling area design from that used in the central western Cascades was due to the difference in the pattern of road and urban center distribution in southeast Zaire. Lubumbashi, the main city, is in the southwest study site, and the other city, Likasi, is in the northwest part near the study area boundaries. If samples were taken along the road linking these two cities, they would have likely helped in the detection of urban-to-urban forest cover pattern rather than the intended urban-to-rural pattern. For this reason the northwesternward road connecting these two cities was not selected for such a study. This sampling design also was due to the need to have a gradient more comparable to the west-east distance gradient identified in the central western Cascades of Oregon.

Since the sampling area was expected to include a road corridor and to help analyze the urban-rural forest cover gradient, another sampling area format was needed. For an area to fit these criteria a buffer of about 11 km was delineated along the northeastern road from the city of Lubumbashi. Beyond 11 km was believed to have no or less human-related impacts based on an individual's average daily walking distance (Bailey 1982, Allen 1985, Hart and Hall 1996). A total of 558 cells were selected within the delineated area. Then, all cells within the delineated area aligned perpendicular to the northeast road were grouped within same class distance (Figure 2.16).

Four detailed-study sites were also selected to show detail on away-from-roads patterns in Zaire (Figure 2.22). Two were located on the northeastward road; one at the boundary of the urban land of Lubumbashi (area A) and the other one far away in the rural environment (area B). They are about 37 kilometers and 68 kilometers away from the city center of Lubumbashi. The remaining two were located on the

Figure 2.22 Detailed study sites in southeast Zaire



Legend

Detailed study site A: Near Lubumbashi

Detailed study site B: Near Lubumbashi

Detailed study site C: Near Likasi

Detailed study site D: Betwen Lubumbashi and Likasi

0 29

Kilometers

Lubumbashi-Likasi roads (northward road from Lubumbashi) where one sub-study site was located at the boundary of the urban land of Likasi (area C) and the other between the two cities (area D). Area C is about 125 kilometers, and area D about 57 kilometers away from the city center of Lubumbashi. In contrast to the central western Cascades of Oregon where four detailed study areas represented four different land ownership spatial distributions, here two replicates each of Urban versus Rural areas were selected since the spatial distribution of southeast Zaire land ownership types was not as diverse as in the central western Cascades of Oregon.

2.4 Data analysis

To get data required for the production of graphs additional steps were involved. First, images resulting from forest cover/loss classification, distance gradient delineation, and land ownership division were overlaid using the GIS overlay subroutine in ERDAS. Then, using the SUMMARY subroutine, images resulting from the overlay procedure were overlaid with the already created image with cell identifier to generate data which were transferred to MICROSOFT EXCEL spreadsheet software.

Tables consisting of several columns were created in MICROSOFT EXCEL software. The first column represented cell identification numbers. There were a total of 2391 cells in the central western Cascades images and 8089 in the away-from-roads and 558 in the away-from-cities gradients in images for southeast Zaire. The rest of columns were related to distance classes away from cities or from transportation systems.

Each distance class was also divided into several land ownership sub-columns. The central western Cascades of Oregon had eight sub-columns representing the eight land ownerships (USFS, BLM, STATE, PNI, PI, NODATA, MISC, AND WILDERNESS lands) and southeastern Zaire had two sub-columns representing Urban and Rural lands.

The sum of each column from each created table gave the total of the land ownership for the related distance class. The total of forest cover for a distance class was obtained by adding all forest covers from every land ownership within that distance class. Two percentages were calculated. First, the percentage of forest cover per land ownership per distance class was calculated. This percentage resulted from dividing the forest cover of a land ownership type by the total of that land ownership area within that distance class. Second, the percentage of land ownership within that class distance was also computed. It consisted of dividing the total land occupied by one land ownership type by the total of all lands (forests and non-forests) within that distance class. Graphs were then generated for analysis and from which equations were derived to test the hypotheses. This same procedure was performed in generating data used in the analysis of patterns of forest loss rates.

2.5 Hypotheses

2.5.1 Statement of hypotheses

This study tested the following hypotheses. The rationale behind each is explained in 2.5.2:

1. Forest cover increased with distance (a) from cities and (b) from roads for both forest definitions in each study site (8 tests).
2. Forest cover increased more rapidly with distance from roads/cities for forests defined as including all forested areas (extended forest definition) than for those defined as unmanaged forests (restricted forest definition).
3. Forest cover increased more rapidly with distance away from roads than with distance away from cities.
4. Forest cover increased more rapidly away from roads/cities in southeast Zaire than in the central western Cascades of Oregon.
5. The rate of forest change from 1973 to 1989 in southeastern Zaire was higher than the 1972-1988 rate in the central western Cascades. (This tested whether the central western Cascades fell in E and southeastern Zaire in B category according to Figure 1.4).

2.5.2 Hypothesis rationale

Hypotheses 1 through 4 are related to the test of the distance decay model, and hypothesis 5 is related to the deforestation model.

Hypothesis 1 was based on the fact that forest resources likely to be depleted were those located in a more accessible environment (around roads and cities). If the away-from-cities gradient was considered then lands close to urban centers were likely to be cut beforehand. If on the other hand, the away-from-roads were considered, areas close to the roads were more likely to be cut than those located away from roads. This pattern resulted from an assumption that the population involved had some limitations related to the type of existing infrastructure (road quality), and to the choice of their technology to access the resource.

Hypothesis 2 was based on the assumption that the extended forest definition would have more forest cover than that of the restricted forest definition. As a result, use of the extended forest definition would obscure some of the patterns.

Hypothesis 3 was based on the assumption that the density of the secondary road network was high around cities and decreased as the distance away from cities increased. A move away from cities coincided with a move through a progressive decrease of road network and therefore a progressive decrease of forest cuts. On the other hand, the secondary road network around highways/roads was not as high as around cities, the transition from less to more forested areas was expected to be more abrupt in the away-from-highways/roads gradient than in the away-from-cities gradient.

It was assumed in hypothesis 4 that distance is a greater constraint in southeast Zaire than in the central western Cascades of Oregon because of socio-economic and technology differences. The central western Cascades of Oregon has sufficient financial capability to afford adequate tools and means to overcome the constraint of distance.

As a result of this financial capability during the study period, good roads and trucks help people move several loads of logs from the far end to processing areas in cities within a shorter period of time in the central western Cascades of Oregon than in southeast Zaire.

Constraints in the central western Cascades may not always be related to distance, other factors such as laws and regulations governing forest cutting also may affect patterns of forest cuts. In Oregon, for example, the land division into private, public/non-wilderness, and wilderness imposed an additional gradient on the deforestation pattern so that private lands, no matter where they were, had less forest cover than wilderness areas. In the case of Zaire, where such a subdivision was almost non-existent, the difference is due to accessibility.

The fifth hypothesis was based upon the assumption in the deforestation model that an increase in socio-economic development would lead local people to decrease their reliance on forests as their prime energy resource supply, and a low population growth rate would put less pressure on forest environment. In Oregon, a high per capita income and a high purchasing power would allow people afford alternative energy sources such as electricity and gas. Hence, southeast Zaire was expected to have a faster population growth rate but greater reliance on wood, compared to the central western Cascades of Oregon.

Chapter III. Results of analysis of distance-decay model application

3.0 Introduction

The purpose of this chapter is to analyze results related to each forest classification type and distance variables within each study site and between the two study sites. Two forest classification techniques and distance gradients were used to investigate forest cover variation as a function of distance. Descriptions of the classification procedure and distance gradients used were provided in remote sensing data and sampling design sections of the previous chapter. The first part of this chapter presents the results of an analysis of forest cover patterns in central western Cascades of Oregon. The second part describes the results of a similar analysis in southeast Zaire. The third part (discussion) reviews forest cover patterns in each study site, and gives a comparison of results between study sites with reference to the first four hypotheses. The last part summarizes results of hypothesis testing.

3.1 Results of analysis in the central western Cascades of Oregon

Two types of gradients were considered: away-from-cities and away-from-highways gradients. In each case, a general profile of land ownership patterns, and the patterns of the two forest definition types were analyzed. First, forest defined as areas with at least 30 percent canopy cover were analyzed, and forest defined as unmanaged forest were analyzed later. The last part of this section will analyze patterns of forest cover in four detailed study sites.

3.1.1 Analysis of the away-from-cities gradient

3.1.1.1 Overview of land ownership distribution

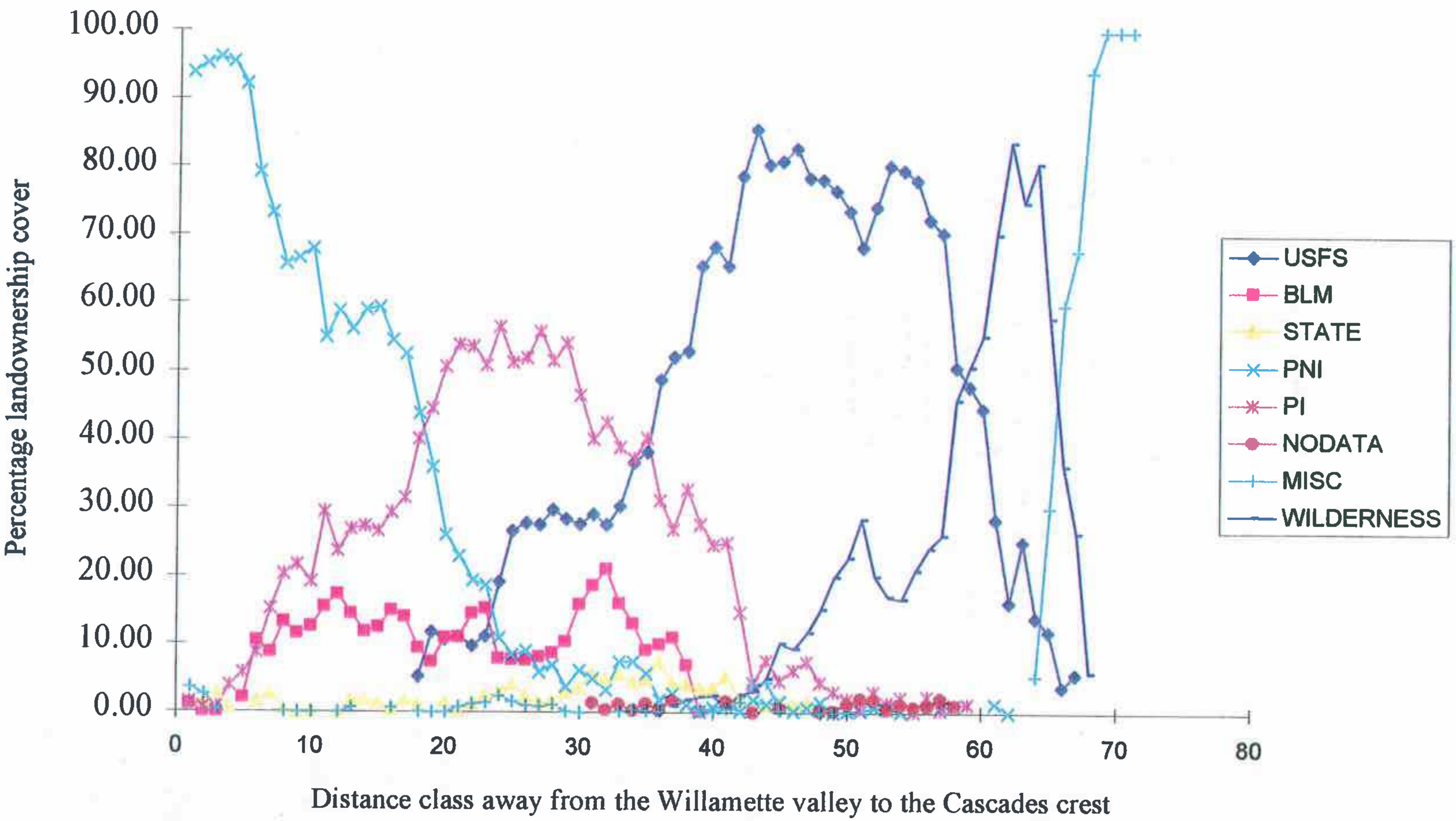
Several land ownership types with different management practices exist in the central western Cascades of Oregon (Cohen et al. 1995, Spies et al. 1994, Sollins 1995). Sollins (1995) produced a map depicting eight land ownership classes that was used in this analysis of forest cover pattern (section 2.3.4). These classes include United States Forest Service (USFS), Bureau of Land Management (BLM), State lands, private non industrial (PNI), private industrial (PI), no data class, miscellaneous, and Wilderness lands. The distribution of these classes is shown in Figure 2.19. Public lands, which include USFS, BLM, States, and Wilderness areas, have more restrictions to forest harvest. For example, USFS and BLM have experienced distributed patch clearcutting of up to more than 20% area over the past 40 years which have produced particular patterns on the landscape (Spies et al. 1994). On the other hand, private lands, such as PNI and PI lands, have fewer restrictions than public lands on forest harvest, and have a different pattern (Spies et al. 1994). Forest cut restrictions on public lands include rotation lengths of more than 70 years, which preclude the harvest of younger trees, and regulations such as National Environmental Protection Act (NEPA, 1969)-mandated Environmental Impact Statements required for actions within federal lands such as USFS and BLM lands.

Land ownership is one of variables useful in the understanding of present-day patterns of forest cover in the central western Cascades of Oregon. The spatial pattern of land ownership was examined by plotting percentages of land ownership types as a function of distance (each distance class is 1.6 km) away from the western boundary of the study area (Figure 3.1). From figure 2.19, it can be seen that land ownership is spatially distributed into north-south bands. Figure 3.1 depicts this segregation of land ownership classes relative to the western boundary away into more rural lands.

Three land ownership types (nodata, miscellaneous, and state classes) were not considered in the analysis because their cover per distance class was less than 10 percent, so that their relevance to this landscape study is relatively small. These classes were also omitted because it was difficult to differentiate embedded subclasses. The nodata class for example, is a class of private lands which could not be categorized as either industrial or nonindustrial ownership. Miscellaneous is a class consisting of several other sub-classes such as Army Corps of Engineers, electrical power lines, and Indian reservations (Cohen et al. 1995).

Private lands occupy most areas near cities (Eugene-Springfield and Salem), which are all in the western side of the image, and their proportion decreases with distance away from cities (western boundary) (Figure 3.1). PNI lands occupy more than 90 percent of areas within the first 5 distance classes (8 km). This percentage declines to less than 10 percent at about 40 km (25 distance classes). Beyond 60 km (38 distance class) less than 1 percent of land is in the PNI category. On the other hand, PI lands occupy less than one percent of the area in the first 3 distance classes (5 km). As distance away from the western boundary of the study area increases, PI land cover increases to a maximum of about 50 percent between the 20th and 30th distance classes

Figure 3.1. Percentage of land ownership distribution per distance class delineated away from the western boundary of the central western Cascades of Oregon, U.S.



(32 and 46 km). Beyond that distance it gradually decreases to below 10 percent beyond the 43rd distance class (68.8 km) away from cities.

Public lands also are spatially distributed into overlapping north-south bands, with increasing cover away from cities on the western boundary of the study area (Figure 3.1). The Public-lands gradient is a result of distance constraints in late 1800's and early 1900' and lower productivity of lands located to the east (Loy 1976). BLM lands are clustered closest to cities and the western boundary, occupying less than 3 percent of the area of each distance class within the first 5 distance classes. As the distance away from cities increases, the percentage of land area owned by the BLM also increases, reaching a maximum of 23 % at the 32nd distance class (about 51 km). All BLM lands are located within the first 39 distance classes. BLM lands also are spatially distributed in two distinct regions--the Eugene-Springfield and Salem districts. Salem BLM lands are located in the central northern part and Eugene-Springfield lands are in the southwestern part of the study area (Figure 2.19).

As BLM lands decrease from west to east in the study area, other land ownership types become more predominant. USFS lands are first found at the 18th distance class (28.8 km) with 3 percent cover. Their percentage cover gradually increases to a maximum of 84 percent at the 43rd distance class (68.8 km). Between the 39th and 57th distance classes (62.4 to 91.2 km away from the western boundary), USFS lands occupy more than 60 percent of every distance class. Further eastward, beyond the 65th distance class (104 km), USFS lands occupy less than 10 percent of land cover in each distance class. USFS lands are more compact (contiguous) than BLM lands (Figure 2.19).

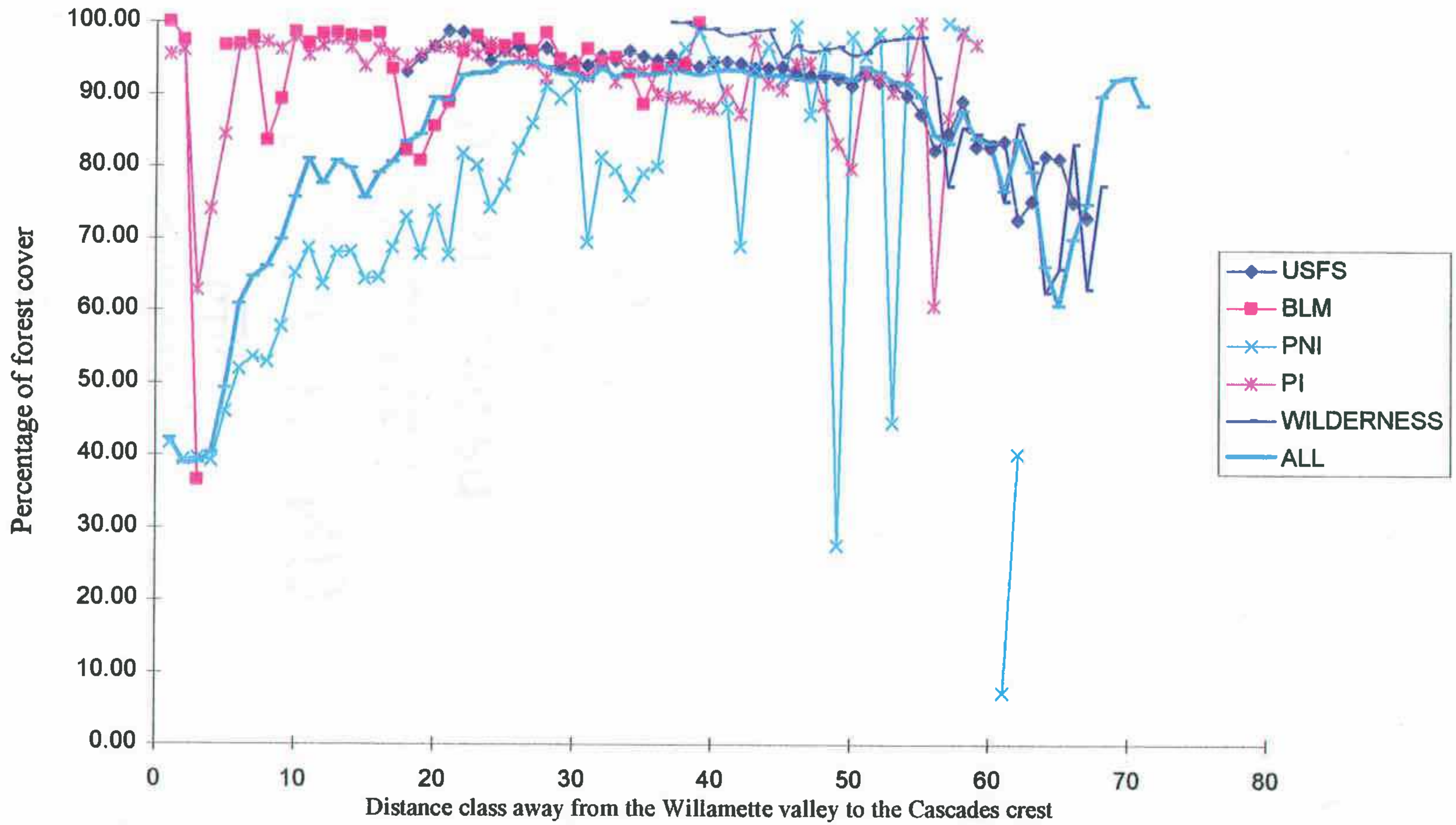
Wilderness areas are located in the far east of the study area. They occur from the 38th distance class (about 60 km) from the western boundary of the study area. The percentage of Wilderness land cover increases to reach a maximum of 84 percent at the 63rd distance class (about 100 km) away from the western boundary of the study area.

This brief analysis of the land ownership distribution pattern in the Western Cascades of Oregon, combined with the contrasting land use practices among land owners, suggests that land ownership patterns may strongly influence the patterns of forest cover distribution away from cities. Most private lands are located in the western portion of the study area where cities and urban centers are located. On the other hand, most restricted lands (Public lands) are located in the eastern part of the study area which is also relatively far away from urban centers, and have lower productivity and non-forestry land use emphasis in some cases. Thus, distance away from cities, land ownership (public vs. Private lands), and land use objective will contribute to an expected forest cover pattern with less forest cover in the western part and greater forest cover in the eastern part of the study area.

3.1.1.2 Patterns of forest cover defined as areas with at least 30 percent canopy cover

The overall trend of forest defined as areas with at least 30 percent canopy cover shows the increase in forest cover as distance away from the western boundary increases (Figure 3.2). The average forest cover distribution per distance class per

Figure 3.2. Percentage of forest defined as areas with at least 30% canopy cover per land ownership per distance class delineated away from the western boundary of the central western Cascades (1988).



ownership is summarized by the curve identified in Figure 3.2 as ALL. Within the first five distance classes of the ALL curve, forest cover represents less than 50 percent. Beyond the 19th distance class all distance classes have more than 90 percent forest cover. The low percentage forest cover within the first five distance classes is attributable in part to the history of European settlement of the Willamette Valley, which began in the 1840's. Areas within this distance are mostly lands which have been permanently converted to urban and agricultural activities (Cohen et al. 1995). The relative decrease of percentage forest cover beyond the 50th distance class is associated with the exposure of rocks, lava flows from recent volcanism, and the change in vegetation types from Douglas-fir (*Pseudotsuga menziesii*)/western hemlock (*Tsuga heterophylla*)-dominated forest to the subalpine region dominated with mountain hemlocks (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa*), and further east, to the ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*) zones.

The percentage of forest cover per distance class in the central western Cascades of Oregon is very high (Figure 3.2). This generally high percent forest cover is attributable in part to the forest classification (definition) used. Forest defined as an area having at least 30 percent canopy cover includes both managed and unmanaged conifer and deciduous forests. Such a broad definition captures many vegetation types and therefore shows a very high percent cover per distance class (Figure 2.2). Nevertheless, some contrasting patterns emerge in a detailed examination of percentage forest cover broken down by land ownership.

Percentage of forest cover within most land ownership is not very sensitive to proximity to cities and urban environments. Public lands (USFS, BLM, and WILDERNESS) have higher than the average percent forest cover represented by ALL curve (Figure 3.2) and show no trends with distance from cities. Forest cover in BLM, USFS, and Wilderness lands is more than 90 percent on average per distance class. PI lands also have the same distribution pattern as that of public lands. Patterns in State, Nodata and Miscellaneous ownership classes were not considered for reasons explained previously. In addition, some of these ownerships show very irregular patterns inherent to the variability in owner types and land uses, compounded by the very small areas (Figure 3.1). This is especially true with State lands and those classified as Miscellaneous.

PNI forest lands display a different pattern of forest cover with at least 30 percent cover by distance from cities compared to other land ownership. Most PNI lands have less than the average forest cover per distance class. PNI forest cover percentage is much lower than average near cities and urban centers. Within the first five distance classes (8 km), PNI land ownership is more than 90 percent of area (Figure 3.1), but forest cover in PNI lands is less than 50 percent of land area only (Figure 3.2). Within the first 17 distance classes 39 to 70 percent of PNI lands meet the forest cover definition (have forest with more than 30 percent tree cover).

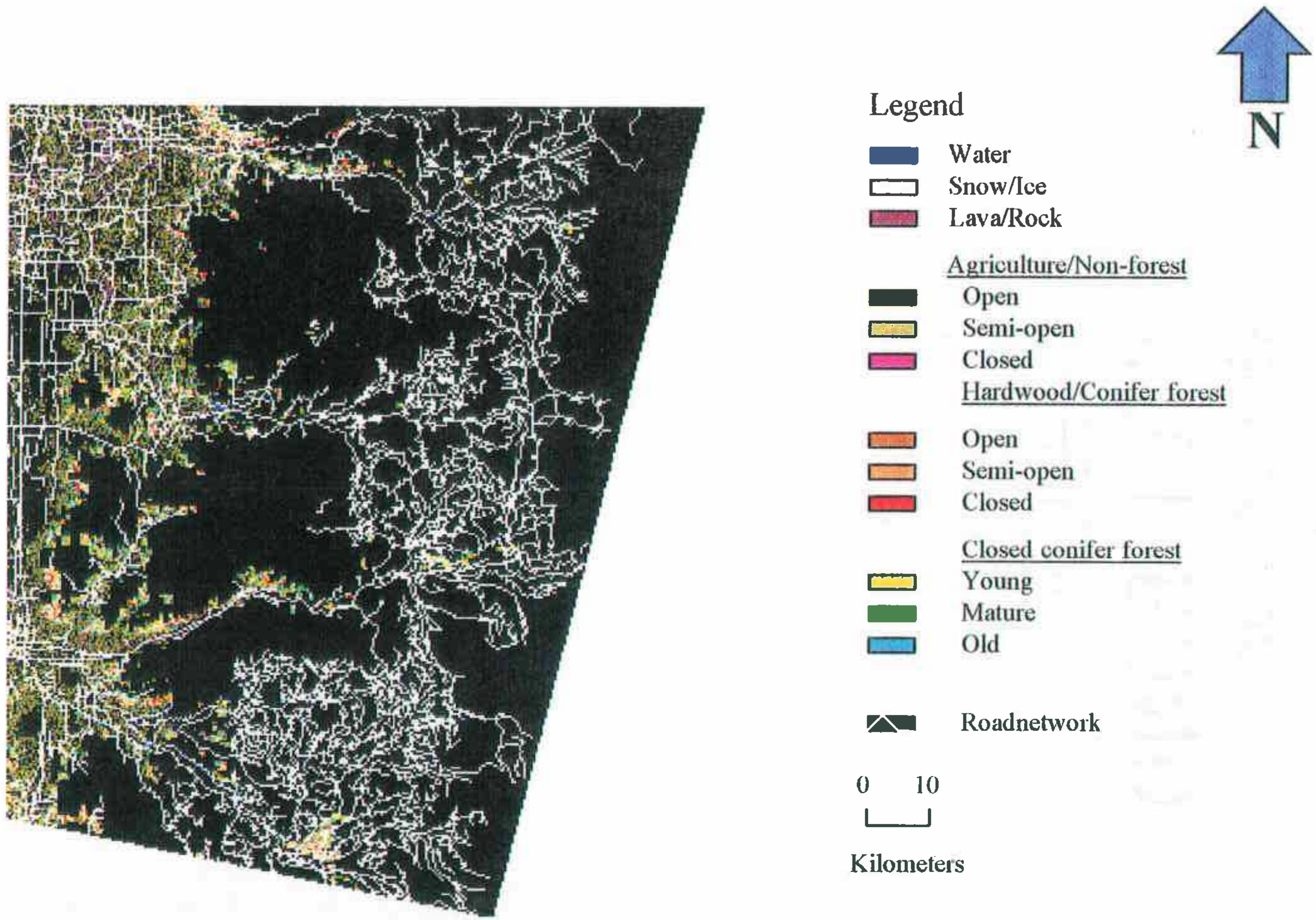
PNI forest cover increases with distance away from cities (Figure 3.2). There is an inverse relationship between the amount of land area in the PNI land ownership class and forested areas in the PNI land ownership class. PNI lands located beyond distance class 25 (40 km) represent less than 10 percent of land area, and in most distance classes beyond 40 km, PNI lands represent less than 2 percent of total areas per distance class (Figure 3.1), but about 80 percent of these lands are forested (Figure 3.2).

Several reasons explain PNI forest cover patterns. The high percentage of forest cover beyond distance class 25 may be due to land use differences (agricultural versus forest lands), and also to accessibility constraints. PNI land owners may not have the finances to build roads to remove timber from remote lands (Figure 3.3). Forest cover patterns might also be due to the predominance of small size PNI lands beyond distance class 25 away from the western border. Owners of small-size land parcels may have harvested their timber 20 to 30 years prior to 1988 for these areas to be classified as forested. The high percentage might also be a result of classification errors (Cohen et al. 1995).

It can be concluded that with the exception of PNI lands forest defined as areas with at least 30 percent canopy cover does not show any clear pattern with distance away from cities. Based on this definition, percentage of forest cover within most land ownerships is not very sensitive to proximity to cities and urban environments. Forest area on Public lands (USFS, BLM, and Wilderness) and PI lands show no trends with distance from Willamette Valley.

The pattern from Figure 3.2 is however, a result of the forest definition used in the analysis and also of the difference in regulations and practices on every type of land ownership. Because of the forest definition used in this case, forested areas within

Figure 3.3 Road network and forest cover distribution in the PNI land ownership category



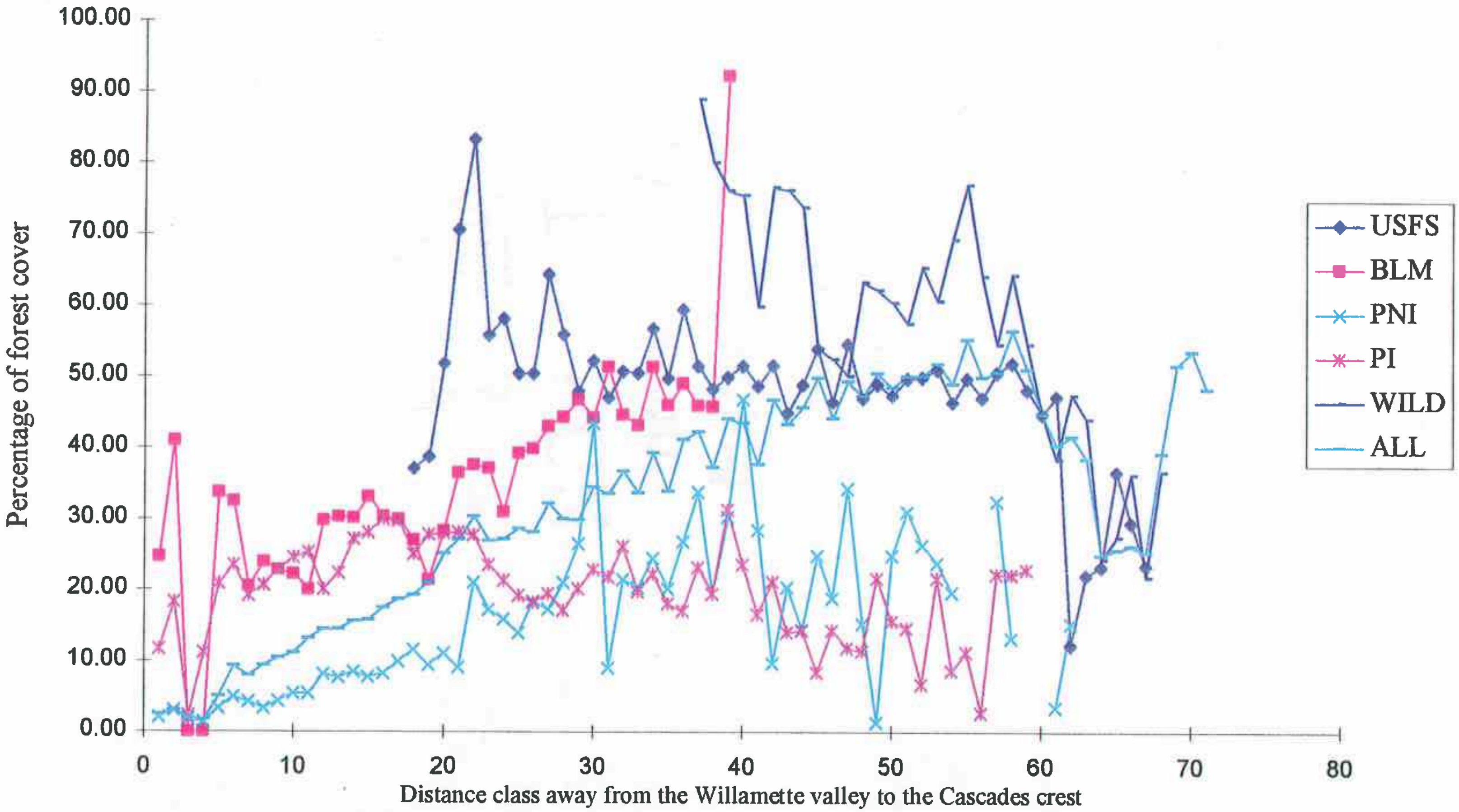
Source: adapted from Cohen et al. 1995 and Sollins 1995 public and PI lands appear, to be almost undisturbed. More than 90 percent of land area in these ownership categories has forested areas with at least 30 percent tree cover. However, much of this forest cover consists of Hardwood/conifer forest (open, semi-open, and closed), and young closed conifer forest (Figure 2.1). Therefore, differences among land owners in the proportion of mature or old growth conifers versus young conifers or mixed hardwood forests cannot be determined using this forest cover definition. To reveal these differences it was necessary to examine patterns using a more limited definition of forest cover.

3.1.1.3 Patterns of forest cover defined as unmanaged forest

To better discriminate the forest cover patterns in the central western Cascades of Oregon, Cohen et al.'s vegetation map (Figure 2.1) was reclassified as described in Chapter 2 in two groups--forest and others. Mature and old-growth conifer forests were grouped to create the forest class. According to Cohen et al.'s (1995) classification, mature and old-growth forests are at least 80 years old. This class is believed to have been less affected by human activities, and for this reason it will be referred to hereafter as "unmanaged forest". Figure 3.4 shows the percent forest cover broken down by land ownership category by distance class away from the western boundary, using this more specific definition of forest cover.

The positive relationship between distance away from cities and urban centers and unmanaged forest cover is evident in Figure 3.4. This relationship is also a function of land ownership and use types as it will be shown later. First of all, the overall

Figure 3.4. Percentage of forest defined as unmanaged forest cover per land ownership per distance class delineated away from the western boundary of the central western Cascades of Oregon, U.S. (1988).



percentage forest cover in Figure 3.4 is less than that found in Figure 3.2 at every distance class. The average unmanaged forest cover for all distance classes in Figure 3.4 (see ALL curve) is about 33 percent, compared to 83 percent cover by forests defined as areas with more than 30 percent canopy cover (Figure 3.2). The lowest percentages are found near cities near the western boundary of the study area. According to the ALL curve, the first nine distance classes from the western boundary each has 2 to 10 percent forest cover compared to 38 to 70 percent using the broader definition (Figure 3.2). As the distance away from cities in the western boundary increases, so does the forest cover. This increase is gradual and reaches a maximum of 57 percent at distance class 58 (92.8 km), then decreases but remains above 20 percent.

The analysis by land ownership class shows the same general pattern of overall lower percentage forest cover compared to Figure 3.2 because of the narrower definition of forest. Public lands (USFS, BLM and Wilderness lands) have less unmanaged forest cover than forest cover defined more broadly as in Figure 3.2. The average percentage of forest cover is 48, 37, and 57 percent, for USFS, BLM, and Wilderness, respectively. Public lands also have greater than average unmanaged forest cover in almost all distance classes (Figure 3.4). Both private land owned classes (PNI and PI) on the other hand, have less forest percentage cover than that of the ALL curve, with an average of 16 and 20 percent, respectively.

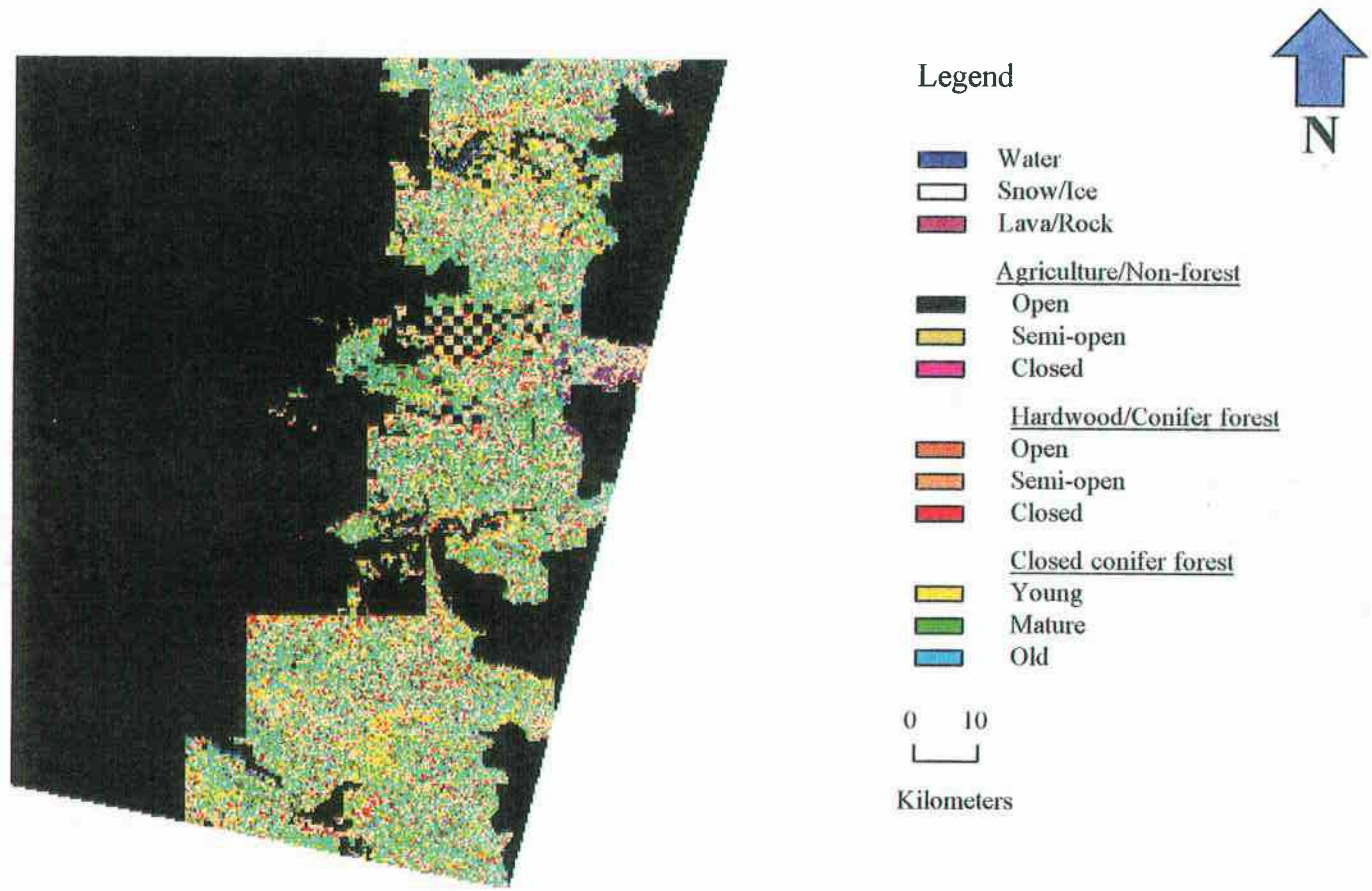
In distance classes 18 to 25 and 62 to 67, where USFS lands represent less than 25 percent of land area (Figure 3.1), forest cover in USFS lands oscillates between 37 and 83 percent (distance classes 18 to 25) and 12 to 37 percent (distance classes 60 to

65). Between distance classes 25 and 62, where USFS land reaches 80 percent of land ownership, unmanaged forest cover on USFS land is relatively stable at around 50 percent. This pattern shows a relatively evenly distributed forest disturbances within the USFS land ownership, independent of the distance from cities and towns (Figure 3.5).

The average cover by forest more than 80 years old expected in USFS owned lands is about 75 percent because only about 25 percent of area has been cut in the past 80 years, and mostly in the past 40 years. However, in most USFS lands the observed unmanaged forest cover is 50 percent. The difference between the expected and the result is mostly attributable to the pattern of natural fires. Studies (Morrison and Swanson, 1990, Teensma 1987, and Burke 1980) have found that wild fires, for example, have played an important role in shaping the forest environment including the amount of unmanaged forest cover. While human-caused fires have been concentrated near transportation network and human settlements, natural fires are more randomly distributed over the landscape. Almost 60 percent of all fires between 1910 and 1970 were caused by lightning (Burke 1980). They are more frequent at higher elevations, less severe, and affect a relatively small area both individually and in aggregate.

Anomalously high percentages of unmanaged forest cover are found within distance classes 21 and 22 (71 and 83 percent). These are lands located in the southern part of the study area around Lookout Point reservoir along the Middle Fork Willamette River. Most lands in the USFS area around the reservoir have not experienced any change related to fire or logging in more than 80 years (see Figure

Figure 3.5 Vegetation distribution in the USFS land ownership category



Source: adapted from Cohen et al. 1995 and Sollins 1995

2.4). The decline in percentage forest cover beyond distance class 60 is due to the transition to high-elevation forest types on recent volcanic flows.

BLM forest lands show two distinct patterns with increase of distance away from cities (Figure 3.4). In the first part of the curve, between distance classes 1 and 20, unmanaged forest cover varies between 20 and 34 percent with an average of 25 percent per distance class. The other part, from 21^{rst} to 38th distance classes, has a relatively higher percent forest cover varying between 31 and 51 with an average percentage per distance class of 46 percent. This forest cover variability is due to the difference in the logging history of the two BLM districts. The BLM district located nearest the western boundary in the Eugene-Springfield BLM district has less unmanaged forest cover, while the BLM district in distance classes 21 to 38 in the Salem district appears to have relatively more unmanaged forest cover. The difference may be attributable to the fact that the Eugene-Springfield district has harvested more timber than the Salem district (Sessions 1990).

Wilderness areas have the highest average percentage forest cover of all land ownerships. As illustrated by Figure 3.4, Wilderness lands are found only beyond distance class 37, and the average unmanaged forest cover percentage per distance class is 60 percent. Higher percentages occur between the 37th and 59th distance classes: at the 37th distance class, for example, forest cover is 89 percent. The highest percentage of forest cover (more than 80%) is in distance classes 37 and 38 (in the upper Middle Santiam river), where according to Figure 2.4 no forest change has been noticed in more than 80 years.

Figure 3.4 shows an overall decline in unmanaged forest cover in Wilderness areas away from cities. Since Wilderness areas by legislation have no logging, this trend may be mostly attributable to the transition to high-elevation forest cover, increased amounts of bare rock above treelines and recent volcanic flows below treelines, and possibly to increased fire frequency associated with grazing at the turn of the century (late 1800s up to 1910) (Burke 1980).

On PI lands percentage of unmanaged forest cover varies between 2 and 30 percent with a mean of 20 percent. There is no detectable trend with distance away from cities. The majority of distance classes have more than 20 percent forest cover. It can be concluded from this forest cover distribution pattern that the forest cutting pattern within this land ownership is not related to the distance away from cities. Economies of scale in large private forest industrial corporations may have allowed them to overcome constraints of distance and terrain accessibility.

On the other hand, PNI lands show a slightly different pattern. First of all, percent cover by unmanaged forest is lower in PNI lands than in any other land ownership, with an average of 16 percent cover per distance class. The low percentage forest cover near cities is suggestive of more hardwoods, and frequent high-severity past disturbances. The overall percentage forest cover per distance class is much lower within the first 25 distance classes on PNI lands (less than 10 percent) than in PI lands (10 to 30 percent). The percent of unmanaged forest cover on PNI lands increases slightly as the distance away from cities increases. There is no clear pattern of unmanaged forest cover on PNI lands beyond the 30^{th} distance class, where the percentage of PNI land owned is less than 5 percent per distance class (see Figure 3.1). It can be deduced from such a forest cover pattern that distance is not a strong factor determining more than 80 years old-forest cover distribution on PNI lands in the central western Cascades of Oregon. PNI forest cover pattern might reflect the variability among land owners, their financial background, their property size, and the environment.

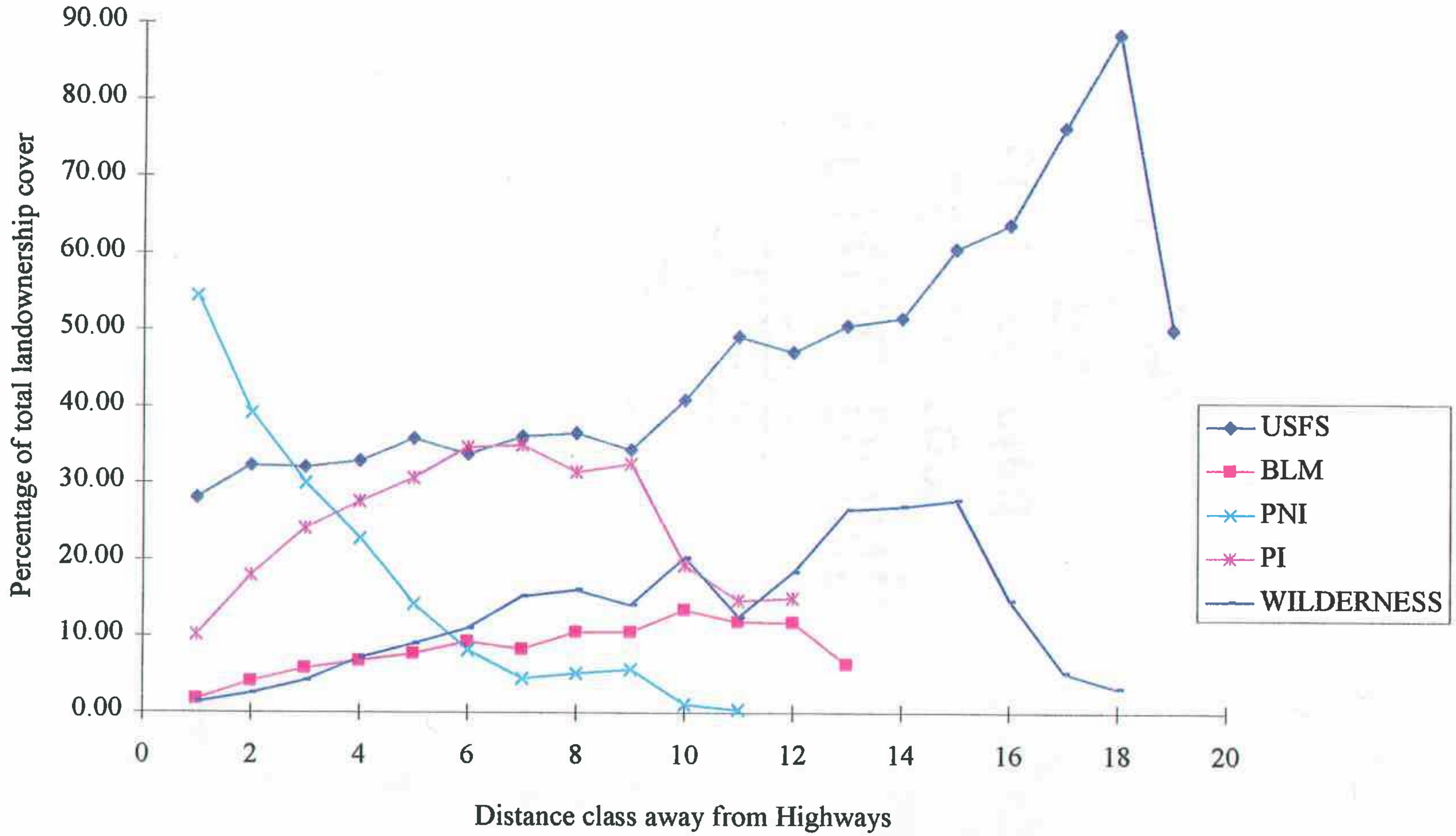
3.1.2 Analysis of the away-from-highways gradient

3.1.2.1 Overview of land ownership distribution

There are similarities in the percentage land ownership distribution away from highways represented by Figure 3.6 with the distribution pattern away from cities and urban centers in Figure 3.1. However, the overall west-to-east gradient (Figure 3.1) makes patterns in Figure 3.6 misleading. As also highlighted by Figure 3.1, most private lands are located in the western portion, and most public lands are located in the eastern portion of the study area. As a result, away-from-highways patterns on Figure 3.6 are affected by this unbalanced west-east land ownership distribution.

PNI lands for example, show the same pattern of decreasing land area away from highways as away from cities (Figures 3.1 and 3.6). Most PNI lands are located within the first four distance classes and especially near highways (more than 54 percent in distance class 1) (Figure 3.6). This graph obscures some aspects of spatial patterns because an average of 95 percent PNI ownership near highways are on the

Figure 3.6. Percentage of total land ownership distribution per distance class away from highways in the central western Cascades of Oregon, U.S. (1988)



west side of the side area and almost zero percent near highways on the east side of the study area (Figures 2.19, 3.1, and 3.3).

According to Figure 3.6, about 10 percent of total land near highways are PI lands. The percentage increases as the distance away from highways increases. More than 30 percent of areas between distance classes 5 and 9 (8 to 15 km away highways) are in PI lands. No private land exists beyond distance class 12 (17.6 km away from highways) which are areas located in the northeastern and southeastern parts.

Public land distribution has also patterns similar to that identified on Figure 3.1. In most cases the percentage of land in public management increases as the distance away from highways increases. Figure 3.6 shows the same distinguishable land ownership distribution as the north-south bands identified in Figures 3.1 and 2.19. This characteristic land ownership pattern is more recognizable by looking at the patterns of curve peaks on Figure 3.6. BLM, USFS, and Wilderness peaks are located far away from highways.

The percentage of public lands near highways is smaller than that of PNI lands (Figure 3.6) but much higher than near the western boundary of the site on Figure 3.1. According to Figure 3.6, within the first distance class USFS, BLM, and Wilderness lands make up 28.4 percent, 1.8 percent, and about 1.4, of land area, respectively. This pattern results from the west-east land ownership distribution highlighted in Figure 3.1.

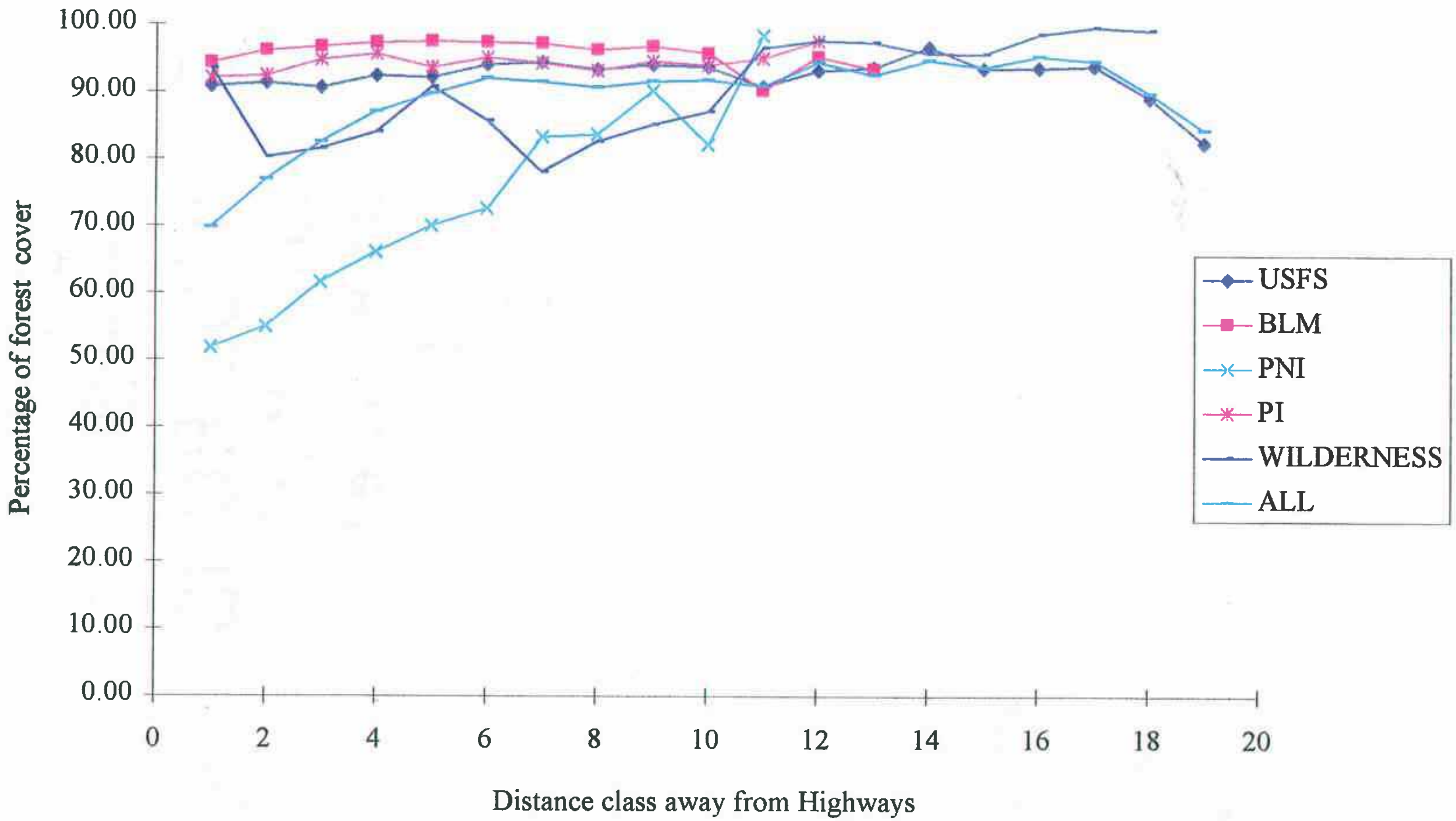
3.1.2.2 Patterns of forest cover defined as areas with at least 30 percent canopy cover

The trend of more than 80 year old forest cover distribution away from highways (Figure 3.7) is relatively the same as away from cities (Figure 3.2). The trend of all forest land ownerships is summarized by the ALL curve. About 70 percent of lands within the first distance class are forested according to this broad definition of forest cover. At the fourth distance class the percentage forest coverage reaches 90 percent and remains almost constant thereafter. The relatively low percentage represented by the ALL curve with reference to most curves across distance classes is mainly attributable to the low PNI forest cover.

Forested lands by land ownership show two types of distribution as a function of distance. There are those showing a forest environment that is little affected by the proximity of highways. They include public lands such as USFS, and BLM lands which have on average more than 90 percent of their areas forested every distance class. Wilderness lands also show relatively small forest disturbances due to highway closeness. But Wilderness forest distribution patterns are different from USFS and BLM lands, especially between the first and tenth distance classes with 80 to 90 percent cover. The rest of distance classes have more than 90 percent forest cover. Among private lands, PI forest cover has the same distribution as public lands. That is, the percentage of forest cover does not change as the distance class increases.

On the other hand, forest cover distribution within the PNI lands is related to the presence of the road network. Percentage forest cover increases as the distance away from highways increases. The first two distance classes from highways have

Figure 3.7. Percentage of forest defined as areas with at least 30 percent canopy cover per land ownership per distance class away from highways in the central western Cascades of Oregon, U.S. (1988).



about 50 percent of their lands covered with forests. The percentage of forest cover increases gradually to 98.4 percent at the 12th distance class. Several possible reasons may explain this pattern. First, it may be an artifact of more roads on the west side (Figure 3.3), and since more PNI lands are located in the west portion of the study area, the result is a lower PNI forest cover on the west side than on the east side of the study area. Second, lands within the first distance class are likely to be in permanently transformed areas such as agricultural and urban lands in the west part of the image (Figures 2.1 and 3.3). Areas within the first distance class may include flat main river valley floors where PNI owners may have home, pasture, and other non-forest uses. Third, PNI landowners may not have adequate financial capability and equipment to harvest lands located away from highways in less accessible environments or do not convert remote lands to farm use. Less accessible environments include areas in high elevation and those on flat terrain but with no easy linkage to highways (Figure 3.3).

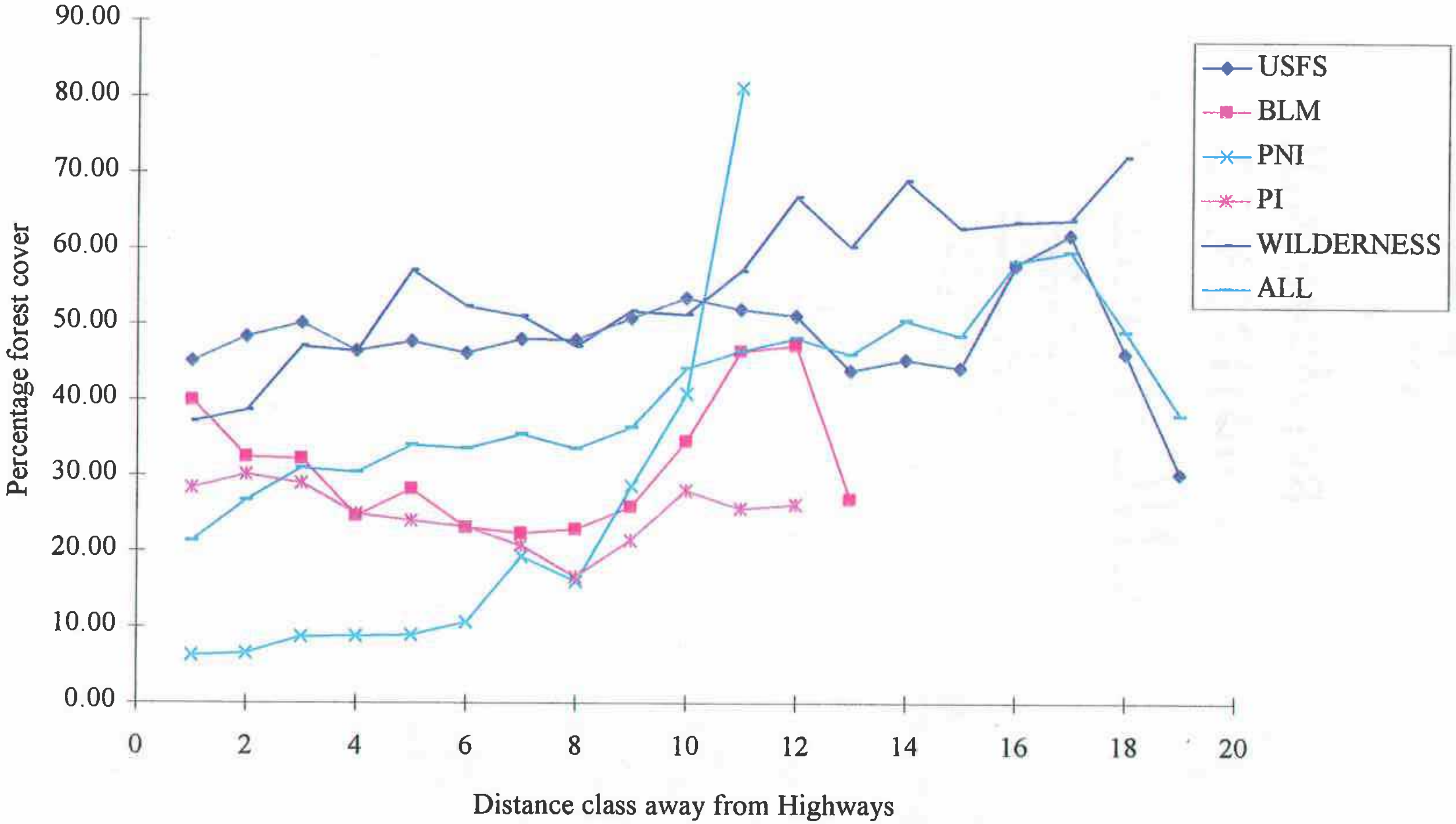
The conclusion from patterns of forest defined as areas with at least 30 percent canopy cover in the away-from-highways gradient (Figure 3.7) is similar to that of the away-from-cities gradient (Figure 3.2): the classification includes so many types of forest cover that almost all forest lands appear forested. Nevertheless, owners' timber harvest and growing techniques, and government land restrictions are reflected to some degree in the forest cover distribution pattern. PNI land owners, for example, may be less likely to invest more in genetically improved plants or site preparation. This is usually not the case with PI landowners, so the pattern of forest cover with distance differs between these two private land owners. On the other hand, PI and public land owners have similar forest cover patterns with distance.

3.1.2.3 Patterns of forest cover defined as unmanaged forest (Figure 3.8)

The average percentage of unmanaged forest cover per land ownership is about 50 percent lower in Figure 3.8 than that presented in Figure 3.7, where the much broader definition of forest is used. In fact, public land including USFS, BLM, and Wilderness have 48, 31, and 55 percent forest cover, respectively, when the narrower definition of only mature and old growth forest is used (Figure 3.8), compared to 92, 96, and 91 percent when the broad definition is used (Figure 3.7). PI lands have also less unmanaged forest cover than PI in Figure 3.7 with an average of about 25 percent per distance class compared to 94 percent when the broad definition is used (Figure 3.7). The greater differential in forest cover for PI lands 25 versus 95 percent compared to USFS/public lands 50 versus 95 percent reflects the increase in area of young, closed canopy plantations in PI lands. PNI lands have 22 percent on average compared to 74 percent with the broader definition. The PNI percent average is affected by the presence of almost undisturbed forest lands in the 11th distance class.

Forest variation as a function of distance away from highways in every land ownership per distance class was also considered. There is a general upward trend as the distance class increases (Figure 3.8). Forested areas in distance class 1 average about 21 percent of all land ownerships according to the ALL curve. Percentage forest cover per distance class increases gradually away from highways. The maximum

Figure 3.8. Percentage of forest defined as unmanaged forest cover per land ownership per distance class away from highways in the central western Cascades of Oregon, U.S. (1988).



average unmanaged forest cover of 60 percent is found at the 17th distance class away, in the southeast and northeast portion of the study area where no private lands exist.

Beyond the 14th distance class, public lands including USFS and Wilderness are the dominant land ownership types. Public lands within these distance classes occur at high elevation in the northeast and southeast portion of the study area (see Figures 2.17 and 2.19) where the declining percentage cover of unmanaged forest is attributable to a change in vegetation from Douglas fir to high elevation conifer with large patches of bare areas (rocks and lava) due to recent volcanic activities. The vegetation cover type changes and the percentage forest cover decreases.

Wilderness and PNI lands are among the land ownerships with a positive relationship between forest cover and distance. Thirty seven percent of Wilderness lands located within the first distance class are classified as unmanaged forest. Away from highways, forest cover increases. It is about 57 percent five distance classes away from highways, 67 percent at the 12th distance class, and 72 percent at the 18th distance class. The relatively low percentage of forest cover in Wilderness lands near highways may be attributable to human-induced forest disturbances such as fires and highways-related clearings.

The percentage of PNI forest cover is low near highways, for example, it is only six percent within the first distance class. The low percentage of forest cover in PNI lands along the road network may be due to permanently cleared areas located in the western part mostly dominated by urban centers and agricultural lands (see Figure 2.1). Forest cover increases regularly to 17 at the 8th distance class. A sharp forest cover increase is noticeable beyond the 8th distance class. The sharp increase may be related to, as previously explained, the difficulty of accessing remote areas due to financial constraints among PNI land owners, to the presence of very small and uneconomical holdings, and also to the small sample size. No more than 5 percent of lands in these distance classes is in PNI lands (Figure 3.6).

Forest cover pattern in USFS and PI lands are relatively stable along the away-from-highways gradient. The average percentage of forest cover per distance class in USFS is 48. Forest cover variability around the average is relatively low. PI lands have 25 percent forest cover on average per distance class, with little variation around the average.

BLM lands display a more complex forest variation pattern. First, there is a decrease in percentage forest cover with distance until the 8th distance class, then an increase thereafter followed by a decrease from the 12th distance class. This pattern of BLM forest cover may be the result of the difference in cutting patterns between areas such as Eugene-Springfield and Salem districts. The Eugene-Springfield district has more mature and old growth forest cuts than the Salem district (Sessions 1990).

3.1.3 Analysis of detailed study sites

3.1.3.1 Patterns of forest cover defined as areas with at least 30 percent canopy cover

Detailed study areas were carefully selected in locations where the general land ownership spatial distribution was known and an expected pattern of forest cover away from highways could be predicted. The selection procedure was previously explained in Chapter 2. The aim of this detailed analysis is to determine whether land ownership is a stronger factor than distance from highways or cities in explaining forest cover pattern.

The pattern, as shown by four figures related to percentage forest cover distribution per distance class, does not seem to indicate any consistent variability with distance. This is due in part to the use of a very broad definition of forest cover as areas with at least 30 percent canopy cover (explained in the large scale analysis), and also to other variables such as presence of secondary roads, elevation and slope steepness.

Detailed study area A is located across Highway 22 in the Eastern side of the study area in an environment dominated by two public land ownerships (Figures 2.21 and 3.9). According to these two figures, USFS lands cover most of the western side of the Highway 22, and most of areas within the first three distance classes. Wilderness areas are dominant on the eastern side of Highway 22 from the sixth distance class.

If the distance away from Highway 22 was a major factor in detailed study area A, the percentage of forest cover would be expected to be lower near than away from the highway. However, due to forest cutting regulations on public lands, especially in USFS and Wilderness areas, it is expected that percentage forest cover will likely be similar near and away from Highway 22.

USFS and Wilderness have a percentage forest cover pattern almost unaffected by the distance away from the highway (Figure 3.10). They have more than 80 percent of forest cover per every distance class. Forest cut regulations may be a major factor in determining this forest cover pattern.

Figure 3.9. Percentage of total land ownership distribution per distance class in detailed study site A in the central western Cascades of Oregon, U.S. (1988)

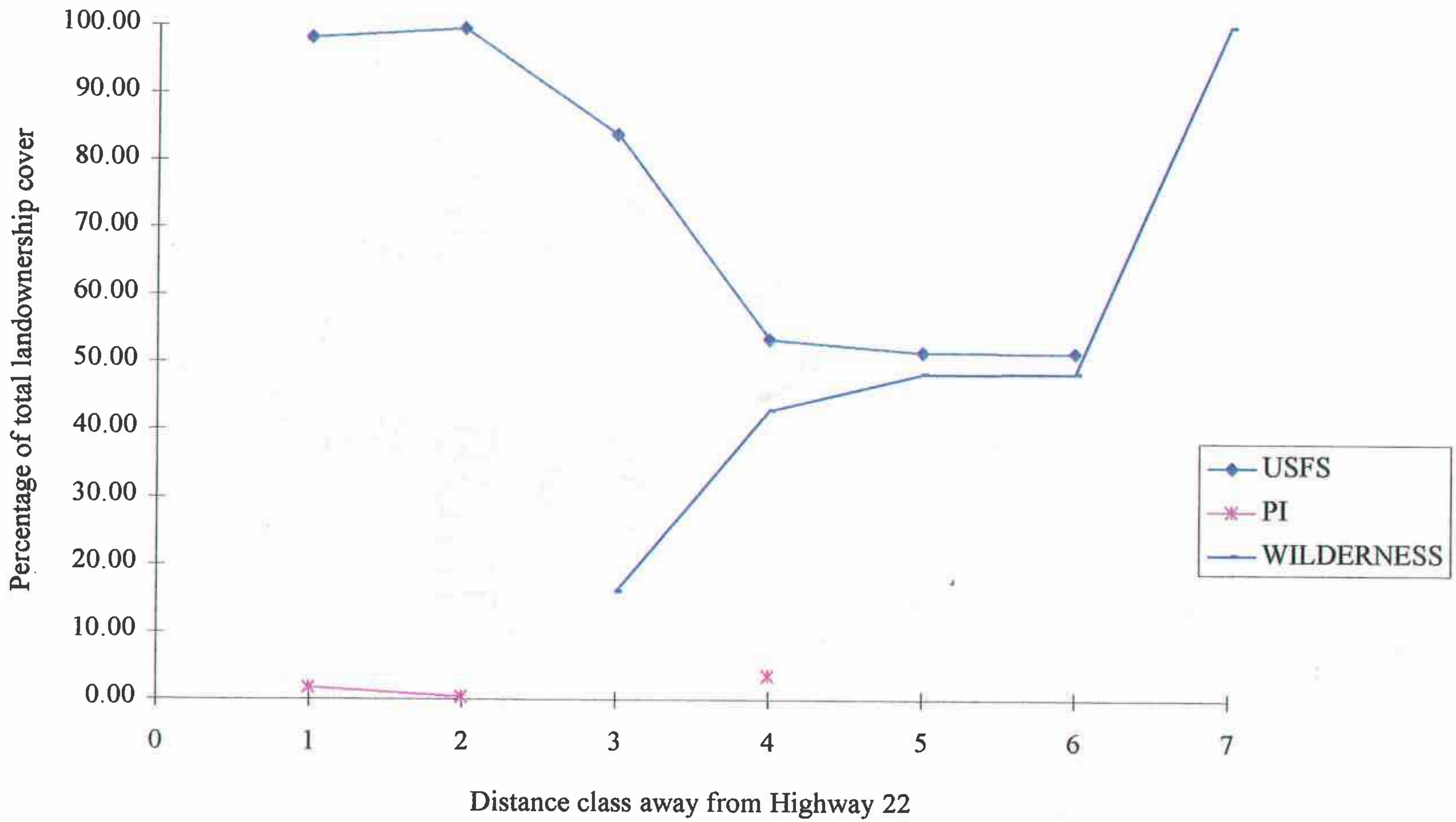
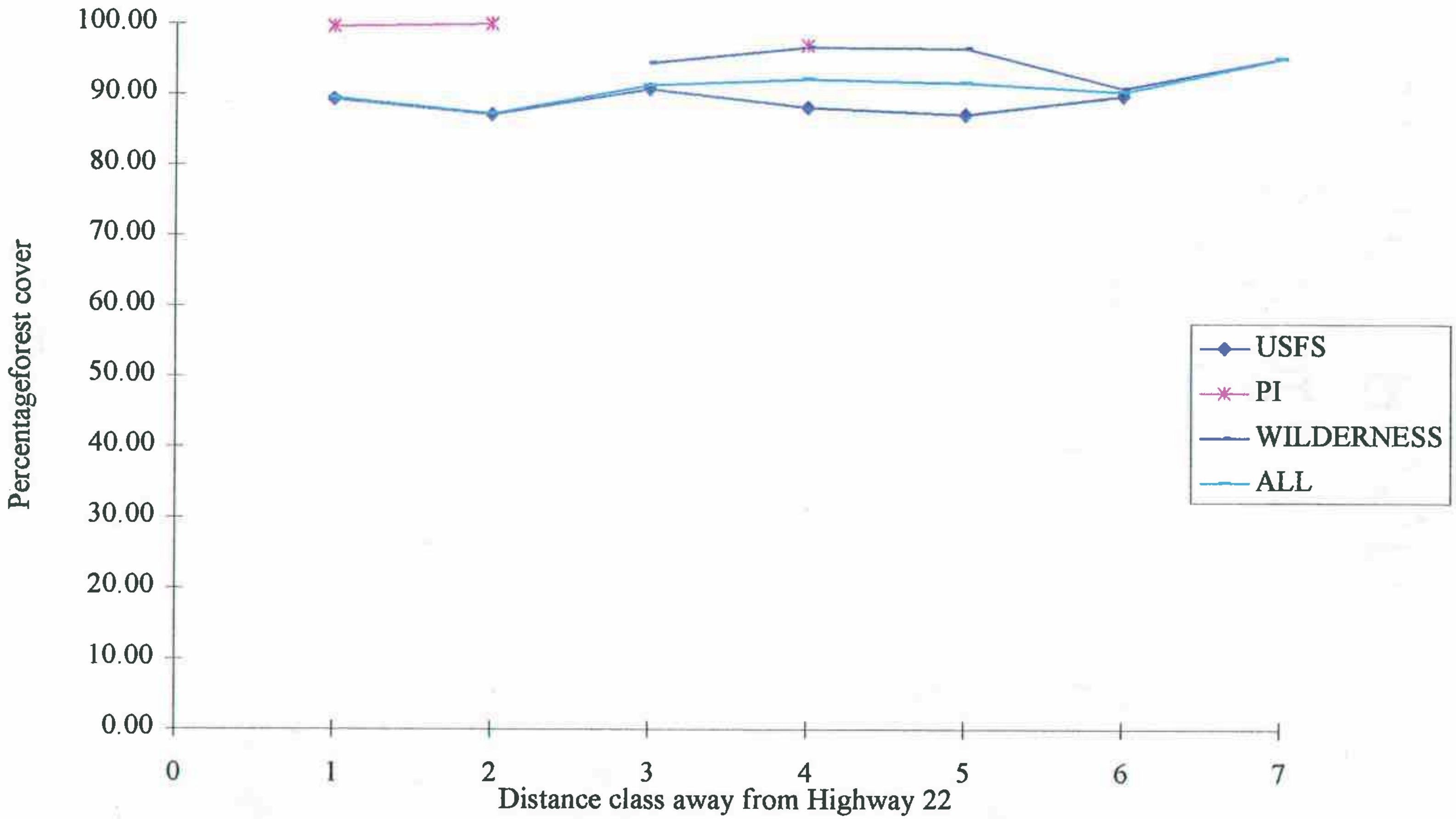


Figure 3.10. Percentage of forest defined as areas with at least 30 percent canopy cover per land ownership per distance class in detailed site A in the central western Cascades of Oregon, U.S. (1988).



Detailed study area B is located in the central part of the study area across Highway 20. In addition to less dominant lands such as Wilderness and PNI, USFS lands are mostly dominant near the highway, and away the Highway 20 PI lands prevail (Figure 3.11). The percentage forest cover in USFS and Wilderness lands is expected to be high and evenly distributed with distance away from highway 20 because of USFS forest cut regulations. In PI lands percentage forest cover is expected to be low and evenly distributed because distance is not expected to be a major constraint.

Percentage forest cover per distance class per land ownership is displayed in Figure 3.12. The figure shows that broadly defined forest cover in USFS and Wilderness lands varies little with distance class. They have each an average of more than 90 percent forest cover per distance class. In the case of PI lands the percentage forest cover per distance class did not conform with the expected forest cover patterns. Despite the relatively high percentage PI forest cover, there is a slight downward trend as the distance away from Highway 20 increases. The percentage forest cover in the first distance class is more than 96 percent and in the 7^{th} distance class it is about 81 percent.

Detailed study area C is located in the southcentral part across Highway 126 in an environment with a mixture of BLM and private lands near the highway and a dominance of PI away from the highway (Figure 3.13). Because of the dominance of PI lands in this study area, and also due to the fact that distance is not a major constraint in PI lands, the forest cover pattern is expected to vary little with distance away from the highway. The expected pattern is confirmed by the result on Figure 3.14 where the

Figure 3.11. Percentage of total land ownership distribution per distance class in detailed study site B in the central western Cascades of Oregon, U.S. (1988)

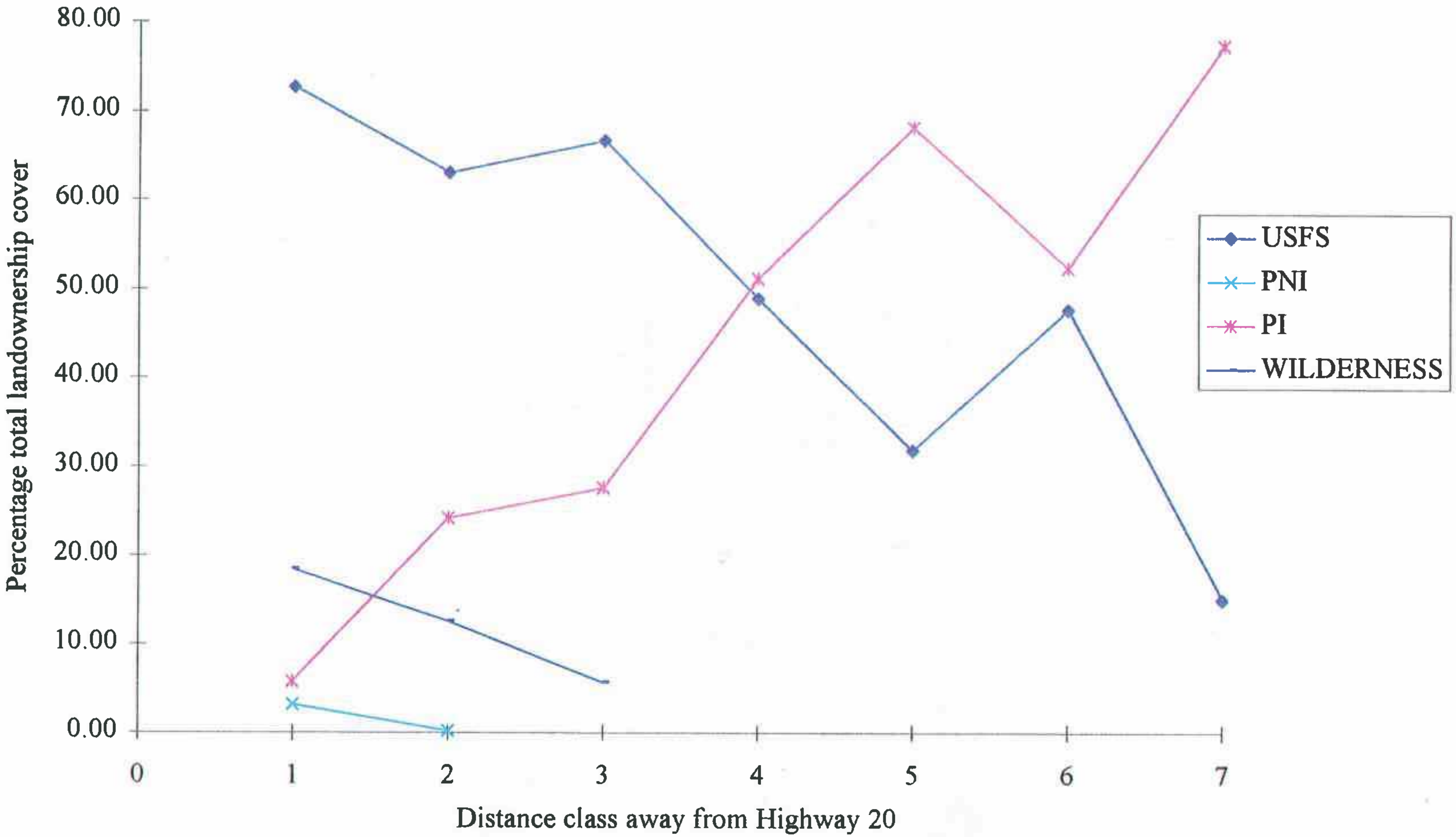


Figure 3.12. Percentage of forest defined as areas with at least 30 percent canopy cover per land ownership per distance class in detailed study site B in the central western Cascades of Oregon, U.S. (1988).

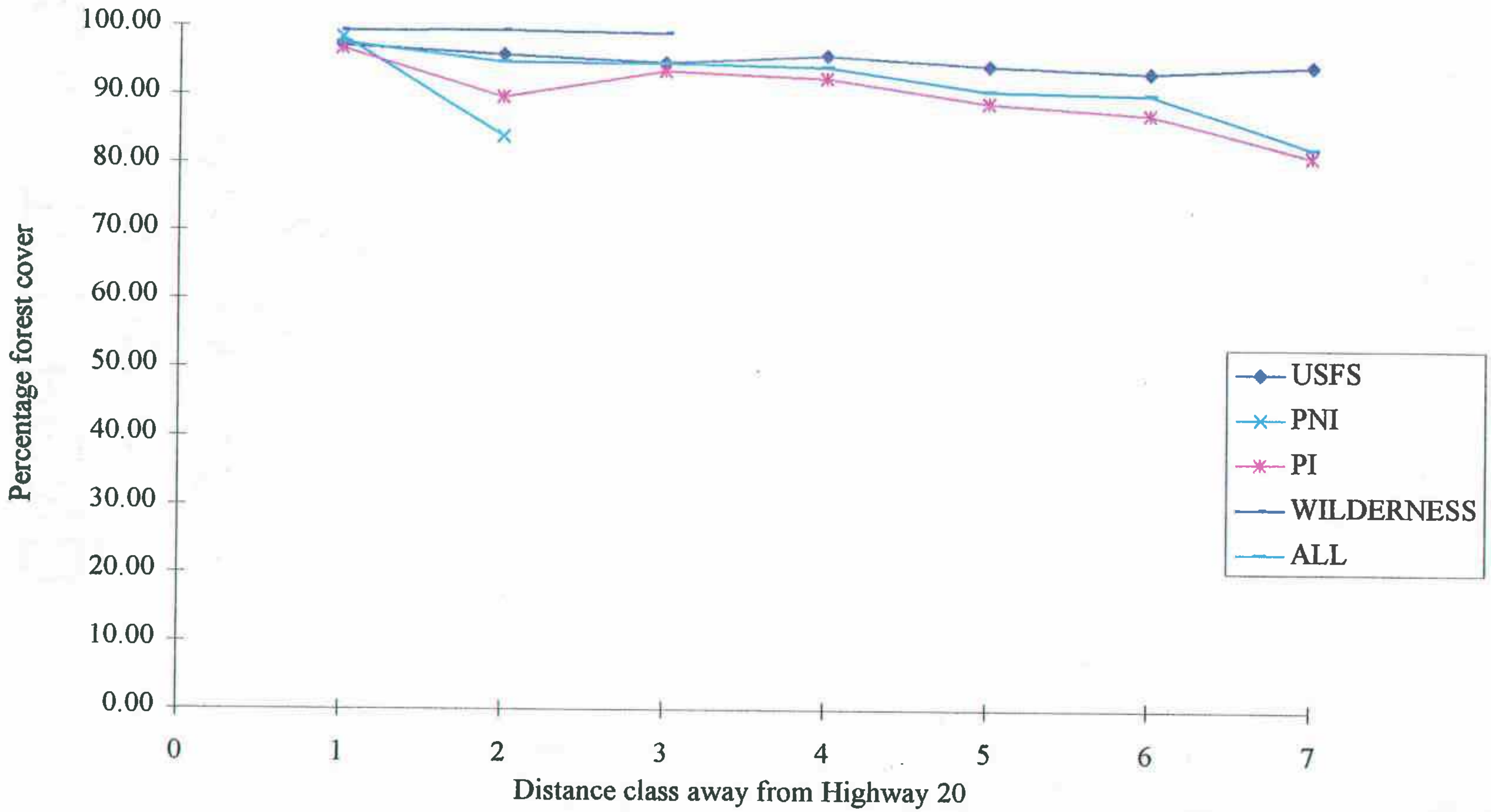


Figure 3.13. Percentage of total land ownership distribution per distance class in detailed study site C in the central western Cascades of Oregon, U.S. (1988)

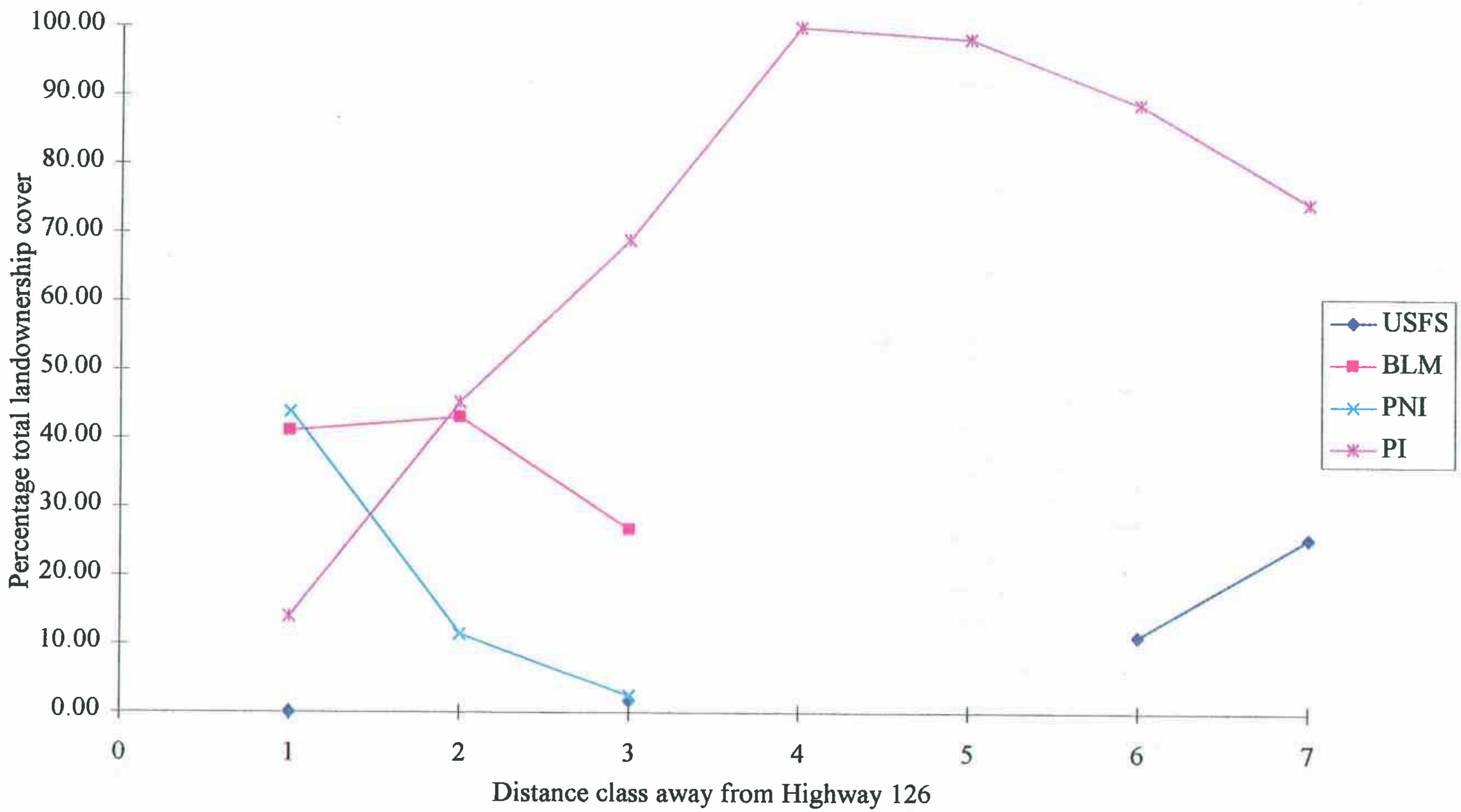
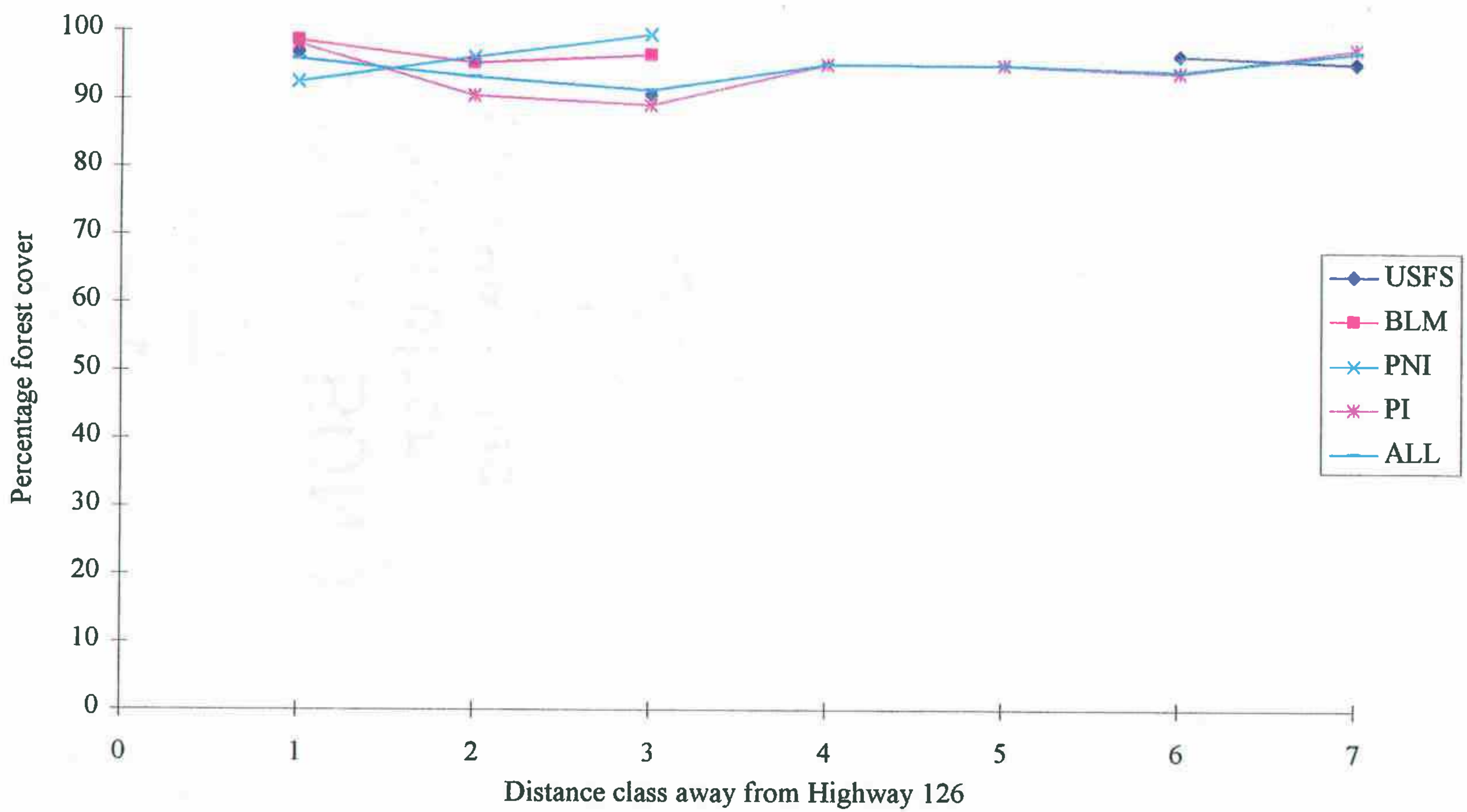


Figure 3.14. Percentage of forest defined as areas with at least 30 percent canopy cover per land ownership per distance class in detailed study site C in the central western Cascades of Oregon, U.S. (1988).



percentage forest cover per land ownership per distance class does not vary as much with the distance away from the highway. The average percentage forest cover per distance class in PI lands for example varies around 94 percent.

Detailed study area D is positioned in the southwestern part across Highway 58. It is a complete mixture of land ownership distribution (Figure 3.15) with a predominance of public lands away from highway. In such an environment, the percentage of forest cover is anticipated to be smaller in private lands than in public lands due to fewer restrictions on forest cut on private lands. It is also expected that because of financial restrictions in PNI land, the percentage of forest cover would increase as the distance away from the Highway 58 increases. According to Figure 3.16, all land ownership types have on average more than 90 percent forest cover per distance class. All ownership types except BLM lands are almost invariant with distance. The percentage of forest cover per distance class in BLM lands increases with the distance up to distance class 3 beyond which it remains stable.

It can be concluded from the analysis of the percentage forest cover in these four detailed study areas that the broad forest cover definition poorly illustrates forest cover patterns, especially in privately owned lands. In most cases, PNI and PI percentage forest cover per distance class is much higher than expected. The distance away from highways is not a major factor in explaining the pattern of forest cover. This is due in part to the broad definition, and also to other variables such as the topographic environment of the study area which might explain the departure from the predicted pattern.

Figure 3.15. Percentage of total landownership distribution per distance class in detailed study site D in central western Cascades of Oregon, U.S. (1988)

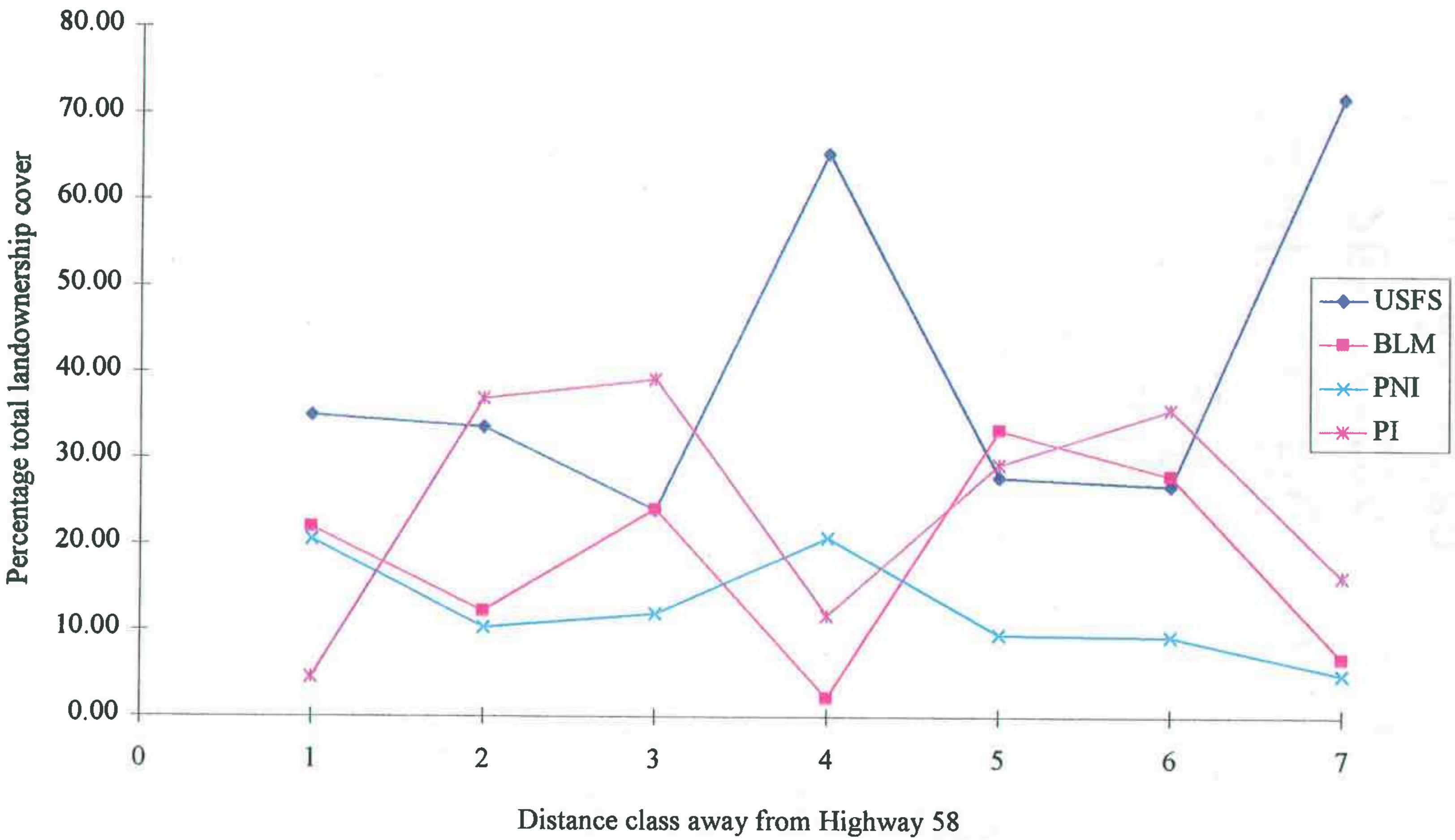
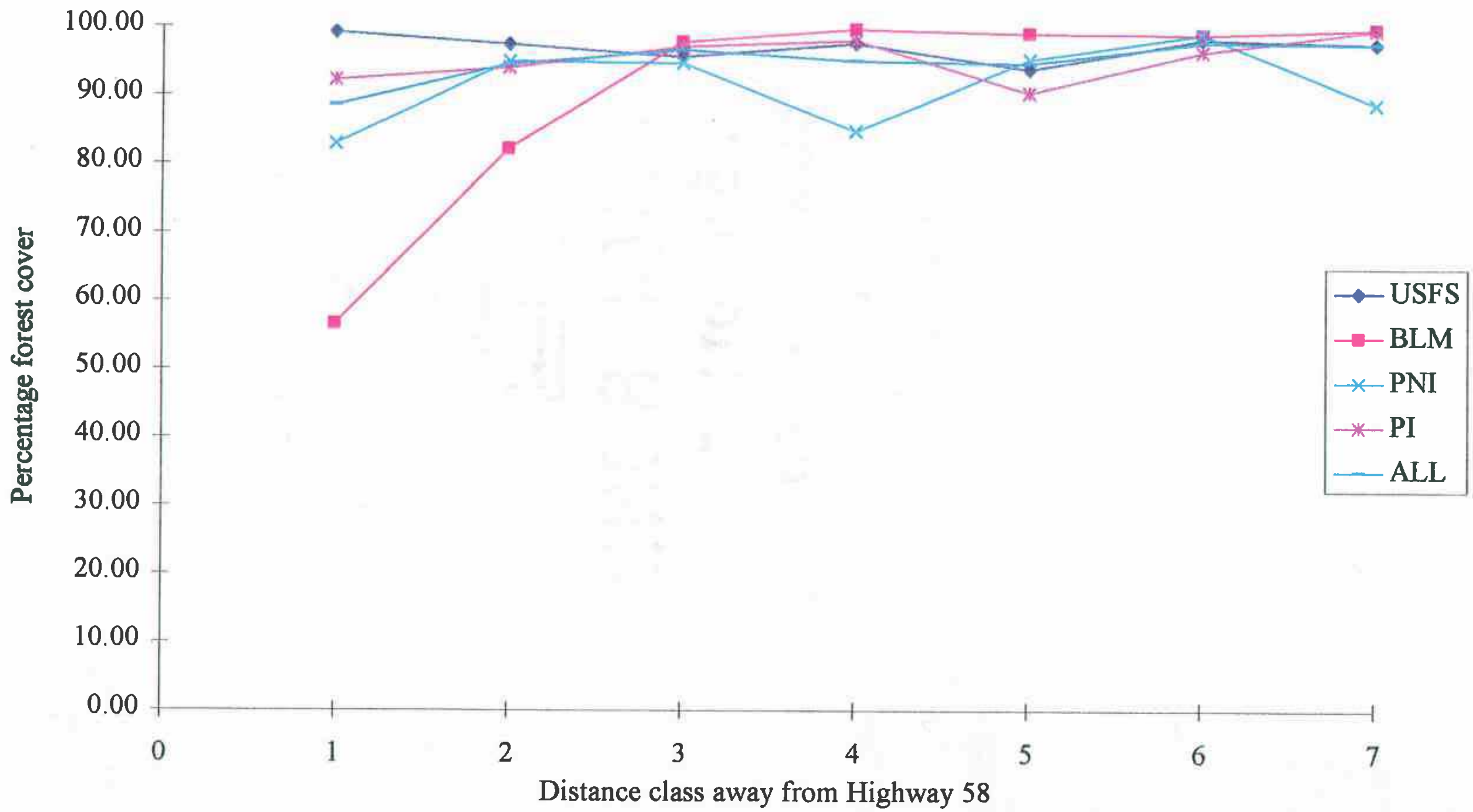


Figure 3.16. Percentage of forest cover defined as areas with at least 30 percent canopy cover per land ownership per distance class in detailed study site D in the central western Cascades of Oregon, U.S. (1988).



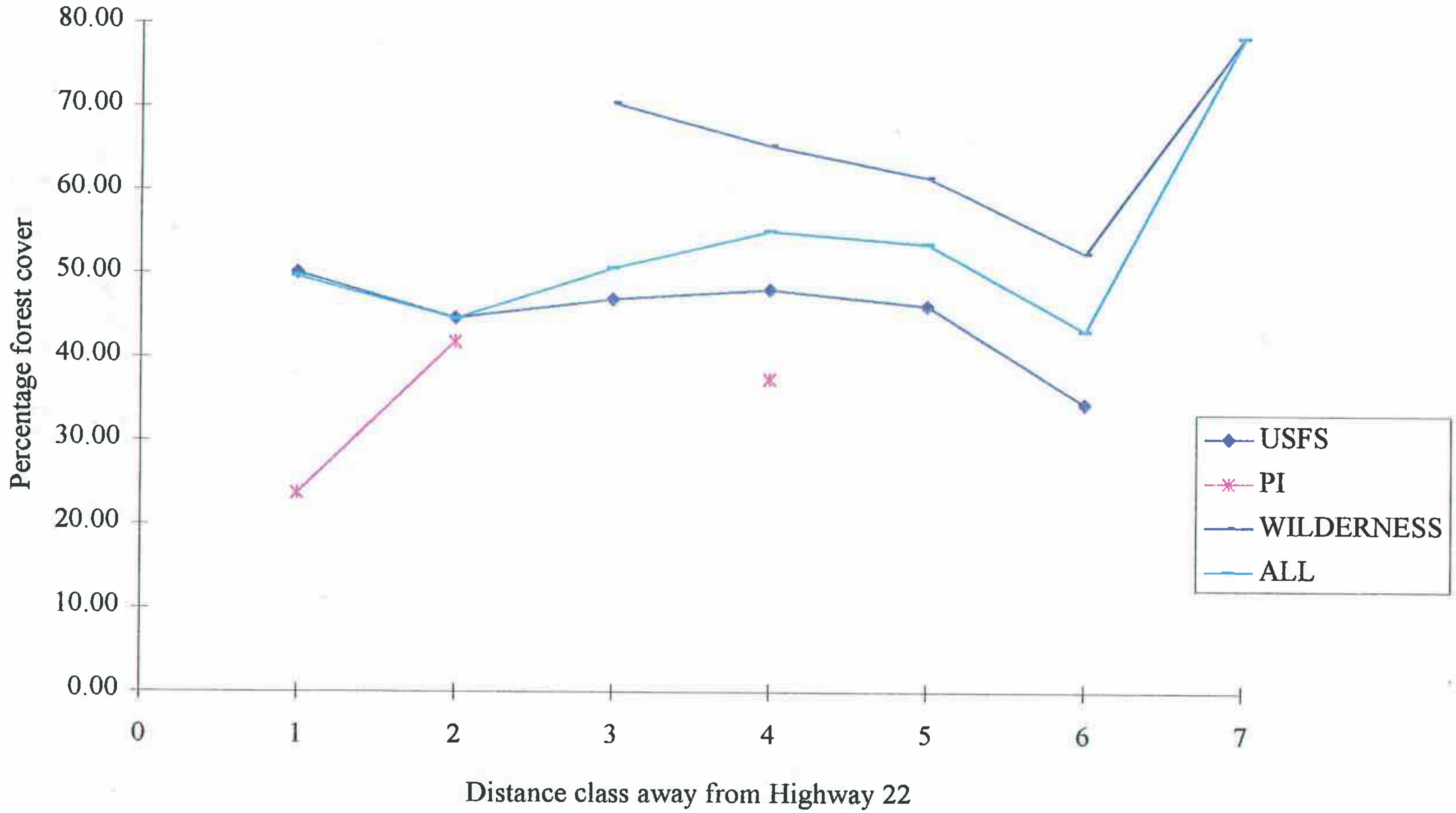
3.1.3.2 Patterns of forest cover defined as unmanaged forest

In the analysis of forest defined as areas with at least 30 percent tree cover, the same four detailed samples were also examined using the second forest definition. Their respective patterns are displayed in four different figures. In each case reference will be made to expected forest cover patterns as described earlier to see whether they can be confirmed or denied by actual findings.

In detailed study area A, the overall forest cover pattern per distance class (ALL curve) according to Figure 3.17 is relatively the same (54 percent on average). There is about 50 percent of forest cover within the first distance class. The percentage remains almost the same away from the highway. The seventh distance class is an exception with about 80 percent of forest cover. The percentage forest cover pattern from the ALL curve conforms with the predicted pattern.

The ALL curve pattern summarizes the average percentage forest cover of three land ownership types--PI, USFS, and Wilderness lands. For example, forested Wilderness lands are found from distance class 3. From the third to the sixth distance classes, they show according to Figure 3.17 a declining percentage forest cover as the distance away from Highway 22 increases. Seventy percent of Wilderness land within the third distance class is forested. The next three distance classes have a downward forest cover trend with the lowest being 53 percent at the sixth distance class. In the seventh distance class the percentage forest cover is 78 percent compared to the average 66 percent per distance class. Forest cover variability in Wilderness lands might

Figure 3.17. Percentage of forest defined as unmanaged forest cover per land ownership per distance class in detailed study site A in the central western Cascades of Oregon, U.S. (1988).



be attributable to change in vegetation from Douglas fir to high elevation conifer with large patches of bare areas.

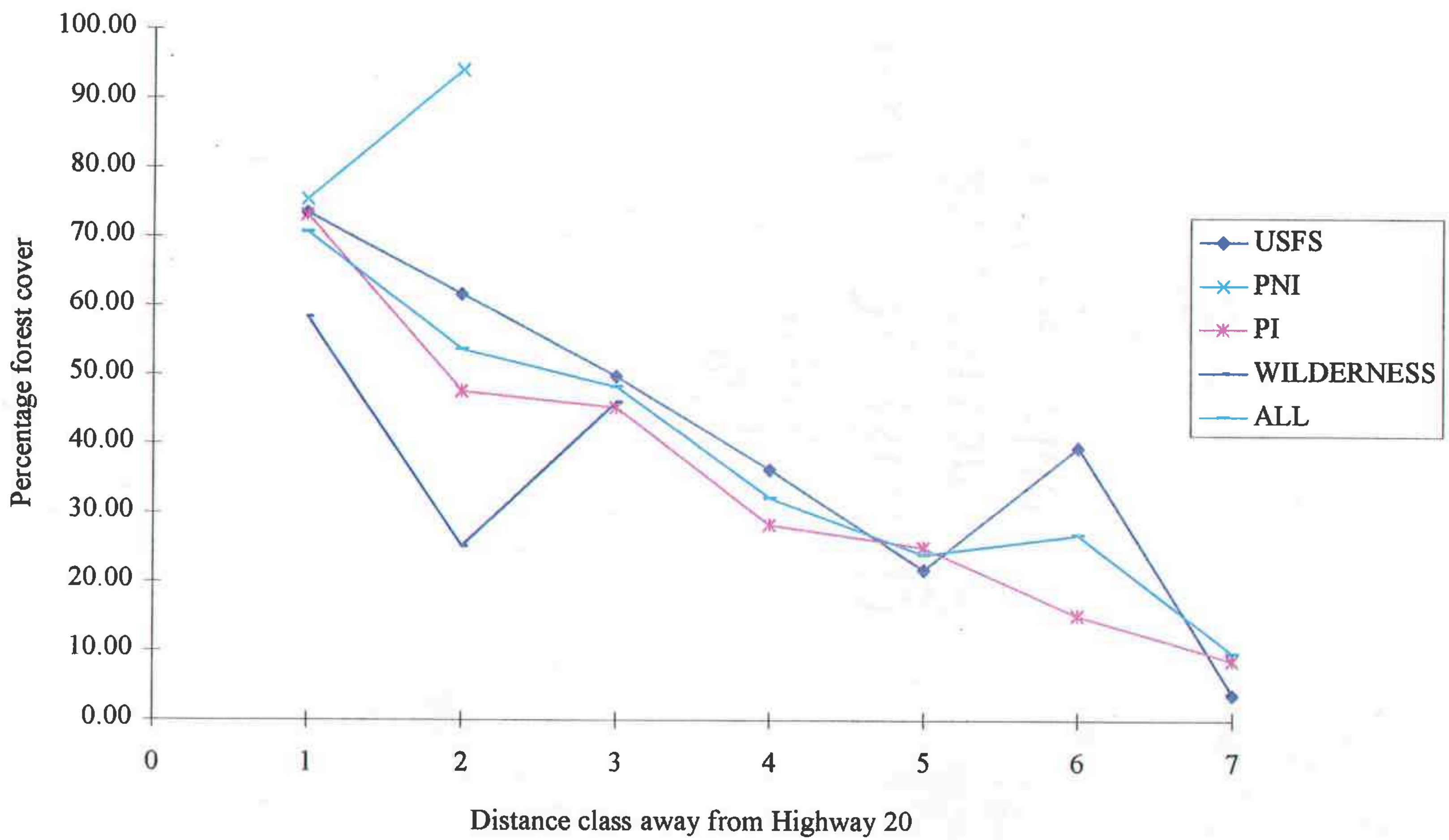
In contrast, USFS lands vary less between the first and the fifth distance classes. The average between the second and the fifth distance classes is about 47 percent. At distance class 6, the percentage forest cover is 34, about 20 percent less than what it was in the first distance class. There are about 50 percent USFS forest lands within the first distance class.

In detailed study area B, the percentage forest cover downward trend noticed in the ALL and PI curves in Figure 3.11 has sharply increased in Figure 3.18. USFS lands also show a percent forest cover decrease with distance away from the Highway 20.

All land ownership types in detailed study area B experience a decline in percentage forest cover with distance except in PNI lands (Figure 3.18). The average percentage of forest cover, according to the ALL curve, is about 38 percent compared to 92 percent in Figure 3.12. In the first distance class, for example, forest cover is about 71 percent, and about 10 at the seventh distance class. Because of the general dominance of USFS lands near, and PI lands away Highway 20, the pattern of the ALL curve does not fit the expected overall pattern in the detailed study area B.

Downward trends in USFS and PI forest cover are probably due to several factors. The timber harvest trend may have started more than 80 years ago from the Highway toward the interior. More than 80 years later those close to the Highway are mature while the harvest is still progressing into the hinterland. Stands near the highway may have not reached 80 years. PI land owners might also have focused on

Figure 3.18. Percentage of forest defined as unmanaged forest cover per land ownership per distance class in detailed study site B in the central western Cascades of Oregon, U.S. (1988)

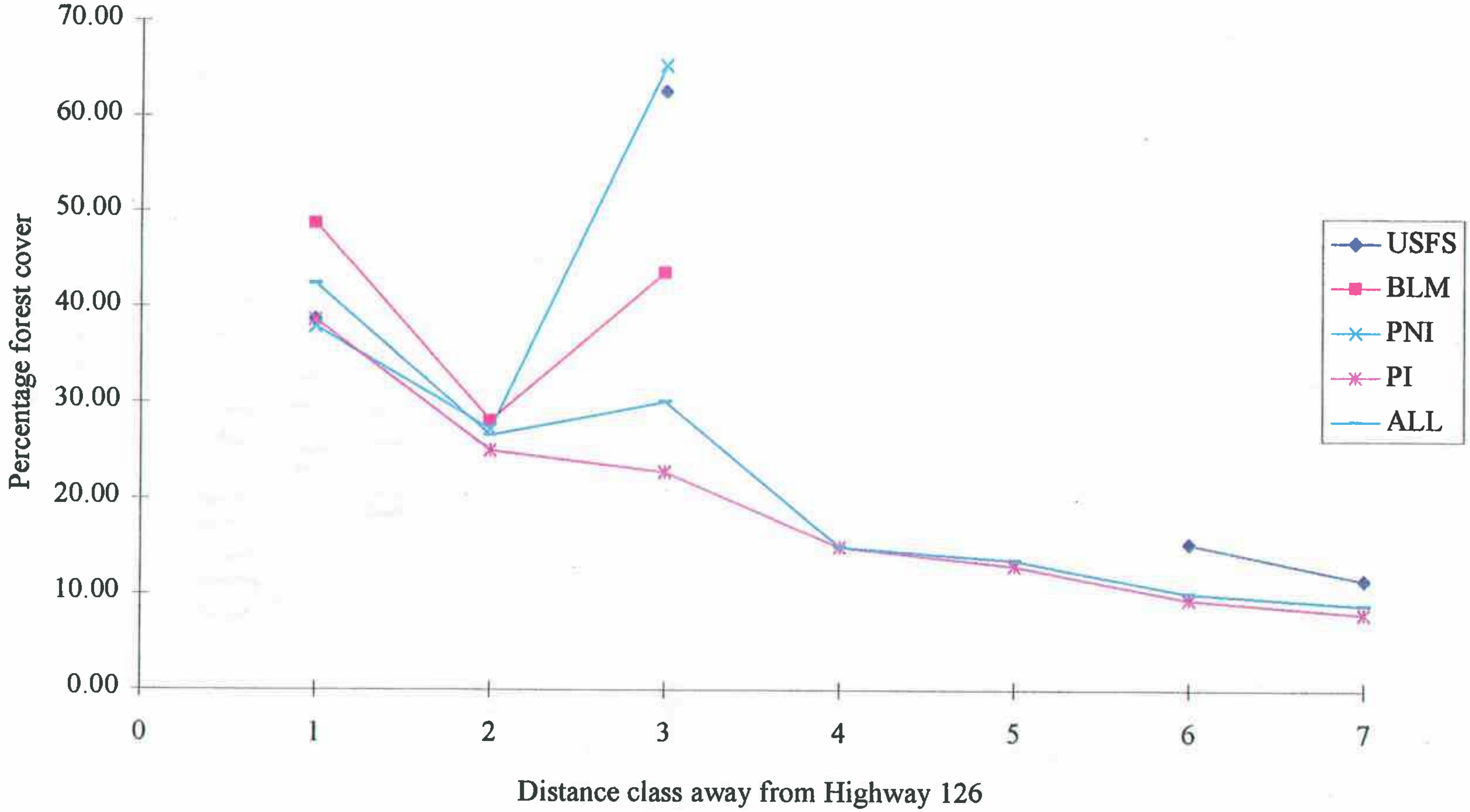


cutting more economical forest lands located away from the highway. Secondary roads, not included in this study, may have increased access to remote lands. Natural fires may have affected forested areas located away from the Highway since they are likely to be at high elevations, and predisposed to lightning fires.

In detailed study area C, the same pattern identified in Figure 3.18 is also found in Figure 3.19. Forest cover decreases as the distance away from the Highway 126 increases (Figure 3.19). This pattern is different from the relatively constant percentage forest cover variation with distance presented in Figure 3.14. The average according to the ALL curve is 42 percent within the first distance class, and 9 at distance class 7 compared to 96 percent and 97 percent at respective distance classes in Figure 3.14. The difference between Figure 3.14 and Figure 3.19 also is in the overall percentage forest cover per distance class. It is lower in Figure 3.19 than in Figure 3.14. The mean forest cover is 21 percent in Figure 3.19 and 95 percent in Figure 3.14.

The decreasing forest cover in PI lands is due to the same reasons advanced in the case of PI lands to explain patterns in detailed study area B. The forest harvest rotation period may have not been reached near the Highway. PI lands may be economically too small to be cut by land owners because of the mixture of public lands and private lands near Highway 126 (Figure 3.13). Fires may also have affected forest areas located away from the Highway because they are likely to be on high altitudes more prone to lighting fires. In addition, since PI lands are almost the only existing land ownership type away from the Highway, PI land owners might also have focused on cutting more financially profitable forest lands located away from the Highway. Access

Figure 3.19. Percentage of forest defined as unmanaged forest cover per land ownership per distance class in detailed study site C in the central western Cascades of Oregon, U.S. (1988)



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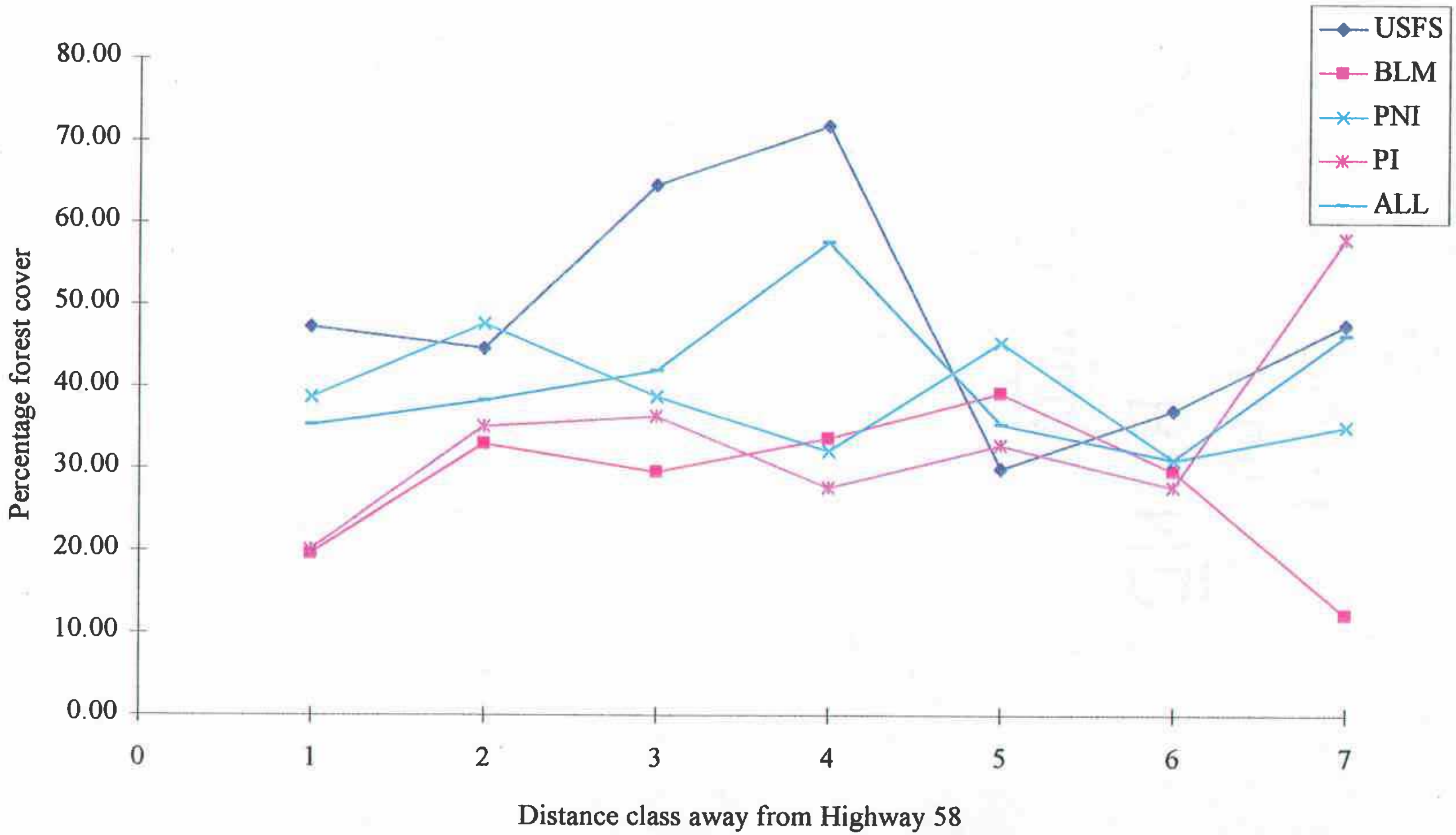
to remote lands may have been increased by the presence of secondary roads not included in this study. As a result less affected forests (unmanaged forests) are found near the Highway.

In detailed study area D there is no clear percentage forest cover pattern (Figure 3.20). The average from the ALL curve is about 41 percent. Most percentage of forest covers per land ownership per distance class are relatively stable with the exception of USFS forest lands. Percentage of forest cover in USFS lands increases up to the fourth distance class. Then, from the fourth to the seventh it decreases.

Forest cover patterns in public lands were expected to be constant with distance because forest cuts are not necessarily allocated with reference to terrain accessibility. This may explain the variability of USFS forested lands on Figure 3.20 as the distance away from Highway 58. PNI forests were expected to increase with distance. However, Figure 3.20 shows a pattern of PNI forest cuts not affected by the distance away from the highway. The presence of other road types not considered in this study might explain such a pattern. The access to remote lands away from Highway 58 could have been increased by the high density of other road types.

From the analysis of these four detailed study areas, the restricted forest cover definition did not help as anticipated to explain the pattern of forest cover in every study area. The distance away from highways did not always explain well expected patterns. Detailed study areas B, C, and D have a declining forest cover pattern instead of the expected increasing or constant pattern. This is due to several factors. Other road networks may have reduced the impact of away-from-highways constraints. The

Figure 3.20. Percentage of forest defined as unmanaged forest cover per land ownership per distance class in detailed study site D in the central western Cascades of Oregon, U.S. (1988)



topography of a detailed study site may have increased natural fire likelihood at some places more than at others. Forest cuts within a certain distance away from highways may be regulated for scenic purposes.

Additional analyses of the central western Cascades detailed study sites were made using 1988 color infrared air photos. Similarities were found between patterns of forest cover depicted by Figures 3.17, 3.18, 3.19 and 3.20, and air photos forest/non-forest cover distribution. Air photo analysis showed that the topography was complex with several valleys and mountains. The presence of secondary roads on air photos related to detailed study sites B and C may explain forest cover patterns highlighted by Figures 3.18 and 3.19 where fresh cuts could be found away from highways. Rock outcrop and ice cover detected on the eastern area of air photos related to detailed site A may explain the relatively low percent forest cover in Wilderness lands away from Highway 22 (Figure 3.17).

3.2 Results of analysis in southeast Zaire

The same presentation used in the central western Cascades of Oregon will also be used in southeast Zaire. That is, two types of gradients will also be considered: away-from-cities and away-from-highways gradients. In each gradient, a profile of land ownership patterns and the patterns of the two forest definition types will be examined. First, forest defined as areas with at least 10 percent canopy cover will be analyzed, and forest defined as unmanaged forest will be analyzed later. Then, the patterns of forest cover in four detailed study sites will be analyzed followed by a summary of causes of forest patterns in southeast Zaire.

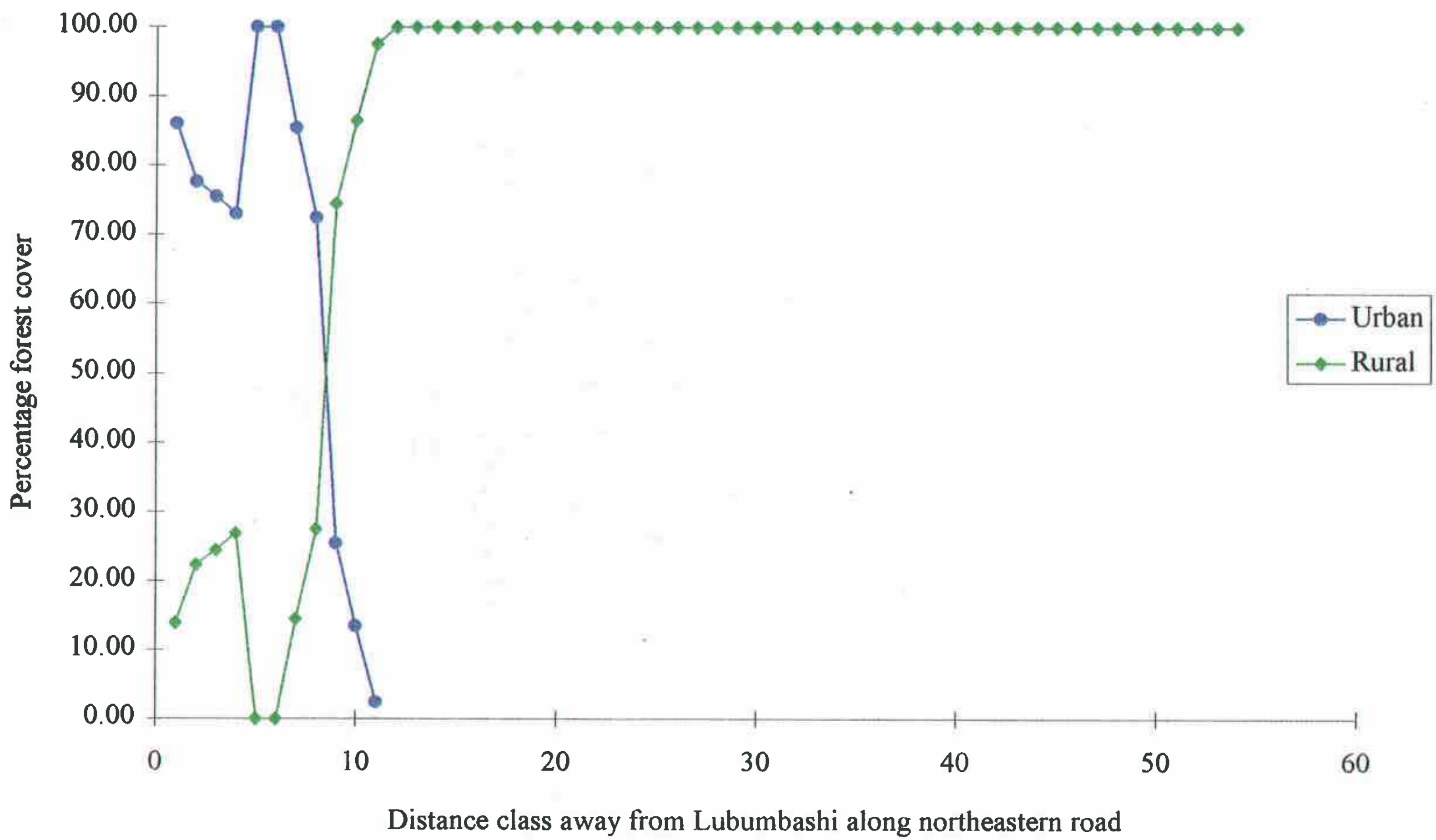
3.2.1 Analysis of the away-from-cities gradient

3.2.1.1 Overview of land ownership distribution

There are two land ownership types in Zaire (Figure 2.21) as opposed to the eight found in the central western Cascades of Oregon. Urban lands are delineated around cities such as Likasi and Lubumbashi. All lands located outside city boundaries are Rural lands. Figure 3.21 gives an overview of land distribution as a function of distance away from the city of Lubumbashi along the northeastern road. The technique used in delineating this study area for the analysis of the away-from-cities pattern was explained in Chapter 2. It consisted of delineating a buffer of more than 11 km on each side of the road and analyzing the percentage forest cover in 558 1600 m by 1600 m cells perpendicular to the road.

Land ownership distribution, displayed in Figures 3.21 and 2.20, reveals a dominance of urban lands within the first eight distance classes (more than 70 percent of lands). The variation in percentage urban land distribution (Figure 3.21) is due to the shape of urban boundaries (Figure 2.20) and the perpendicular position of cells, causing some cells to also cover Rural lands. For example, more than 86 percent of lands in distance class 1 are in Urban area. There is a relative decrease (76 percent) in distance class 4. Between the fifth and sixth distance classes all lands (100 percent) are in Urban

Figure 3.21. Percentage of land ownership per distance class delineated from Lubumbashi along the northeastern road in southeast Zaire.



areas. In the eighth distance class they are 72 percent in Urban areas. From the ninth distance class they are just 26 percent, and the lowest percent is at the 11th distance class (2.4 percent). No Urban lands are found beyond the 11th distance class.

Inversely, Rural lands are less represented within the first eight distance classes. About 14 percent are located in the first distance class. From distance class 12, all lands are Rural lands.

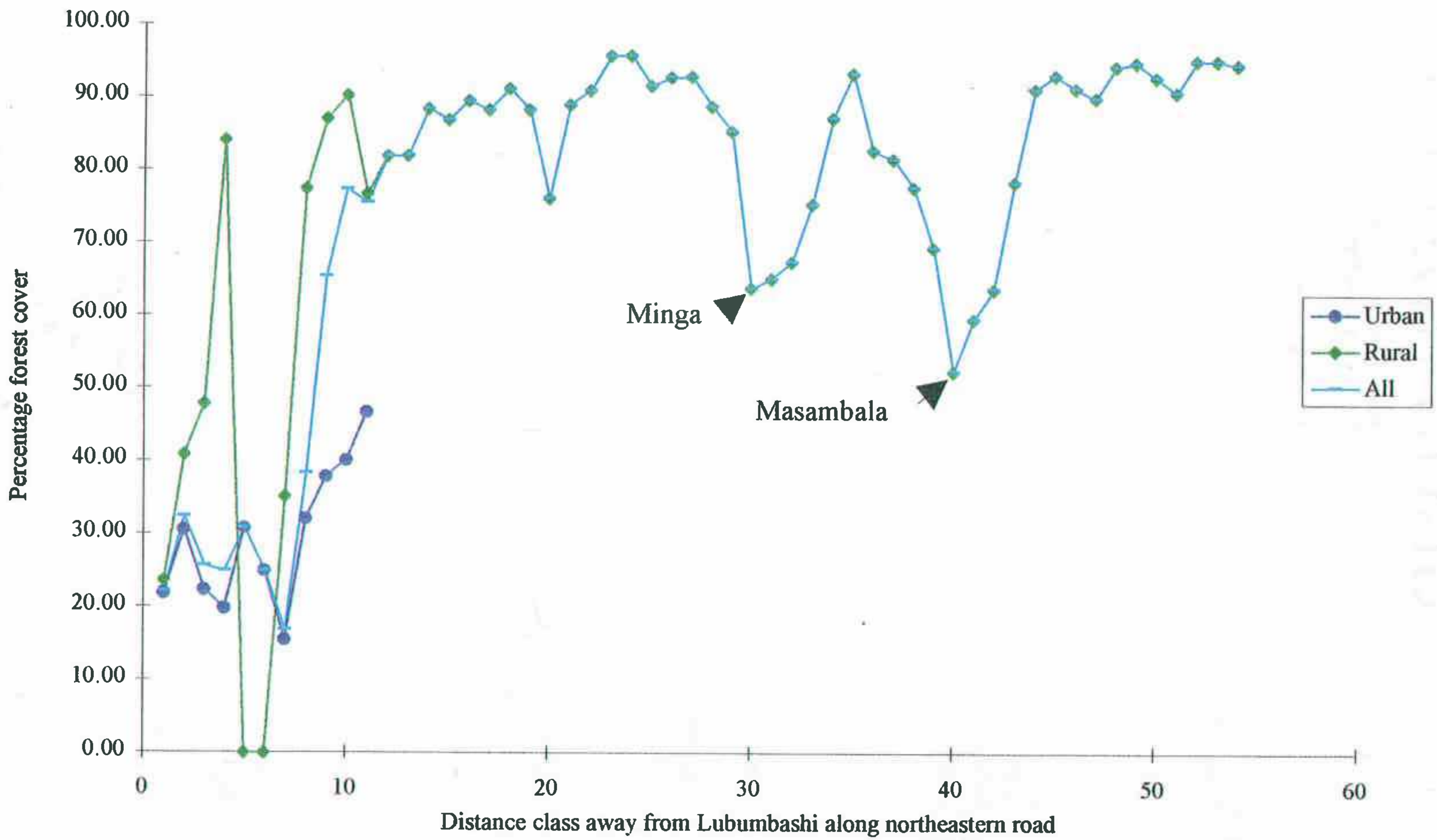
3.2.1.2 Patterns of forest cover defined as areas with at least 10 percent canopy cover

Figure 3.22 depicts the pattern of percentage of forest cover along the northeast road away from Lubumbashi. The average percentage of forest cover is represented by the ALL curve on the graph, and refers to forest cover within the first 11 distance classes. Beyond the 11th distance class the pattern is the same as that represented by the rural curve since no urban lands are found in any of these distance classes.

According to this classification procedure, the average percentage of forest cover is relatively high. On average there is 75 percent forest cover per distance class. Forest cover varies along the transect around this average. The lowest percentages of forest cover are found within the first eight distance classes, where it varies between about 17 and 38 percent. These low percentages, as will also be described later, are due to intense urban-related activities.

From the 11th distance class the percentage of forest cover is generally higher than the average. The percentage of forest cover is more than 80 percent, with the

Figure 3.22. Percentage of forest defined as areas with at least 10 percent canopy cover per land ownership per distance class delineated from Lubumbashi along the northeastern road in southeast Zaire (1989).



exception of places within and surrounding two villages (Minga and Masambala) along the road where the percentage of forest cover is low.

In Urban areas the percentage varies between 16 and 47 percent. The average percentage of forest cover per distance class is 29 percent. It is about 25 percent within the first eight distance classes.

Forest cover pattern within these eight distance classes is possibly due to several factors. During the image classification process (see section 2.2.2), the CLUSTR subroutine was applied to the original image to create 27 classes which were later reclassified into two classes--forest and non-forest. The classification procedure might have led to the inclusion of grasses and marshy environments in the forest category. In addition, some areas in the urban environment categorized as forests might have been, in fact, planted trees. They include street trees planted by Belgians in parks as well as, around churches and schools.

Beyond the first eight distance classes, the trend increases as the distance away from the city increases. From the ninth distance class there is more than 37 percent of forest cover per distance class.

In Rural areas, the percentage of forest cover is much higher than, and the pattern different from, that found in urban areas. The average percentage of forest cover per distance class within rural areas is more than three times (81 percent) that of urban areas. The percentage of forest cover is about 24 percent within the first distance class. It increases sharply thereafter as the distance increases to reach a relatively stable percentage forest cover pattern from the ninth distance class, generally more than 80 percent.

There are cases where the percentage of forest cover is lower than the average. Images were taken late in the wet and early dry season when the forest may have begun to lose its leaves. Low percent forest cover may be related to the decrease in the crown cover due to the deciduous nature of the forest environment and the variability in the soil texture. A drier soil has less water content, leading to a much faster decrease in canopy cover. The percentage of forest cover decrease might also be due to the impact of human activities. This is more noticeable between distance classes 27 and 35 and between 35 and 44, where the patterns are due to the impact of two villages, Minga and Masambala.

The overall pattern shows that the percentage of forest cover pattern is a function of distance from cities and populated areas. About eight distance classes away from populated areas the forest cover becomes relatively stable. This is obvious as one moves away from Lubumbashi and also as one considers the forest cover pattern around the two villages along the northeast road. This pattern of increasing forest cover with increasing distance to urban centers is mainly a consequence of the poor economic situation and the quality of the road system. High fuel costs associated with few vehicles limits the search for and transport of wood fuels and charcoal to areas around the city of Lubumbashi. Furthermore, intermittent road repair has led to less suitable roads and to fewer trucks traveling to remote areas.

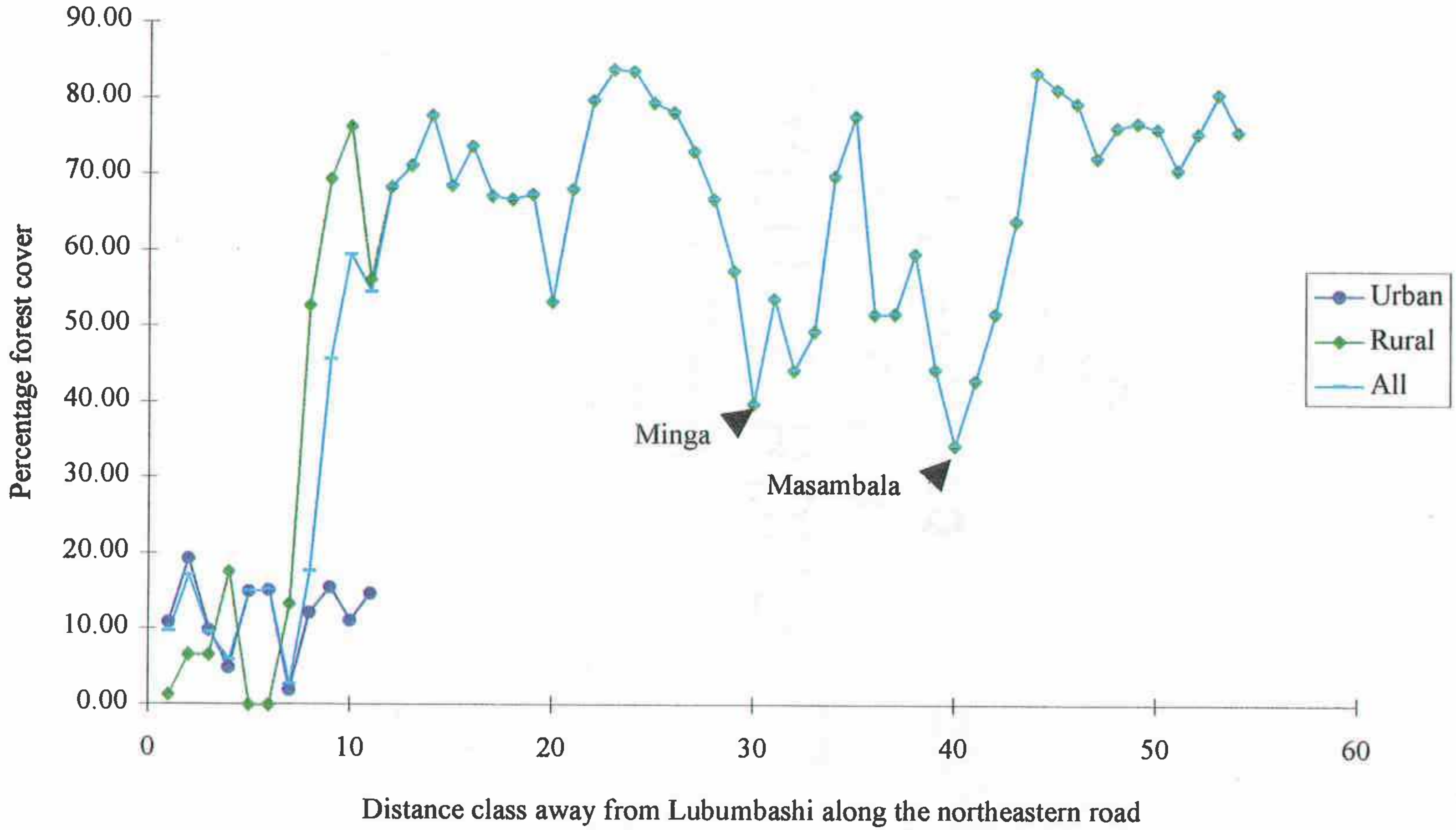
In addition to the low suitability of the roads, forest cover pattern is also explained by a generalized lack of purchasing power among the population. Few or no individuals can afford to buy or rent a truck for the shipping of wood and wood products from rural areas to cities. Most people resort to walking. As a consequence, the traveled distance is limited to nearby uninhabited areas. The daily walking distance was estimated to about 11 km (about seven distance classes) which is about the maximum walking distance estimated by Allen (1985) and Hart and Hall (1996).

Some of identified nonforest cover is related to the characteristics of an open forest during the dry season. Since the satellite imagery was taken at the end of June 1989, it was expected that most of grasses would be dried to the point that the only greenness to be detected would be related to tree cover. However, some trees might have lost their leaves sooner than others leading to more open areas. Riparian forests in the western and northeastern parts of the study site (Figure 2.6) are likely to hold their leaves longer than other forest types. Areas located at watersheds and where the major road network is also located are likely to lose their leaves sooner than those located in a humid environment, and may have been misclassified as non-forested areas.

3.2.1.3 Patterns of forest cover defined as unmanaged forest (Figure 3.23)

The percentage of forest cover pattern according to this classification procedure is similar to the classification defining forests as areas with at least 10 percent tree cover. The similarity is more obvious when considering the Rural and ALL curves (Figure 3.23). In both cases, the percentage of forest cover is very low within the first

Figure 3.23. Percentage of forest defined as unmanaged forest cover per land ownership per distance class delineated from Lubumbashi along the northeastern road in southeast Zaire (1989).



eight distance classes. From the ninth distance class, the percentage drastically increases. A further distance increase shows the same pattern as was the case in Figure 3.22; that is, the percentage of forest cover decreases between 27 and 35 distance classes and again between 35 and 44 distance classes, showing the pattern of human disturbances. As mentioned earlier, this pattern is related to the presence of the two villages of Minga and Masambala.

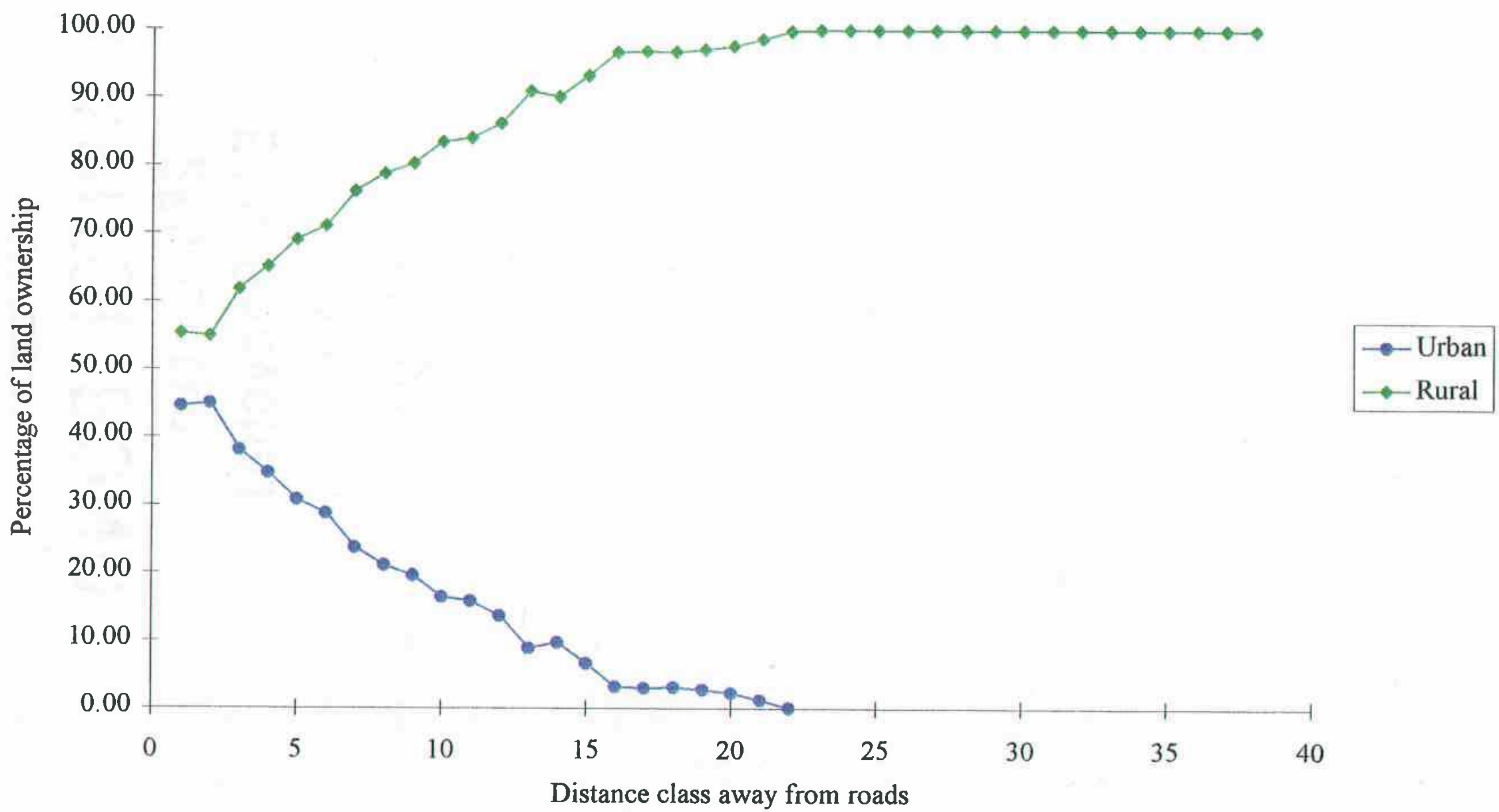
There are, however, some differences between Figures 3.22 and 3.23. One difference is related to the disparity in the average percentage forest covers. In Figure 3.22 it is 75, but in Figure 3.23 it is 58. This difference is due to the reclassification procedure to highlight the pattern of forest cover in areas less affected by human activities (unmanaged forest). While the reclassification has changed the average percentage forest cover in the entire study area, it has altered forest cover pattern in Urban areas the most. This pattern is attributable to the fact that most affected forests are located within and/or near inhabited areas. Urban environments have the highest population density and related forests are the most likely to be affected. In Figure 3.22 the percentage forest cover increases from the eighth distance class. In Figure 3.23 the average is 12 percent per distance class and does not increase with distance class.

3.2.2 Analysis of the away-from-roads gradient

3.2.2.1 Overview of land ownership distribution (Figure 3.24)

There are two distinct patterns in land ownership distribution as a function of distance away from roads. Urban lands occupy more than 44 percent of lands in the

Figure 3.24. Percentage of land ownership per distance class delineated from roads in southeast Zaire (1989).



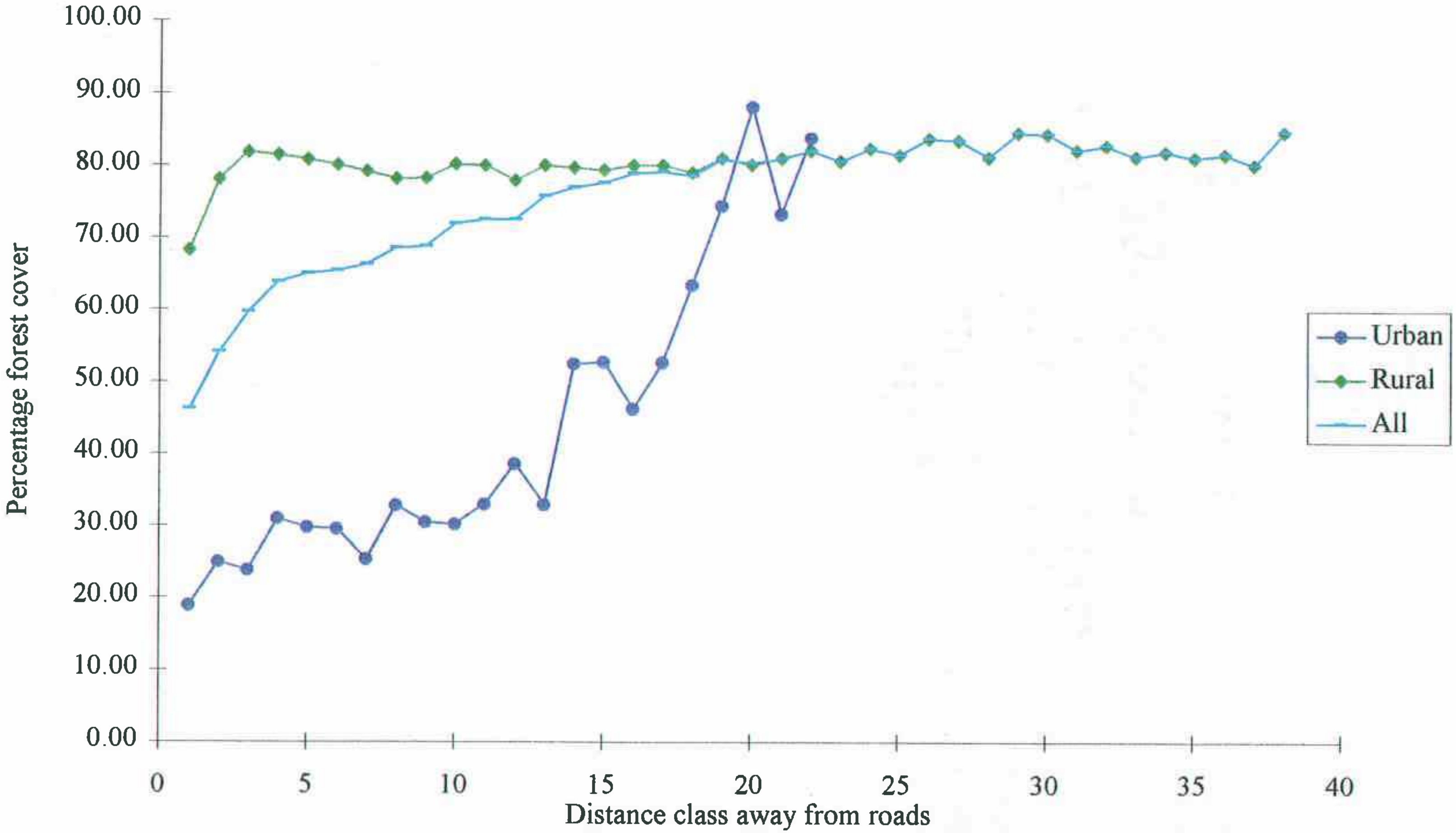
first distance class. The percentage of urban lands decreases as the distance away from roads increases. At the 22nd distance class it is 0.2 percent. Rural lands on the other hand, occupy 55 percent within the first distance class. The percentage of Rural lands increases with the increase of distance class away from roads. From the 23rd distance class all lands are located in Rural lands.

3.2.2.2 Patterns of forest cover defined as areas with at least 10 percent canopy cover (Figure 3.25)

In most cases there is a positive relationship between the percentage of forest cover and distance class away from roads. The overall percentage of forest cover distribution represented by the ALL curve has an average of about 76 percent per distance class. The lowest percentage of forest cover (46 percent) within this category is located within the first distance class. It progressively increases, and from the 19th distance class it reaches a plateau with more than 80 percent of lands forested.

The percent of forest cover in rural areas is not related to the proximity of roads. In the first distance class it is more than 68 percent. From the second distance class the percentage of forest cover is almost constant and is about 80 percent. From the 23rd distance class forest cover was expected to be 100 percent because of the absence of urban lands. This has not been the case for two reasons. First, even undisturbed Miombo woodlands have less than 100 percent canopy cover (canopy does not occupy 100 percent of the area for reasons not related to human activities). Second, the data were obtained at a time of year where the chance of having more open areas was relatively high (dry season).

Figure 3.25. Percentage of forest defined as areas with at least 10 percent canopy cover per land ownership per distance class from roads in southeast Zaire (1989).



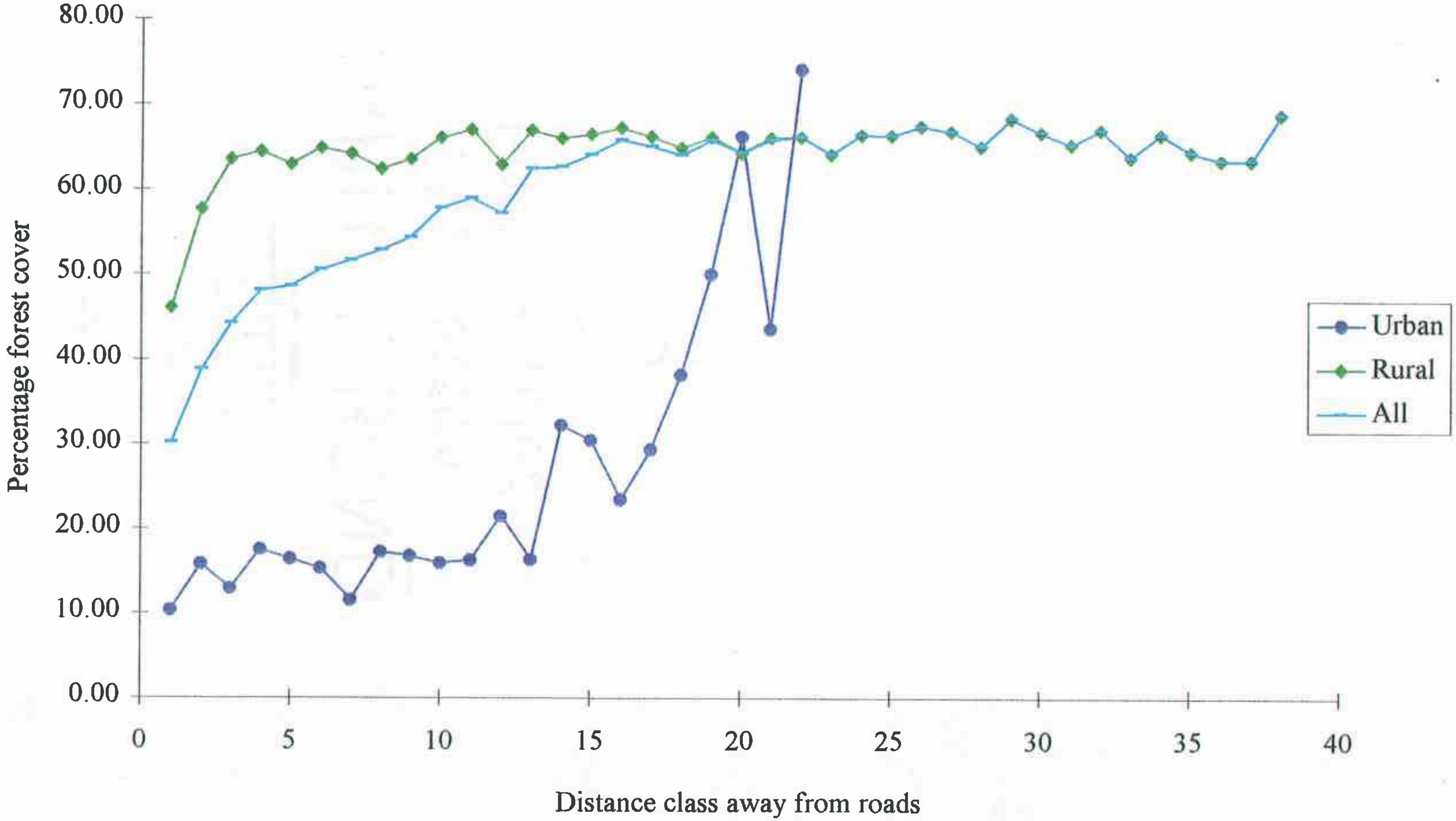
Forested lands in urban lands are the most affected by the presence of a road network. This trend, which is inversely related to the percentage of land ownership in Figure 3.24, highlights the impact of distance away from roads on human-induced disturbances. Within the first distance class forest cover is less than 20 percent. As the distance away from roads increases so does the amount of forest cover. The highest percentage of forest cover is found at the extreme end of urban boundaries.

3.2.2.3 Patterns of forest cover defined as unmanaged forest (Figure 3.26)

The forest cover pattern as represented in Figure 3.26 is almost identical to that represented in Figure 3.25. The overall percentage forest cover (ALL curve) increases as the distance increases and reaches a plateau at the 16th distance class. The percent of forest cover in Rural lands shows almost no variation with distance, as in Figure 3.25. Forest cover in urban lands (Figure 3.25) also shows the same pattern as urban lands in Figure 3.26. They are the most affected by the presence of road network. As the distance away from roads increases the percentage of forest cover also increases.

The difference between forest cover defined as areas with at least 10 percent canopy cover (Figure 3.25) and forest defined as unmanaged forest cover (Figure 3.26) is in the overall amount of forest cover. The average percentage of forest cover per distance class is much lower in Figure 3.26 than in Figure 3.25. Forest cover for all ownerships combined is 76 percent in Figure 3.25 and 60 percent in Figure 3.26. The percentage of forest cover is more than 15 percent less in Figure 3.26 than in Figure 3.25. This difference is mostly due, as was also noted between Figures 3.22 and 3.23,

Figure 3.26. Percentage of forest defined as unmanaged forest cover per land ownership per distance class delineated away from roads in southeast Zaire (1989).



to the change in forest classification procedure. Forest defined as areas with at least 10 percent canopy cover may have included grasses and shrubs in the forest class.

3.2.3 Analysis of detailed study sites

3.2.3.1 Patterns of forest cover defined as areas with at least 10 percent canopy cover

Four detailed study areas were selected to analyze the pattern of forest cover at a relatively smaller spatial scale. Detailed study areas A and B are located on the northeastern road. Detailed study areas C and D are located on the northwestern road. Detailed study areas A and C are in an environment where urban and rural lands are mixed. Detailed study areas B and D, on the other hand, have been selected from a completely rural environment. As a consequence of these locations, the percentage of forest cover is expected to be higher in areas B and D than in areas A and C.

There is a similarity in the pattern of forest cover distribution in both rural and urban areas within study area A (Figure 3.27). The percentage of forest cover in both cases is very low near the road and increases with distance away from it. The impact of human disturbance on forest cover is mostly located within the first distance class, where the percentage of forest cover is less than 40 percent. From distance class 3, the percentage of forest cover is more than 80 percent. The average forest cover per distance class according to the ALL curve is 81 percent.

In detailed study area B, located far away from the city in a completely rural environment, forest cover is almost unaffected by the presence of the road (Figure 3.28), as was the case in Figure 3.27. According to the ALL curve, the average forest

Figure 3.27. Percentage of forest defined as areas with at least 10 percent canopy cover per land ownership per distance class delineated away from the northeastern road in detailed study site A in southeast Zaire (1989).

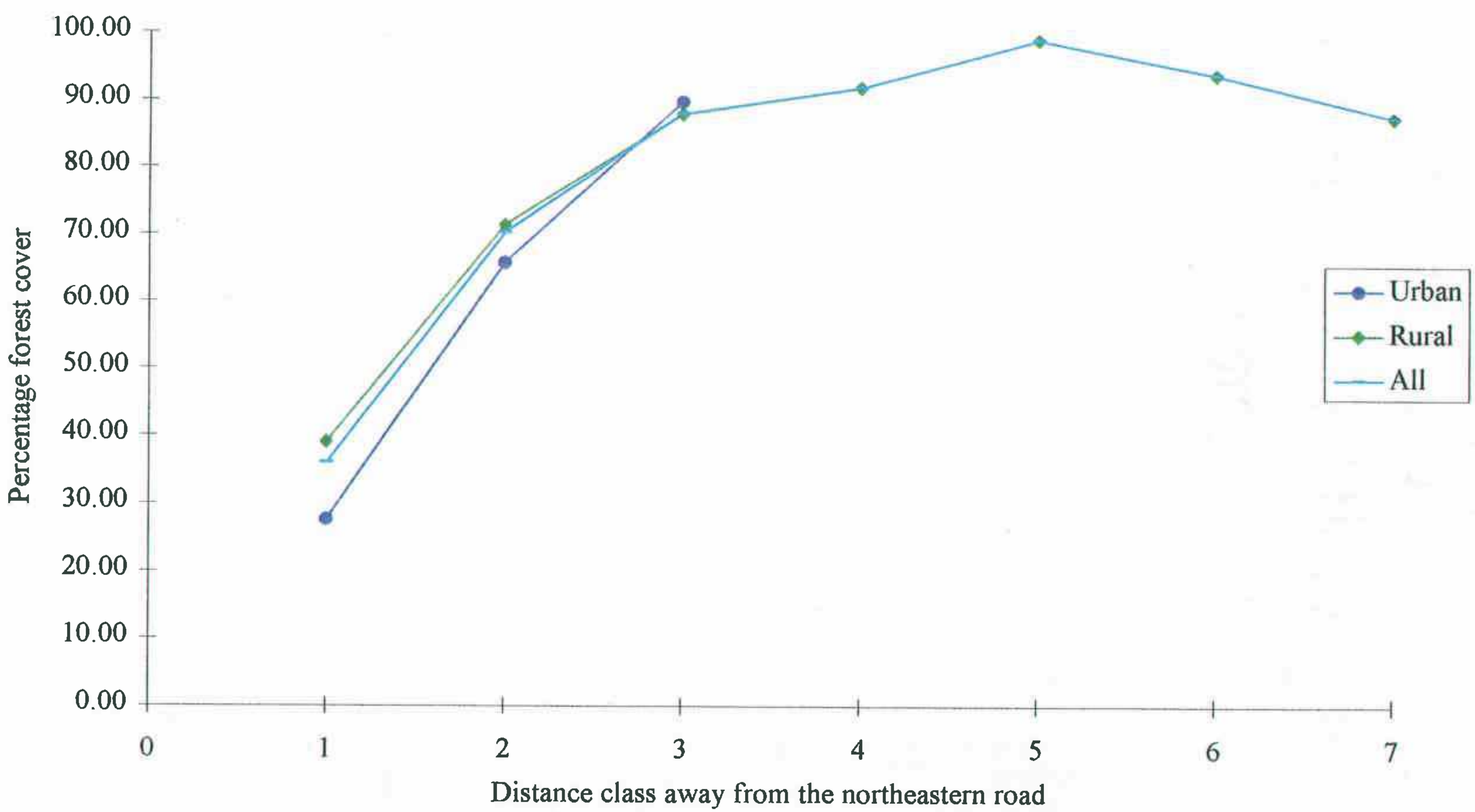
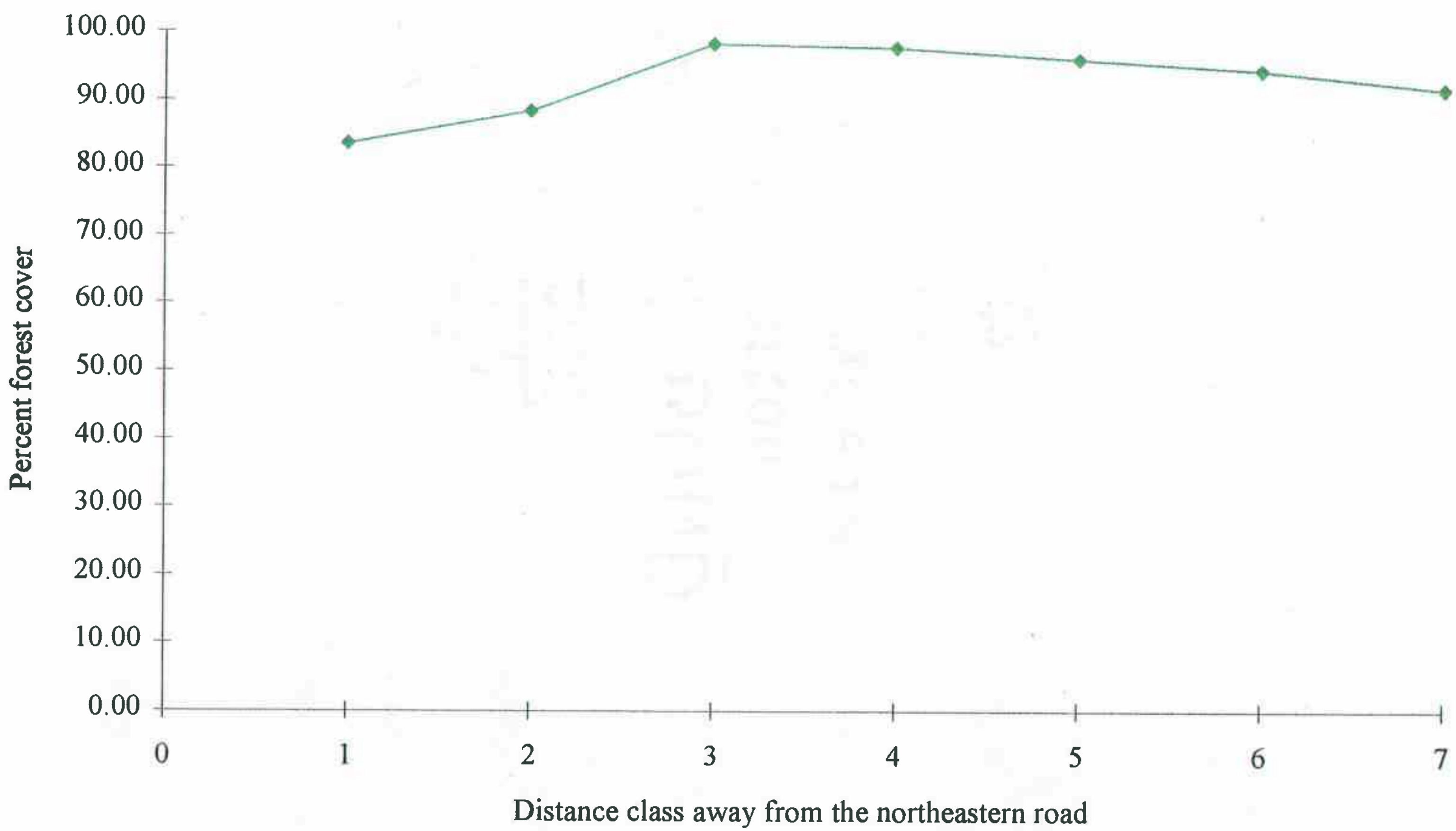


Figure 3.28. Percentage of forest defined as areas with at least 10 percent canopy cover in Rural areas per distance class delineated away from the northeastern road in detailed study site B in southeast Zaire (1989).



cover per distance class is 93 percent. The percentage of forest cover within the first distance class is 84 percent. It increases to more than 90 percent from the 3rd distance class.

In detailed study area C (Figure 3.29) the average percentage of forest cover per distance class is very low (about 40 percent) and is relatively stable as the distance varies. The percentage of forest cover in Rural area is much higher (more than 70 percent) than the detailed study area average but does not show a clear pattern. The pattern of forest cover in the Urban land is the same as that represented by the ALL curve up to the fifth distance class. Beyond this distance class the percentage of forest cover decreases considerably. This forest cover pattern is a result of the north-south orientation of the detailed study area (see Figure 2.22). From the road, a northward distance class increase is a move toward the city center and the southward direction is a move away from the city. The sixth and seventh distance classes in Urban lands (Figure 3.29) are located in the northern part of detailed study area C which is also likely to be less forested.

The pattern in detailed study area D (Figure 3.30) is similar to that represented in detailed study area B. Because the detailed study area is located mid-way between Lubumbashi and Likasi in a completely rural environment, there are very few noticeable human impacts. The average percentage forest cover per distance class is 93 percent. Areas relatively affected by human activities are located within the first and the second distance classes and have 84 and 76 percent forest cover, respectively.

Figure 3.29. Percentage of forest defined as areas with at least 10 percent canopy cover per land ownership per distance class delineated away from the northwestern road in detailed study site C in southeast Zaire (1989).

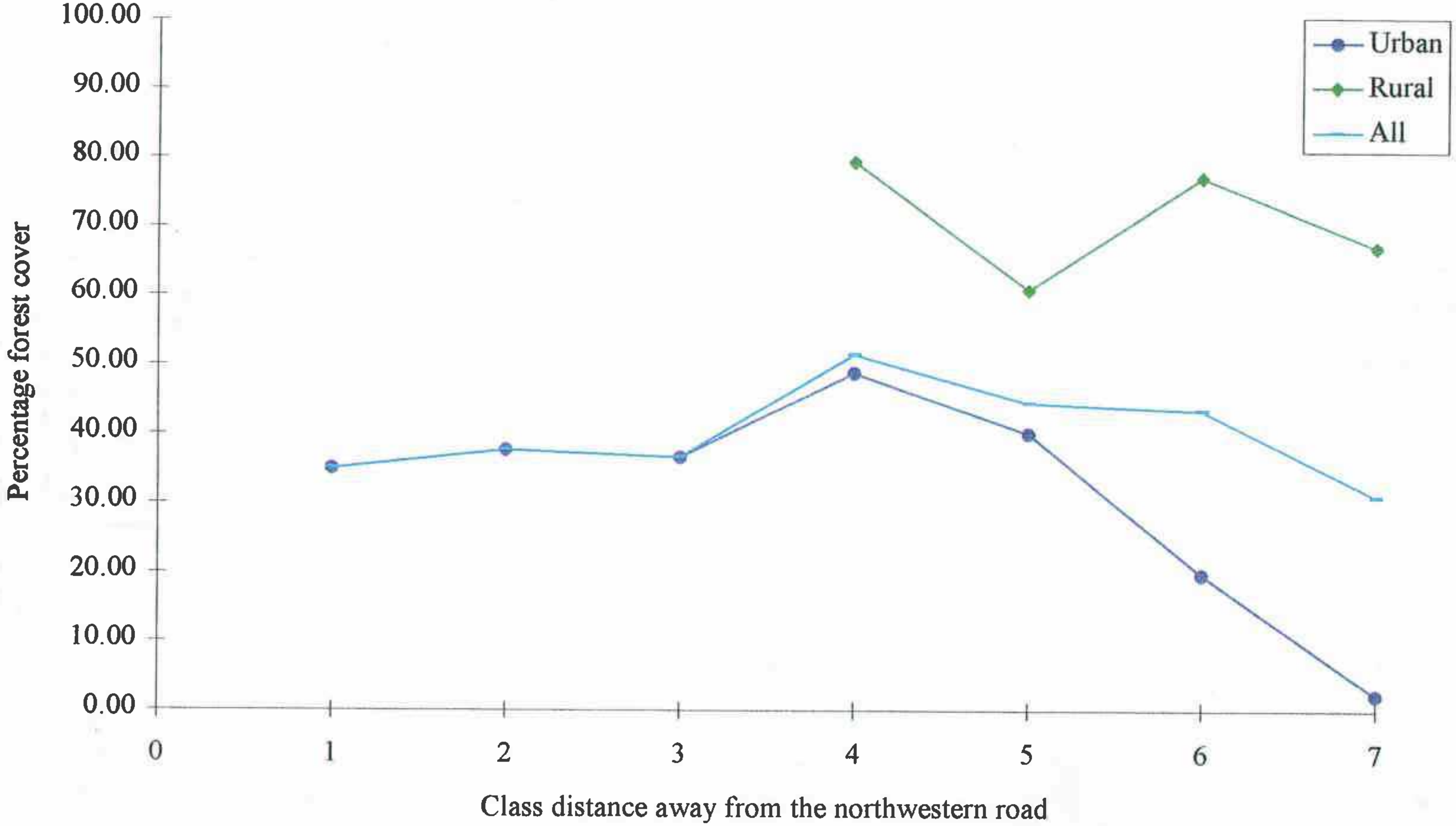
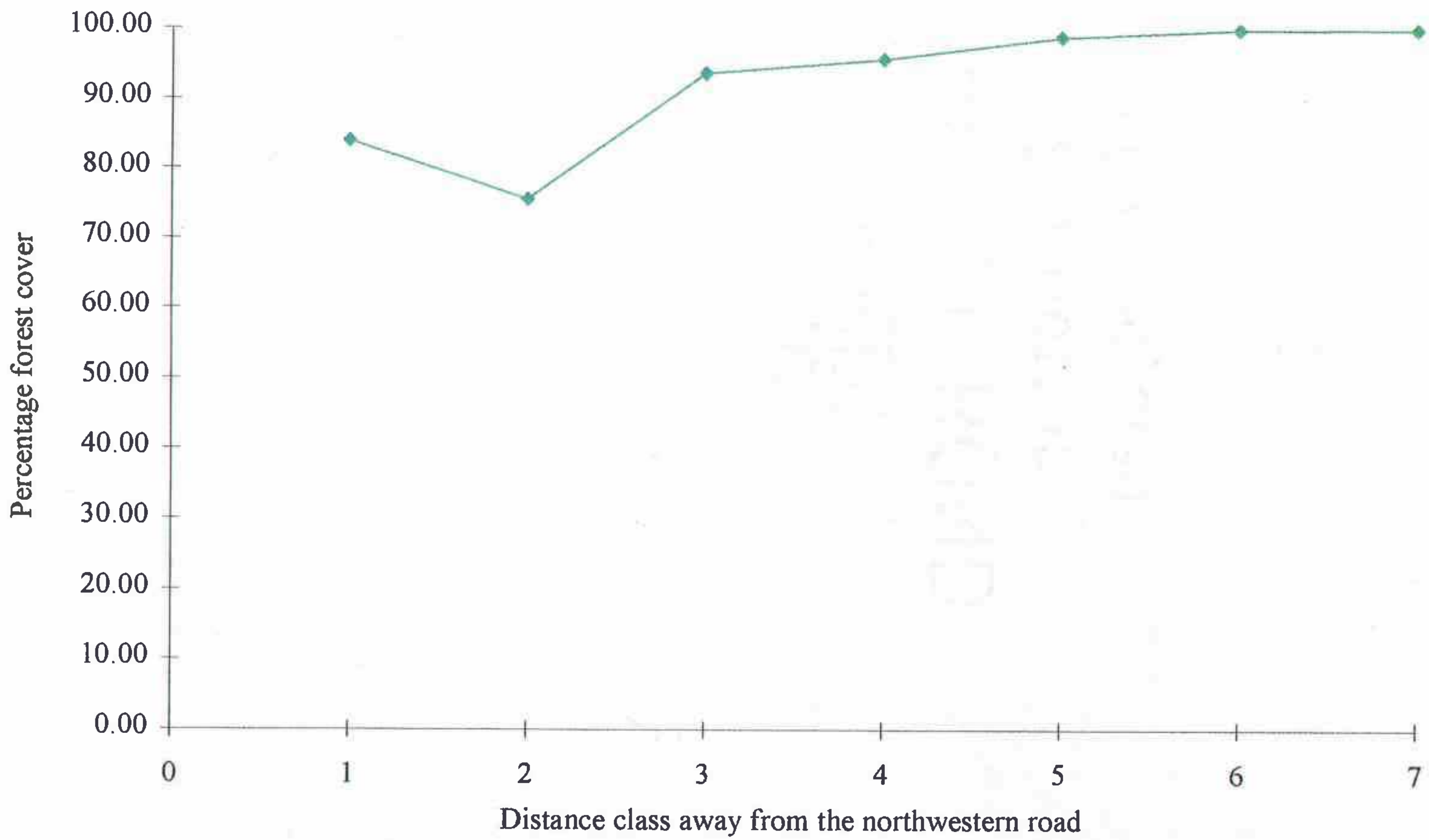


Figure 3.30. Percentage of forest defined as areas with at least 10 percent canopy cover in Rural areas per distance class delineated away from the northwestern road in detailed study site D in southeast Zaire (1989).



3.2.3.2 Patterns of forest cover defined as unmanaged forest

After image reclassification, the same four detailed study sites were used to analyze the pattern of forest cover. The results, reported in Figures 3.31, 3.32, 3.33, and 3.34, did not show any major differences in the patterns compared to Figures 3.27, 3.28, 3.29, and 3.30. The most important difference was the expected overall drop in the percentage forest cover. Figures 3.31 and 3.32 have been used to illustrate similarities and differences with Figures 3.27 and 3.28, respectively.

Patterns of forest cover distribution for forest defined as areas with at least 10 percent canopy cover and forest defined as unmanaged forest cover were similar for both Rural and Urban areas in detailed study area A (Figures 3.27 and 3.31). The low percent of forest cover defined as unmanaged forest (Figure 3.31) near roads was found to be mostly related to human-related disturbances in both ownership types. Less than 10 percent of forest cover per distance class is found near the road. Away in the hinterlands the percentage is higher. From the fourth distance class, more than 70 percent of the lands are forested.

Forest cover patterns also were similar in detailed study area B for both forest definitions (Figures 3.28 and 3.32). The major difference is in the low proportion of forest cover defined as unmanaged forest in Figure 3.32. In forest defined as areas with at least 10 percent canopy cover (Figure 3.28) forested areas cover an average 93 percent of areas per distance class, whereas in Figure 3.32 the average is 80 percent. Lower percentages are found within the first two distance classes, 63 and 70 percent,

Figure 3.31. Percentage of forest defined as unmanaged forest cover per land owernship per distance class delineated away from the northeastern road in detailed study site A in southeast Zaire (1989).

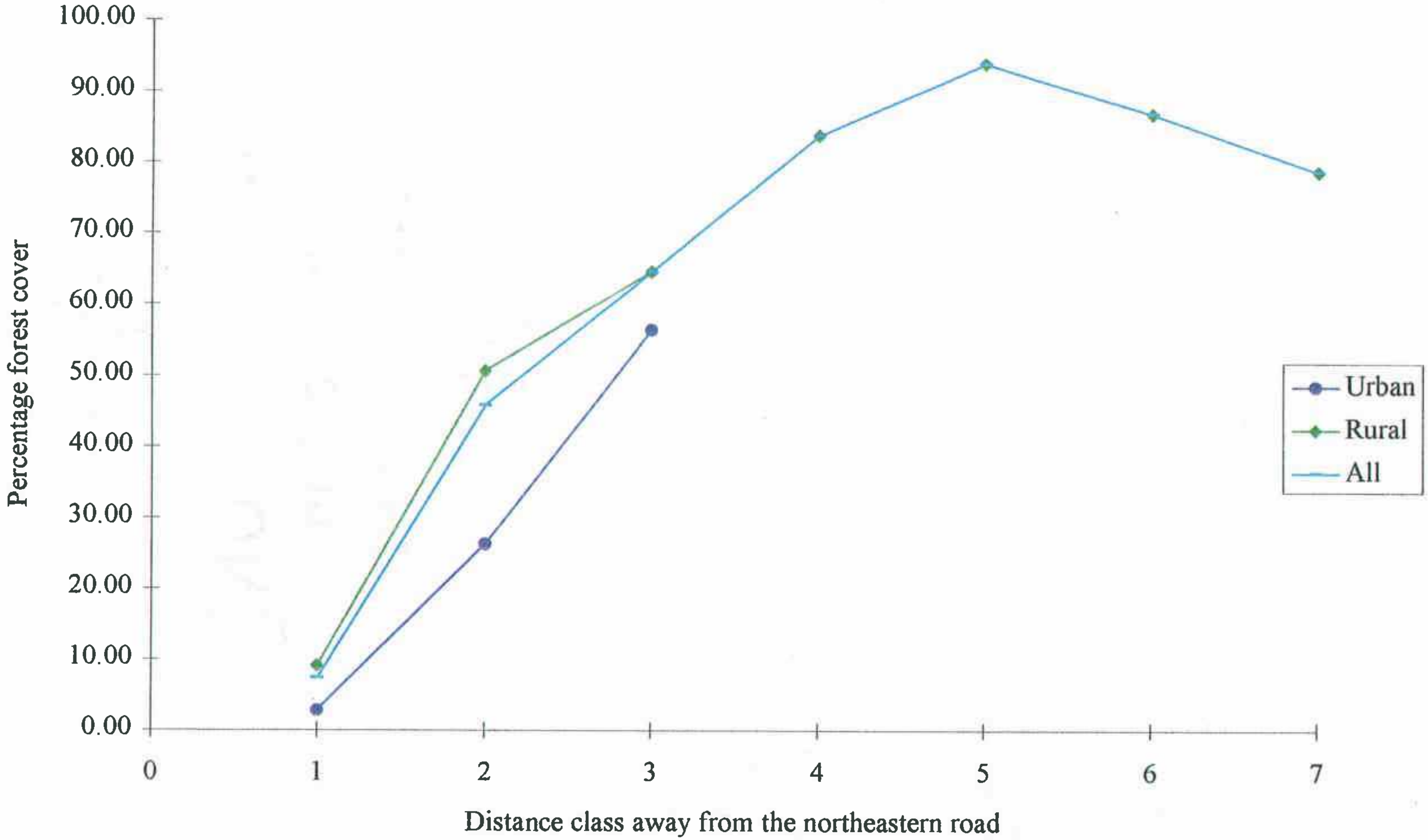


Figure 3.32. Percentage of forest defined as unmanaged forest cover in Rural areas per distance class delineated away from the northeastern road in detailed study site B in southeast Zaire (1989).

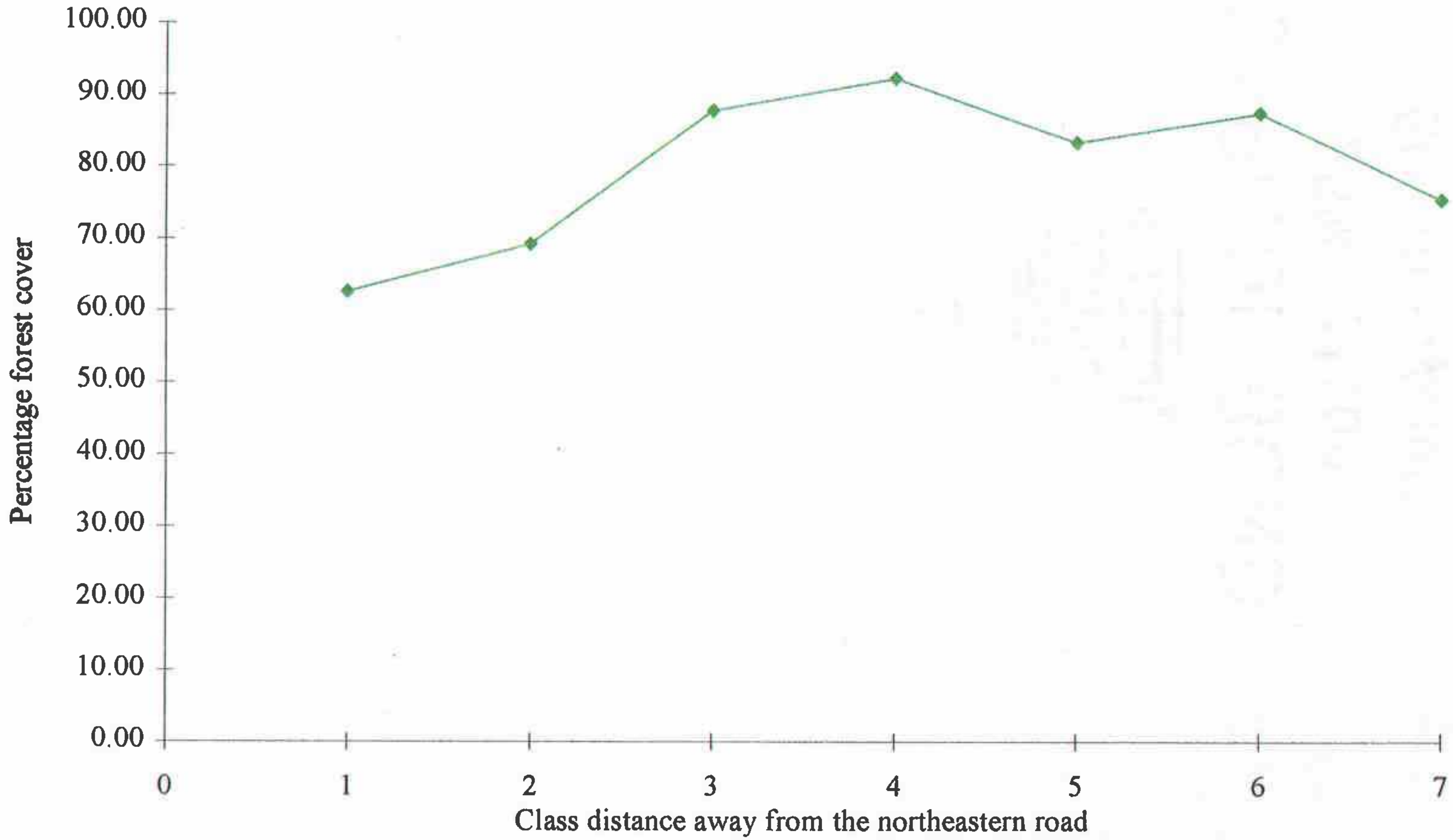


Figure 3.33. Percentage of forest defined as unmanaged forest cover per land owernship per distance class delineated away from the northwestern road in detailed study site C in southeast Zaire (1989).

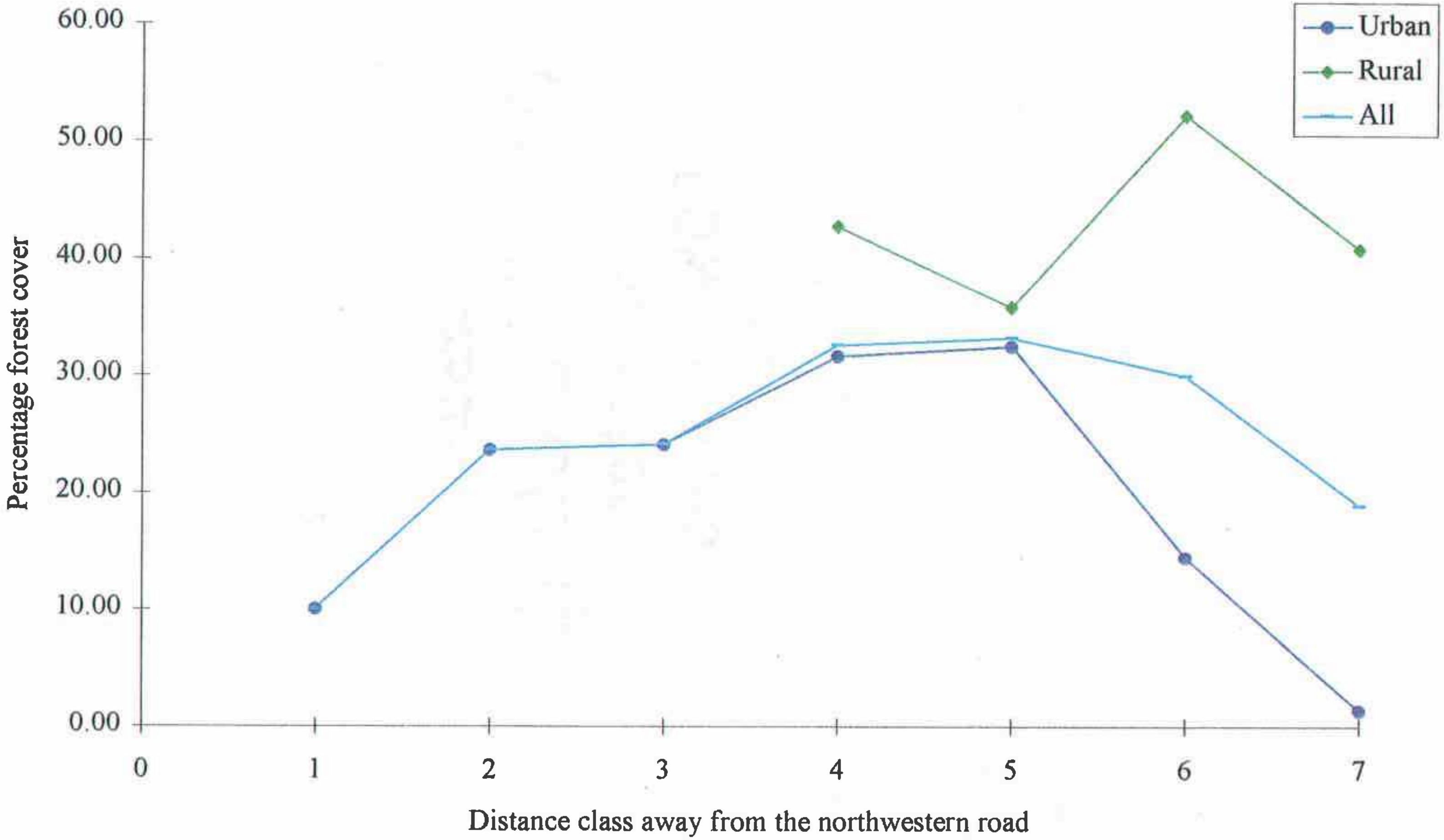
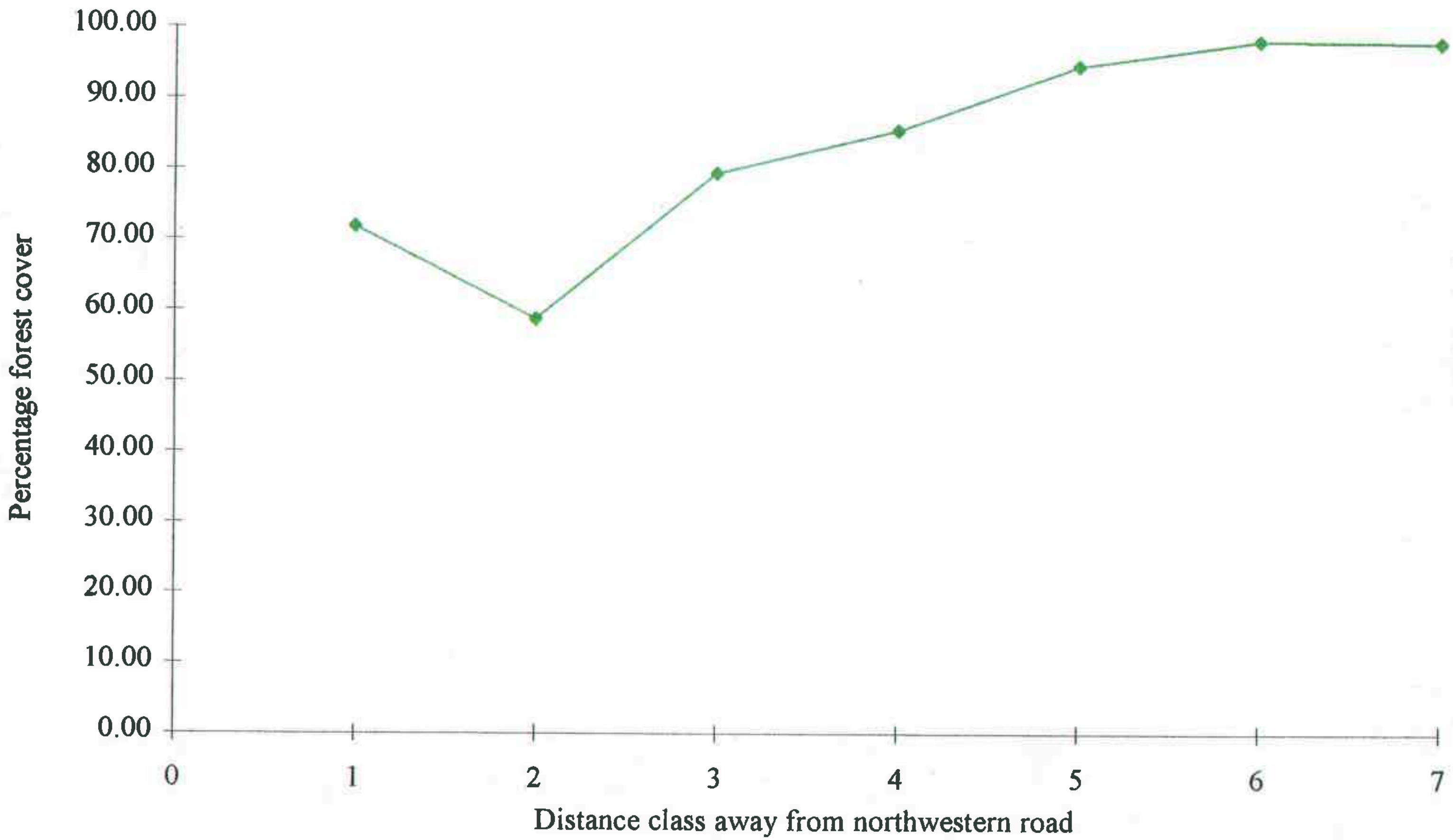


Figure 3.34. Percentage of forest defined as unmanaged forest cover in Rural areas per distance class delineated away from the northwestern road in detailed study site D in southeast Zaire (1989).



respectively. The near-road forest changes are related to human activities. On the other hand, percent forest cover shows a decreasing pattern from the fifth distance class. The low percentage of forest cover from the fifth distance class and beyond is probably due to natural factors, such as the inherent characteristics of open areas in Miombo woodlands, the existence of marshy environment (detectable on the original image (Figure 2.6) and maps (Bruneau and Pain 1990)), and the image classification method since human activities are believed to be almost nonexistent.

Forest cover patterns also were similar for both forest definitions in detailed study areas C (Figures 3.29 and 3.33), and D (Figures 3.30 and 3.34). In detailed study area C, forest cover defined as unmanaged forest increases away from the northwestern road. Detailed study area D also shows the same increasing forest cover patterns but it is relatively less affected by the distance.

3.2.4 Summary of causes of forest cuts in southeast Zaire

Patterns of forest cover are a result of two factors. Agriculture and fuel wood are two major land uses in southeast Zaire which have an impact on the pattern of Miombo woodlands. They are motivated and maintained in part by the open access resource lands policy (Mather 1990) and a poorly-defined Zairian land tenure system (Hart and Hall 1996, Salacuse 1985).

Shifting cultivation is the most common form of agriculture used in Miombo woodlands. Several reasons explain the persistence of such a technique. Low fertility of the soils (Higgins and Kassam 1984, Lal 1984, United Nations Environment

Programme 1992, Stock 1995) and the absence of a more advanced agriculture technology are among the major factors. In addition, the inability to afford fertilizers due to the low level of economic development in Zaire and low per capita income also preserve this agricultural practice.

Fuel wood and charcoal production may also help explain the pattern of forest cover in southeast Zaire. These forest products are used not only for subsistence but also are marketed (Lootens-De Muynck et al. 1982). Fuel wood cutting and charcoal production are in most cases rudimentary. The tremendous increasing demand for fuel wood in cities has increased exploitation of Miombo woodlands along roads and other accessible areas (Celander 1983). The increased demand and the cutting pattern are due, in part, to the generalized lack of purchasing power among the population to buy alternative energy and to the low maintenance of the road network (Fraser 1988). Infrequent road repairs lead to fewer trucks traveling to remote areas. In addition, high fuel costs associated with few vehicles restrict forest cuts to areas around the city.

Because of the reasons listed above, people may resort to walking to reach less accessible areas. Areas affected by walking people are more obvious in the away-from-road forest cover analysis. Individuals or families dominate forest exploitation in southeast Zaire but companies with heavy equipment and larger labor force dominate in the central western Cascades of Oregon. The traveled distance by foot in sub-Saharan Africa is estimated to an average of seven distance classes away from the road (Allen 1985, Hart and Hall 1996).

However, despite these human-related forest cuts, the low level of forest cover identified in southeast Zaire is also related to the low level of the crown cover due to the deciduous nature of the Miombo woodland environment. In Miombo woodlands, some trees shed their leaves during the dry season, so that some forested areas may appear to be deforested during the dry season.

The date satellite image data were collected may also have an impact on identified forest cover patterns. An image taken at the beginning of the dry season will show more leaves than one taken at the end of the dry season. The southeast Zaire image was taken at the end of June 1989, when it was expected that most of grasses would be dry leaving the only detectable greenness related to tree cover. However, some trees might have lost their leaves because of drier than usual climatic conditions in 1989 (Cane et al. 1994, Magadza 1994, US Department of Commerce National Oceanic and Atmospheric Administration 1989) leading to more than expected open areas. This dry season-related misclassification is most often found in areas located far from watershed and swampy environments which are likely to be the first places most affected by the impact of a dry climate.

3.3 Discussion

3.3.1 Introduction

Several scales of analysis have been dealt with in this study. The first two sections (3.1 through 3.2) of this chapter involved a detailed description of the pattern of forest cover per study site, per distance class, and per land ownership. In addition to the land ownership scale (eight land use classes in the central western Cascades of Oregon and two in southeast Zaire), four detailed study areas also were analyzed.

In this section, the analysis will concentrate on the overall pattern of forest cover by focusing on hypotheses 1 to 4 from Chapter 2. Thus, only forest cover patterns highlighted by the profile of the ALL curve in each of the eight graphs related to the overall study area analysis will be considered. Patterns of these ALL curves are summarized in Figures 3.35 and 3.36. ALL curves related to the analysis of forest cover patterns away from cities and urban centers are highlighted in Figure 3.35. Figure 3.36, on the other hand, highlights away from highways/roads forest cover patterns. OR-1 and Z-1 represent the pattern of the extended forest definition, and OR-2 and Z-2 the pattern of the restricted forest definition.

The first four hypotheses dealt with in this section are related to the distance decay model applied to forest cover analysis. Figure 3.37 summarizes these hypotheses. According to this model (Figure 3.37), forest cuts decrease and forest cover increases as the distance away from cities and highways/roads increases. The distance is assumed to be more a constraint in southeast Zaire than in the central western Cascades of Oregon because of poorer economic conditions in Zaire than in Oregon. It is believed that the per capita income in Oregon is higher than in southeast Zaire, allowing people to afford appropriate equipment to overcome the distance constraint. It is also hypothesized that from a certain distance human-related forest disturbances decrease to such a point that the amount of forest cover will remain nearly the same despite any

Figure 3.35 Percentage of forest cover as represented by ALL curves in the central western Cascades of Oregon (1988) and southeast Zaire (1989) away from cities

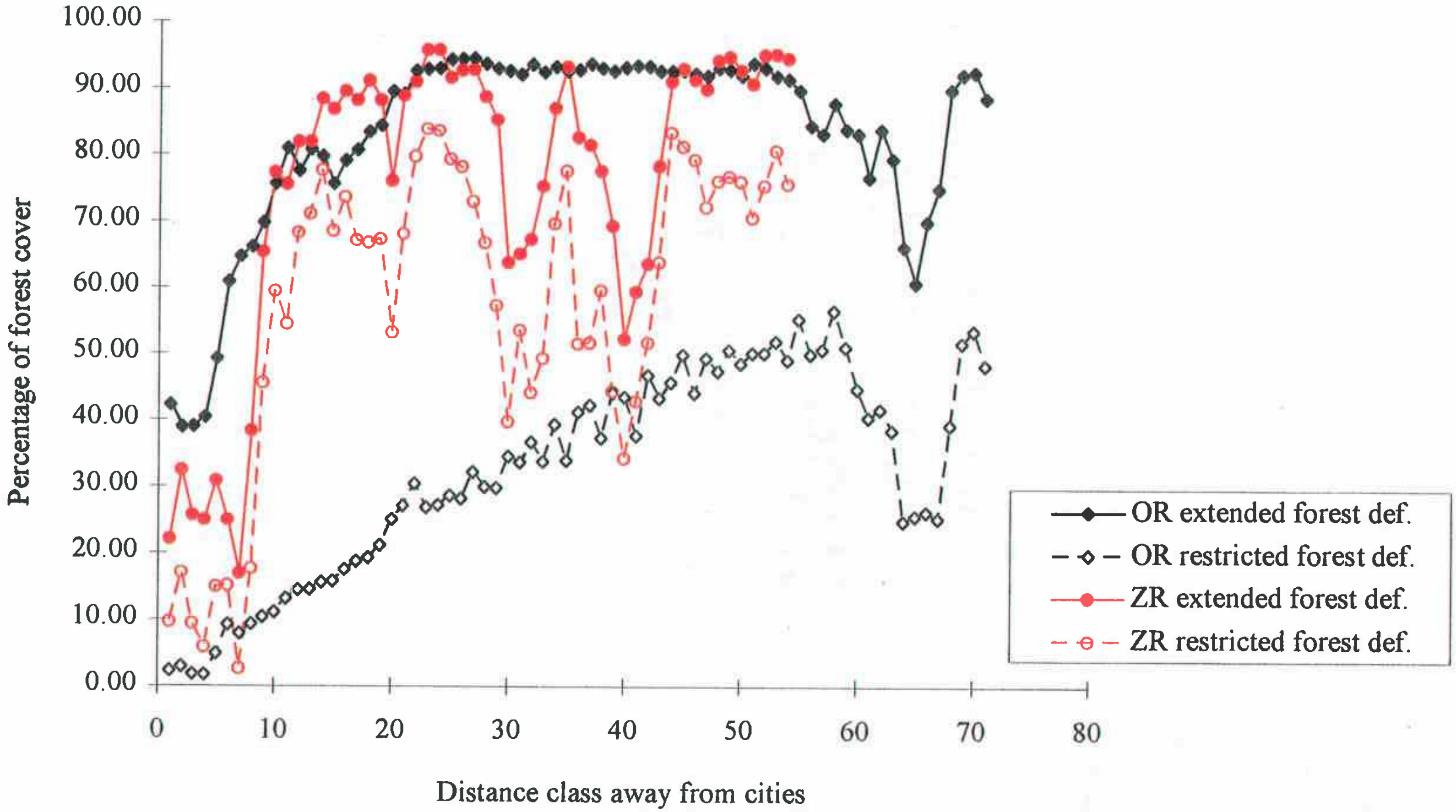


Figure 3.36 Percentage of forest cover as represented by ALL curves in the central western Cascades of Oregon (1988) and southeast Zaire (1989) away from highways/roads

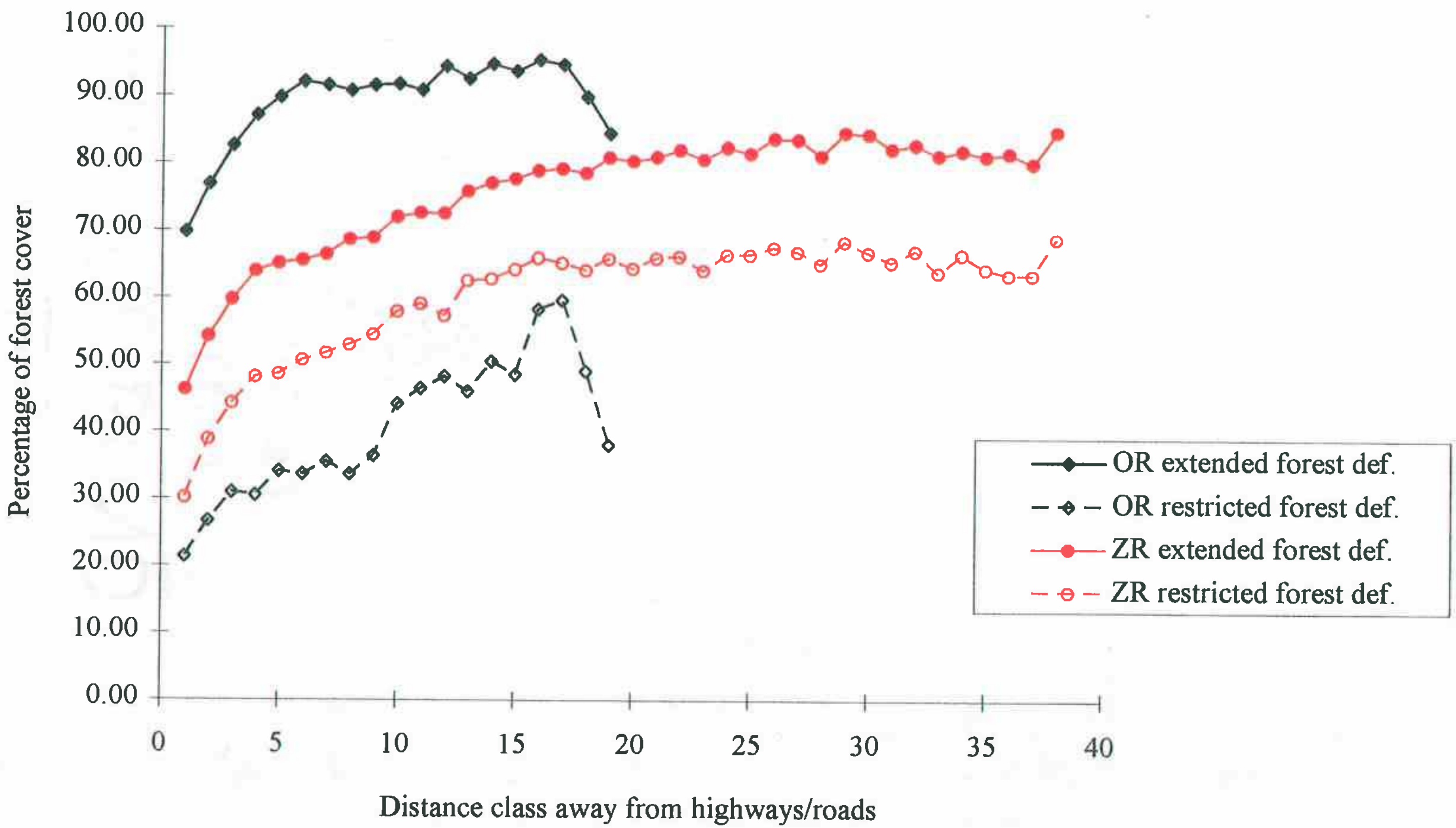
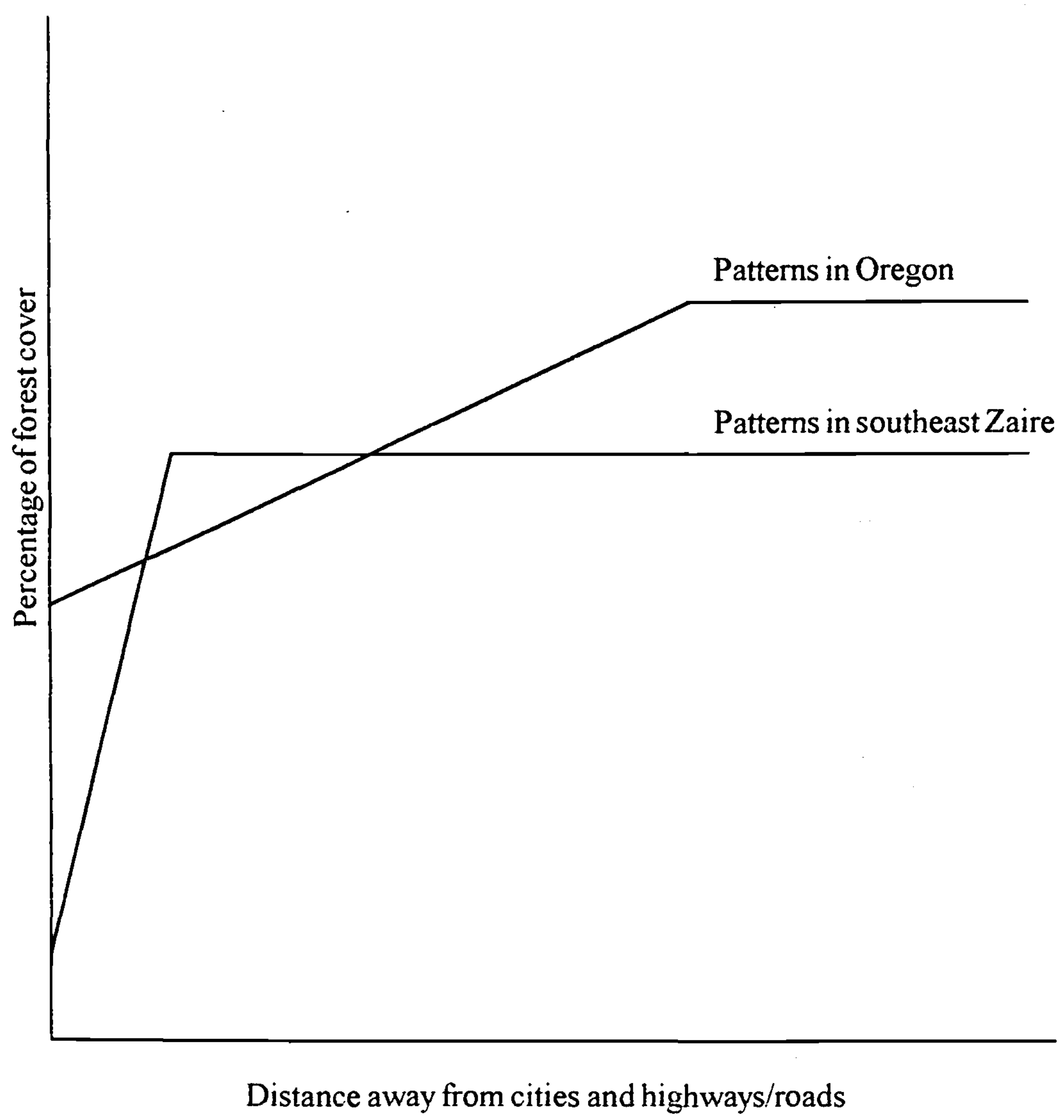


Figure 3.37 Hypothesized forest cover patterns as a function of distance in the Central Western Cascades of Oregon, U.S. and southeast Zaire.



increase in distance. This pattern is expected to be found in both forest classification types and both study sites.

However, the analysis of forest cover pattern in the previous two sections has demonstrated that the assumption of forest cover constancy beyond a certain distance was difficult to meet. Forest cover variability in areas less affected by human activities is due to several factors. Some variability is due to a random distribution of open areas in the study area, others to the change in the spatial distribution of vegetation types from Douglas fir to high elevation conifer forest in the central western Cascades of Oregon, and to the seasonal variation in greenness in southeast Zaire, and others to the impact of cities and road locations. For these reasons, areas where forest cover variation was identified as due mostly to natural vegetation characteristics were not considered.

Because of these naturally occurring variabilities, and in order to test the four hypotheses, the distance considered was located within the areas where forest cover was identified as varying with distance due mostly to human disturbances; the rest of the graph beyond that distance was not examined. For each graph, a fitted line was drawn and the related equation deduced. Additional information from the fitted line includes the coefficient of correlation and the standard error (SE) of the slope (Table 3.1).

Table 3.1 Values of fitted lines from ALL curves by study site and distance gradient

Study sites	Distance gradients	Ranges (km)	Extended forest definition						Restricted forest definition					
			Slope	SE	Int	SE	p-value	r2	Slope	SE	Int	SE	p-value	r2
Central western Cascades	Away from cities	40	2.3	0.18	42.90	2.65	0.00	0.88	1.0	0.02	2.20	0.69	0.00	0.97
	Away from highways	9.6	4.4	0.47	67.60	1.85	0.00	0.96	2.0	0.15	21.80	1.42	0.00	0.93
Southeast Zaire	Away from Lubumbashi	28.8	5.0	0.54	10.05	5.90	0.00	0.84	5.9	0.86	-10.60	7.32	0.00	0.80
	Away from roads	30.4	1.6	0.13	54.20	1.49	0.00	0.89	1.9	0.16	36.59	1.55	0.00	0.91

Extended forest definition is defined as areas with at least 30% canopy cover in the Central Western Cascades of Oregon, and areas with at least 10% canopy cover in southeast Zaire.
Restricted forest definition is defined as unmanaged forest cover in both study sites.

3.3.2 The central western Cascades forest cover patterns

The first hypothesis asserts that forest cover increases with distance from highways and cities. This hypothesis was tested by analyzing separately the two distance gradients considered during this study--distance away from highways and distance away from cities. The away-from-cities variable was examined first and the away-from-highways second.

Two graphs (Figures 3.38 and 3.39) representing the patterns of ALL curves away from cities were drawn from Figures 3.2 and 3.4 (see also Figure 3.35). In addition, Figure 3.38 depicts forest cover defined as areas with at least 30 percent canopy cover, and Figure 3.39 depicts forest cover defined as unmanaged conifer forest. The area where forest cover was affected by the distance away from cities was located between the 1st and the 25th distance classes in Figure 3.2, and between the first and the 53rd distance classes in Figure 3.4. After drawing the fitted line in both cases, it was found that there exists a positive relationship between forest cover and the distance away from cities (Table 3.1). The slope coefficient of both fitted lines is positive, 2.3 for Figure 3.38 and 1.0 for Figure 3.39.

Forest cover pattern highlighted in the two figures is attributable to human activities. Areas of least forest cover are located in the Willamette Valley where major urban centers and agricultural areas are also located. The distance from urban centers seems to have played a major role in the actual forest cover pattern. Forest cover near the western boundary are mostly younger forests (Figure 2.1); older forests (Mature

Figure 3.38. Percentage of forest defined as areas with at least 30 percent canopy cover per distance class delineated away from the western boundary of the central western Cascades of Oregon (1988).

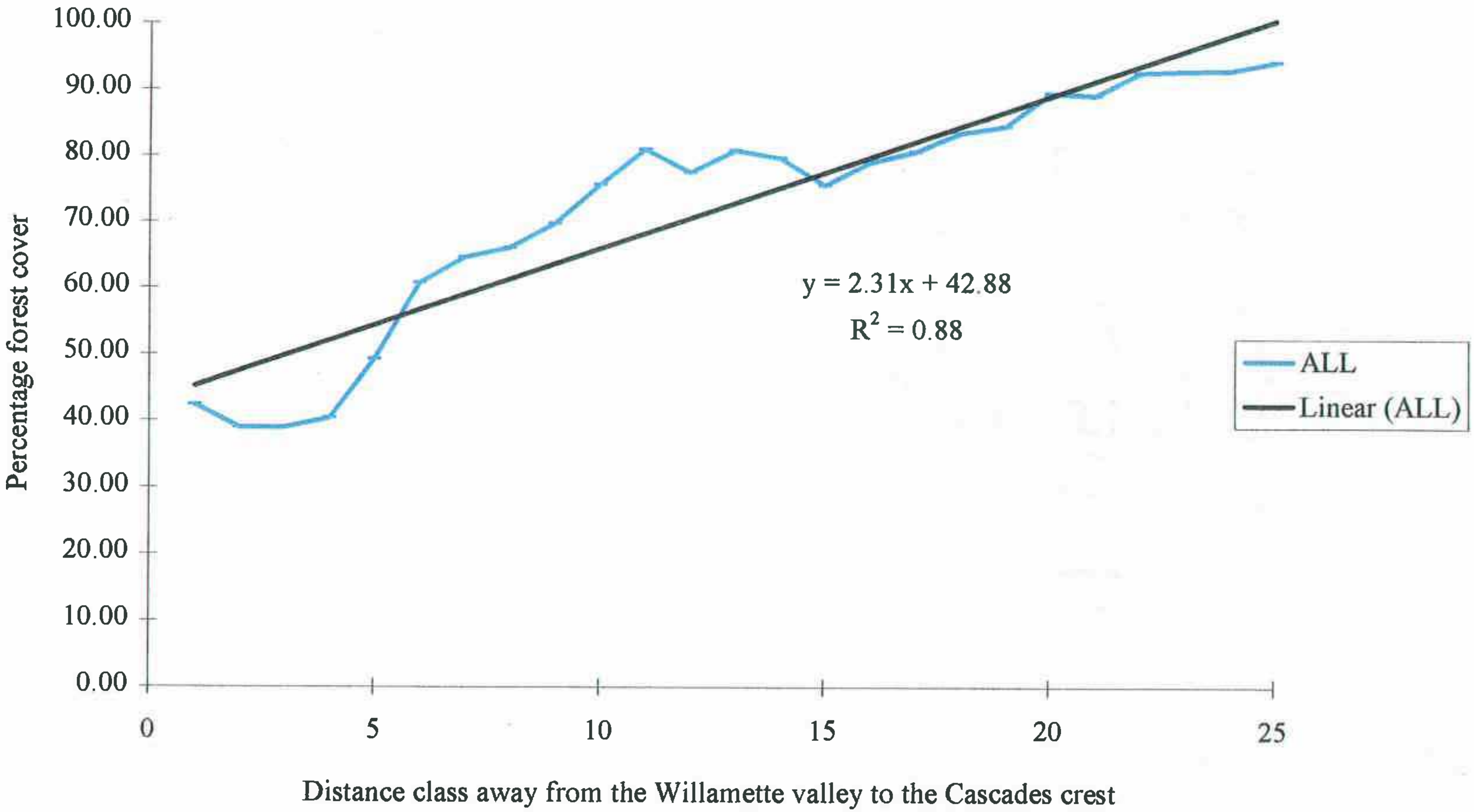
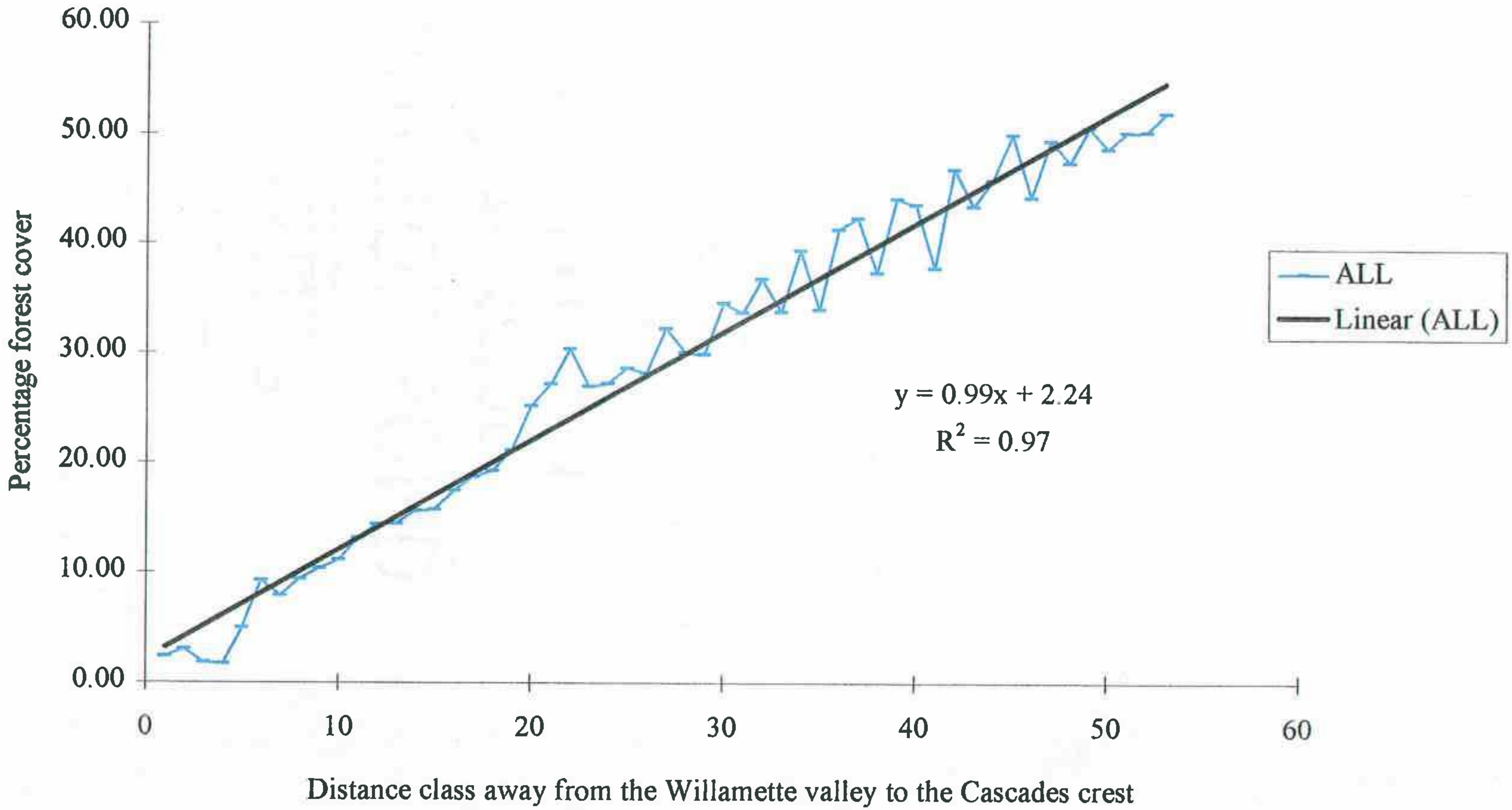


Figure 3.39. Percentage of forest defined as unmanaged forest cover per distance class delineated away from the western boundary of the central western Cascades of Oregon, U.S. (1988).



and Old-growth conifer forests) are located far away from the western boundary (Figure 3.4).

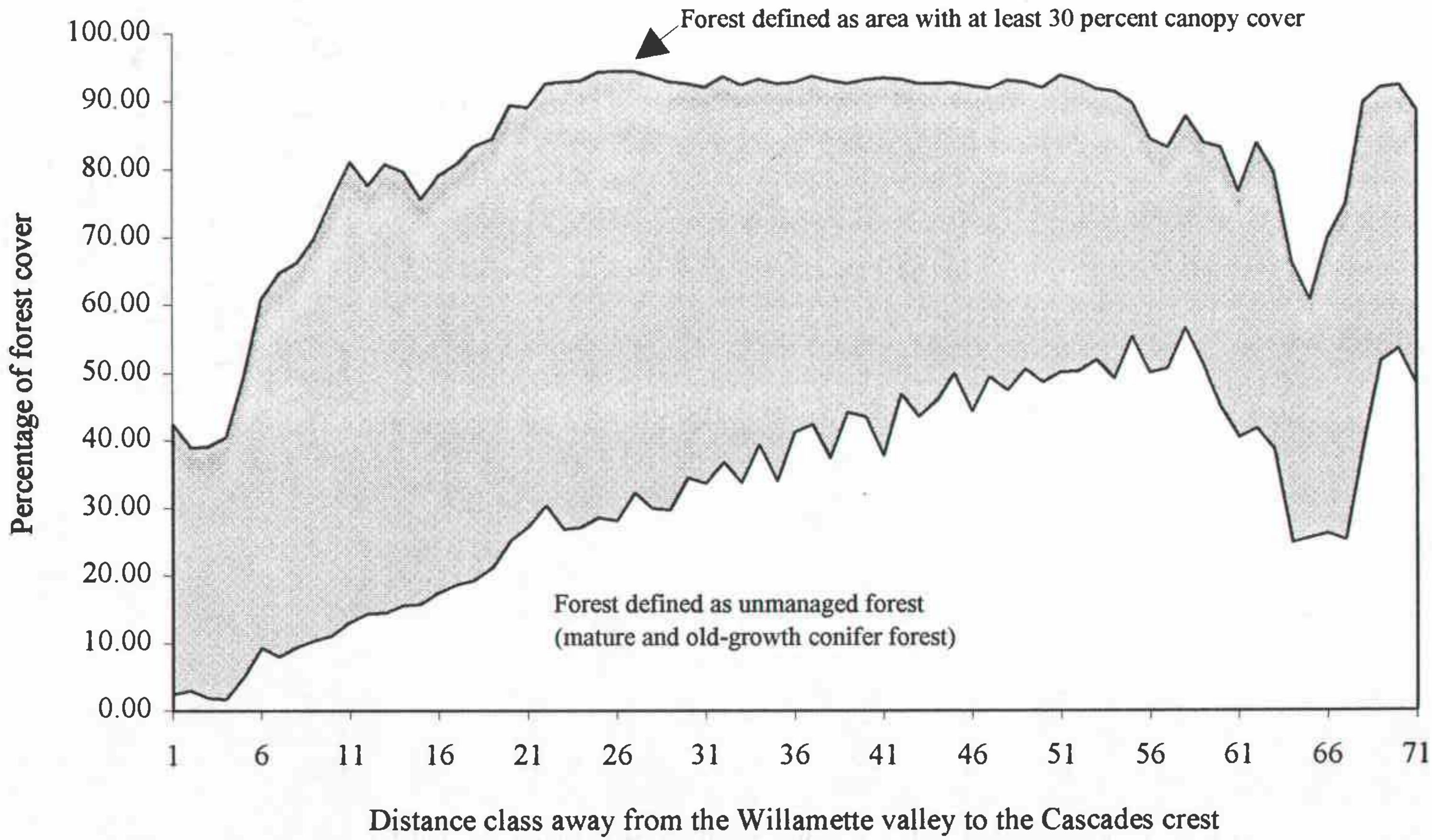
Land ownership spatial distribution and the related land use restrictions also help explain the positive relationship between forest cover and distance away from cities. As explained in the first section of this chapter, less restricted lands (private lands) are mostly located in the western part of the area, while public and more restricted lands are mostly on the eastern side. Since the distance away from cities is measured from west to east, less restricted lands are likely to have less forest cover.

The second hypothesis predicted that forest cover increases more rapidly with distance from cities in forest defined as areas with at least 30 percent canopy cover than in that defined as unmanaged forest. The hypothesis was tested by analyzing the slope coefficient of each equation generated from each fitted line (Figures 3.38 and 3.39). An alternative method consisted of measuring the distance to reach the less human-affected forest environment. To reach a forest cover less affected by human disturbances one has to go 53 distance classes away from urban areas when considering a more restricted forest definition (Figure 3.39), while in the case of a broader forest definition (Figure 3.38) the distance is much shorter (25 distance classes). Human activities appear to have more impacts on forest cover defined as unmanaged forest (Figure 3.39) than on forest defined as areas with at least 30 percent canopy cover (Figure 3.38). The slope coefficient in Figure 3.38 is much larger (2.3) than that in Figure 3.39 (1.0). The difference is very significant because the standard errors (SE) are 1.2 and 0.0, respectively.

This difference is due in part to the difference in the two forest definition types used as also noted in the Section 3.1. Figure 3.39 summarizes the pattern in forest cover defined as Mature and Old-growth, both having trees more than 80 years old. Figure 3.38, on the other hand, describes all forest types including younger conifer and hardwood forests. The difference between these two Figures is highlighted in Figure 3.40 showing the amount of forest cover less than 80 years old and more than 30 years old. As a result, there appears to be more forested areas in Figure 3.38 than in Figure 3.39. This is another reason the slope coefficient in Figure 3.38 is much larger than that in Figure 3.39 (Table 3.1).

The slope coefficient difference is also a result of past forest cover disturbances. A comparison of the two graphs (Figure 3.38 and 3.39) leads one to the conclusion that the difference between them represents younger forests which are the result of several factors (Figure 3.40). They include areas of former mature and old-growth conifer forests which have been harvested during the last 80 years. Human-related disturbances were also recorded by Wiens (1977), Miller (1985), and Gedney and Hiserote (1989). Natural disturbances of low to moderate intensity are also a major factor. These disturbances generate patterns which are not related to distance gradients considered in this study. They include low to moderate intensity fires, windthrow, and disease and age-related death of small groups of trees which affected parts of the study area (Agee 1993, Burke 1980, Morrison and Swanson 1990, Perry 1994, and Teensma 1987).

Figure 3.40 Percentage of Young conifer and Hardwood/Conifer (Semi-open and Open) as represented by ALL curves (shaded area) in the central western Cascades of Oregon (1988) away from the western boundary (Cohen et al. 1995).



The history of human colonization and commercial timber extraction helps explain the trend of forest cuts in the area. Native Americans subsisted and American pioneers settled mostly in the Willamette valley corridor (Ripple 1994) where they cleared and burned forested areas mostly for hunting and agriculture. Since 1945 commercial forest cuts were diversified (Bolsinger 1972). According to Bolsinger (1972) and Wiens (1977), the most important leading causes of forest cuts include road construction, urban and industrial expansion, and farm and pasture clearings. Areas affected most by these causes are located in the western side of the study area (see Figure 2.1).

Land ownership distribution in the study area also reinforced the eastward trend of forest cuts and the shift from solely private commercial to public lands. Private lands occupy most of the western part of the study area while public lands dominate the eastern side. Western Oregon's log production increased in the early 1900s and again during the 1940s as business recovered during the World War II expansion period. Production remained high through the 1960s, based on the high cutting rates in some counties including Linn and Lane (Wall 1972). Timber harvest from Bureau of Land Management lands became increasingly important through the 1950s and the 1960s. The emphasis changed from a timber industry primarily dependent on private forest production in the early 1950s to dependence on both public and private timber during the 1960s (Wall 1972). Each of these changes left its mark on the forest cover pattern.

The above two hypotheses were also examined in the analysis of forest cover pattern from highways into the hinterlands. Figures 3.41 and 3.42 summarize the results

Figure 3.41. Percentage of forest defined as areas with at least 30 percent canopy cover per distance class in the central western Cascades of Oregon, U.S. (1988).

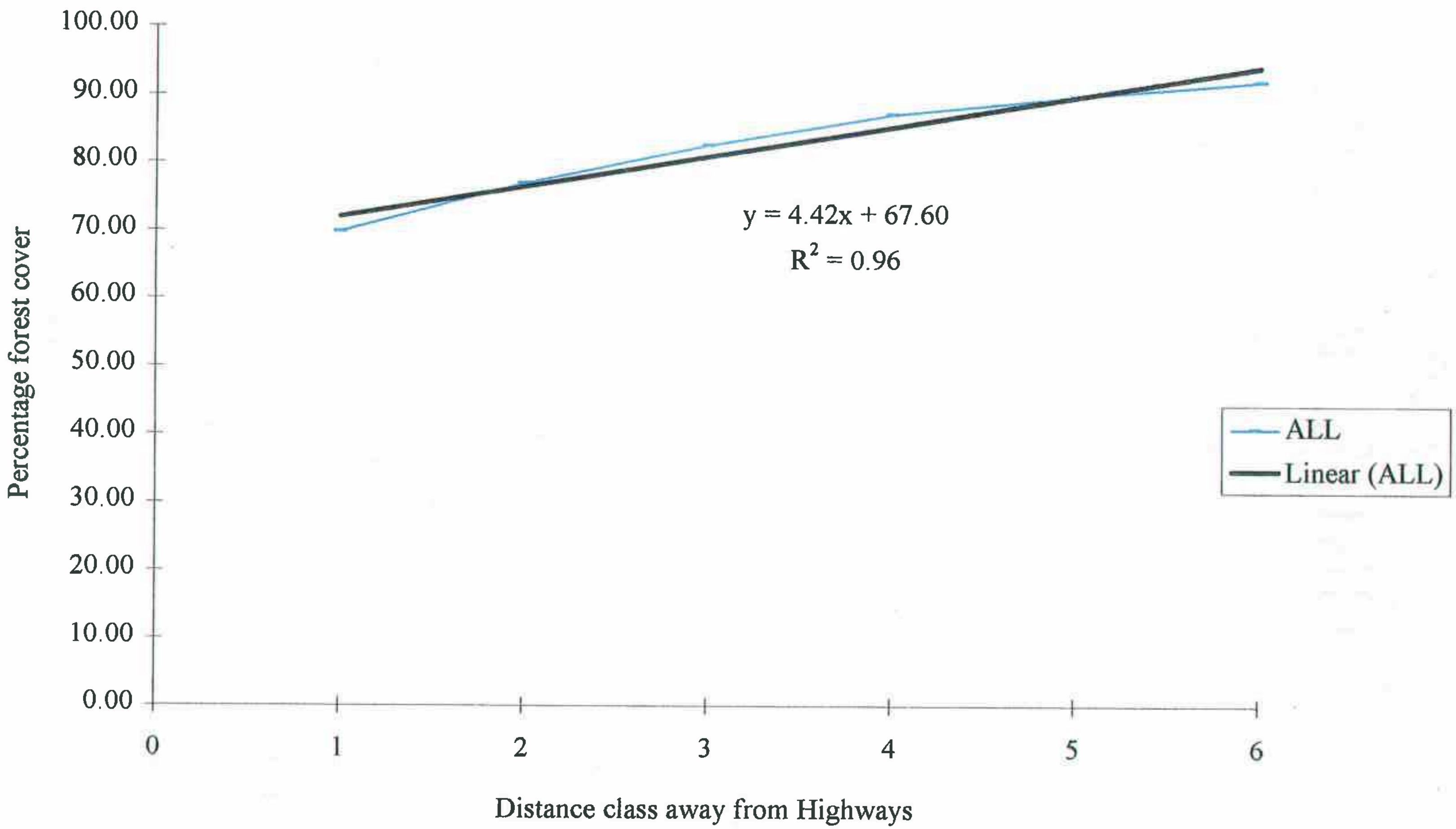
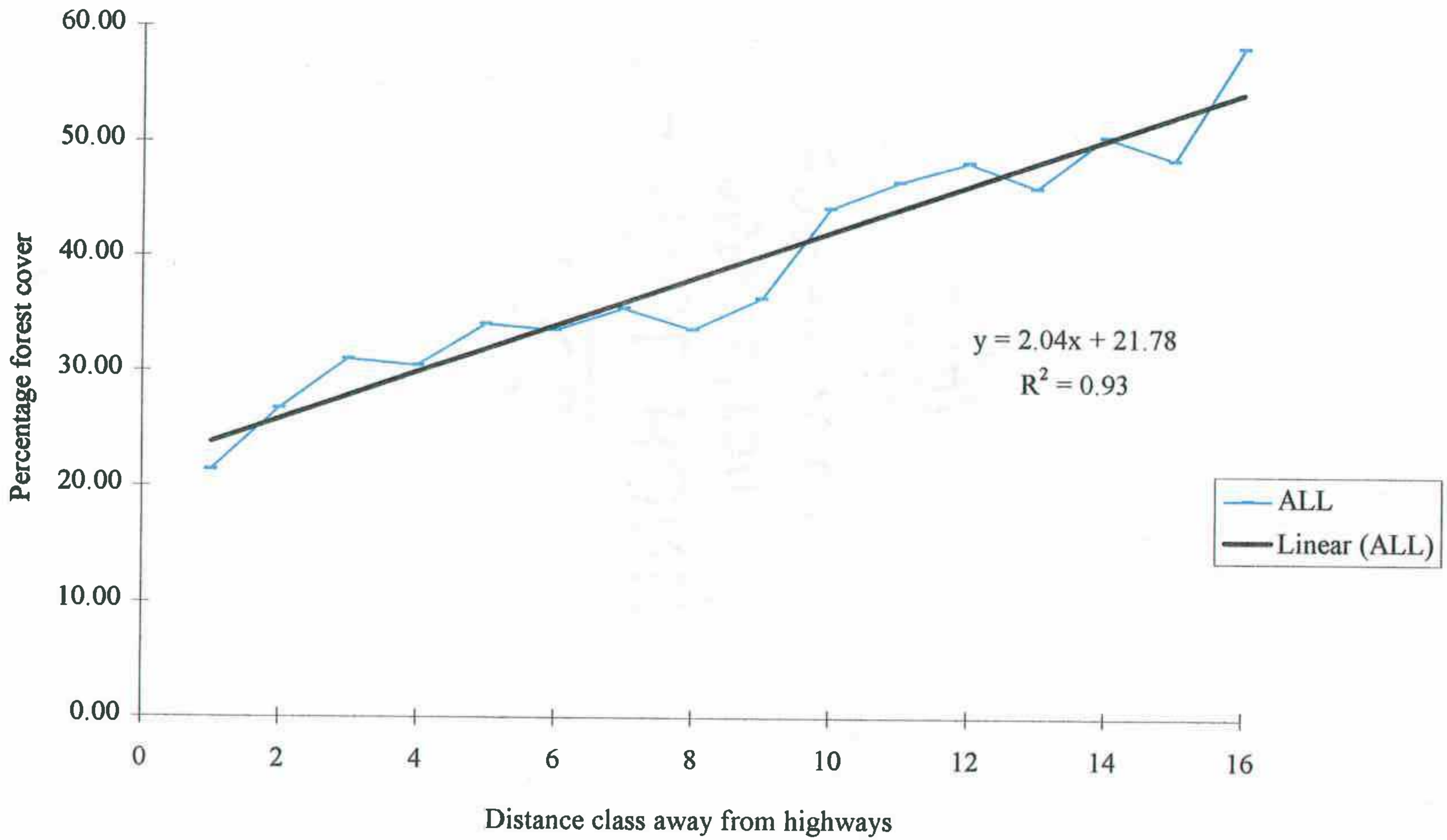


Figure 3.42. Percentage of forest defined as unmanaged forest cover per distance class away from highways in the central western Cascades of Oregon, U.S. (1988).



of the findings. The increase in forest cover as the distance increases (Hypothesis 1) is also found in the away-from-highways analysis. Slope coefficients are positive in both cases--4.4 and 2.0, respectively. Distance appears to be a more deterrent factor for forest defined as areas with at least 30 percent canopy cover (Figure 3.41) than for forest defined as unmanaged forest (Figure 3.42). These differences are significant because their SEs were estimated to be 0.5 and 0.2, respectively.

The reasons for the differences are due, to some extent, to the same reasons mentioned above in the analysis of the away from cities forest cover pattern. The more rapid increase in forest cover with distance in Figure 3.41 is due to the broader forest classification used. Forest defined as areas with at least 30 percent canopy cover includes hardwood/conifer forests (semi-open and closed) and conifer forests (young, mature, and old) (Cohen et al. 1995), whereas forest defined as unmanaged forest cover includes mature and old-growth conifer forests. There is also a legacy of past forest land use, especially for areas located in the western side of the study area.

The third hypothesis stated that forest cover increases more rapidly with distance away from highways than with distance away from cities. The test of this hypothesis compared the slope coefficients and SEs of the away-from-cities to away-from-highways graphs (Figures 3.38 to 3.41 and Figures 3.39 to 3.42). The results confirmed the hypothesis because the slope coefficients in the away-from-highways graphs are higher than that of the away-from-cities graphs. The slope coefficient for forest defined as areas with at least 30 percent canopy cover away from highways (Figure 3.41) is 4.4 (with SE equal 0.5) and for forest defined as areas with at least 30 percent canopy cover away from away from cities (Figure 3.38) it is 2.3 (with SE equal 0.2). On the other hand, the slope coefficient for forest defined as unmanaged forest cover away from highways (Figure 3.42) is 2.0 (SE = 0.2) and for forest defined as unmanaged forest cover away from cities (Figure 3.39) it is 1.0 (SE = 0.0).

In addition to reasons such as past land use legacy and land ownership restriction, the pattern in both graphs (Figures 3.41 an 3.42) is more importantly a result of terrain accessibility. Most highway systems are located in major river valleys. Highways 20, 22, and 126, for example, meander along the South Santiam, North Santiam, and McKenzie rivers, respectively. These east-west drainages have sharply dissected the landscape in areas of low (valley bottoms) and high elevations (watersheds). An increase of distance from highways into the hinterland is more likely an increase of slope and altitude. So, areas close to highways are more accessible than those away from highways. As a consequence, forests in higher altitudes are less likely to be cut, whereas the west-east distance increase (from the Willamette Valley to the crest of the Cascades) is relatively gentler.

3.3.3 The southeast Zaire forest cover patterns

The same three hypotheses were used in the analysis of the pattern of forest cover variation as a function of distance using both forest cover types in southeast Zaire. The away-from-cities (Lubumbashi) pattern was the first to be analyzed. Figures 3.43 and 3.44 summarize the results of forest cover pattern according to each forest

Figure 3.43. Percentage of forest defined as areas with at least 10 percent canopy cover per distance class delineated away from Lubumbashi along the northeastern road in southeast Zaire (1989).

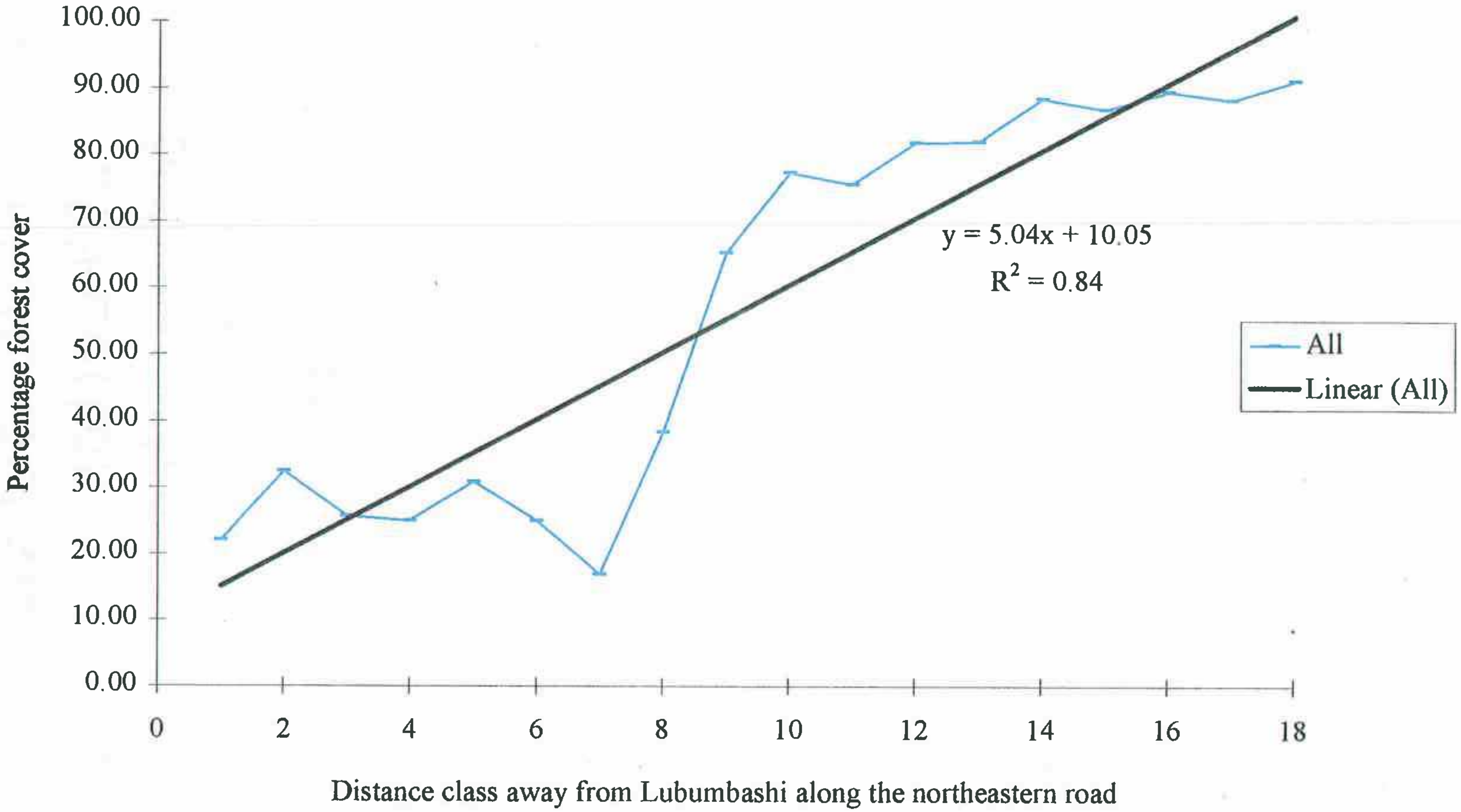
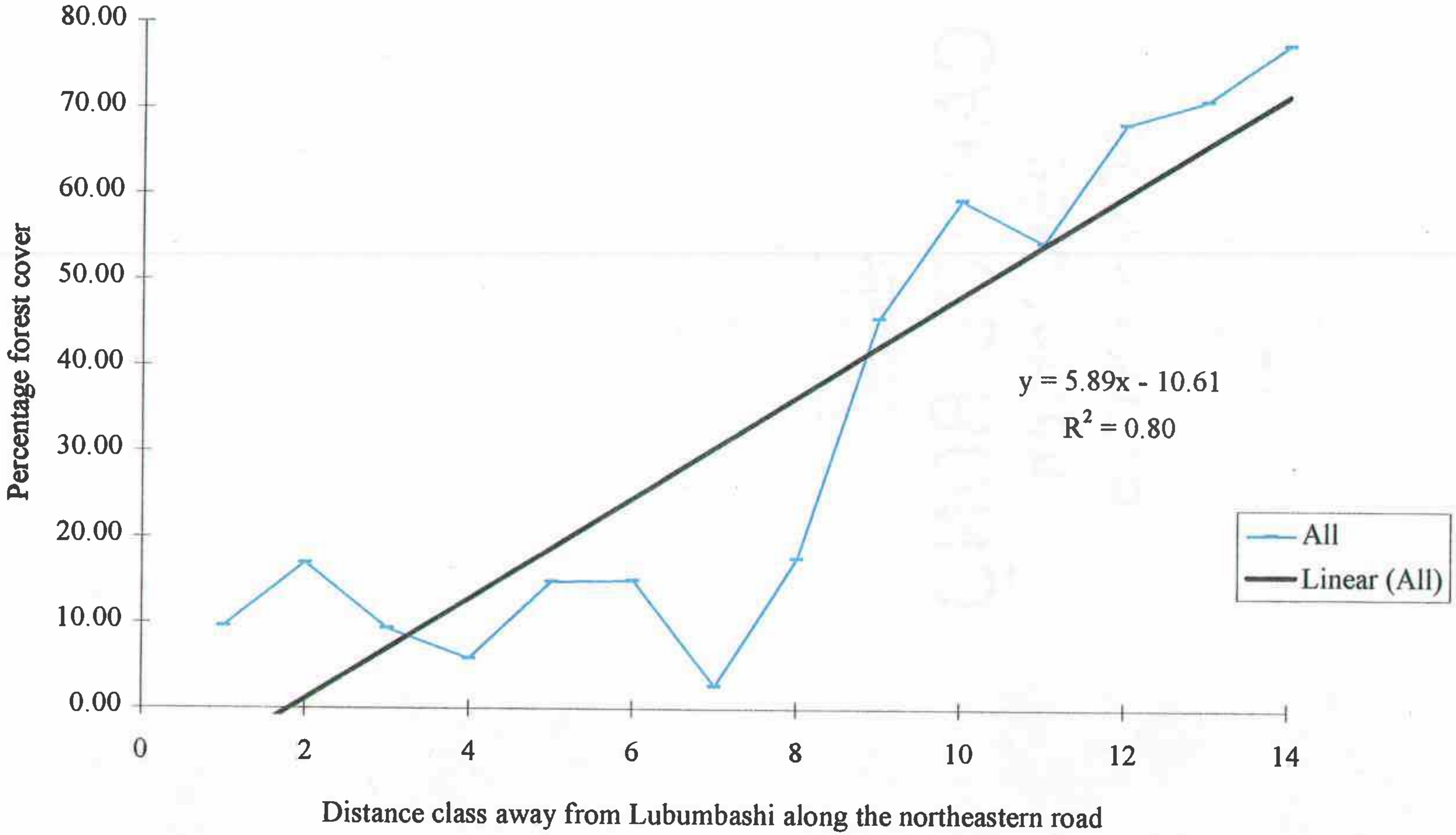


Figure 3.44. Percentage of forest defined as unmanaged forest cover per distance class delineated away from Lubumbashi along the northeastern road in southeast Zaire (1989).



cover definition (forest defined as areas with at least 10 percent canopy cover and forest defined as unmanaged forest).

The first hypothesis, related to the increase of forest cover with the increase of distance, was confirmed. Slope coefficients in forest defined as areas with at least 10 percent canopy cover (Figure 3.43) and in forest defined as unmanaged forest cover (Figure 3.44) are positive--5.0 and 5.9, respectively.

The second hypothesis, related to the difference between the forest definition, was difficult to verify. The difference was not significant because slope coefficient SEs for forest defined as areas with at least 10 percent canopy cover was 0.5, and it was 0.9 for forest defined as unmanaged forest cover. This finding shows that the selection of forest to be cut is not necessarily related to certain tree criteria, but rather to distance away from the city. Any forest type close to the city is likely to be cleared. This pattern is expected in the analysis of the away-from-cities gradient and is a result of a long-term forest cut practices. Around Lubumbashi, the permanent search for fuel wood and charcoal have led to a permanent and increasing non-forested buffer (Bruneau 1989a). The search, which started with selected trees, has eventually led to the exploitation of previously disregarded larger trees as the demand and the distance to available and relatively smaller trees increased.

The first and second hypotheses were also used to analyze forest cover pattern along the away-from-roads gradient (Figures 3.45 and 3.46). It was found that the slope coefficient for forest defined as areas with at least 10 percent canopy cover (Figure 3.45) was not significantly lower (1.6, SE = 0.1) than for forest defined as

Figure 3.45. Percentage of forest defined as areas with at least 10 percent canopy cover per distance class delineated away from roads in southeast Zaire (1989).

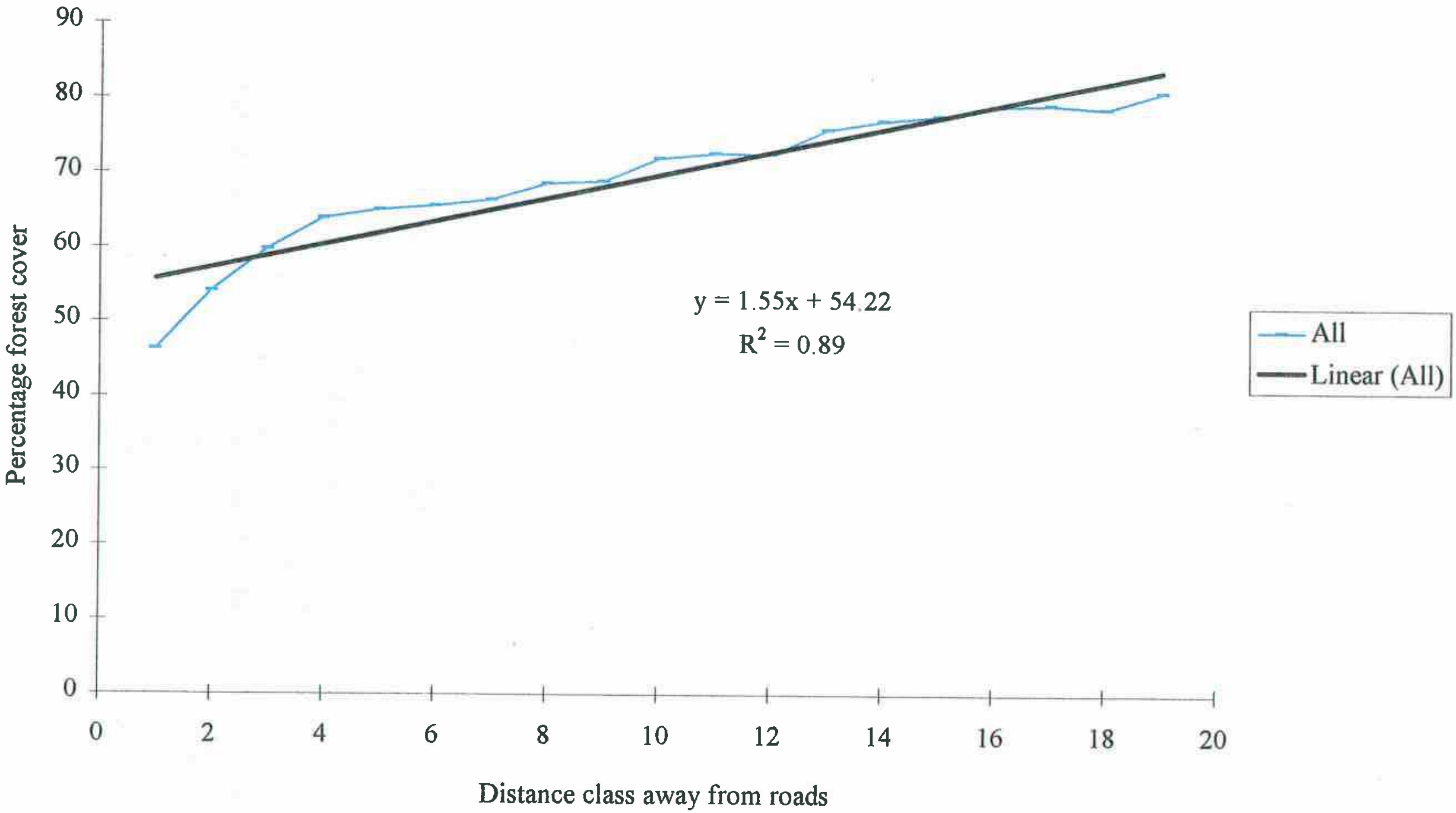
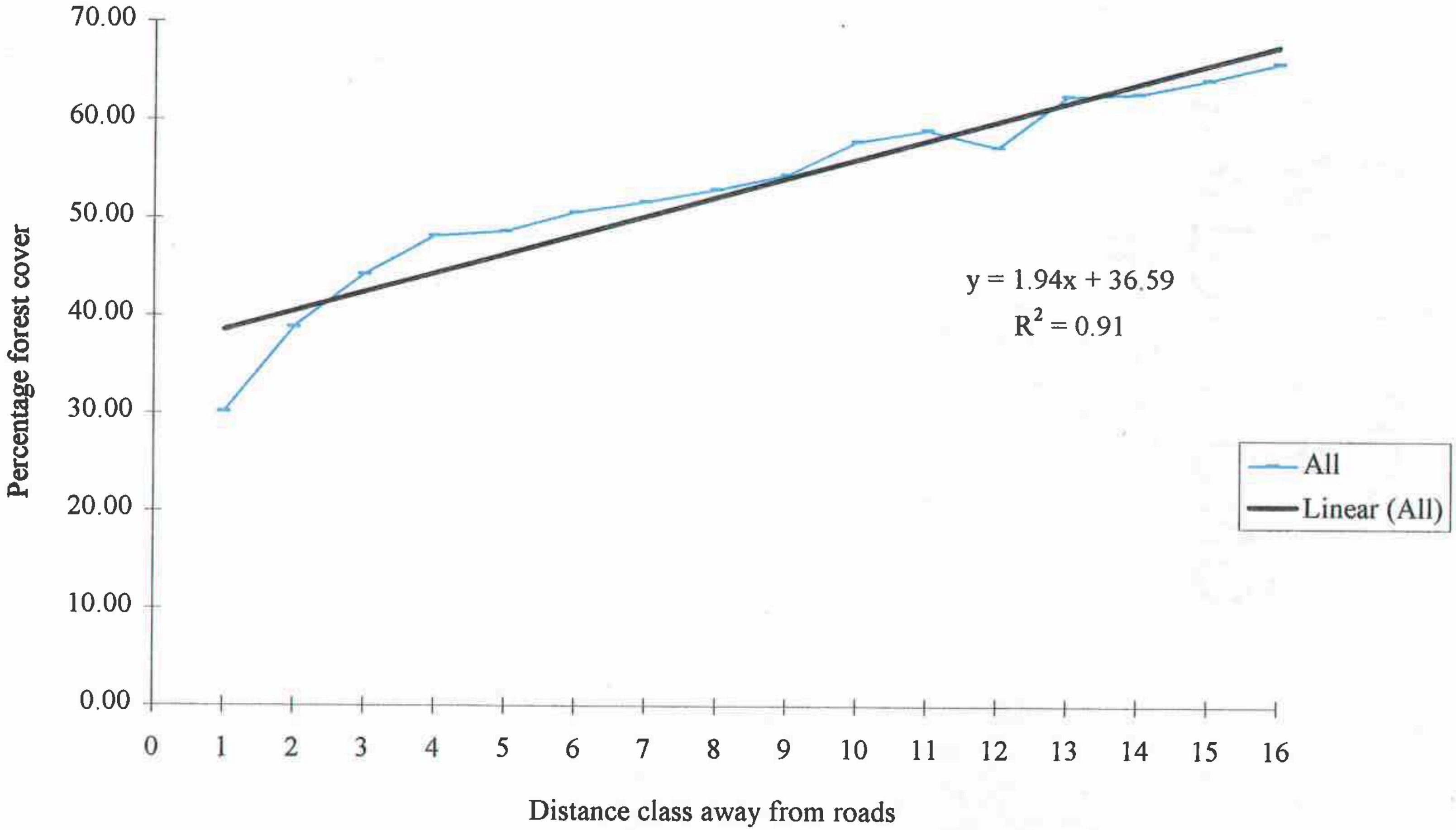


Figure 3.46. Percentage of forest defined as unmanaged forest cover per distance class delineated away from roads in southeast Zaire (1989).



unmanaged forest cover in Figure 3.46 (1.9, SE = 0.2) (Table 3.1). This is due in part to the technique used in differentiating these two forest types which was mostly based on the intensity of human activities on the forest environment.

The selective tree cutting pattern may mask fine scale human-related forest disturbances. Larger trees (more abundant in forest defined as unmanaged forest) are less likely to be selected first. In Rural areas and around villages the selective collection of fuel wood is not likely to produce the same impact as in cities because the pressure on the fuel wood supply and forested areas is not as intense as in cities. As a result, the change of forest definition may not substantially change the slope values (Table 3.1).

As was the case in the central western Cascades of Oregon, the third hypothesis addressed whether forest cover increased more rapidly with distance in the away-from-roads than in the away-from-cities gradients. The opposite was found after reviewing the results from Figures 3.43, 3.44, 3.45, and 3.46. Slope coefficients in the away-from-roads gradient are much smaller (1.6 and 1.9) than in the away-from-cities gradient (5.0 and 5.9). The reason for this finding lies in the contrast of percentage forest cover between the first and the last distance classes considered in each case. The higher the contrast, the larger the slope coefficient. The contrast is larger for both forest definitions in the away-from-cities gradient (Figures 3.43 and 3.44) than in the away-from-roads gradient (Figures 3.45 and 3.46). There is less forest in the first distance class in the away-from-cities gradient than in the away-from-roads gradient because of the high intensity of human activities.

The high intensity of human activities within Urban lands is due to several factors. These factors include higher population density within Urban compared to Rural areas, a flexible land use system, urban poverty due to economic stagnation, difficulty among urban dwellers affording alternative energy sources, and lack of a strong forest cut policy. For these reasons, lands close to the city are more likely to be cleared for fuel wood and agriculture.

3.3.4 Cross study areas forest cover patterns

Hypothesis 4 predicted that forest cover increased more rapidly away from roads/cities in southeast Zaire than in the central western Cascades of Oregon. It was found that this was true for the analysis of forest cover pattern away from cities. Slope coefficients are 5.0 and 5.9 (with SEs equal to 0.5 and 0.9, respectively) for southeast Zaire and 2.3 and 1.0 (with SEs equal to 0.2 and 0.0, respectively) for the central western Cascades of Oregon. However, this hypothesis was not supported in the away-from-highways/roads gradient because southeast Zaire slope coefficients are smaller (1.6 (SE = 0.1) and 1.9 (SE = 0.2)) compared to slope coefficients of the central western Cascades of Oregon which are 4.4 (SE = 0.5) and 2.0 (SE = 0.15) (Table 3.1).

This result may be due to several reasons. On one hand, it may be the impact of ranges and intercepts (Table 3.1). For example, the range for the extended forest definition is larger in southeast Zaire (30.4 km) than in the central western Cascades of Oregon (9.6). The intercept for the restricted forest definition is higher in southeast Zaire than in the central western Cascades of Oregon. On the other hand, the distance may not be restrictive, other transportation systems such as helicopters may be used, and also some laws and regulations governing forest cutting may have affected the pattern of deforestation. In the case of Oregon, for example, the land division into private, public, and wilderness imposes an additional gradient on the deforestation pattern so that private lands, no matter where they are, have less forest cover than wilderness areas. In the case of Zaire, where such a subdivision is almost non-existent, the difference in forest patterns with distance is due to accessibility. Along the roads from urban centers, forests are more accessible than away from roads where foot paths provide the only access to forest.

3.5 Summary of hypothesis tests.

Hypothesis 1, a test of the overall distance decay model, was found to conform with actual results. In the central western Cascades of Oregon and southeast Zaire forest cover increases with distance away from cities and highways/roads for both forest definitions. Slope values for both forest definitions and distance gradients are positive (Table 3.1).

The second hypothesis predicted that forest cover increased more rapidly with distance for an extended forest definition than for a more restricted forest definition. This hypothesis was only validated in one study site (Table 3.1). In the central western Cascades of Oregon, forest defined as areas with at least 30 percent canopy cover was found to have higher slope values (2.3 and 4.4) than forest defined as unmanaged forest cover (1.0 and 2.2). In southeast Zaire however, slope values for forest defined as areas of at least 10 percent canopy cover were lower (5.0 and 1.6) than that of the restricted forest definition (unmanaged forest (5.9 and 1.9)) in both distance gradients. Nevertheless, in Zaire the difference in slope values between the two forest definitions was not significant because of the methodology used in defining both forest types. In southeast Zaire, unmanaged forest definition was based on the intensity of human activities.

It was expected according to hypothesis 3 that forest cover increased more rapidly with distance away from highways/roads than with distance away from cities. This was true in the central western Cascades of Oregon where away-from-highways slope values were higher than the away-from-cities slope values (Table 3.1). It was the opposite in southeast Zaire where away-from-cities slope values were higher than the away-from-roads slope values.

Hypothesis 4 predicted forest cover to increase more rapidly away from roads/cities in southeast Zaire than in the central western Cascades of Oregon. The away-from-cities results supported the hypothesis. Southeast Zaire slope values in the away-from-cities gradients were higher than the central western Cascades slope values (Table 3.1). However, slope values in the away-from-highways gradient were lower in southeast Zaire than in the central western Cascades of Oregon.

The variation of these results is a result of the complexity of underlying processes which generated these patterns. Some of the complexities are inherent to the natural characteristics of the environment. The forest environment is different in the two study sites. Southeast Zaire has a mostly deciduous forest (Miombo woodland) while the central western Cascades of Oregon forest environment is mostly coniferous but more deciduous in valley bottoms. Wildfires have affected the central western Cascades of Oregon (Agee 1993, Burke 1979, Morrison and Swanson 1990, Perry 1994) more than southeast Zaire where they are almost nonexistent (Malaisse 1978). Non-human related open areas associated with the exposure of rocks and lava flows from recent volcanism in the central western Cascades of Oregon, and with giant termite mounds and Dambos (treeless grasslands) (Bruneau and Pain 1990, Campbell 1996, Malaisse 1978) in southeast Zaire may also have affected patterns of forest cover.

The difference in the topography may also have an impact on forest cut patterns. Southeast Zaire is relatively flat (about 1200 m altitude). The central western Cascades of Oregon has an irregular and mostly mountainous environment with smooth west-east topographic gradient (Willamette valley to the crest of the Cascades) dissected by relatively smaller rivers with sharp topographic gradients).

Other causes of forest cut patterns may be human-related causes. The density of the road network is higher in the central western Cascades of Oregon than in southeast Zaire. This increases accessibility to the central western Cascades of Oregon hinterlands than to the southeast Zaire hinterlands. In addition, the timber industry is more developed, well founded and equipped in the central western Cascades of Oregon than in southeast Zaire. The timber industry is almost nonexistent in southeast Zaire. Forest product harvest is mostly done by poor local population mostly for local consumption. Furthermore, the value of timber is higher in the central western Cascades of Oregon than in southeast Zaire.

Land use policy may also have an impact on forest cut patterns. In the central Western Cascades of Oregon land uses are more restricted, especially in public lands, than in southeast Zaire. In southeast Zaire land use restrictions are almost nonexistent and those existing are poorly enforced.

Chapter IV. Results of analysis of forest loss rates (deforestation model)

4.0 Introduction

The purpose of chapter 3 was the analysis of forest cover pattern in 1988 (for the central western Cascades of Oregon), and 1989 (for the southeast Zaire) as a function of distance. The objective of the analysis was to test four hypotheses related to the distance decay model. The underlying concept in the distance decay model is that forest disturbances decrease as the distance away from the source of forest product demand increases. Distance variables considered for the analysis were: away from highways (roads) networks and away from urban centers and cities. Two forest definitions were also used, based on age classes and the impact of human activities.

This chapter will analyze changes in forest cover which took place in the 16 year period prior to 1988 or 1989, using the same areas as those used in the analysis of forest cover distribution. Forest loss detection and sampling methods are explained in chapter 2 related to materials and methods. Forest losses were defined as forested areas which became non forested areas at the end of the study period. The central western Cascades of Oregon change image was produced from the 1972-1991 forest change image by Cohen et al. (1996) (Figure 2.4). The study period for the central western Cascades of Oregon is from 1972 to 1988. In the case of southeast Zaire, Tasseled Cap brightness images were used to perform forest change analysis based on 1973 and 1989 satellite imagery data.

Analytical procedures used in the previous chapter were also applied to investigate the pattern of forest loss rates. They consisted of dividing the change images along two gradients--away from highways (roads) and away from urban centers and cities. The delineation procedure of the away-from-highways and away-from-cities variables is explained in the sampling design section of chapter 2. Each distance class away from highways/roads or cities is 1600 m, and each cell size is 1600 m by 1600 m. The detailed study areas used in Chapter 3 were also used to identify forest loss patterns for smaller areas with contrasting land ownerships.

This forest loss rate analysis will follow the same structural outline used in the previous chapter. First, the central western Cascades of Oregon will be investigated by analyzing the away-from-urban-centers-and-cities forest loss rate pattern and then the away-from-highways/roads pattern. In the second part southeast Zaire will be analyzed following the same structure. The last part will examine hypothesis 5 of this study, which predicts that the rate of forest loss from 1973 to 1989 in southeastern Zaire is higher than the rate from 1972-1988 in the central western Cascades of Oregon. In fact, it tests whether the central western Cascades of Oregon falls in category E, and southeastern Zaire in category B according to the deforestation model (Figure 1.4).

4.1 Results of analysis of forest loss rate between 1972 and 1988 in the central western Cascades of Oregon

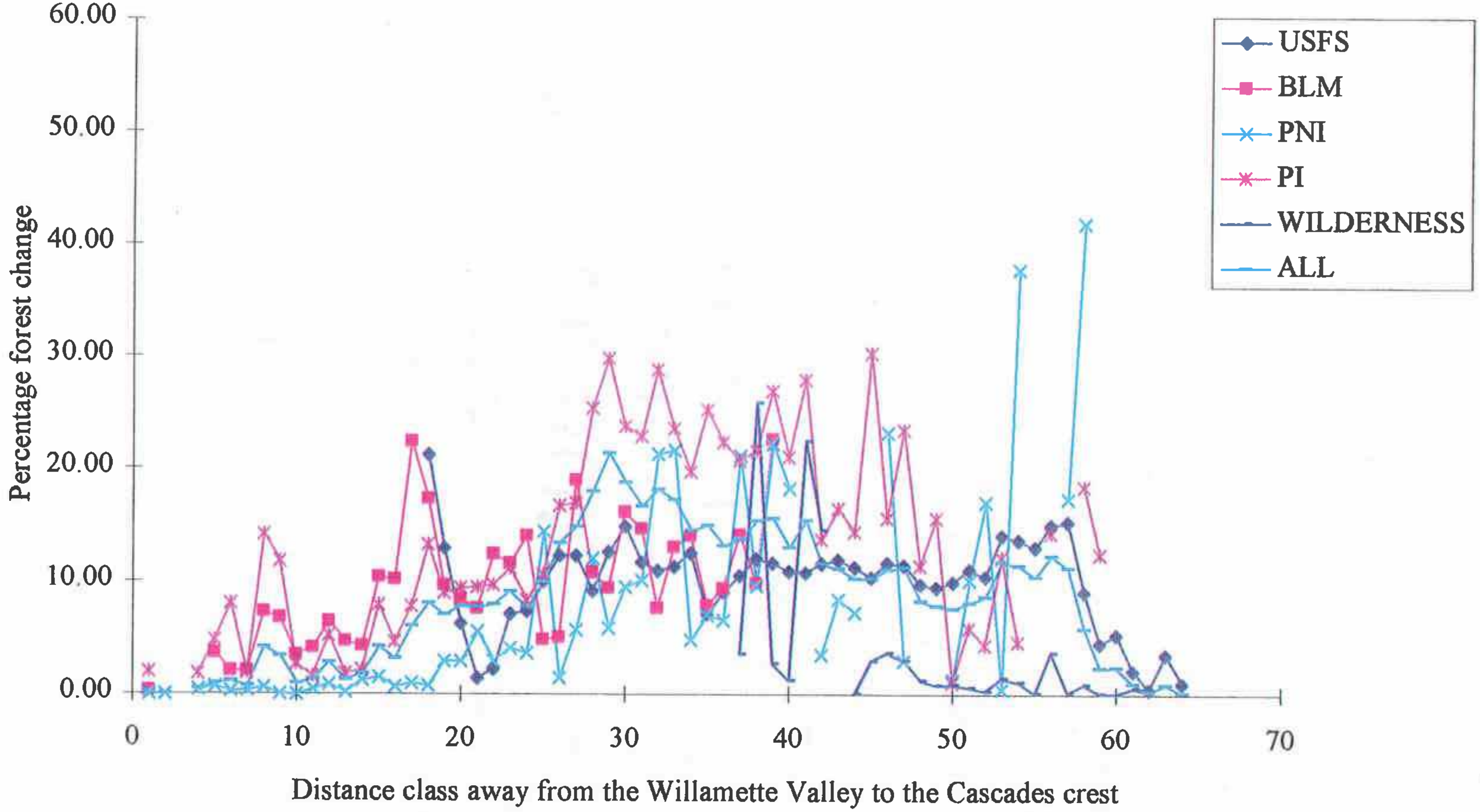
4.1.1 Analysis of the away-from-cities gradient

The average forest loss rate during the 16 year-study period irrespective of distance is relatively low. It is about 8.4 percent, equivalent to 0.53 percent of forested areas changing every year. Percents of forest loss rates were tabulated based on the data and pattern of the ALL curve (Figure 4.1) which averages the trend for all land ownership types. Tasseled cap difference images used to generate forest loss rates could not discriminate losses by forest definitions used in the distance decay model in chapter 3 because the technique involved raw satellite images.

Losses of forest cover during the sixteen year-study period have mostly occurred far away from urban areas and cities. The general trend for the overall forest loss rate is highlighted by the ALL curve (Figure 4.1). According to the ALL curve, areas of high forest loss rates are located between the 25th and the 47th (40 and 75 km), and between the 53rd and the 57th (84.8 and 91.2 km) distance classes away from the western boundary. In both cases more than 10 percent forest cover per distance class have been affected. The remaining distance classes have mostly experienced a relatively low percentage forest loss rate. For example, the average percentage of loss for 1972-88 between the first and the 24th distance classes is about 4 percent. It is only about 2 percent beyond the 57th distance class.

Forest loss rates are palpable expressions of policy restrictions imposed on land ownerships: the most restricted lands have experienced the least changes. This is for

Figure 4.1 Percentage of forest loss per land ownership per distance class delineated away from the western boundary of the Central Western Cascades of Oregon, U.S. between 1972 and 1988



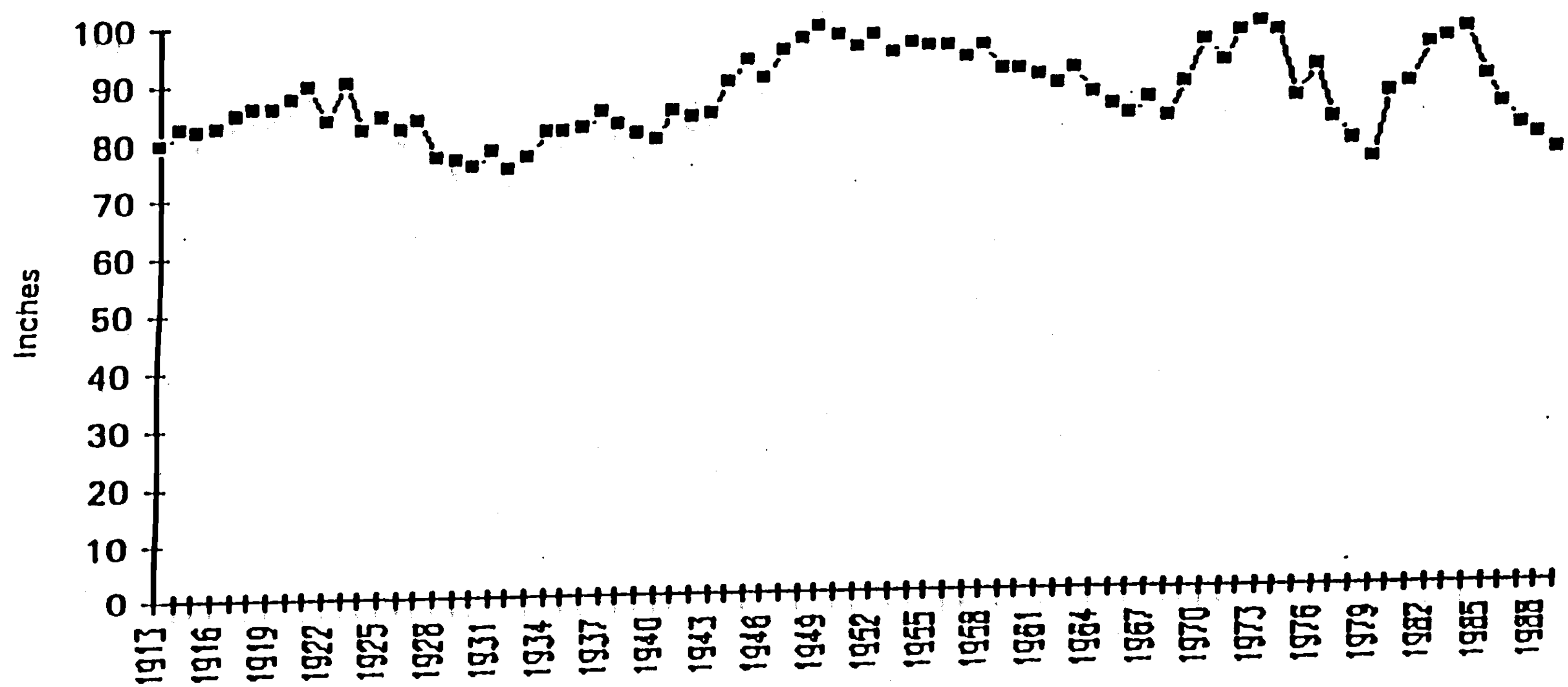
example the case with Wilderness lands. They are found beyond the 37th distance class (Figure 4.1). On average only 3.7 percent (0.23 percent per year) per distance class of forested areas in Wilderness lands were lost. Most of distance classes have each less than one percent of forest loss.

The 0.23-percent-per-year average of forest loss in Wilderness areas is attributable to several factors. Natural disturbances may have an impact on this loss. Low to moderate natural fires have been documented in the area (Agee 1993, Morrison and Swanson 1990, Teensma 1987). Other small scale natural disturbances including wind, insect outbreaks, and senescence of old trees may have affected parts of Wilderness areas (Perry 1994). Road construction may also have affected forest cover during the 16 years of this study.

In addition to above factors, climatic conditions may have had an impact on the decrease of forest cover. According to Greenland's (1993) five year running mean values of total water year precipitation at the H.J. Andrews Experimental forest, climatic conditions in 1988 were drier than those in 1972 (Figure 4.2). Although, there is no evidence that the amount of leaf area would make conifer forest changes less detectable using satellite images, the 1988 dry climatic condition may have led to a relative decrease of canopy cover which in turn may have decreased the percentage of 1988 forest cover and resulted in this unexpected forest loss in Wilderness lands.

Despite public land restrictions, some Wilderness areas have experienced more losses than others. The 39th and the 41rst distance classes on Figure 4.1 have each a very high forest loss rate during the 16 year period--more than 20 percent changes of their

Figure 4.2. Andrews forest precipitation by water year five year running mean



Source: Greenland 1993

areas. These areas are located around upper Middle Santiam river which also conform with Cohen et al.'s (1996) change detection map (Figure 2.4) as forested areas which were lost over the 1972-89 period. Wilderness lands within this areas occupy less than 3 percent of total areas per distance class.

USFS and BLM lands do not show any identifiable pattern of forest loss with reference to the distance-away-from-cities variable (Figure 4.1). First of all, they have experienced more forest loss than Wilderness lands and than the average forest loss rate tabulated from the ALL curve. They underwent about 10 percent of losses within the 16 year-study period--about 0.6 percent per year. BLM lands are located within the first 39 distance classes, and the majority of BLM forest losses are located beyond the 15th distance class. Most of these losses took place in the southwest study area in the Eugene-Springfield district (Figure 2.4). Some of these areas (17th and 39th distance classes) were subjected to more than 20 percent forest losses (1.25 percent per year).

USFS lands on the other hand, are found beyond the 17th distance class. There is less variability in forest loss per distance class in USFS lands than in BLM lands. Most changes per distance class vary around the 10 percent average except for changes located between the 18th and the 25th, and between the 58th and the 64th distance classes. Between the 18th and 25th distance classes high forest loss rates are located in the extreme southwest part of the study area where a relatively large forest loss area took place in the 18th and 19th distance classes (see Figure 2.4). Between the 19th and the 25th distance classes forest loss rates are relatively smaller (about 5 percent per distance class on average). The average forest loss on USFS lands beyond the 58th distance class is also very low--4 percent.

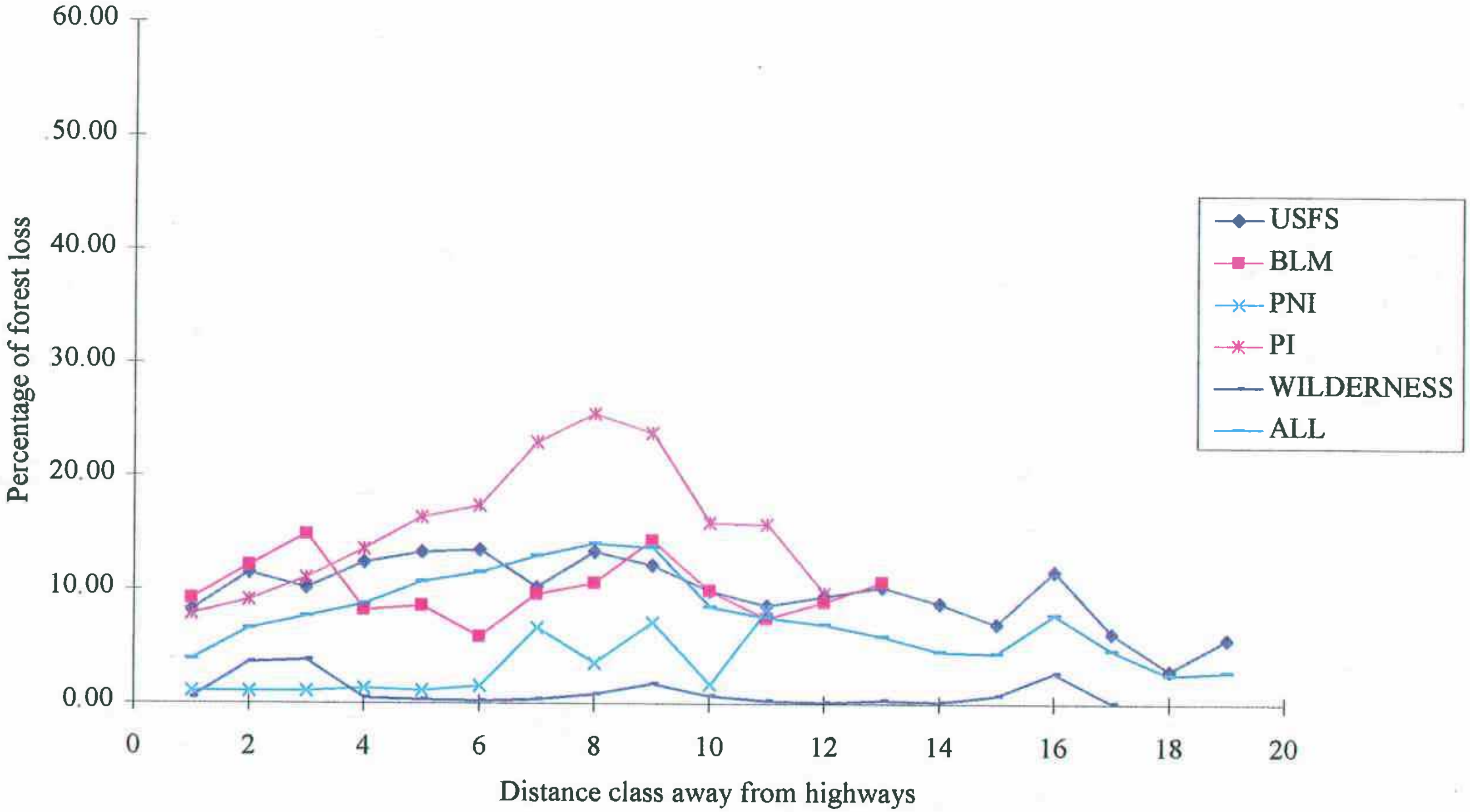
Forest loss on private lands varies according to the private land ownership category. Forests in PNI lands have experienced about an 8 percent change during the 16 year period (about 0.5 percent per year). Most PNI forest losses occurred between the 25th and the 58th distance classes with more than 10 percent of forested areas changed. Forest losses within these distance classes took place along major rivers such as the McKenzie and Middle Santiam rivers, which also are sites of major highways.

Forest cover in PI lands has greater losses than on PNI lands. Almost 14 percent of their forested areas were lost during the last 16 years (0.9 percent per year). This is the highest average forest loss rate of all land ownership types. Although there is no clear pattern of change with reference to the distance away from urban centers and cities, changes were mostly taking place far away from cities. From the 28th distance class and beyond, PI lands in the majority of distance classes have lost more than 20 percent of their forested area (more than 1.25 percent per year).

4.1.2 Analysis of the away-from-highways gradient (Figure 4.3)

There is a similarity in the pattern of forest loss rate between the distance-away-from-cities and away-from-highways variables. In the case of distance away-from-cities variable, forest losses mostly took place far away from cities. In the case of the distance away-from-highways gradient, higher forest loss rates also are located at some distances away from highways. The general forest loss distribution in the away-from-

Figure 4.3. Percentage of forest loss per land ownership per distance class delineated away from highways in the Central Western Cascades of Oregon, U.S. between 1972 and 1988.



highways pattern is depicted on Figure 4.3 by the pattern of the ALL curve. The average forest loss rate per distance class from the ALL curve during the 16 study period is 7.71 percent (about 0.5 percent per year). Since averages were not weighed, differences in average forest rates between away-from-cities and away-from-highways gradients may be found.

Areas with more than 10 percent forest loss per distance class are found between the 5th and the 9th distance classes. The high forest cut rate within this distance class is due to the fact that most commercially valuable timber (mature and old growth conifer forest) between the first and the fifth distance classes may have been harvested prior to 1972. As a consequence, less cutting took place within the first and the fifth distance classes during the study period, and also the majority of marketable and harvestable trees were only located beyond the fifth distance class. On the other hand, the low percentage of forest loss rates far away from highways (beyond the 10th distance class) may be due to accessibility constraints (PNI land ownership) in addition to cutting regulations (USFS, BLM, and PI land ownerships).

Two land ownership types, PNI and Wilderness lands, have a forest loss rate with distance from highways lower than that represented by the ALL curve. They also show a forest cut rate distribution pattern different from the ALL curve. Wilderness areas have experienced about one percent forest loss in the 16 year period (about 0.1 percent per year). Higher Wilderness forest loss rates are found near highways where more than 3 percent of areas have changed. High forest loss rates near highways may be attributable in part to human-related fire disturbances, as also suggested by Ripple

(1994). The rest of wilderness areas almost did not change during the 16 year study period.

PNI lands also are among land ownerships with a low forest cut rate. There has been more than 3 percent of forest losses during the 16 year period (0.2 percent per year) in PNI lands. In this case areas located beyond the sixth distance class have a higher forest loss rate--a mean change per distance class of about five percent--than areas located between the first and the sixth distance classes. Between the first and the sixth distance classes forest losses have a rate varying around one percent per distance class. The low forest cut rate pattern may be mostly due to the lack of adequate tree age and size (mature and old conifer trees) close to highways, since it is believed they were harvested prior to the 1972-1988 period.

The three remaining land ownership types--USFS, BLM, and PI lands--have each a higher rate than the average forest loss rate represented by the All curve. PI lands have the highest mean forest loss rate with about 16 percent changes in 16 years (about one percent per year) per distance class. PI forest loss rate patterns are similar, but percents are much higher than that of the ALL curve pattern (Figure 4.3). Areas of less forest loss are located near highways and at the other end of the transect. The highest changes are found between the fifth and the tenth distance classes. Reasons for such a pattern include depletion of marketable timber products near highways during past harvests and/or fires.

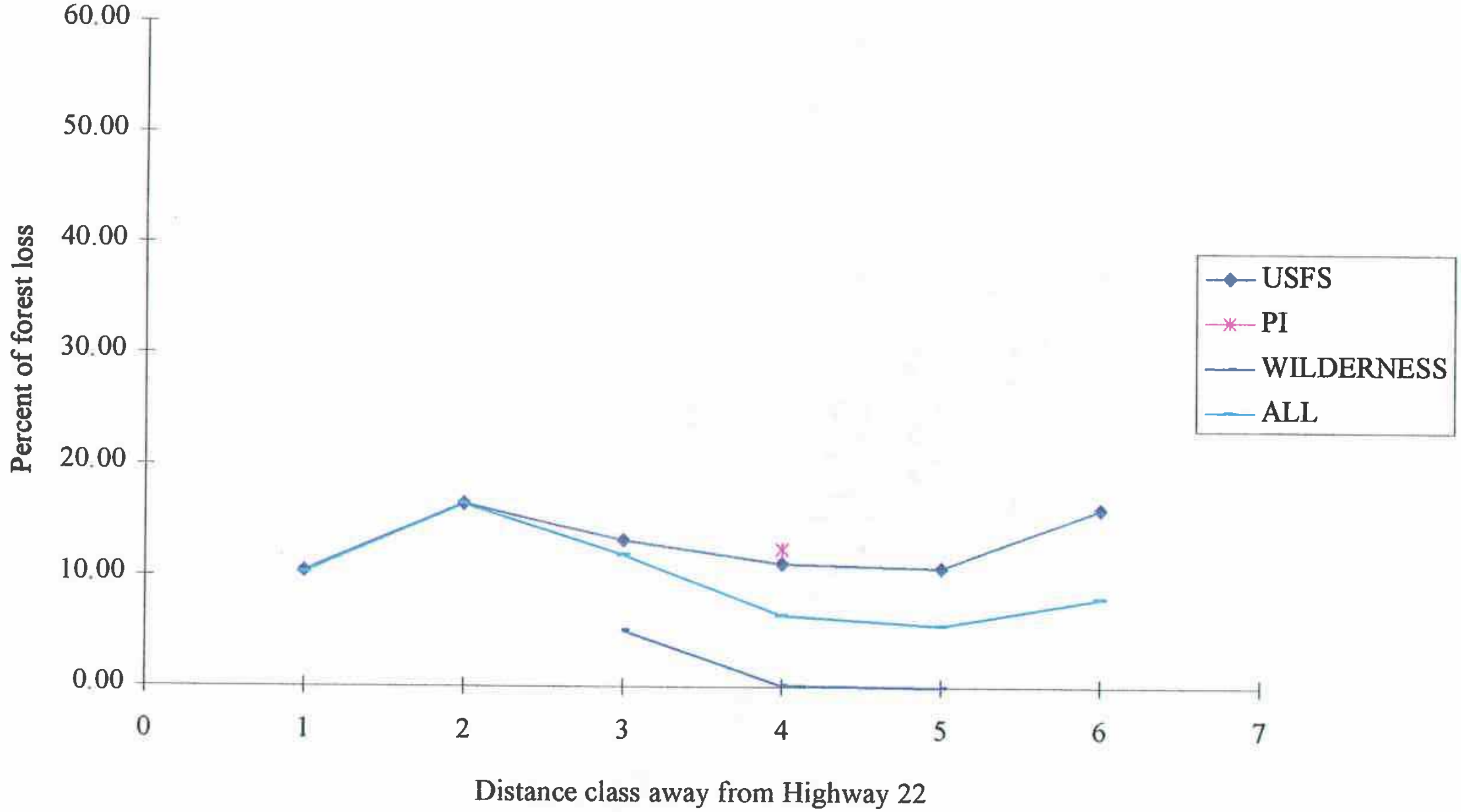
Unlike PI lands, USFS and BLM lands have no clear forest loss rate patterns due especially to the government cutting regulation. This is especially true with BLM lands. The average forest loss rate is about 10 percent during the 16 years (0.6 percent per year). However, USFS lands show a relatively high forest loss rate between the first 10 distance classes, with more than 10 percent per distance class on average than between the 10th and the 19th distance classes (about 8 percent change per distance class).

4.1.3 Analysis of detailed study sites

Detailed area A is located in an environment dominated by two land ownership types--USFS and Wilderness (Figure 3.9). USFS lands cover most of the western side of Highway 22 and Wilderness areas prevail on the eastern side. The overall detailed area mean forest loss rate for 16 years is 10 percent (about 0.6 percent per year) per distance class as summarized by the ALL curve. The ALL curve shows high forest loss rates near highways (within the 3 first distance classes) with more than 10 percent (about 0.6 percent per year) of forested areas lost during the study period (Figure 4.4). Beyond the third distance class the average forest loss is about seven percent per distance class (0.4 percent per year).

Differences in forest cutting regulations have led to differences in forest loss rates between USFS and Wilderness lands. Wilderness lands, for example, are very restricted, and underwent the lowest mean forest loss rate per distance class (1.7 percent during the 16 years (0.1 percent per year)). Areas close to Highway 22 are the most affected. The third distance class which is the closest to Highway 22 has the

Figure 4.4. Percentage of forest loss per land ownership per distance class delineated away from Highway 22 in detailed study site A in the Central Western Cascades of Oregon, U.S. between 1972 and 1988



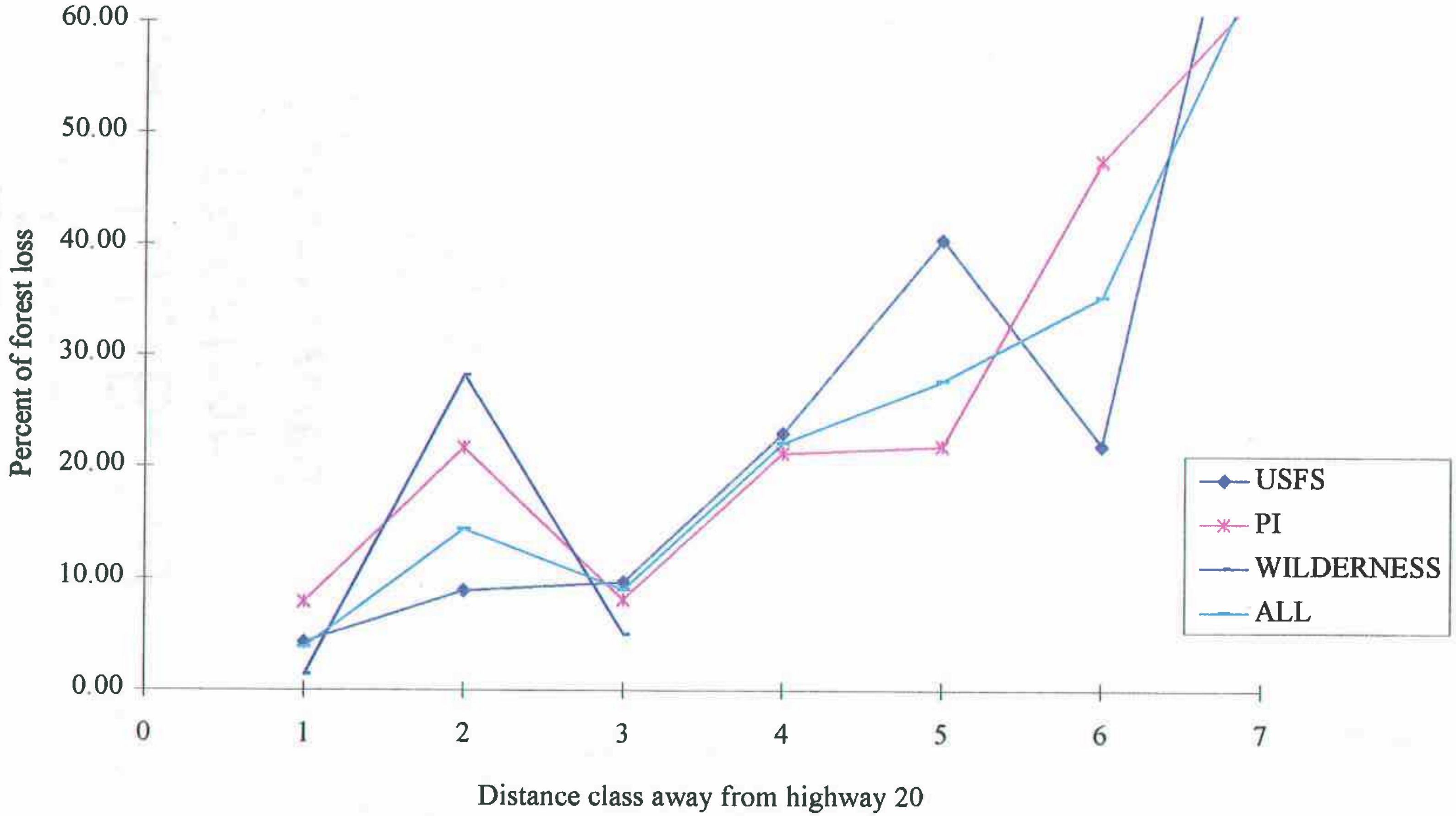
highest forest loss with 5.1 percent losses from 1972-1988 (about 0.32 percent per year). The rest of the distance classes almost did not experience any change.

USFS lands, on the other hand, have about nine times higher forest loss rates than Wilderness lands. The mean forest loss per distance class is 13.1 percent during the 16 year-study period per distance class (0.8 percent per year). There is no clear pattern as the distance away from highway increases due to the cutting policy of spreading out clearcuts.

Detailed study area B is located in the central part of the study area. USFS lands are dominant near the highway while away from the highway PI lands predominate. There are additional and less dominant land ownerships such as Wilderness and PNI (Figure 3.11). Figure 4.5 summarizes patterns of forest loss rate distribution. According to this figure the mean forest loss rate for the 16 years is 26 percent (1.6 percent per year) per distance class. The ALL curve shows an increasing percentage forest loss as the distance away from highways increases. For example, there was less than four percent forest loss in the first distance class because of the predominance of USFS lands and more than 66 percent in the seventh distance class where PI lands are predominant.

Public and private lands show the same forest loss pattern of increasing forest loss with distance away from highways, despite the dominance of one type of land ownership near the highway and another type away from the highway. This pattern may be attributable to the depletion of mature and old growth conifer trees located near the highway prior to 1972 so that forest cuts between 1972 and 1988 were taking place

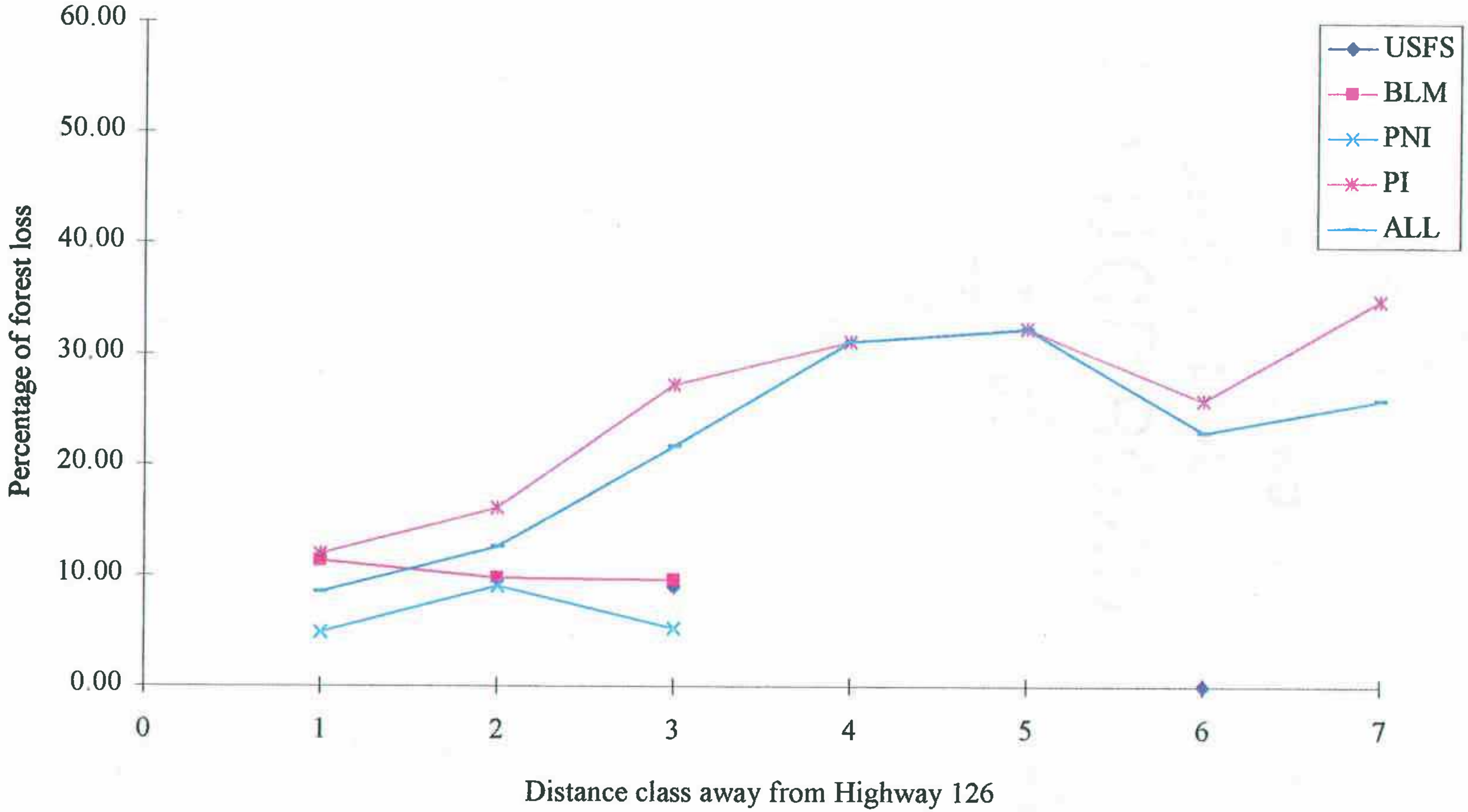
Figure 4.5. Percentage of forest loss per land ownership per distance class delineated away from Highway 20 in detailed study site B in the Central Western Cascades of Oregon between 1972 and 1988.



away from the highway in both forest land ownerships. USFS lands, for example, have about four percent forest loss in the first distance class and about 85 percent in the seventh distance class. PI lands have about eight percent in the first distance class and more than 63 percent in the seventh distance class. The USFS average forest loss rate per distance class is about 28 percent (about 2 percent per year), and the PI average rate is 27 percent (about 2 percent per year) per distance class. Wilderness lands have the lowest forest loss of 12 percent (0.7 per year) in the 16 year period which may be due to factors previously specified (Section 4.1.1) including low to moderate natural fires (Agee 1993, Burke 1979, Morrison and Swanson 1990), insect outbreaks, and tree senescence (Perry 1994).

Detailed study area C is located in the south-central part of the study area in an environment with a mixture of BLM and private lands near the highway and a dominance of PI away from the highway (Figure 3.13). The mean forest loss rate during the 16 years is 22 percent (1.4 percent per year) per distance class (Reference All curve Figure 4.6). Forest loss rate is relatively lower in the two first distance classes (9 and 13 percent in the first and second distance classes, respectively). There is no major variability as the distance away from the highway increases beyond the third distance class. PI forest loss pattern is similar to that represented by the ALL curve. PI average forest loss is relatively high--26 percent (1.6 percent per year) per distance class. The rest of land ownership types have a low average forest loss rate per distance class--USFS lands have five percent (0.3 percent per year), BLM lands have ten

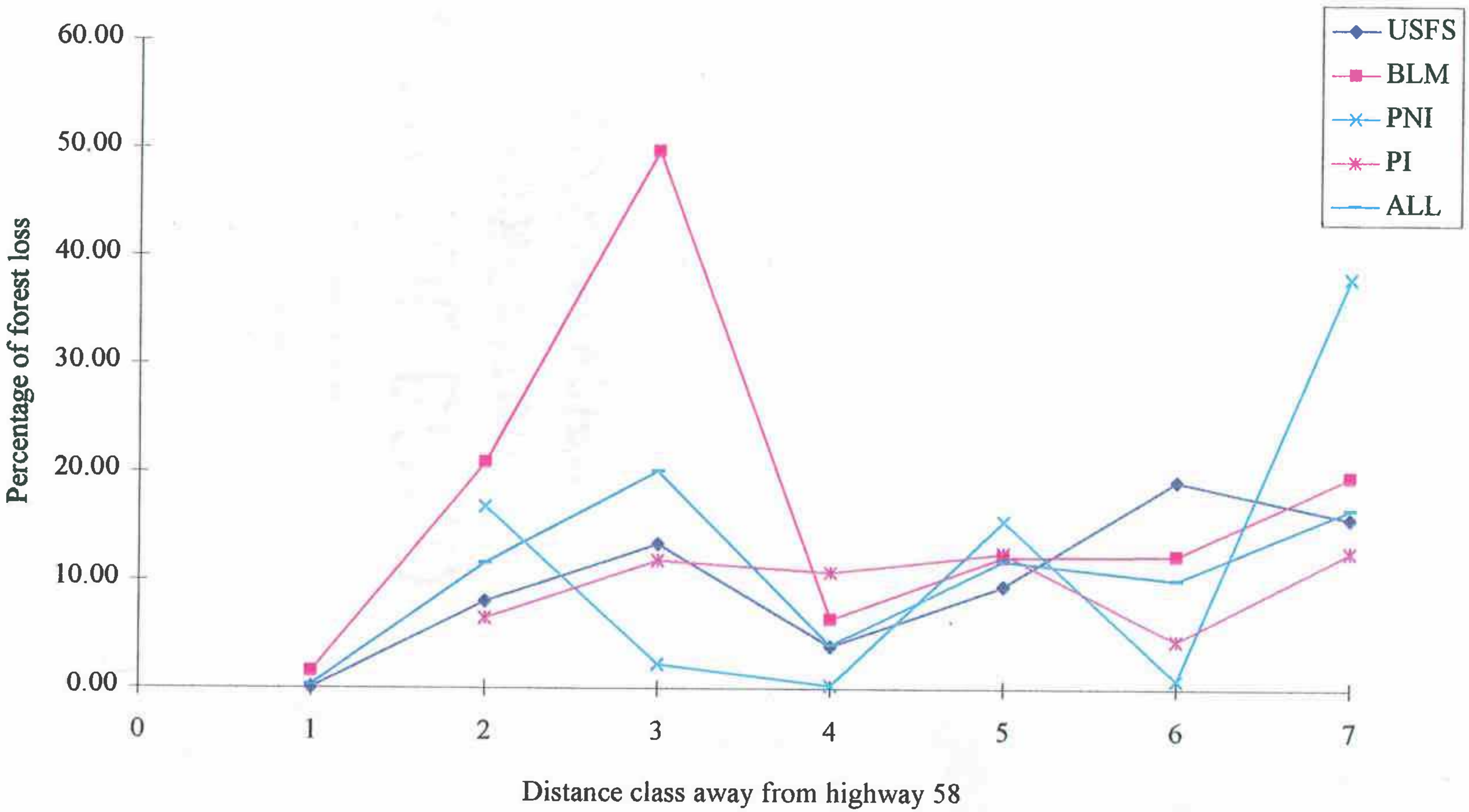
Figure 4.6. Percentage of forest loss per land ownership per distance class delineated away from Highway 126 in detailed study site C in the Central Western Cascades of Oregon between 1972 and 1988



percent (0.6 percent per year), and PNI lands have seven percent (0.4 percent per year) forest loss during the 16 year-study period.

Detailed study area D, delineated from the southwest of the study area, has a different land ownership distribution. Land ownership types in detailed study area D are distributed randomly with no clear spatial pattern with reference to the distance away from the highway but with an overall relative predominance of public lands (Figure 3.15). Figure 4.7 represents the pattern of forest loss rate in detailed study area D. The average forest loss rate on Figure 4.7 is illustrated by the pattern of the ALL curve. The mean forest loss rate for the 16 year period is 11 percent (0.6 percent per year) per distance class. As was the case with the land ownership distribution in Figure 3.15, the ALL curve does not show any identifiable pattern of forest loss rate with distance away from the Highway. USFS and PI lands both have a pattern similar to that presented by the ALL curve. There are, however, two land ownership types with a relatively different pattern from the ALL curve: BLM lands have a very high percentage forest loss in the third distance class (about 50 percent changes), and PNI lands have a high percentage forest loss in the seventh distance class (more than 38 percent of losses (2.4 percent per year)).

Figure 4.7. Percentage of forest loss per land ownership per distance class delineated away from Highway 58 in detailed study site D in the Central Western Cascades of Oregon between 1972 and 1988.



4.2 Results of analysis of forest loss rate between 1973 and 1989 in southeast Zaire

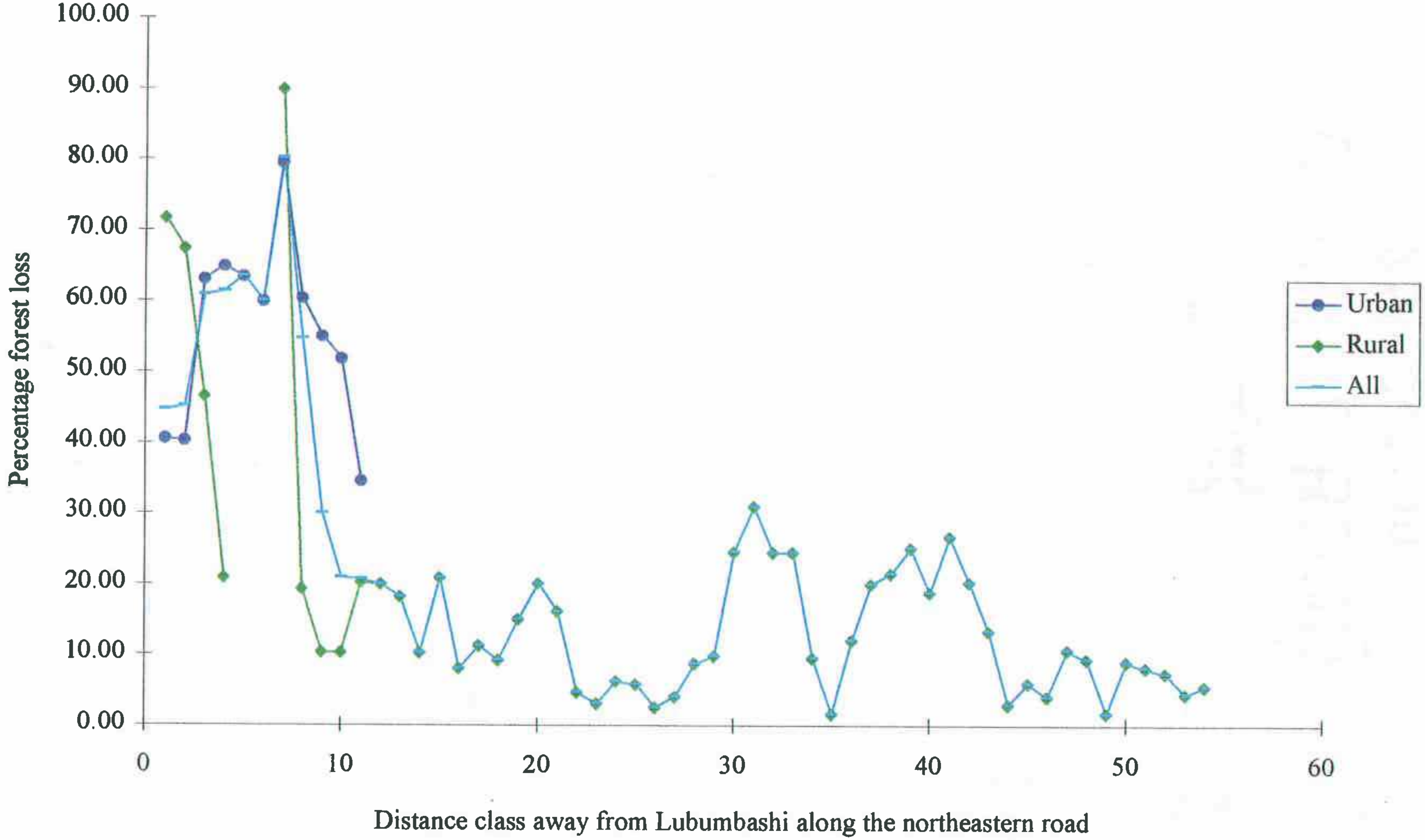
4.2.1 Analysis of the away-from-cities gradient

The same area used in the analysis of forest cover pattern away from Lubumbashi was also used in the analysis of forest loss during the 16 year period between 1973 and 1989. The sample layout and the selection of cells were explained in the second chapter.

Figure 4.8 shows the result of the pattern of forest loss during the study period. The pattern from this figure is similar to that presented in Figure 3.20 related to the pattern of forest cover distribution. Areas of high forest loss rate are mostly located near the city of Lubumbashi. The average forest loss per distance class is 20 percent (1.3 percent per year). The first 10 distance classes have the highest percentage forest loss rate per distance class with more than 30 percent during the 16 year period. Beyond the tenth distance class the percentage is generally below the 20 percent average per distance class.

However, some areas along this transect beyond the tenth distance class (Figure 4.8) have a percentage forest loss per distance class higher than the 20 percent average. These areas are located between 30th and 41^{rst} distance classes where also are located two villages--Minga and Masambala. The high forest loss rate around villages are mostly associated with human-induced disturbances. The rest of forest losses which are

Figure 4.8 Percentage of forest loss per land ownership per distance class delineated away from Lubumbashi along the northeastern road in southeast Zaire between 1973 and 1989



below the average per distance class are mostly due to differences in climatic conditions between 1973 and 1989.

In 1989 conditions were drier than in 1973. The southeast Zaire satellite image data were taken in June of the two study years during the dry season to increase the chance of detecting forest cover from grass cover. There is rarely any rainfall in June (Bruneau and Pain 1990). Soil humidity and tree canopy cover are affected by the previous rainy season. However, as shown by Cane et al. (1994), Magadza (1994), and the US Department of Commerce: National Oceanic Atmospheric administration (N.O.A.A) (1973 and 1989), climatic conditions in Zambia and Zimbabwe were drier in 1989 than in 1973. Because of the absence of data from the southeast Zaire, it was inferred from these studies that climatic conditions in southeast Zaire were also drier in 1989 than in 1973. As a consequence of these drier conditions, trees may have shed most of their leaves by June of 1989 since the environment is a deciduous forest, whereas in June 1973 trees may still have been in leaf.

The analysis of each land ownership type stresses once more the impact of human population, wood harvest techniques, and transportation systems on the rate of forest loss. Urban lands for example, have the highest percentage rate of forest loss (on average 56 percentage (about 4 percent per year) per distance class). Most areas have experienced more than 60 percent of forest loss during the study period. Areas of lower forest loss rate in Urban lands are those located at the fringe of the city of Lubumbashi. They have less than 50 percent of forest loss per distance class in 16 years. The rate of forest loss in urban areas shows a decreasing trend as the distance away from the city of Lubumbashi increases.

Rural lands, on the other hand, have 17 percent forest loss per distance class on average (1.1 percent per year). The pattern of forest loss in rural lands is displayed in Figure 4.8 and is in most part close to that presented by the ALL curve. The first part of the Rural-lands curve between the first and the eighth distance classes has an average per distance class higher than the rest of the curve--53 percent. These areas located near the city of Lubumbashi are subject to high forest loss rates since they are close to urban lands. Beyond the eighth distance class, the pattern of rural lands forest loss rate is the same as that of the ALL curve since no Urban lands are found beyond the twelfth distance class.

Observed patterns beyond the eleventh distance class result from the same processes which were described as the underlying causes in explaining the pattern observed in the case of the ALL curve. That is, human-induced disturbances may explain some of forest losses between the 11th and 54th distance classes. This is the case with forest losses between the 30th and 41st distance classes where two villages are located--Minga and Masambala. Other forest losses may be due to 1989 climatic conditions drier than in 1973 (Cane et al. 1994, Magadza 1994, US Department of Commerce N.O.A.A. 173 and 1989) which may have led trees to shed more leaves in 1989 than in 1973.

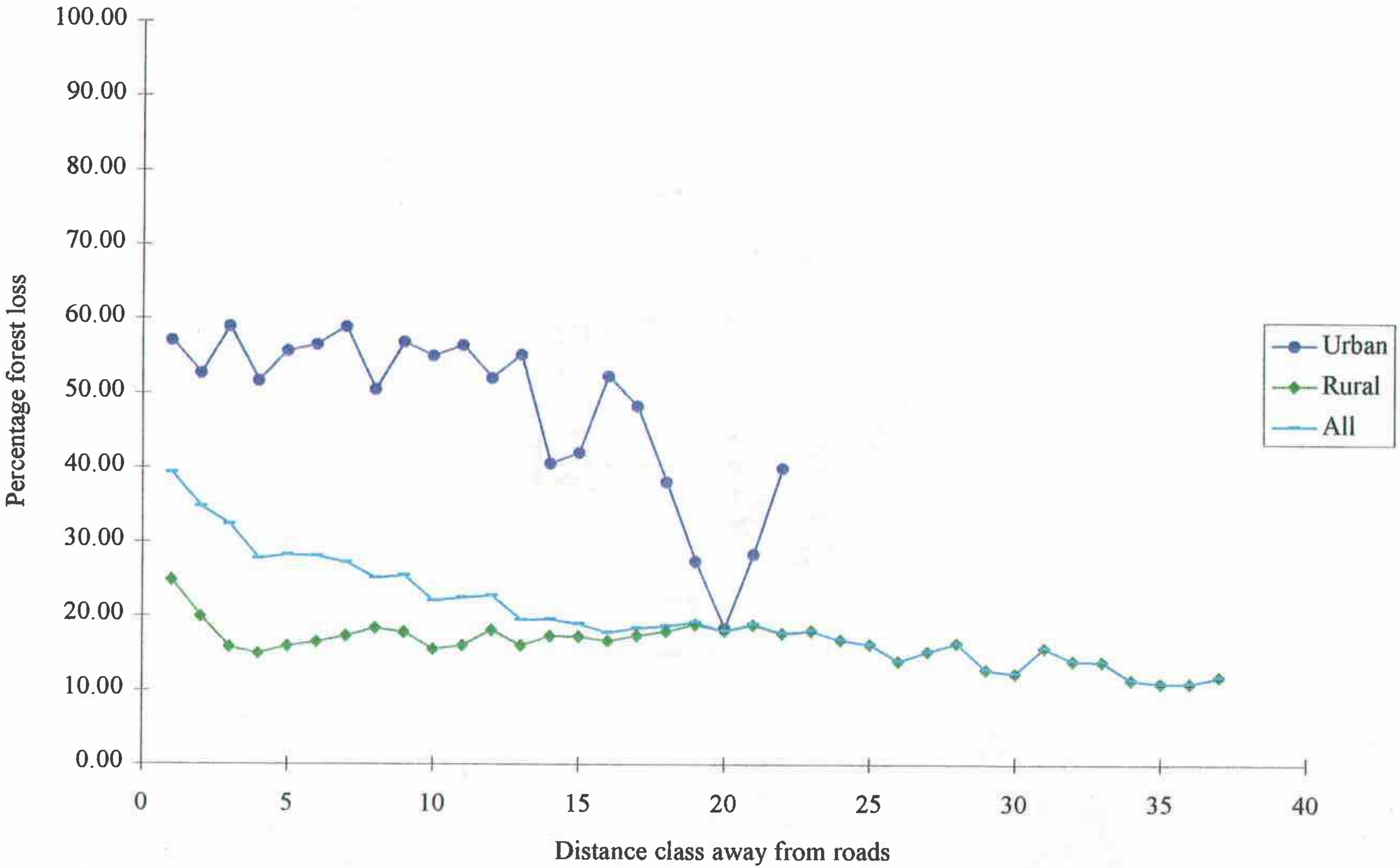
4.2.2 Analysis of the away-from-roads gradient (Figure 4.9)

The rate of forest loss was also analyzed using the away-from-roads-distance gradient. According to Figure 4.9, the average forest loss rate for the 16 year study period is about 20 percent (1.2 percent per year) per distance class similar to the average of the away from cities variable. The overall spatial pattern shows once again the impact of human activities and socio-economic factors as the distance increases. The forest loss rate is high near the road and decreases with distance away from it. Between the first distance class and the 12th distance class the rate of forest loss is above the average. The highest rate is located within the first distance class (about 40 percent of forest loss in 16 years (2.5 percent per year)). At the 12th distance class it is about 23 percent (about 1.4 percent per year).

Every distance class considered for analysis has experienced some form of forest loss. It was found from Figure 4.9 that the lowest forest loss rate during the 16 year period is about 11 percent per distance class. This percentage can be expected because climatic conditions in 1989 appear to be drier than in 1973 (Cane et al. 1994, Magadza 1994, US Department of Commerce N.O.A.A. 173 and 1989).

Areas in the urban environment have the highest forest loss rate per distance class. The average forest loss is about 48 percent/16 years (3 percent per year) per distance class. Forest loss distribution shows a decreasing pattern with distance away from roads. Between the first and the 17th distance classes forest loss has a relatively low variability around the average of 53 percent per distance class. The decrease is very

Figure 4.9 Pertcentage of forest loss per land ownership per distance class delineated away from roads in southeast Zaire between 1973 and 1989.



sharp beyond the 18th distance class where the average is about 30 percent per distance class.

Rural lands have a relatively constant forest loss rate as the distance away from roads increases. The average forest loss rate in the 16 year period is 16 percent per distance class. The first two distance classes away from roads has relatively high forest loss rates--25 and 20 percent, respectively. Most of the remaining distance classes have forest loss rates uniformly distributed along the northeast road. This pattern confirms the fact that the distance away from the road has a major impact in determining the rate and patterns of forest loss. Two main reasons explaining this constraint are lack of road networks into the hinterland, and insufficient financial capability to afford adequate wood cutting tools, transport equipment, and roads.

4.2.3 Analysis of detailed study sites

The same four detailed study areas used in the analysis of the pattern of forest cover (Chapter III) were also used in the analysis of the rate of forest loss. Two of these areas are located on the northeastern road and the two others on the northwestern road. Two are located near or within the urban environment and two others are completely away from urban areas in rural areas. In every case, forest loss distribution underscores the impact of distance away from roads, and rudimentary wood exploitation technology.

Detailed study area A has two types of land ownerships--Urban and Rural lands. Rural lands are dominant in every distance class. Urban lands are restricted to the first three distance classes. In both of these land ownership types, patterns of forest loss rates as represented in Figure 4.10 are socio-economic and distance-related losses. Forest loss rate decreases as the distance increases. The mean forest loss rate for the 16 years is 17 percent (about 1 percent per year) per distance class. The highest forest loss rate occurred in the first distance class where more than 55 percent of forest loss occurred. There is less than 10 percent forest loss beyond the fourth distance class. Within the first three distance classes, the forest loss rate is more than 30 percent per distance class.

Detailed study area B is completely in Rural lands. Because of its location (far away from Lubumbashi), the impact of human activities is relatively low. As a result the rate of forest loss is very low (Figure 4.11). The average rate is five percent (0.3 percent per year) per distance class. It is relatively higher in the first distance class (more than eight percent (0.5 percent per year)). It is, however, generally very low as the distance increases.

Detailed study area C has a land ownership distribution pattern different from that of detailed study area A. Each of the seven distance classes has a certain percentage of Urban lands. Rural lands are found beyond the fourth distance class. This land ownership distribution is due to the north-south position of the detailed study area with reference to the city of Likasi. A northward trend from the road is a move into the Urban area, and a southward trend is a move toward more Rural lands.

As an outcome of this land ownership distribution, Urban lands (Figure 4.12) have increasing forest loss rates with increasing distance away from the road. The

Figure 4.10 Percentage of forest loss per land ownership per distance class delineated away from the northeastern road in detailed study site A in southeast Zaire between 1973 and 1989

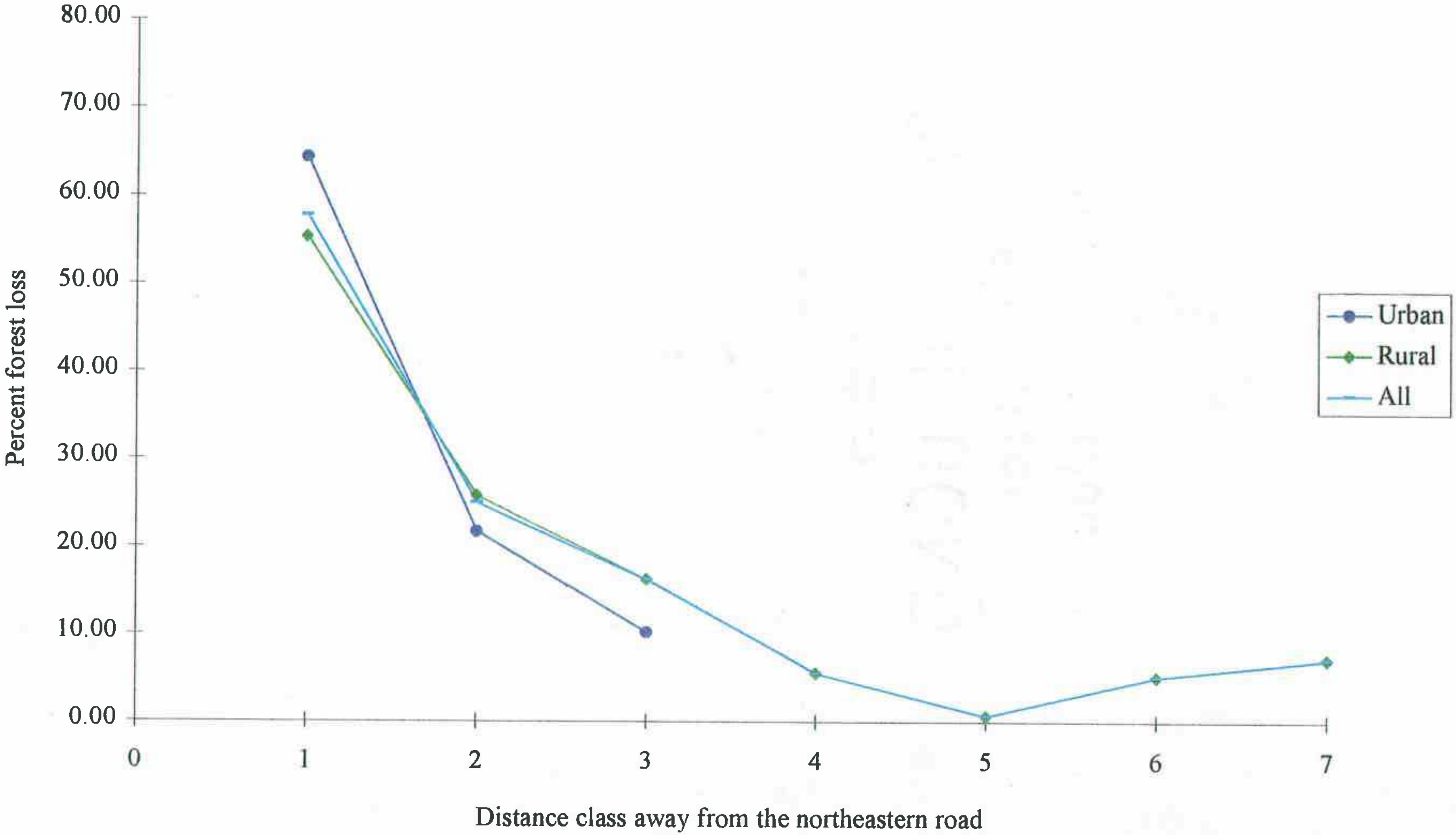


Figure 4.11 Percentage of forest loss in rural lands per distance class delineated away from the northeastern road in detailed study site B in southeast Zaire between 1973 and 1989

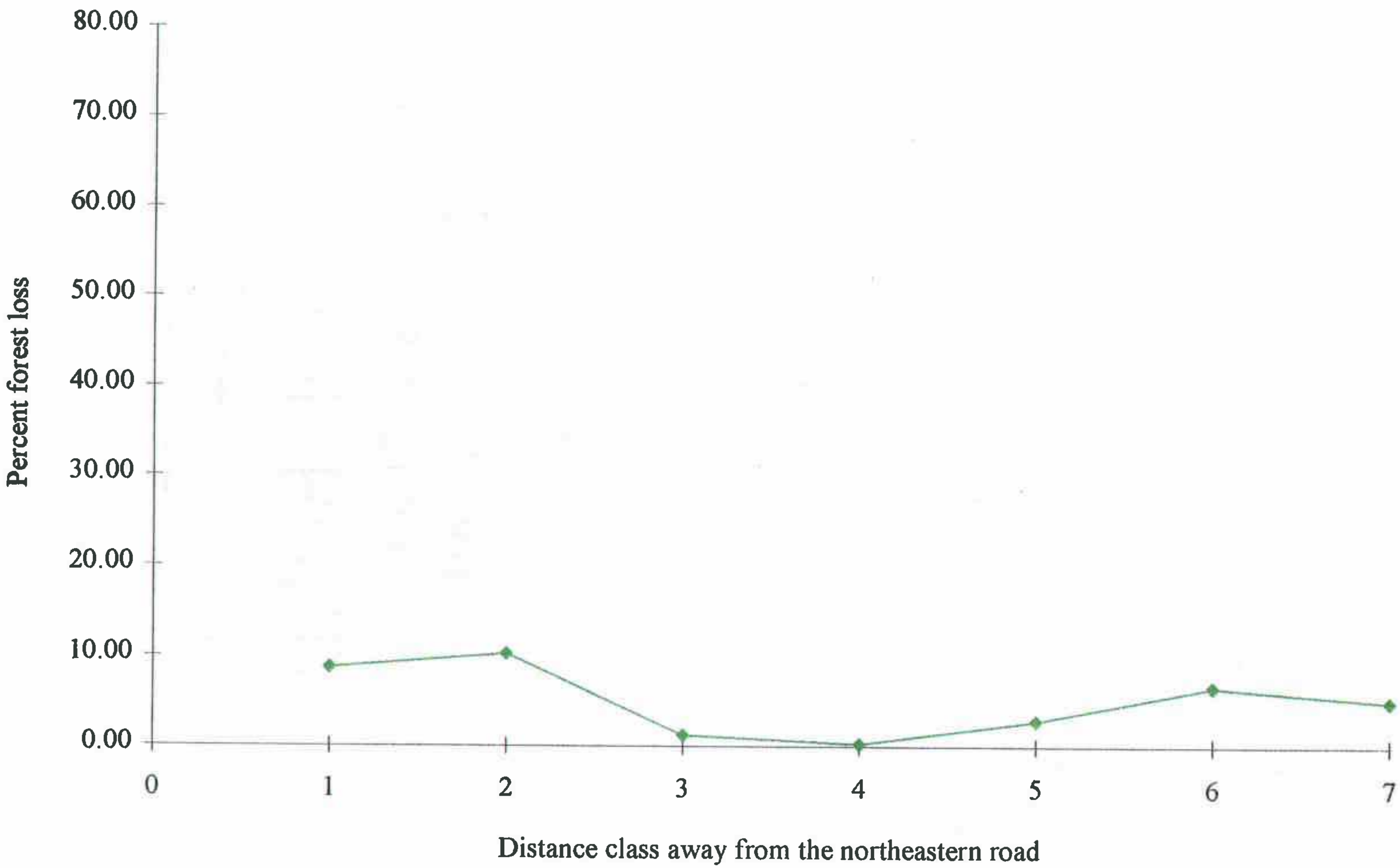
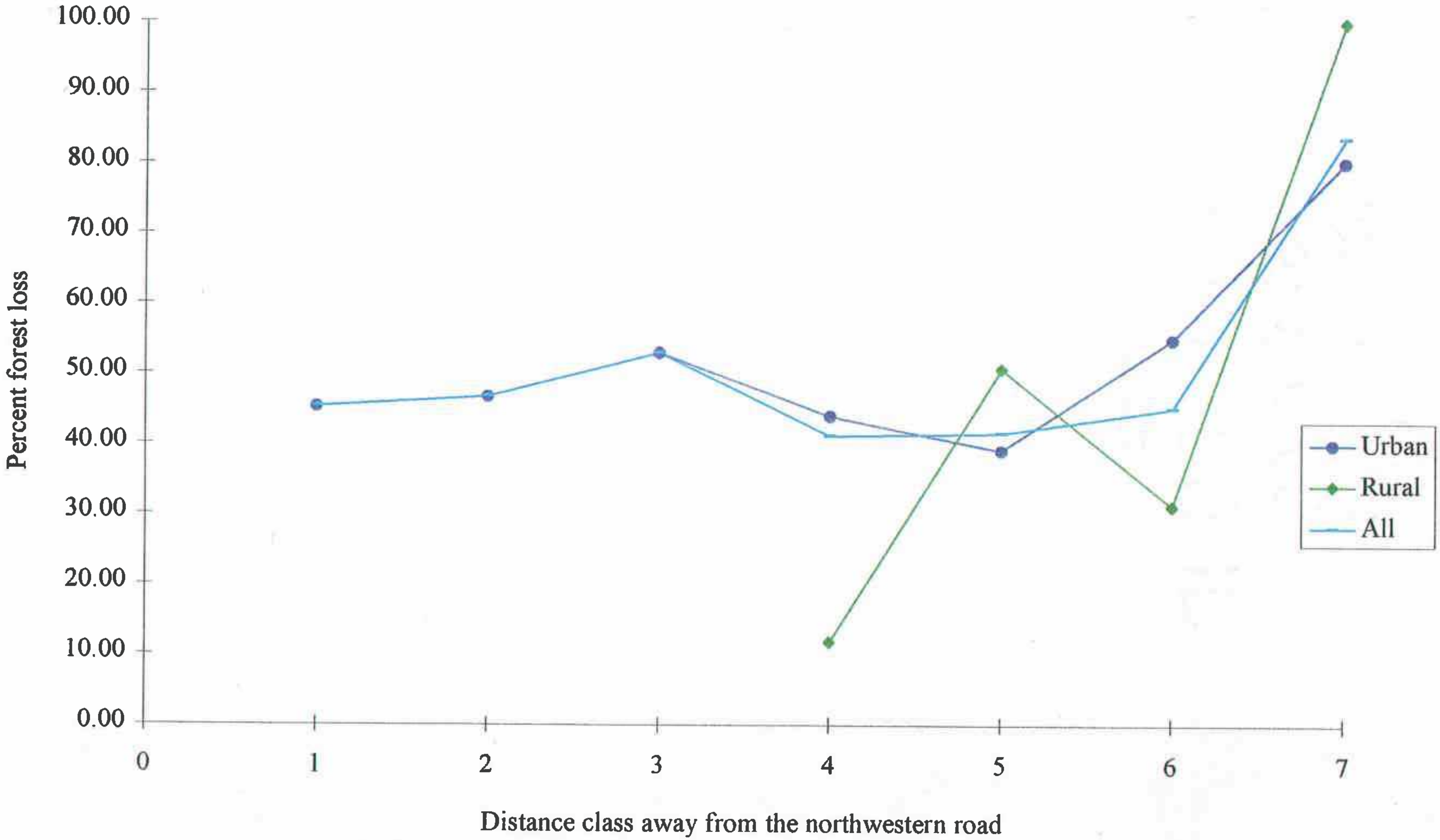


Figure 4.12 Percentage of forest loss per land ownership per distance class delineated away from the northwestern road in detailed study site C in southeast Zaire between 1973 and 1989



average forest loss rate per distance class is about 52 percent/16 years (about 3.2 percent/year). Near the road the rate is about 45 percent/16 years (about 2.8 percent per year) per distance class. The seventh distance class has 80 percent/16 years (5 percent/year). This pattern conforms with the previously described forest loss rate distribution related to the impact of distance and urban centers on the rate of forest loss. That is, high forest loss is concentrated near Lubumbashi.

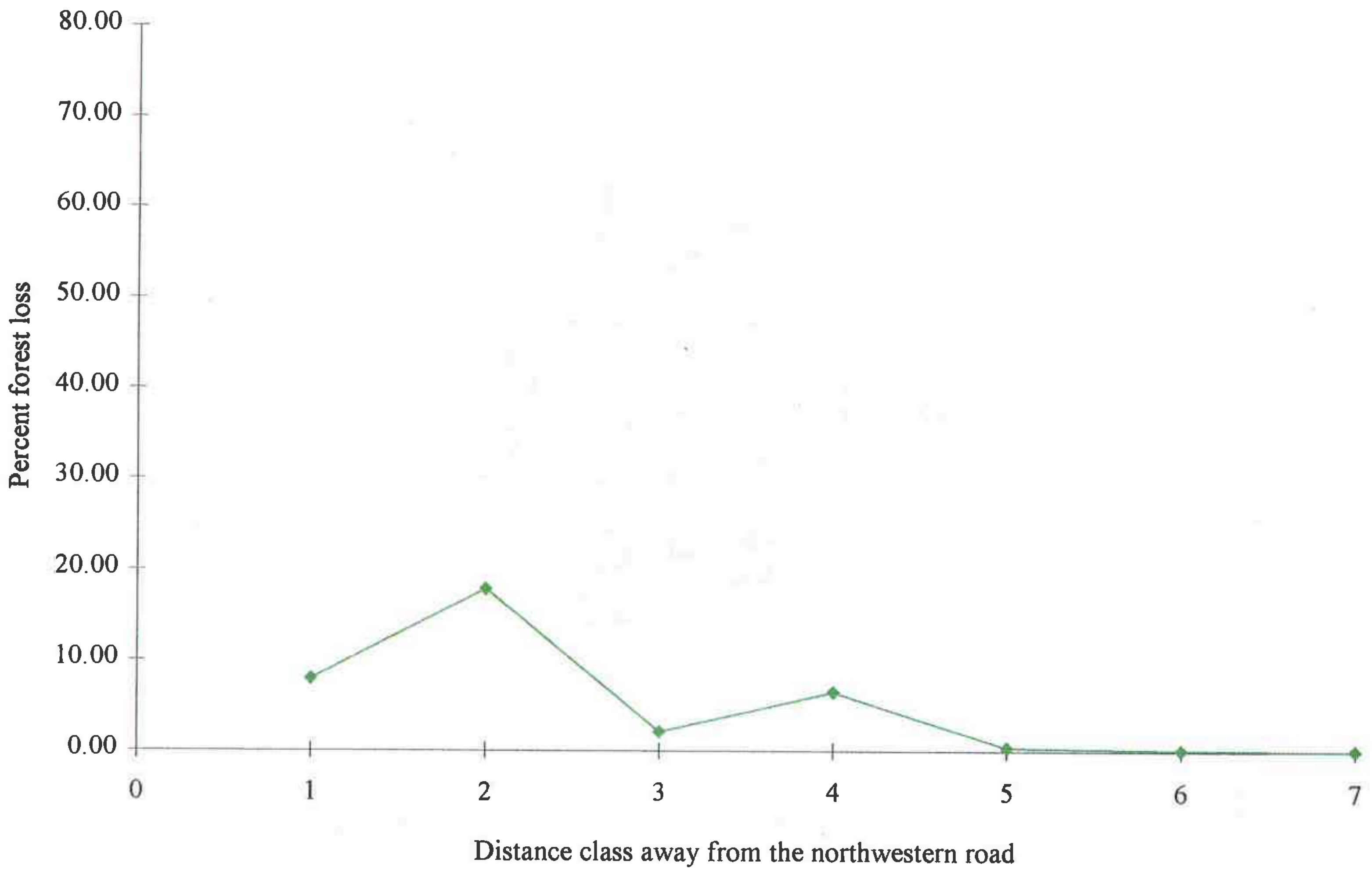
The increasing forest loss rate with distance away from roads noticed in Rural lands is due to recent industrial waste and mining activities, in addition to the increase in agricultural lands, and fuel wood related cuts (Bruneau 1989a, Bruneau and Kakese 1989). The rate of forest loss varies from about 12 percent at the fourth distance class to 100 percent at the seventh distance class. The average forest loss per distance class is 49 percent.

The pattern of forest loss in detailed study area D (Figure 4.13) is relatively similar to that of detailed study area B (Figure 4.11). Human disturbances are very restricted to areas near the transportation system. Higher forest loss rates are located near the road, with more than eight percent per distance class in the first two distance classes and almost no change in most of remaining distance classes. Average forest loss per distance class is 5 percent during the 16 years (0.3 percent per year).

4.3 Comparative analysis of forest loss rates in the central western Cascades of Oregon and southeast Zaire

As was stated at the beginning, the purpose of this chapter is to test the hypothesis that forest loss rate in southeastern Zaire is higher than in the central

Figure 4.13 Percentage of forest loss in rural lands per distance class delineated away from the northwestern road in detailed study site D in southeast Zaire between 1973 and 1989



western Cascades of Oregon. The same hypothesis affirms that socio-economic factors also explain forest loss rate and patterns, such that according to Figure 1.4 the central western Cascades falls in category E (recovery stage), and southeastern Zaire in category B (Rapid destabilization stage).

Three additional variables, population growth rate, per capita money income (MI) and per capita gross national products (GNP), were introduced to investigate this hypothesis. Population growth rate and per capita MI were used in the case of the central western Cascades of Oregon, and per capita GNP and population growth rate were used in southeast Zaire. Per capita GNP was used as the socio-economic indicator in the case of southeast Zaire due to lack of per capita MI data. Per capita GNP is a measure of the total economic activity in a country per inhabitant, and therefore does not give a reliable level of per capita MI at a local level. Nonetheless, it is the only relative measure available of Zairian population's wealth.

According to section 4.1 and 4.2 the overall forest loss rate is higher in southeast Zaire than in the central western Cascades of Oregon. It was found, for example, that when considering the away-from-cities patterns the average forest loss is 0.5 percent per year per distance class in the central western Cascades of Oregon (Figure 4.1), and 1.3 percent in southeast Zaire (Figure 4.8). The away-from-highways/roads patterns also show forest loss in southeast Zaire higher than in the central western Cascades with 1.2 (Figure 4.9) and 0.2 percent (Figure 4.3), respectively. The methodology, Tasseled Cap difference image, used in the analysis of forest loss rates could not differentiate between the two forest definitions used in the analysis of the distance decay model because, as previously said, the technique required raw satellite images. However, these findings are believed to represent the result of the extended forest definition--forest with at least 30 percent canopy cover in the central western Cascades of Oregon, and with at least 10 percent canopy cover in southeast Zaire.

The spatial distribution of forest loss per distance classes between the central western Cascades of Oregon and southeast Zaire is different. In the central western Cascades high forest loss rates are located far away from urban centers and highways (Figures 4.1 and 4.3). High forest loss rates in southeast Zaire are located around inhabited areas (Figures 4.8 and 4.9).

The difference in forest loss rates between the study areas is attributable to several factors. First, satellite image data used have different spatial resolutions. The TM image data set used in the central western Cascades of Oregon has a higher resolution (the ground resolution of a pixel is 30 m) than the MSS image used in southeast Zaire (80 m ground resolution). Canopy cover of some trees in southeast Zaire could not be detected, especially when trees have shed most of their leaves. Additional factors explaining this difference, according to the deforestation model, include differences in population growth rates and per capita revenue.

Population data for the Western Cascades of Oregon were obtained from 1970 and 1990 population census data (US Department of Commerce Bureau of the Census, 1971 and 1991) (Table 4.1). The selection of this time scale is due to lack of detailed population data for 1972 and 1988 study period. About 48 out of 75 towns and cities

Table 4.1 Census of population in the Central Western Cascades study site.

City	County	Population		City	County	Population	
		1970	1990			1970	1990
Rosedale	Marion			Holley	Linn		
Sunnyside	Marion		4423	Mabel	Lane		
Turner	Marion	846	1281	Belknap Sprin	Lane		
Aumsville	Marion	590	1656	Wendling	Lane		
Sublimity	Marion	634	1491	McKenzie Bri	Lane		
Young	Marion			Marcola	Lane		
Stayton	Marion	3170	5011	Rainbow	Lane		
Mehama	Marion			Blue River	Lane		
Breitenbush H. S.	Marion			Vida	Lane		
West Stayton	Marion			Coburg	Lane		
Lyons	Marion	645	938	Finn Rock	Lane	713	763
North Santiam	Marion			Nimrod	Lane		
Gates	Marion	250	499	Leaburg	Lane		
Mill City	Linn	1123	1555	Deerhorn	Lane		
Marion	Marion			Walterville	Lane		
Detroit	Marion	328	331	Thurston	Lane		
Shelburn	Linn			Eugene	Lane	79028	112669
Jefferson	Marion	936	1805	Springfield	Lane	26874	44683
Idanha	Marion	280	289	Glenwood	Lane		
Scio	Linn	447	623	Springfield Ju	Lane	2373	3670
New Idanha	Linn	102		Jasper	Lane		
Millersburg	Linn		715	Goshen	Lane		
Draperville	Linn			Pleasant Hill	Lane		
Crabtree	Linn			Fall Creek	Lane		
Marion Forks	Linn			Winberry	Lane		
Lacomb	Linn			Trent	Lane		
Lebanon	Linn	6636	10950	Lowell	Lane	567	785
Weldwood	Linn			Creswell	Lane	1199	2431
Crowfoot	Linn			Dexter	Lane		
Waterloo	Linn	186	191	Walker	Lane		
Sodaville	Linn	178	192	Saginaw	Lane		
Plainview	Linn			Cottage Grove	Lane	6004	7402
Narrows	Linn			Hemlock	Lane		
Foster	Linn			Westfir	Lane		278
Cascadia	Linn			Oakridge	Lane	3422	3063
Sweet Home	Linn	3799	6850	Willamette Cit	Lane		
Brownsville	Linn	1034	1281	Kitson Hot Sp	Lane		
Crawfordsville	Linn			**Total**		141364	215825

Source: US Department of Commerce Bureau of the Census, 1971 and 1991.

identified in the study area did not have population data. Towns and cities within the study area with available population data were selected. It was then found that in 1970 141,364 people were living in the central western Cascades of Oregon, and in 1990 the population increased at 215,825. This population growth is estimated to be about 53 percent during the 20 year period (2.6 percent per year).

Population data used for the southeast Zaire study area are that of the city of Lubumbashi. In 1973 the population was estimated 412,000 (Bruneau and Lootens-De Muynck 1990). The most recent and reliable population data for this city are that of 1984 during which it was estimated at 560,000 (Bruneau and Lootens-De Muynck 1990). During this same period the population growth rate was estimated at about 36 percent (about 3.3 percent per year).

Population growth rates of the two study areas show in both cases an upward trend (2.6 and 3.3 percent per year). The deforestation model predicted the central western Cascades of Oregon to have a stable population growth rate. Stage E is characterized by countries with no increasing population growth rate. The difference between the population growth rate predicted by the model and that found in the central western Cascades of Oregon underscores the fact that the population growth rate component of the deforestation model may be a variable applicable only at the national level. Its application at a local level may therefore produce different results.

The Pacific Northwest is indeed the last frontier of economic development, with environmental settings distinguishable from the rest of the country (Cronon 1991). Population has been increasing in the Western Cascades of Oregon especially through the immigration process. According to Figure 1.4, western Oregon can be classified in two stages at the same time. On the one hand, it is in stage B characterized by high forest cuts for wood export to other states and abroad, and by an increasing population in-migration from surrounding neighboring states. On the other hand, it is in stage E where the government forest policy and population awareness have led to forest regrowth in previous clearcut forest areas.

In the case of the central western Cascades of Oregon the per capita MI at the county level was collected. The study area includes a part of Lane, Linn, and Marion counties. Each county has an estimated money income in 1975 of $4,797, $4,378, and $4,576, respectively, and in 1987 of $10,627, $9,816, and $10,290, respectively (Table 4.2). For the entire state of Oregon it was $5.004 in 1975 and $11,045 in 1987 (US Department of Commerce Bureau of the Census, 1991).

Per capita GNP data used as socio-economic indicators in the case of southeast Zaire are those of the entire country due to lack of local data. The study period selected is that of available years close to the study period of 1973 and 1989. In 1987 the per capita Gross National Product was estimated at $153 (The World Resources Institute 1990) and it was $140 in 1973 (World Bank 1975) (Table 4.2).

Table 4.2 Per capita money income in the central western Cascades of Oregon in 1975 and 1987, and per capita gross national product in 1973 and 1989 in Zaire (in US dollars).

State/County	1973	1975	1987	1989
Lane	-	4,797	10,627	-
Linn	-	4,378	9,816	-
Marion	-	4,576	10,290	-
Oregon	-	5,004	11,045	-
Zaire	140	-	-	153

It can be inferred from the per capita MI and GNP that people in the central western Cascades study area are wealthier than those in southeast Zaire. It was found for example that from 1977 to 1987 per capita GNP growth rate was stagnant (0.2 percent change per year) (The World Resources Institute 1990). Economic stagnation results in increased unemployment and some urban dwellers resort to subsistence agriculture, fuelwood, and charcoal production activities around cities (Bruneau and Kakese 1989; Bruneau 1989b, Lootens-De Muynck et al. 1982). The search for agricultural and fuelwood areas increase the forest loss process due also to rising wood energy demand from urban areas. This demand is associated with the increasing people of Lubumbashi and especially with the difficulty of people affording either the cost of installing electricity or buying electrical appliances as substitutes for wood.

Most forest losses in southeast Zaire are found around inhabited areas, as was noticed in Figure 4.8 and 4.9. They develop first around cities and inhabited areas, and along the main road network then move outward into the hinterland through trails as the immediate environment is depleted.

In the central western Cascades of Oregon, because of advanced transportation systems and relatively high socio-economic well being, local population dependence on local forests as a source of energy, or as an agricultural lands source, is relatively low. Timber producers targeting larger markets cover much larger areas than in southeastern Zaire. Tools used for timber harvest in the central western Cascades of Oregon are much larger, mechanized, and motorized compared to manual practices in southeast Zaire.

As a consequence, forest losses are not restricted to areas around cities and transportation networks in the central western Cascades of Oregon. In both Figures 4.1 and 4.3 high forest loss rates are found away from cities and highways. This pattern has been reinforced by forest cut restrictions operating within public land ownerships. The result of this legislation and the type of land ownership is a distinct spatial distribution of the pattern of forest cuts.

Chapter V. Discussion and conclusion

5.0 Introduction

This chapter evaluates the effectiveness of the two models used in characterizing forest cover patterns as a function of distance. The first part reviews contributions and identifies limitations of techniques and results used in this study. The second part summarizes and evaluates the results with reference to the distance decay model and the deforestation model. The last part includes recommendations and a general conclusion.

5.1 Evaluation of the methodology

5.1.1 Contributions

One of the contributions of this study is the capability it has shown to analyze and compare the pattern of forest cover as a function of distance in both developed and developing countries. The analysis of forest cover trends at a sub-country and land-ownership scales has helped identify and illustrate differences and similarities of forest cover trends within each study area. In addition, it has demonstrated that sub-national scale forest cover patterns may differ from the national trend portrayed in global forest cover/loss studies. The use of land ownership variables such as USFS, BLM, PI, PNI, and Wilderness lands in the central western Cascades of Oregon, and Rural and Urban lands in southeast Zaire also demonstrated the complexity of the forest cover/loss trend as one moves from one land ownership to another.

This study has added to the results of previous large scale studies which used remote sensing data to investigate the impact of distance and human population on forest cover distribution and forest loss (Medley et al. 1995, Ripple 1994, Turner et al. 1994, Wear and Flamm 1993, McDonnell and Pickett 1990, Skole and Tucker 1993, Dale et al. 1993, and Sader and Joyce 1988). More than 12,000 square kilometers in the central western Cascades of Oregon, and more than 40,000 square kilometers in southeast Zaire were used to test the distance decay and the deforestation models. One distance gradient evaluated forest cover away from cities and urban centers, and the other gradient analyzed forest cover pattern as a function of distance away from highways/roads. Population growth rates were used to test the validity of the deforestation model. The sampling technique used consisted of selecting every other 1600 m by 1600 m sample of the study area, and has proven to be an important technique in large scale environmental studies.

The methodology used in this study has provided a tool in the analysis and evaluation of forest cover in less-studied and data-deficient environments. Southeast Zaire provides a good example of an area lacking adequate ground data. Despite the lack of ground data, the technique used in image classification has helped discriminate forested from non-forested areas.

Studies related to human impacts on forest environment in Zaire are scarce. There have been very few studies which assessed forest cover in Zaire and especially

Miombo woodland in southeast Zaire by the means of satellite data and the distance decay model, and none using the deforestation model. Known studies include rain forest satellite image classification by Laporte et al. (1995), and Vanoverstraeten and Trefois (1992). Additional studies include assessment of Miombo woodland around Lubumbashi by Castiaux et al. (1991), Bruneau (1989a), and Soyer and Wilmet (1986). There has been no studies to our knowledge which address the impact of distance from cities and roads on forest cover distribution.

This study explored the effects of using different forest definition types in forest cover analysis. The introduction of forest defined as unmanaged forested or forest less affected by human activities areas, in addition to the more comprehensive definition, has helped explain and understand some patterns which might have been otherwise overlooked.

In addition to the above techniques used to identify forest cover patterns, the Fragstats software (McGarigal and Marks 1995) was applied on six selected sub-study areas in the central western Cascades of Oregon to examine forest patch characteristics within each land ownership type. Landscape indices selected include the class area (CA), the mean patch size (MPS), the patch number (NP) the patch size coefficient of variation (PSCV), and the ratio class area/total class area (CA/TA). This preliminary study showed that forest patch characteristics differ among ownerships (Kikombo et al. 1995) , and it emphasized the uniqueness of each individual land ownership type.

This study has demonstrated that forest cover distribution and forest losses were a function of several variables. The likelihood of forest cover being disturbed depended upon the type of owner, the distance to roads and/or market centers. Additional variables included the policy of forest harvest and residential development, and agricultural suitability. These relationships also were demonstrated by Medley et al. (1995, Turner et al. (1994), Spies et al. (1994), Wear and Flamm (1993), McDonnell and Pickett (1990), Skole and Tucker (1993), Dale et al. (1993), and Sader and Joyce (1988).

5.1.2 Limitations

Despite above mentioned study contributions, limitations were also identified. Some of them were related to the accuracy assessment of satellite data classification. In the case of the central western Cascades of Oregon image classification and accuracy assessment, Cohen et al. (1995) used air photos and ground reference stands. The overall accuracy for classified forested classes was 82 percent. Accuracy for the southeast Zaire study area was difficult to evaluate because of lack of ground truth including air photos. The southeast Zaire image classification relied on the unsupervised classification technique, maps and atlases (Bruneau and Pain 1990), and the field knowledge of the study area by the researcher. It was found that most of known forested and non-forested areas were accurately classified.

However, other areas within the southeast Zaire study site could have been misclassified. Two types of errors might be introduced--errors of omission and commission. That is, some pixels in non forest classes may have been classified as forest classes, and those in forest classes may have been classified as non-forest classes. The size of these errors could not be estimated without reliable ground truth.

The sensitivity of the results to the type of forest definition limited the ability for generalization. It was found for example, that the pattern of forest cover as a function of distance depended upon forest definition. In a forest defined as areas with at least 30 percent or 10 percent of canopy cover, the percentage of forest cover was higher than that of a forest defined as an unmanaged forest (for example mature and old-growth conifer forests). The first forest cover definition could have led one to the conclusion that there was lesser impact of distance on the pattern of forest cover distribution than in the second forest definition. Different conclusions about patterns are reached with different forest definitions.

The selection and definition of other variables used in this study may also have affected the result. The road network selected in the analysis of forest cover in the central western Cascades of Oregon was limited to highways. Additional road network systems exist which were not considered but could have had an impact on the pattern of forest cover distribution. Their density exceeds the 1600 m by 1600 m grain size of this study. They were not considered in this study because their high density would have made it more difficult to highlight the impact of distance on forest cover distribution.

In the case of southeast Zaire the selection of major roads for this analysis was due to several reasons. On one hand, no reliable reference maps with accurate geographic coordinates could be obtained to facilitate the digitizing and overlay on the satellite imagery data. On the other hand, since roads were identified and digitized on the monitor, only those roads (major roads) which could appear on the image were used. As a result, this procedure could have displaced the location of the road by some pixels, and it precluded mapping of secondary road network systems.

Another potential deficiency in this study was due to the selection of different socio-economic variables for the analysis of forest loss and the interpretation of the deforestation model. Per capita gross national products (GNP) in southeast Zaire and per capita money income (MI) in the central western Cascades of Oregon were used as indices of the economic development in both study areas. Even though their use was justifiable, these indices have different meanings, and interpretations. In addition, the GNP applied to the southeast Zaire study area was an estimate from the entire country and could not represent exactly the situation within the study area.

In addition, population data used in this study were just estimates and may have not represented the actual population count within each study area. In southeast Zaire study area, the only population estimates available were of one major city, Lubumbashi, instead of the overall population within the study area including villages. In the central western Cascades of Oregon population estimates for some towns were missing and were not taken into consideration.

The delineation of land ownership boundaries could have also introduced biases. Indeed, the boundaries of Urban and Rural areas in southeast Zaire were delineated on the monitor using a map as a visual reference. Some areas included in Urban areas may have been in fact Rural areas and vice versa. Despite the inaccuracy in the delineation process, this separation was necessary because of the difference in land acquisition and land use between these two types, and also because the purpose of the study was the analysis of forest cover by land ownership and as a function of distance away from roads. For example, urban areas are areas under a modern type of administration and rural areas are administered by the traditional chief of the land.

The boundary delineation error in the central western Cascades was not as large as in southeast Zaire. In the central western Cascades of Oregon, highway and land ownership coverages were digitized from more accurate maps with relatively more accurate geographic coordinates. Errors in this case were minimized and much smaller compared to the southeast Zaire study area. However, additional and less significant errors which could not be assessed, errors related to the conversion from vector based coverages to grid-based coverages.

Another limitation associated with this study was the problem related to the ability of the satellite imagery to detect patches of forest cuts (Table 5.1). The central western Cascades of Oregon classified image was resampled to 25 m by 25 m pixel size. This is equivalent to 625 m^2 which is about 0.02 percent of the 1.6 km by 1.6 km sample size used in this study. Most forest cuts which took place in the central western Cascades of Oregon were larger than the ground resolution of the pixel size and likely to be detected on the satellite image. In the case of the southeast Zaire on the other hand, the average pixel size was about 80 m by 80 m, equivalent to 6400 m^2, or about 0.3 percent of the sample size. The southeast Zaire image ground resolution could not be resampled to be made consistent with that of the central western Cascades of

Table 5.1. Factors influencing the ability of satellite remote sensing to detect vegetation loss rates.

	Western Cascades of Oregon	Southeastern Zaire
Forest cut pattern	Distinct patch clearcutting from surrounding forest	Indistinct selective cutting may provide only a small change on greenness with no distinct shape
Regeneration rate	Fast(10-20m^3/ha/yr)	Slow(1m^3/ha/yr) (Allen 1985)
Succession	May go through natural succession stage or may be replanted with even aged Douglas fir stands	Reverts from natural succession: shrubland then woodland
Change in greenness over time	Within the first 10 yrs detection of regeneration, hardwood and old clearcuts clearly distinguishable from bare ground and uncut forest	Within the first 10 yrs maybe shrub recovery producing greenness levels which can't be distinguishable from uncut forest
Resolution	Better spatial resolution. Temporal resolution of about 50 yrs of clearcut history	Poor spatial resolution Temporal scale detectable maybe only last 10yrs

Oregon due to lack of geographic coordinates required in the resampling of the satellite imagery data. As a consequence of the 80 m by 80 m ground resolution, an individual agricultural plot was difficult to identify since the average plot size was estimated to be 0.5 hectare (Bruneau et Kakese 1989).

Areas where forest disturbance was also difficult to detect included the front line of firewood search (Table 5.1). The fuelwood search always starts with selected and relatively smaller trees, and eventually leads to the exploitation of previously disregarded trees as the demand and the distance to available trees increase (Malaisse and Bizangi 1985). In the first phase of firewood search the detection of such a disturbance could also have been difficult due to the ground resolution of the remotely sensed data. This was especially true around possible villages where the human pressure on fuelwood supply was not as big as around cities.

The temporal resolution used in this study may also have obscured forest losses which could have taken place in a time span shorter than the temporal grain of the study (Table 5.1). Some forest disturbances permanently changed the environment and others lasted for a relatively shorter period. Among disturbances that permanently change the environment were agricultural activities. Most agricultural lands in the central western Cascades of Oregon located close to inhabited areas were transformed many years ago and were easily classified as non-forested areas. Short lasting disturbances including logging and human/natural fire were spread out throughout the study period but were captured by the Cohen et al. (1996) classification procedure in which the temporal resolution was divided in several temporal smaller scales--1972-

1976, 1976-1984, and 1984-1988. It was difficult to obtain smaller scale temporal resolution data for the southeast Zaire study area due to the lack of data between 1973 and 1989. As a consequence, rapid forest changes in condition could not be captured in southeast Zaire. Changes related to short lasting disturbances detected on the southeast Zaire image may have been related to changes which took place during the last period of the study period.

Agricultural activities were not likely to produce the same result on forest cover in southeastern Zaire as they did in the Western Cascades of Oregon. In southeastern Zaire shifting cultivation was the main agricultural practice. It consists of growing crops on the same field for about two to four years and letting it remain fallow for the next 15 to 20 years (Laporte et al. 1995). Population increase has led to a shortening of the fallow period. However, the lack of adequate income to afford fertilizers and improve yields still force most inhabitants to migrate to newer locations. The result of this agricultural-related migration was a short lasting impact of agricultural activities on the environment. The detection of such agricultural activities by a satellite imagery especially in a large temporal scale analysis may have been difficult.

Climatic conditions which prevailed during the collection of satellite image data may have affected the amount of forest losses. In 1988 climatic conditions were drier than in 1972 in central western Cascades of Oregon (Greenland 1993). Conditions in 1989 in southeast Zaire were also drier than in 1973 (US Department of Commerce National Oceanic and Atmospheric Administration 1973 and 1989, Cane et al. 1994, Magadza 1994). Spectral signatures of vegetation cover may have been reduced leading to relatively smaller forest cover than if climatic conditions had been similar during data collection in both periods.

5.2 Summary and model evaluation

5.2.1 Distance decay model validation

5.2.1.1 Overview of study results

An important question asked at the conclusion of this study was whether the distance decay model was applicable to any forest type in any physical setting. It was found that several assumptions made by Von Thunen could not be met. The terrain was not as flat and uniform as that hypothesized by Von Thunen. Because of the mountainous terrain in the central western Cascades of Oregon some areas were more accessible than others. Forest cover in both study areas was not as evenly distributed as assumed by the model. There were variations in forest cover distribution due to the change of dominant species, and also to a natural variation in tree size and density. Such a forest pattern may have had an impact on tree selection by consumers, and the shape of the distance decay curve may have been affected by this natural vegetation variation.

In addition to the inherent vegetation characteristic impact, the results from this study showed that the distance decay model curve pattern was found to depend upon the type of forest definition. In the central western Cascades of Oregon, for example, two types of forest definitions were used--areas with at least 30 percent canopy cover and unmanaged conifer forest. Results from Figures 3.2 versus 3.4, and 3.7 versus 3.8 showed a different pattern as the forest definition changed. The impact of distance was more identifiable in the case of forests defined as unmanaged forests than in forest defined as areas with at least 30 percent canopy cover.

The distance decay model was found to be valid for describing the pattern of forest cover only in the case where the overall forest cover was considered. According to Table 5.2 positive slope values showed by the ALL curves were indicative of a forest cover increase with distance. This finding was corroborated in each study area and forest definition type.

However, slope values were found to vary according to the study area and the type of forest definition. In the central western Cascades of Oregon, forest defined as areas with at least 30 percent canopy cover was found to have higher slope values (2.3 and 4.4) than forest defined as unmanaged forest cover (1.0 and 2.2). Difference in forest definition and also cumulative effects of past forest cover disturbances were among the reasons for the difference in slope values. Cumulative effects of past disturbances include all timber harvest and natural disturbances which took place prior to this study period and left a landmark on the landscape. Such a legacy, for example, has an impact on old growth forest distribution. Areas harvested within 80 years prior to 1988 were categorized as young conifer forests.

Slope values also were found to vary according to the distance gradient considered. Slope values in the away-from-highways gradient were found to be higher (4.4 and 2.0) than in the away-from-cities and urban centers (2.3 and 1.0). A

Table 5.2. Fitted line ranges and slope values from the ALL curves by study site

Study sites	Distance variables	Extended forest definition				Restricted forest definition			
		Range (km)	Slope	SE	r2	Range (km)	Slope	SE	r2
Central western Cascades of Oregon	Away from Cities	40	2.3	0.18	0.88	84.8	0.99	0.02	0.97
	Away from highways/roads	9.6	4.4	0.47	0.96	25.6	2.0	0.15	0.93
Southeast Zaire	Away from cities	28.8	5.0	0.54	0.84	22.4	5.89	0.86	0.80
	Away from highways/roads	30.4	1.6	0.13	0.89	25.6	1.9	0.16	0.91

Extended forest definition is defined as areas with at least 30 percent canopy cover in the central western Cascades of Oregon, and areas with at least 10 percent canopy cover in southeast Zaire.
Restricted forest definition is defined as unmanaged forest cover in both study sites

combination of factors were found as possible explanation for such a difference. These factors include a relatively smoother topographic transition from the Willamette valley to the crest of the Cascades compared to abrupt changes from some highways away in the hinterland--sections of some highways located in the bottom valley of some rivers versus high elevation away from highways. Additional factors include land use policy and the population settlement trend in the region which led to a high population density in the western border (Willamette valley) and to more restricted public lands in the eastern part of the study site.

Analyses of slope values in southeast Zaire showed different results compared to the pattern presented in the central western Cascades of Oregon. It was found for example that in the case of southeast Zaire slope values for the extended forest definition (areas of at least 10 percent canopy cover) were lower (5.0 and 1.6) than that of the restricted forest definition (unmanaged forest (5.9 and 1.9)) in both distance gradients. Nevertheless, the difference in slope values between the two forest definitions was not significant because of the methodology used in defining both forest types. The forest cover defined as unmanaged forest cover in southeast Zaire was based not on tree ages as was the case in the central western Cascades of Oregon, but on the buffer zone around Lubumbashi which had a relatively low human disturbance impacts. The relative similarity between the pattern of the two forest definition types may also have been due to the types of tools used in tree cutting which force people to focus on smaller trees in the first place.

Slope values by distance gradients in southeast Zaire also were different. Slope values in the away-from-roads gradient were smaller (1.6 and 1.9) than in the away-from-cities gradient (5.0 and 5.9). Despite the significance of this difference (see SEs in Table 5.2), this result did not mean the distance was more a constraint in the away-from-cities than in the away-from-roads. The difference was found to be due to the forest cover contrast between the first distance class and the distance class from which forest cover was considered to be constant. There were less forested areas in the first distance class in the away-from-cities gradient because in part of high population density and activities than in the away-from-roads gradient. Resulting slope values were larger in the away-from-cities than in the away-from-roads in both forest definitions.

A further question asked at the end of this study was whether the distance decay model was valid for all land ownerships. Results showed that this was not always the case. Table 5.3 shows that some land ownerships have positive slope values (validating the distance decay model) while others have negative slope values. Those with positive slope values in both forest definition types and distance gradients included PNI forest cover in the central western Cascades of Oregon, as well as Urban and Rural lands in southeast Zaire. PNI land owners and each land owner in southeast Zaire were more likely to be affected by economic constraints. Insufficient financial capability and lack of adequate tools to overcome the constraint of distance were found to be major reasons to explain the similarity in trends with distance for these three classes of land owners, despite the difference in context.

Table 5.3. Fitted line ranges and slope values from each land ownership curve by study site.

Study sites	Distance variables	Ownership	Extended forest definition				Restricted forest definition			
			Range (km)	Slope	SE	r2	Range (km)	Slope	SE	r2
Central western Cascades of Oregon	Away from Cities	USFS	28.8-107.2	-0.39	0.04	0.71	28.8-107.2	-0.46	0.09	0.34
		BLM	0-62.4	0.48	0.25	0.09	0-62.4	1.03	0.14	0.59
		PNI	0-62.4	1.29	0.10	0.82	0-86.4	0.48	0.07	0.47
		PI	0-94.4	-0.06	0.06	0.02	0-94.4	-0.12	0.05	0.10
		WILD.	59.2-108.8	-1.00	0.12	0.69	59.2-108.8	-1.49	0.19	0.68
	Away from highways/roads	USFS	0-30.4	-0.09	0.12	0.03	0-30.4	-0.05	0.27	0.00
		BLM	0-20.8	-0.24	0.14	0.19	0-20.8	0.42	0.65	0.04
		PNI	0-17.6	4.32	0.37	0.94	0-17.6	5.42	1.37	0.64
		PI	0-19.2	0.25	0.10	0.37	0-19.2	-0.39	0.32	0.13
		WILD.	0-28.8	1.04	0.22	80.61	0-28.8	1.69	0.21	0.81
Southeast Zaire	Away from cities	URBAN	0-17.6	1.99	0.69	0.48	0-17.6	0.04	0.50	0.00
		RURAL	0-16	5.60	3.55	0.24	0-16.0	8.07	2.01	0.67
	Away from highways/roads	URBAN	0-35.2	2.92	0.29	0.83	0-35.2	2.25	0.34	0.69
		RURAL	0-4.8	6.79	1.71	0.94	0-6.4	6.11	1.70	0.87

On the other hand, mixed slope values were found to exist in other land ownership types in the central western Cascades of Oregon. Some land ownerships have positive slope values when considering one type of forest definition or one type of distance gradient, and negative slope values when considering another type of forest definition and another type of distance gradient. Those with such mixed slope values included PI, USFS, BLM, and Wilderness lands. Financial constraints were not considered a major reason to explain positive slope values of the distance decay curves in these cases. In the case of public lands forest cutting pattern followed a predefined policy, and were not dictated by the constraint of distance. Natural disturbances such as forest fires also influenced forest cover distribution. West-east forest cover change from Douglas fir forest type to a high elevation forest cover also explained the negative trend of slope values.

5.2.1.2 Comparison with other landscape analyses

Patterns of forest cover were also found to be a function of distance in other urban-to-rural forest gradient studies. Along a 20-km wide and 140-km transect from New York City, Medley et al. (1995) found that as the distance away from New York City increased forest cover also increased. They found for example that forest fragmentation decreased as the distance away from New York City increased. The mean forest patch size increased and forest-to-urban edges decreased. In the southern Appalachian Highlands, Wear and Flamm (1993) identified several factors which increased the likelihood of a forest cover disturbance. These factors include the type of land owner, and locational variables such as the distance to roads or market centers. In western Oregon, Ripple (1994) estimated prelogging forest patterns and found a direct relationship between distance from rivers and percent of mature and old-growth conifer forest cover with about 64 percent at distance 0 km and 80 percent at 10 km. Ripple (1994) selected riparian areas for his study because they were areas of known human activities.

In tropical environments, studies have also validated the distance decay model. Skole and Tucker (1993) found, for example, that deforested areas decreased from coastal areas, where also are located most of cities and urban centers, to the interior of Brazil. They also found deforested areas along major transportation corridors in the interior of the Amazon., and the hinterland away from roads was forested. Studies in Rondonia, Brazil (Dale et al. 1993), and Costa Rica (Sader and Joyce 1988) demonstrated that in addition to other variables, land use and land-cover changes also were a function of the distance to road network. The percentage of forest cover was higher away from road than near road network. In Zimbabwe, Armentrout (1996) and Vermeulen (1994) also validated the distance decay model in their investigation of forest cover along several firewood collection transects in State forests and Communal lands.

As was shown by results from this study, forest cover depended not only upon the distance away from roads or market centers, but also upon land ownership types. Armentrout (1996) and Vermeulen (1994) found a difference between Wilderness areas and Communal lands. Percents of forest cover were higher in Wilderness areas than in

Communal lands. Wear and Flamm (1993), for example, found that on private lands distance significantly influenced disturbances. No such relationships were found on public lands.

5.2.2 Deforestation model validation

5.2.2.1 Overview of results

The model predicted the central western Cascades of Oregon to be in category E (Recovery stage) and southeastern Zaire in category B (Rapid destabilization stage). Category E consisted of countries with almost zero population growth rate combined with a good socio-economic record, and the government forest policy which could have induced the increase of forest cover. On the other hand, category B consisted of countries with an increasing population growth rate, a stagnant to slow economic development, and a high forest loss rate.

The application of the deforestation model to the central western Cascades of Oregon did not produce the expected pattern. According to Table 5.4 the rate of forest cut was found to be increasing instead of the predicted zero or decreasing growth rate. The average rates of forest loss was about eight percent over the 16 year study period (0.5 percent/year) in the away-from-cities, and in the away-from-highways per distance class. The population growth rate also showed a trend different from the expected zero population growth rate. Population was estimated to have been increased by 53 percent from 1970 to 1990 (2.6 percent per year). These results suggest that based on the

Table 5.4 Percentage of forest change per distance class per land ownership

Country	Distance gradient	Land use	Distance classes													Mean	Mean/yr
			1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	61 to 65		
Oregon	Away from cities	USFS				13.49	5.63	12.27	10.75	10.86	11.21	10.47	12.49	9.86	1.77	9.9	0.6
		BLM	1.96	4.32	6.00	13.61	10.11	12.09	11.48	14.02						9.7	0.6
		PNI	0.36	0.27	0.88	1.68	6.18	6.96	13.03	15.59	6.44	9.18	16.37	29.63		7.8	0.5
		PI	2.85	7.69	3.75	8.83	9.87	22.53	24.05	22.54	20.57	13.44	6.75	15.03		13.6	0.9
		WILD.								8.38	10.03	1.94	0.72	0.99	0.45	3.7	0.2
		ALL	0.49	2.07	2.28	6.43	8.51	17.30	16.33	14.22	11.77	9.23	10.09	6.85	0.59	8.4	0.5
	Away from highways	USFS	11.14	11.84	8.86	6.63										9.7	0.6
		BLM	10.61	10.06	9.04											10.0	0.6
		PNI	1.19	4.15	8.25											3.2	0.2
		PI	11.61	21.14	12.75											15.8	1.0
		WILD.	1.79	0.83	0.35	1.46										1.0	0.1
		ALL	7.56	12.18	5.93	4.52										7.7	0.5
Zaire	Away from cities	Urban	54.55	61.40	34.62											55.9	3.5
		Rural	51.67	32.52	17.96	12.78	7.23	10.01	18.26	19.55	13.87	7.01	6.43			17.2	1.1
		ALL	55.17	49.26	18.07	12.78	7.23	10.01	18.26	19.55	13.87	7.01	6.43			20.0	1.3
	Away from roads	Urban	55.26	55.62	49.29	36.96	34.22									47.9	3.0
		Rural	18.35	17.16	16.98	17.86	17.58	14.19	13.28	40.98						16.2	1.0
		ALL	32.50	25.64	20.69	18.47	17.61	14.19	13.28	40.98						19.9	1.2

population growth rate pattern, the central western Cascades of Oregon falls in B category.

On the other hand, the application of the deforestation model to southeast Zaire was validated. Forest loss rates, whether in the away-from-cities or in the away-from-roads gradients, were high and conformed with model predictions. The overall forest loss rate during the study period was estimated to 20 percent (1.3 percent per year) per distance class. During the same study period the population growth rate was estimated to have been increased by about 36 percent (3.3 percent per year).

As a result of the model behavior in these two study sites, questions were raised related to the scale at which the deforestation model should be applied. In the case of Oregon, for example, it was found that local population growth rate was not the only factor having a direct and major impact on the high rate of forest loss. Causal factors of forest loss were found to also be external to the area and may have included high international timber demands. The deforestation model as specified here--where population growth was computed for local area only--ignored external factors influencing forest loss. Foreign markets, for example, may have played a major role in determining the rate of forest loss. The existence of foreign market pressures on resource utilization is common among developing countries in stage B, but not in southeast Zaire. It was also difficult considering such external factors to delineate the appropriate spatial scale to include in the model.

Forest losses were not always the result of external demands. In the case of southeast Zaire, for example, it was found that external factors were almost nonexistent. Causes of forest cuts were mostly within the study area and included shifting cultivation and fuelwood search to meet energy demands of local population. In this regard the increase of population was likely to have a direct impact on forest loss rate. From the overall pattern in the southeast Zaire it was concluded that the deforestation model was validated.

It was also found from this study that, in addition to population and economic factors, forest loss rates were affected by land ownership types. In the central western Cascades of Oregon, PI lands were identified as having the highest forest loss rate with 14 percent in the away-from-cities, and 16 percent in the away-from-highways analyses during the 16 year study period (0.9 percent and 1 percent of forest loss per year, respectively) (Table 5.4). In addition to fewer restrictions on private lands than on public lands, a larger targeted market and more financial capabilities to afford equipment for timber harvest were assumed to be major reasons among PI land owners for clearing more areas compared to PNI land owners, for example.

Forest cut policy had also an impact on the forest loss rate. Wilderness lands with more restriction, for example, had the least forest loss with four percent in the away-from-cities and one percent in the away-from-highways analyses during the same 16 year period (0.3 percent and 0.1 percent per year, respectively). These losses may have resulted from low to medium-severity fires (Morrison and Swanson 1990), and/or from a 1988 drier climatic conditions than in 1972 (Greenland 1993). They may also have resulted from classification errors because the central western Cascades change detection image by Cohen et al. (1996) was not 100 percent accurately classified. For example, of the total number of pixels they classified as harvest, 2 percent could have been attributable to 1988 vegetation map classification errors (Cohen et al. 1996).

Population density may have an impact on forest loss rates. In southeast Zaire urban lands have experienced higher forest loss rates (60 percent in the away-from-cities (3.8 percent per year), 48 percent in the away-from-roads (3.0 percent per year)) than rural lands (17 percent in the away-from-cities (1.1 percent per year) and 16 percent in the away-from-roads (1.0 percent per year)). Increased forest loss rates in urban lands were more related to higher population density than in rural lands.

The deforestation model also interacted with the distance decay model. In the central western Cascades of Oregon with an overall good economic condition the general forest loss rate depicted by the ALL category was not limited by distance. High forest loss rates were found away from cities and urban centers between the 26th and 45th distance classes where changes affected more than 10 percent of every sample on average (more than 0.6 percent of forest loss per year). Higher forest loss rates were also found in the away-from-highways gradient between the sixth and the tenth distance classes where also more than 10 percent of samples were identified as forest losses.

Because of poor economic conditions in Zaire, distance accessibility had an impact on the distribution of areas with high forest loss rates. Higher forest loss rates in the southeast Zaire study area were confined within the first 10 distance classes in both cases, away from cities and away from roads, corresponding to the average walking distance day (Allen 1985, Hart and Hall 1996).

In western Oregon, at land ownership scale, high forest losses were in most cases located away from cities. This is especially true in the analysis of the away-from-highway gradient where USFS, BLM, PI in the central western Cascades had all high forest loss rates starting from the 26 distance classes. The pattern of forest losses within these land ownership types is similar to that presented by the rates in category ALL (Table 5.4).

High forest loss rates were also found near highways and cities. Urban and Rural lands in southeast Zaire, for example, had high forest loss rates within the first 10 distance classes.

5.2.2.2 Comparison with other landscape changes

Although forest loss rates by distance gradients were not specifically addressed, forest loss rates were detected in most studies in the United States of America (Cohen et al. 1996, Turner et al. 1994, Spies et al. 1994) and in developing countries (Rudel and Roper 1996, Biodiversity Support Program 1993 (Table 10), Skole and Tucker 1993, Bruneau 1989a, Rudel 1989, Myers 1989, Sader and Joyce 1988, Soyer and Wilmet 1986, Allen and Barnes 1985). In the Olympic Peninsula, Washington, and the southern Appalachian highlands of western North Carolina, Turner et al. (1994) found, for example, that forested areas decreased on both private and US National Forest lands from 1975 to 1986. They found that the decrease was more pronounced on private lands than on US National Forest lands. The average forest loss per year was estimated to 0.02 percent on US National Forest lands and 0.12 on private lands. On the other hand, Spies et al. (1993) found that between 1972 and 1988 conifer forest lost about 13 percent (0.8 percent per year) in Oregon. Conifer forest losses were greatest on private lands with 22.4 percent (1.4 percent per year), and the least on Wilderness lands with about 0.1 percent loss per year.

Differences exist between this study and Spies et al.'s (1994) results. According to Table 5.4 of our actual study results, the overall forest loss rate in the central western Cascades was about 0.5 percent per year. Forested areas in Wilderness lands lost about 0.2 percent per year. In addition to accuracy errors, these differences may also be attributable to the difference between the definition of conifer forest cover used by Spies et al. (1994) and our forest definition, and to the difference between the size and the location of their study sites and our more than 12 thousands square kilometers study site.

Differences between forest loss rates from this study and other developing countries studies also existed. The overall tropical moist forest loss was 1.8 percent per year, and it was estimated at 0.4 percent and 2.3 percent per year in Zaire and Brazil, respectively (Skole and Tucker 1993, Myers 1989). In Costa Rica (Sader and Joyce 1988) forest losses were estimated at 7.7 percent per year in 1983. In southeast Zaire, Bruneau (1989a) and Soyer and Wilmet (1986) estimated forest loss around Lubumbashi to vary between 3.0 and 4.0 percent per year. Our actual study result estimate was about 1.3 percent per year in southeast Zaire.

Several reasons explained the difference within developing countries. Differences may have been due to classification errors. Southeast Zaire satellite image classification errors existed and could not be accurately evaluated. The technique other studies used to evaluate forest losses may have had errors as well. Differences in the type of tropical forest and the type of forest definition used may also explain the disparity. Additional reasons include the time span used in the estimation, and climatic conditions at the time of data collection.

The spatial extent of study areas may also explain differences in developing country forest loss rate estimates. This is especially true between the actual study and studies by Bruneau (1989a) and Soyer and Wilmet (1986). Bruneau (1989a) and Soyer and Wilmet (1986) study area was limited to within 50 km of Lubumbashi while this actual study covers more than 40 thousands km^2. Their results (3 to 4 percent per year) are close to ours when considering only Urban lands. Indeed, according to the away-from-cities gradient the yearly percentage of forest loss rate is 3.8 percent, and 3.0 percent according to the away-from-roads gradient.

Was the deforestation model also validated by other studies? Allen and Barnes (1985) found that in 39 developing countries deforestation was significantly related to the rate of population growth and not related to the growth of per capita GNP. Rudel (1989) found that in some places, deforestation is a process induced by increasing global demands for timber. In other places, Rudel (1989) argues that population growth alone causes deforestation, and still in other places he acknowledges that capital expenditures and population growth interact in creating conditions which increase forest losses. Rudel's (1989) analyses also indicated that political-economic factors contribute to forest losses, especially forest cuts, in some circumstances.

5.3 Recommendations and conclusions

A general recommendation from this study is a cautious attitude toward the applicability of these two models. In this study the validity of distance decay and deforestation models were shown to be dependent upon several factors, including the natural distribution of forest cover on the landscape, the type of forest cover, topographic and physical characteristics of the environment, land use policy, land owners, the socio-economic fabric of the environment, and the extent of the targeted market.

Despite the amount of unknown needed for validation of these models, this study has helped lay the groundwork for future researchers to understand the relationships among forest cut patterns in industrialized and less developed countries, and above all global environment changes. The methodology and results presented have hopefully created an environment for further studies, and possible application of remote sensing, distance decay model, deforestation model to forest environments between industrialized and developing countries. Additional and more detailed data on forest stand structure and texture, and forest product demands in different countries are needed to sharpen the effectiveness of these two models.

Bibliography

Abler, R., J.S. Adams, and P. Gould. 1971. *Spatial organization. The geographer's view of the world. Englewood* Cliffs, New Jersey: Prentice-Hall, Inc.

Agee, J.K. 1993. Fire ecology of Pacific northwest forests. Washington, D.C.: Island Press.

Allen, J.C. 1985. Wood energy and preservation of woodlands in semi-arid developing countries. The case of Dodoma region, Tanzania. *Journal of Development Economics* 19:59-84.

Allen, J.C. and D.F. Barnes. 1985. The causes of deforestation in developing countries. *Annals of the Association of American Geographers* 75(2):163-184.

Amelung, T. and M. Diehl. 1992. *Deforestation of tropical rain forests: Economic causes and impact on development.* Tübingen (Germany): J.C.B. Mohr (Paul Siebeck).

Anderson, D. 1987. *The economics of deforestation: A case study in Africa.* Baltimore: The Johns Hopkins University Press.

Armentrout, C.L. 1996. Estimating the impacts of community use of the Mavuradonha Wilderness in Zimababwe. Unpublished M.S. Research paper, Department of Geosciences, Oregon State University.

Bailey, R. 1982. Development in the Ituri Forest of Zaire. *Cultural Survival Quarterly* 6(2):23-25.

Bein, F.L. 1992. Von Thunen along the Nile. *Geographical perspectives* 63:49-57.

Biodiversity Support Program. 1993. *Central Africa: Global Climate Change and Development—Technical Report*. Landover, Maryland: Corporate Press.

Bolsinger, C.L. 1972. Changes in commercial forest area in Oregon and Washington 1945-70. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experimental Station. PNW-46.

Bruneau, J.C. 1989a. Lubumbashi (Zaïre), une clairière vue du ciel. Connaissance et cartographie de l'environment péri-urbain et de sa dynamique. *Espace Tropicaux* 1:187-209.

Bruneau, J.C. 1989b. Pauvreté urbaine et initiatives populaires au pays du cuivre du Zaire méridional. In *Pauvreté et developement dans les pays tropicaux. Hommage au Professeur Guy Lasserre.* ed. Université de Bordeaux III, 433-456. Talence: CNRS.

Bruneau, J.C. and K. Kakese. 1989. L'émergence d'un espace agricole né de la ville autour de Likasi (Zaire). *Espaces Tropicaux* 1:237-252.

Bruneau, J.C. and M.T. Lootens-De Muynck. 1990. Densité de la population. In *Atlas de Lubumbashi*, ed. J.C. Bruneau, and M. Pain, 29-30. Nanterre: PUBLIDIX.

Bruneau, J.C. and M. Pain. (ed.) 1990. *Atlas de Lubumbashi*. Nanterre: PUBLIDIX.

Bureau d'Études d'Aménagements Urbains. 1982. *Aménagement du territoire: Esquisse d'un schéma national*. Kinshasa: Departement des travaux publics et de l'aménagement du territoire.

Burgess, R.L. and D.M. Sharpe. 1981. Introduction. In *Forest island dynamics in man-dominated landscapes*. ed. R.L. Burgess and D.M. Sharpe, 1-5. New York: Springer-Verlag.

Burke, C.J. 1979. Historic fires in the central western Cascades, Oregon. Unpublished M.S. Thesis, Department of Geography, Oregon State University.

Campbell, B. (ed.) 1996. *The Miombo in transition: woodlands and welfare in Africa*. Bogor, Indonesia: Center for International Forestry Research.

Cane, M.A., G. Eshel, and R.W. Buckland. 1994. Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea surface temperature. *Nature* 370: 204-205.

Castiaux, N., M. Massart, and J. Wilmets. 1991. Evironmental study of a tropical african urban areas by multitemporal satellite imageries (Lubumbashi in Zaire, Central Africa). *Proceedings of the 24th International Symposium on Remote Sensing of Environment*, 24:161-169.

Celander, N. 1983. Miombo woodlands in Africa—Distribution, Ecology and patterns of land use. Uppsala: International Rural development. Working paper No.16.

Cohen, W.B., M. Fiorella, J. Gray, E. Helmeir, and K. Anderson. 1996. Mapping forest harvest activity between 1972 and 1993 in western Oregon using landsat imagery: I. methods development and error assessment (Unpublished).

Cohen, W.B., T.A. Spies, and M. Fiorella. 1995. Estimating the age and structure of forests in a multi-ownership landscape of Western Oregon, U.S.A. *Int.J. Remote Sensing* 16(4):721-746.

Cox, T.R. 1988. The North American-Japanese timber trade: A survey of its social, economic, and environmental impact. In *World deforestation in the twentieth century*, ed. J.F. Richards, and R.P. Tucker. 165-186. Durham: Duke University Press.

Cronon, W. 1991. *Nature's metrolopolis. Chicago and the Great West*. New York: W.W. Norton & Company.

Dale, V.H., R.V. O'Neill, M. Pedlowski, and F. Southworth. 1993. Causes and effects of land-use change in central Rondonia, Brazil. *Photogrammetric Engineering and Remote Sensing* 59:997-1005.

Dikumbwa, N. 1990. Facteurs écoclimatiques et sur les cycles biogéochimiques en forêt dense sèche Zambezienne (Muhulu) du Shaba méridional. *GEO-ECO-TROP* 14(1-4):1-159.

Duvigneaud, P. 1958. La vegetation du Katanga et de ses sols metalliferes. *Bulletin de la Societe Royale de Botanique de Belgique* 90(2):127-283.

Food and Agriculture Organization of the United Nations (FAO). 1992. *Report on forest resources assessment 1990. Paper to the FAO Committee on forestry*, Eleventh session. COFO-93/2. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). 1993a. *Forest resources assessment 1990 Tropical countries*. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). 1993b. The challenge of sustainable forest management: What future for the world's forests? Rome: FAO.

Foster, D.R. 1993. Land-use history and forest transformations in Central New England. In *Humans as components of ecosystems. The ecology of subtle human effects and populated areas*, ed. M.J. McDonnell, and S.T.A. Pickett. 91-110. New York: Springer-Verlag.

Fotheringham, A.S. 1981. Spatial structure and distance-decay parameters. *Annals of the Association of American Geographers* 71(3):425-436.

Franklin, J.F. and C.T. Dyrness, 1988. *Natural vegetation of Oregon and Washington*. Corvallis : Oregon State University Press.

Fraser, A.I. 1988. Fuelwood: A review of its global use. *Outlook on Agriculture* 17(1):7-9.

Gedney, D.R. and B.A. Hiserote, 1989. Changes in land use in Western Oregon between 1971-74 and 1982. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. PNW-RP-165.

Grainger, A. 1993. *Controlling tropical deforestation*. London: Eastscan Publications.

Greenland, D. 1993. The climate of the H.J. Andrews experimental forest and its regional synthesis. Final Report. Eugene, Oregon: U.S.D.A. Forest Service, Pacific Northwest Research Station. PNW 92-0221.

Haggett, P. 1983. *Geography A modern synthesis*. New York: Harper & Row, Publishers.

Haggett, P., A.D. Cliff, and A. Frey. 1977. *Locational analysis in human geography*. New York: John Wiley & Sons.

Hart, J.A. and J.S. Hall. 1996. Status of eastern Zaire's forest parks and reserves. *Conservation Biology* 10(2):316-327.

Higgins, G.M. and A.H. Kassam. 1984. Land, food and population in Africa. In Advancing Agricultural production in Africa. ed. Hawksworth, D.L. Proceedings of CAB's first scientific conference. pps. 337-341.

Jackson, P.L. and A.J. Kimerling. 1993. *Atlas of the Pacific Norhwest*. Corvallis: Oregon State University Press.

Kalapula, E.S. 1989. Woodfuel situation and deforestation. *Ambio* 18(5):293-294.

Kauth, R.J. and G.S. Thomas. (1976). The tasseled cap--a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. Proceedings on the Symposium on Machine Processing of Remotely Sensed Data, 4(b):41-51.

Kikombo, I.N. , J.A. Jones, and D. O. Wallin. 1995. Impacts of pixel size variation on the central western Cascades of Oregon image data. Manuscript in preparation. Forest Sciences Laboratory, Oregon State University, Corvallis, Oregon.

Laarman, J.G. 1988. Export of tropical hardwoods in the twentieth century. In *World deforestation in the twentieth century*, ed. J.F. Richards, and R.P. Tucker. 147-163. Durham: Duke University Press.

Laclavière, G. (Directeur). 1979. *Atlas de la République du Zaïre*. Paris: Éditions Jeune Afrique.

Lal, R. 1984. Management of terrain, soil and water in humid regions of Sub-Saharan Africa. In Advancing Agricultural production in Africa. ed. Hawksworth, D.L. Proceedings of CAB's first scientific conference. pps. 347-352.

Lanly, J. 1982. Tropical forest resources. FAO Forestry Paper No 30, Rome: FAO.

Lanly, J.P. and Y.S. Rao. 1982. *Tropical forest resources assessment project (Framework of GEM)*. Rome: Food and Agricultures Organization of the United Nations (FAO) and the United Nations Environmental Program (UNEP).

Laporte, N., C. Justice and J. Kendall. 1995. Mapping the dense humid forest of Cameroon and Zaire using AVHRR satellite data. *Int. J. Remote Sensing* 16(6):1127-1145.

Leonard, H.H. 1983. *Managing Oregon's growth. The politics of development planning*. Washington, D.C.: The conservation Foundation.

Lillesand, T.M. and R.W. Kieffer. 1987. *Remote sensing and image interpretation*. New York: John Wiley & Sons.

Lootens-De Muynck, M.T., B.D. Mbuyi, and K. Binzangi. 1982. Typologie et aspect socio-économiques de quelques villages de bûcherons et charbonniers des environs de Lubumbashi (Shaba, Zaire). *Geo-Eco-Trop* 6(1):45-63.

Loy, G.W. (dir) 1976. *Atlas of Oregon*. Eugene: University of Oregon.

McDonnell, M.J. and S.T.A. Pickett. 1990. Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. *Ecology* 71(4):1232-1237.

McGarigal, K. and B.J. Marks. 1995. FRAGSTATS: The spatial pattern analysis program for quantifying landscape structure. Portland, OR: U.S.D.A., Forest Service, Pacific Northwest Research Station. PNW-GTR-351.

Magadza, C.H.D. 1994. Climatic change: some likely multiple impacts in southern Africa. *Food Policy* 19(2):165-191.

Malaisse, F. 1990. La couverture vegetale. In *Atlas de Lubumbashi*, ed. J.C. Bruneau, and M. Pain, 29-30. Nanterre: PUBLIDIX.

Malaisse, F. 1978. The miombo ecosystem. *Natural Resources Research* 24:589-606.

Malaisse, F. and K. Binzangi. 1985. Wood as a source of fuel in upper Shaba (Zaire). *Commonwealth Forestry Review* 64(3):227-240.

Mather, A.S. 1990. *Global forest resources*. Portland: Timber Press.

Mbenza, M. 1990. Le climat de Lubumbashi. In *Atlas de Lubumbashi*, ed. J.C. Bruneau, and M. Pain, 29-30. Nanterre: PUBLIDIX.

Medley, K.E., M.J. McDonnell, and S.T.A. Pickett. 1995. Forest-landscape structure along an urban-to-rural gradient. *Professional geographer* 47(2):159-168.

Miller, D. and R. Rose, 1985. Changes in the urban land base and the consequences for the future of forestry. In *Investments in forestry. Resources, Land use, and public policy*, ed. R.A. Sedjo, 73-119. Boulder: Western Press.

Moindrot, C. 1992. Les systemes agraires. In *Encyclopedie de la geographie*, ed. A. Baily, A. et al. 463-487. Paris: Economica.

Morrison, P.H. and F.J. Swanson. 1990. Fire history and the pattern in a Cascades range landscape. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. PNW-GTR-254.

Myers, N. 1980. *Conversion of tropical moist forests*. Washington, D.C.: National Academy of Sciences.

Myers, N. 1989. Deforestation rates in tropical forest and their climatic implications. London: Friends of the Earth Trust.

Nations, J. and D. Komer 1982. Indians, immigrations and beef exports: Deforestation in Central America. *Cultural Survival Quarterly* 6(2):8-12.

Perlin, J. 1993. A forest journey: The role of wood in the development of civilization. Cambridge: Havard University Press.

Perry, D.A. 1994. *Forest ecosystems*. Baltimore: The Johns Hopkins University Press.

Peters, G.L. and R.P. Larkin. 1989. *Population geography*. Dubuque: Kendall/Hunt publishing company.

Postel, S. 1988. Global view of tropical disaster. *American Forests* November/December:25-71.

Richards, J.A. 1993. Remote sensing digital image analysis: An introduction. New York: Springer-Verlag.

Richards, J.F. and R.P. Tucker. (eds). 1988. *World deforestation in the twentieth century*. Durham: Duke University Press.

Ripple, W.J. 1994. Historic spatial patterns of old forests in western Oregon. *Journal of Forestry* 92(11):45-49.

Robert, M. 1950. *Le Katanga physique*. Bruxelles: Presses de l'imprimerie liberator S.A.

Rostow, W.W. 1971. *The stages of economic growth: A non-communist manifesto*. Cambridge: Cambridge University Press.

Rudel, T. 1989. Population, development, and tropical deforestation: A cross-national study. *Rural sociology* 54(3):327-338.

Rudel, T. and J. Roper. 1996. Regional patterns and historical trends in tropical deforestation, 1976-1990: A qualitative comaprative analysis. *Ambio* 25(3):160-166.

Sader, S.A. and A.T. Joyce. 1988. Deforestation rates and trends in Costa Rica, 1940 to 1983. *Biotropica* 20(1):11-19.

Sader, S.A., T.A. Stone, and A.T. Joyce. 1990. Remote sensing of tropical forests: An overview of research and applications using non-photographic sensors. *Photogrammetric Engineering and Remote Sensing* 56(10):1343-1351.

Salacuse, J.W. 1985. The National land law system of Zaire. Report to the Land tenure center, University of Wisconsin and USAID. Kinshasa. Zaire.

Sessions, J. (Coordinator). 1990. *Timber for Oregon's tomorrow: The 1989 update*. Corvallis, OR: Forest Research Laboratory, College of Forestry, Oregon State University.

Skole, D. and C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. *Science* 260:1905-1909.

Sollins, P. 1995. Western Oregon forest land ownership database. Unpublished map, Department of Forest Science, Oregon State University.

Soyer, J. and J. Wilmet. 1986. Environmental changes around African tropical towns (Lubumbashi, Zaire; Bamako, Mali) from Landsat MSS data. *Proceedings of the twentieth International Symposium on Remote Sensing of Environment*, 20:507-519.

Spies, T.A., W.J. Ripple, and G.A. Bradshaw. 1994. Dynamics and pattern of a managed coniferous forest landscape in Oregon. *Ecological Applications* 4(3):555-568.

Stock, R. 1995. Africa South of the Sahara. A geographical interpretation. New York: The Guilford Press.

Taylor, G.H. and A. Bartlett. 1993. The climate of Oregon, climate zone 2. Special Report 914. Corvallis, OR: Willamette valley Agricultural Experiment Station, Oregon State University.

Teensma, P.D.A. 1987. Fire history and fire regimes of the central western Cascades of Oregon. Unpublished Ph.D. Dissertation, Department of Geography, Oregon State University.

Turner, M.G., D.N. Wear, and R.O. Flamm. 1994. Land ownership and land-cover change in the Southern Appalachian highlands and the Olympic peninsula. (Unpublished).

Turner II, B.L., and W.B. Meyer. 1993. Environmental change: The human factor. In *Human as components of ecosystems*, ed. M.J. McDonnell and S.T.A. Pickett, 40-50. New York: Springer-Verlag.

United Nations Environment Programme, 1992. *World atlas of desertification*. London: Edward Arnold.

U.S. Department of Commerce Bureau of the Census, 1971. 1970 Census of population. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Commerce Bureau of the Census, 1991. 1990 Census of population. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Commerce National Oceanic and Atmospheric Administration. 1973. Monthly climatic data for the world. 26(4):1-41.

U.S. Department of Commerce National Oceanic and Atmospheric Administration. 1989. Monthly climatic data for the world. 42(5):1-63.

Vanoverstraeten M. and P. Trefois. 1993. Detectability of land systems by classification from Landsat Thematic Mapper data. Virunga National Park (Zaire). *International Journal of Remote Sensing* 14(15):2857-2873.

Vermeulen, S.J. 1994. Consumption, harvesting and abundance of wood along the boundary between Mafungabusi state forest and Gokwe Communal area, Zimbabwe. Unpublished M.S. Thesis, Department of Biological Sciences, University of Zimbabwe, Harare.

Vogelmann, J.E. 1995. Assessment of forest fragmentation in Southern New England using remote sensing and geographic information system technology. *Conservation Biology* 9(2):439-449.

Wall, B. 1972. Log production in Washington and Oregon: An historical perspective. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experimental Station. PNW-42.

Waring, R.H., H.R. Holbo, R.P. Bueb, and R.L. Fredriksen. 1978. Documentation of meteorological data from the Coniferous Forest Biome primary station in Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. PNW-GTR-73.

Wear, D.N. and R.O. Flamm. 1993. Public and private disturbance regimes in the Southern Appalachians. *Natural Resource Modeling* 7:379-397.

Wiens, J.H. 1977. Land use distributions and changes in the Willamette valley in relation to soil characteristics. Unpublished Ph.D. Dissertation, Department of Soil Science, Oregon State University.

Williams, M. 1989. *Americans and their forests: A historical geography*. Cambridge: Cambridge University Press.

World Bank, 1975. World Bank atlas: Population, per capita product and growth rates. Washington, D.C.: The World Bank.

World Resources Institute (The), 1990. *World Resources 1990-1991*. New York: Oxford University Press.