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Article

Characteristics and Practices of Land Use in the Central Andes of Peru: A Case Study

David Lopez Cornelio*

ABSTRACT

Three major types of land use in Huanuco (central province in Peru) are discussed on the basis of cartographical and socioeconomical data, document reviews, and field surveys. This traditional agricultural region has critical importance for being the gateway for timber transportation from the eastern mountainous tropical forests where also extensive coca plantations forced human emigration, land abandonment, and deforestation. In Peru, ancient agricultural systems still coexist with the intensification of commerce. Property types, rates of land use changes, as well as the use of and the number of farms, are discussed. The type of land use varies periodically among each district within the province. State policies not fully structured indicate a weak understanding of the real needs of the Andean society. From now on they must combine elements of tradition, central planning, and markets.
Keywords: Andes, land use change, land reform, property rights, traditional systems.

INTRODUCTION

The Andes is a mosaic of local habitats with broad tolerant crops overlapping, high elevations, mostly arid, and high eco climatic heterogeneity per area unit (DENEVAN, 2000). Pre-Columbian intensive cultivation supported dense and complex states, but since the conquest it became wasteful of land and labor (KAY, 1998), in contrast with the shift from quantity to quality in food production of European countries (EVANS *et al.*, 2002). Other countries intend to make compatible communal/traditional land tenure systems with structural adjustment and economic reform (RIDELL, 2000).

The effects of population growth are uncertain (SCHERR, 1999), with the cost of land relative to labor increasing as people change their practices to offset declines in productivity due to intensification. Land degradation and intensification occur simultaneously and incomes may increase during degradation (BIRCH-THOMSEN, 2001). In Peru, the costs of soil erosion in Peru (in 73% of its area) are between 5-10% of the agricultural sector production (YOUNG, 1998), affecting the people through reduced food supplies, lower income and increased landlessness. Inadequate institutions can be a main factor for land degradation (SCHWEIK *et al.*, 1997) but also adjustments through them positively affect the environment (MAZZUCATO and NIEMEIJER, 2002).

The study describes main land use of a representative province in the central Andes of Peru. Even though the patterns of land use reflect the current economic model (SILBERSTEIN and MASER, 2000) and are bound to the local development processes, the paper focuses on the actual physical condition of land use in the ten districts of the province. The hypothesis is that the prevalent conditions of land use in the province are able to support economic growth with reduced land degradation within the framework of globalization, which currently tend to widen inequality in developing countries (Van GINKEL *et al.*, 2002). Although a successful combination of local and global know-how is a precondition for development, neo liberal policies in the Andes must be carefully monitored; the irony is that their leading proponents are from countries that heavily subsidize their own agricultural sectors.

MATERIALS AND METHODS

Location

The province of Huanuco is located in the central Andes (Fig. 1) at 08°44'55"-10°20'21"south latitude, and 74°39'00"-77°30'00"west longitude, it has 10 districts with a total area of 409,171ha. The landscape comprehends three main watersheds with semiarid mountains, except the humid tropical

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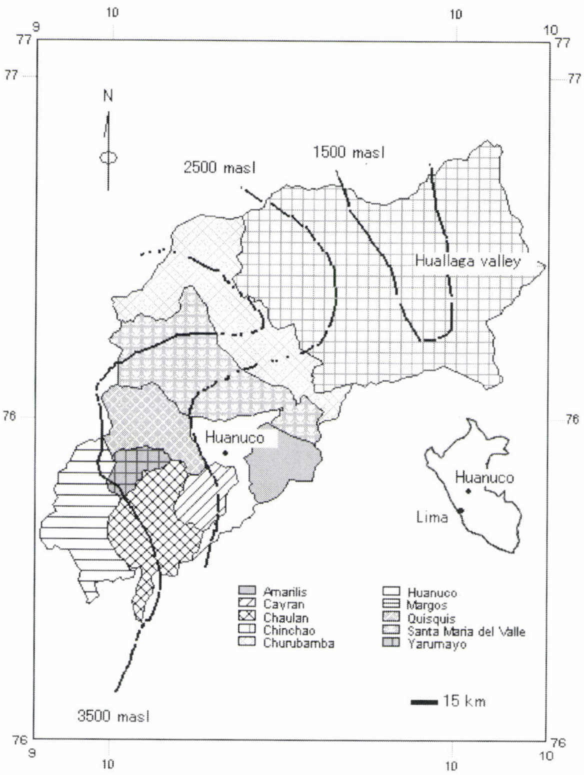

Fig. 1 Location of Huanuco province with delimitation of districts

conditions of Huallaga valley. In this last, 7,217ha (IVES, and MESSERLY, 1999) are planted with coca (*Erythroxylum coca*) with revenues around 4,000$/ha/year (TAMMEN, 1991), double that is realizable from the cultivation of legal crops (HUNEFELDT, 1997). Because of immigration, shantytowns around Huanuco city proliferated. Policies failed to treat land as natural capital that progressively increases its value (SILBERSTEIN and MASER, 2000), but property rights policies alone cannot reduce environmental impacts (KEIPI, 1999).

The population is not equally distributed. Huanuco district has 74,676 habitants, even though covers 4.27% of the provincial area, the same case in Amarilis (3.38% of the total area) with 60,762 habitants, while Chinchao district (44.5% of the total area) has only 22,011 habitants (Table 2). However, the rates of areas suitable for agriculture are relatively high in Huanuco, Amarilis, Chinchao and Santa Maria del Valle (SMValle) (Fig. 8).

Methods

Official statistical data, based on the agricultural unit (AU) from the last two provincial agricultural censuses (1986 and 1996), were analyzed. An agricultural unit is an extension that may comprehend many patches at different altitudes with a unique owner and in the same district. Field visits were carried

Table 1 Contents of questionnaire for field interviews (adapted from MANTANG and SHAOFANG, 1995)

The crops
* Crops raised and purpose.
* Agricultural cycle organization
* Main constraints for yields improvement
The livestock
* Type of livestock and purpose
* Grazing organization
Natural vegetation and trees
* Availability of natural/planted forests. Uses.
* Rights on forest resources. Potential problems.
* Potential multiple use of trees on farms
* Constraints to establish forest plantations.

out from October-December 2000 in 4 districts on farming methods and land management according to a questionnaire (Table 1). The results are discussed in the following subtitles. The methodology considers that the results could be put into a wider context using census and household data in which an important milestone is the land reform of the early 1970s (COTLEAR, 1989).

A map of land use suitability for a central Andean province was built by overlaying 4 land type maps of 1985 (forests, ecological zones, climatic and soils) at a scale of 1/250,000. In the overlaying operation, made by pairs of raster maps, pixels on the same positions in both maps are compared and the occurring combinations of identifiers or values of pixels are stored. These combinations give an output cross map and a cross table. The cross table includes the combinations of input values or IDs, the number of pixels and the area for each combination (ILWIS, 2003). The selected descriptor of each polygon in the resultant map (Fig. 6) is the most concurrent among the four descriptors of each land type map for that polygon (Table 2). The result is a map of optimal land use (ideal map) suitable to the biophysical characteristics of each site, on which the extent of cultivated areas (from a Landsat TM image) was overlaid to get the extension of cropped areas per district. The correlation between the actual (regional census) and ideal distribution of land areas per type was measured by the Spearman's rank correlation coefficient (the population of both variables in the bivariate analysis are not normally distributed). To determine the rate of land use conversion around the city of Huanuco, polygons demarking urban sprawl drawn on aerial photographs with 33 years of time difference were compared.

Table 2 Weights assignment table per types of each map. Ranks 0 and 3 indicate the lowest and highest priorities for land use respectively, chosen according to the description. Final classes after overlaying are denoted as a (agriculture), f (forestry), g (grazing) and c (conservation)

MAP	TYPES	DESCRIPTION	RANKING 0	1	2	3
Climatic	A(r)A'H4	Hot weather, yearlong rainy, very humid.	a	g	f	c
	A(r)B'2H3	Warm weather, yearlong rainy, humid.	c	a	g	f
	B(i)B'1H3	Weather semicalid, scarce rains on winter, humid.	c	g	a	f
	B(o,i)B'3H3	Semicold weather, scarce rains on winter and autumn, humid.	g	a	f	c
	B(0,I)C'H3	Cold weather, rainy, scarce rains on winter and autumn, humid.	a	g	f	c
	C(I)C'H3	Semidry weather, cold, scarce rains on winter, humid.				
Forests	Bh mo	Mountainous environment, shallow soils, exhuberant vegetation.	a	g	f	c
	Cp	In Andean highlands above 3,800 masl, cold, variety of grasses, extensive grazing.	a	g	f	c
	Df	Mainly located at the lower levels of mountaineous forests. Deforested areas occupied by secondary vegetation on different stages of development.	a	c	g	f
	Msh	Shrublands (perennial and decidual), average temperature: 9-18	a	g	c	f
	Pj	Andean graaslands of hard leaves. Above 3800 masl.	a	f	c	g
Soils	A2s(r)	In andean valleys, suitable for annual crops.	c	f	g	a
	A3c-P1c	Conformed by two groups of soil use capacity: (1) with agricultural vocation and weather deficiencies and (mainly tubers on slopes lower than 15%) (2) with pastures vocation, also with weather limitants (on slopes over 20%).	c	f	g	a
	F3c-P2e-A2sc	With vocation for reforestation on areas with low soil quality (40% of the asociation total extension), with vocation for pastures on soils with medium quality (30%) and protected areas on soils with severe restrictions.	a	c	g	f
	P1c-X	Located on high Andean plains, suitable for pastures on low slopes and deep soils, superficial soils on slopes over 75% are denominated of protection.	a	g	f	c
	P2e-X	Steepy phisiography, mainly of protection. Pastures can be produced with suitable practices.	a	f	g	c
	X-F2e	Distributed on mountaineous tropical forests, because of the topography (slopes over 75%) only 30% of its total extension can be used in forestry.	a	g	f	c
	X-F3e	Distributed on mountaineous tropical forests, because of the topography forestry use can be done on slopes less than 50% with careful harvesting systems.	a	g	f	c
	X	Because of topographical and soil limitations cannot be used for forestry, pastures or agricultural activities. Have value for minning, ecotourism and hydrologic cycle maintenance.	a	g	f	c
Ecological zones	bh-PT	Humid forest premountaineous tropical. Total Precipitation/year: 1000-2000mm Annual biotemperature (average): 16-24C	c	f	a	g
	bp-PT	Pluvial forest premountaineous tropical. Total Precipitation/year: 4000-8000mm Annual biotemperature (average): 16-24C	a	g	f	c
	bs-PT	Dry forest premountaineous tropical. Total Precipitation/year: 500-1000mm Annual biotemperature (average): 16-24C	c	g	f	a
	bs-MBT	Dry forest low mountaineous tropical. Total Precipitation/year: 500-1000mm Annual biotemperature (average): 12-16C	c	g	f	a
	bmh-MT	Very humid forest mountaineous tropical. Total Precipitation/year: 1000-2000mm Annual biotemperature (average): 6-12C				
	bp-MT	Pluvial forest mountaineous tropical. Total Precipitation/year: 4000-8000mm Annual biotemperature (average): 6-12C	a	g	f	c
	pp-Sat	Pluvial param tropical subalpine	a	g	f	c

RESULTS

Land Reform

The central government has tried to formalize property rights 22 times since colonial times (DE SOTO, 2000). The land legislation laws of 1849, 1853 and 1909, established various means of access to land in the Amazonian region: land could be bought, received as a temporary or permanent concession, appropriated at no cost, or granted under colonization contract (SANTOS-GRANERO and BARCLAY, 1998). The agrarian reform initiated in 1969-1980, the most striking in Latin America (KAY, 1998), changed the land structure in social terms, but not the land concentration and agricultural output. The argument was that redistributing land was better than costly investments in modern technology, which may also displace labor, and could increase land productivity more easily. At that time, 0.3% of the agricultural units (AU) owned 66% of the agricultural land, while 50% of the smaller AU owned only 2.2% of the land (COTLEAR, 1989). The enforcement of a development model by the central government intended to gain popular support, destroy oligarchic domination, control conflict and rural discontent, improve income distribution, stop massive migration to the cities, and create a stable sector for an expanding internal market. The designed system of price controls and monopoly forced the country to spend 25% of its annual budget on food imports (HUNEFELDT, 1997) and land rents fell from 20% to 2-3% of total household incomes (Van GINKEL *et al.*, 2002). The reform was applied by regions and not by agricultural units to gain time and broader area (MATOS and MEJIA, 1984), moreover, it largely excluded the mass of small holders (the most vulnerable to temporal unemployment) introducing new factors of social differentiation. The probe is that after a decade of land redistribution, peasants which grouped into the *National Confederation of Agriculture* (CAN) and the *Peasants Confederation of Peru* (CCP) forcefully occupied land that was assigned to the created cooperatives and agricultural societies (MATOS and MEJIA, 1984).

The cooperatives seldom succeeded, few of them were able to repay their accumulated debts, and the majority was converted into communities during the 1980s. Their number reached an all-time high of 5,680 in 1994 (HUNEFELDT, 1997). The conversions were authorized by changes in the basic land reform legislation, and were put into effect after majority votes of the cooperative members in each case. Preferences of the people involved were contrary to the original intention.

The main changes in the agrarian structure were: 1) Land owned by rich landlords passed to the workers, 2) the quantity and the quality of land received was variable and unequal, 3) the reform modified the worker status, from salaried to cooperative-salaried, 4) the land received in marginal areas consolidated the traditional production systems, and 5) the land reform affected only 36.7% of AU in the Andes (in contrast

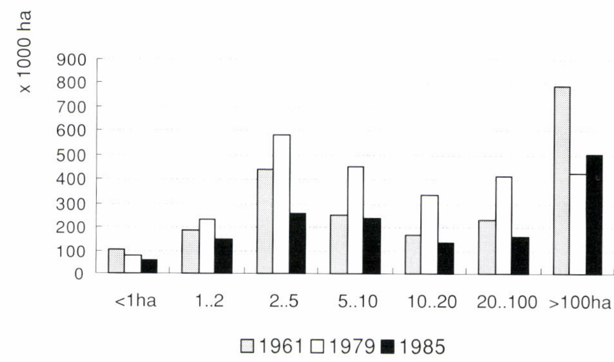

Fig. 2 Evolution of the agrarian structure in Peru (GONZALES de OLARTE, 1994)

with 64.5% of AU affected in the coastal region). After 1980, privatization returned the structure of the AU distribution to near that of the 1960s trend. Fig. 2 shows the evolution of the agricultural unit dimension (changes in percentage from 1961 to 1985) (Gonzales de Olarte, 1994). The total area of AU of 5-10ha increased 4.1%, AU of 1-2ha and AU of 10-20ha increased only 1.3 and 1.4% respectively. The total area of farms within 2-5ha and larger than 100 ha decreased 3% and 2.8% respectively. Globally, from the 30.6 million ha of agricultural and grazing farms in the country, 10 million were affected by the reform, 11 million (mostly grazing farms) came under common property and 10 million are small and medium private holdings. The total agricultural land affected by the reform (43.9% irrigated and 23.5% rain fed) contrast with the grazing areas transferred (23.4%) (MATOS and MEJIA, 1984).

The next period of rural development (1980-85) followed a worldwide trend and included the dismantling of associative enterprises. Traditional communal rights of peasant communities were made more "flexible", land could be sold or mortgaged. This benefited the richer peasants within the peasant communities and alienated those who did not have the resources to purchase land. The divergent period inaugurated with presidents Alan GARCIA (1985-90) and Alberto FUJIMORI (1990-2000) witnessed the intensification of the privatization process. Garcia's plan included a new land-distribution program, particularly for peasant communities, and economic policies (price controls, state subsidies, credits, and privileged exchange rates to favor the purchase of goods) designed to strengthen small-scale producers. Initially associative enterprises were promoted, but turned to privatization. Fujimori's neo liberal program, confronted with hyperinflation and terrorism, could not thoroughly plan rural development (HUNEFELDT, 1997). Two important steps were the enactment of the *Agricultural Law of Promotion and Investments* (DL 26505) in 1998, which ended the restrictions on private ownership imposed by the agrarian reform, and the subsequent special project of land entitlement and cadastre (DS 006-98-AG), which regulates the land tenure, legally and physically amending the properties affected by the agrarian reform. Currently, 73% of the peasant communities and 47% of the private small holders have been registered and entitled (PETT, 2002).

Agricultural and Grazing Systems

Rental contracts such as sharecropping allow for mitigating the capital and risk market failures (ECHEVARRIA, 2001). Sharecropping mechanisms and reciprocal exchanges of labor, oxen, and dung between households alleviate inequalities in land distribution. On fields not used for maize cultivation, the peasant rotates barley, wheat, and beans, followed by a period of fallow, alfalfa, and potatoes, at which point the cycle begins again. Because of modernization, the rate of land under fallow in the Andes decreased from 41% in 1964 to 33% in 1971 (COTLEAR, 1989). The effects of fallow decrements are not fully perceptible, and areas that seem under fallow may actually loss its fertility since the 18% of usable land has been degraded at different degrees (YOUNG, 1998).

Although agricultural production is much more labor intensive and specialized than herding, this last is an important non-technified economic activity that relies on natural grasses and post harvest residues. Livestock serves multiple objectives (quasi money, animal traction, provision of derivate products, purchase of human labor, provision of fertilizer).

Natural grasslands predominate in all districts, ranging from 22.09% (Chinchao) to 76.79% (SMValle) (Fig. 3). Communal pastures shrunk because of privatization and families strive to have high and low altitude grasslands to seasonally move the animals. Grazing is a main economic activity in Amarilis, Chaulan, SMValle and Margos districts, although is complemented with agriculture since do not provide a constant flow of incomes.

Soil erosion in abandoned/fallow fields is due to the unregulated grazing (Harden, 1996). Cattle management rather than the elimination of pastoralism is essential. Table 3 shows the livestock totals per type and they range from 2,133 (Yarumayo) to 7,833 (Margos). The activity is especially important in Amarilis, Margos, Chaulan and SMValle districts.

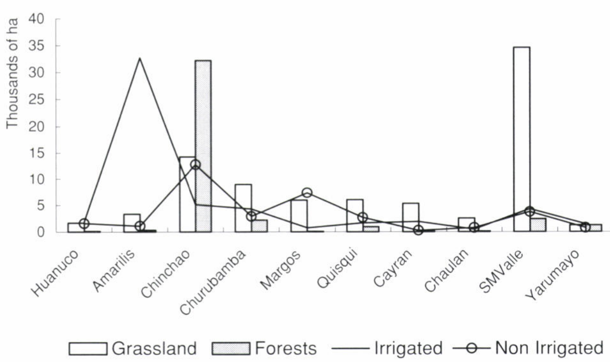

Fig. 3 Land use type (ha) per district (INEI, 1996)

Forest Condition

Forestry development is still insufficient, contrastingly with the intensive use of forests in the Himalayas (IVES and MESSERLY, 1999). Deforestation is consequence of the skewed distribution of arable lands, chronic landlessness and the macroeconomic stresses of the 1980s (KEIPI, 1999).

According to Fig. 3, forested areas range from 0.315% (Margos) and 0.54% (Cayran) to 50.08% (Chinchao, mostly tropical secondary forests) and 25.89% (Yarumayo, mostly eucalyptus plantations). The *National Program for Soil and Water Conservation* (Pronamachcs) directs the reforestation projects in the highlands, and the *Reforestation Committee* in

Table 3 Characteristics of districts

	Alt. (masl)	Latitude	Area ha (%)	Tot. hab	Settlement type*	Livestock**
Huanuco	1,858-3,500	9.55'40"	17,458(4.27)	74,676	32s 05c	5,000s 1,000c 800g
Amarilis	1,900-3,800	9.57'45"	13,815(3.38)	60,762	17t 03c	10,000s 3,000c 1,500g
Cayran	2,060-3,800	9.59'45"	9,942(2.43)	3,940	01t 18s 02c	8,000s 300c 500g
Margos	3,260-4,800	10.01'05"	28,921(7.07)	16,570	22t 06s 02c	20,000s 2,000c 1,500g
Chaulan	2,800-4,185	10.03'07"	28,101(6.07)	5,404	10t 07s 01c	15,000s 1,000c 1,500g
SMValle	1,865-4,400	9.51'45"	49,565(12.11)	17,965	04t 30s 12c	15,000s 1,000c 2,500g
Chinchao	2,000-4,000	9.46'15"	182,307(44.50)	22,011	03t 32s 02c	1,000s 4,000c 1,800g
Churubamba	1,835-3,800	9.46'20"	56,267(13.75)	16,570	04t 30s 07c	8,000s 2,500c 1,000g
Quisqui	2,450-4,170	9.54'06"	16,294(3.98)	5,607	11t 06c	5,000s 1,500c 1,000g
Yarumayo	2,600-3,910	9.55'45"	6,411(1.57)	2,582	04t 05s 02c	5,000s 600c 800g

* towns (t) dispersed households (s) communities (c)

** sheep (s) cows (c) goats (g)

Source: OIA (2000)

the Amazonian basin. Pronamachcs administrates eleven tree-breeding centers in the province with an annual production of 147,500-394,000 seedlings (OIA, 2000). Although 8,267ha have been reforested until 1991, the 24.2% of the province had been deforested (INRENA, 1994), especially in Chinchao district, where for every 4 ha that are deforested, 1 is under actual cultivation and 3 are abandoned (SCHWEIK *et al.*, 1997). In the highlands, woods are used for firewood (90%), construction, (5%) and carpentry (5%) (ESPINEL, 1996). To satisfy energy requirements, a family needs two poles of eucalyptus (50cm dbh) per year. Income from wood is complementary, confined to early stages of agricultural frontier expansion, and tends to be reinvested in agriculture and cattle ranching.

Shrub and grasslands can be converted to more productive categories of forestland. Steep regions supporting woodlands are an invested capital that farmers can use at the most convenient time or give to the inherited. Trees also protect and nurture agricultural lands. They would neutralize the inevitable environmental consequences of overgrazing and continuous cropping. Reforestation costs per ha range between $100 and $800 (MCGAUGHEY and GREGERSEN, 1983), unavailable for most of local farmers. Eco-tourism, as well, would add value to unutilized highlands where most of the archeological sites are located. However, lack of funds is not always the problem but that loan conditions are inappropriate for investments in the sector (MCGAUGHEY and GREGERSEN, 1988). The government commonly funds reforestation (KEIPI, 1999).

Measures of Stratification and Inequality

While poverty and inequality in rural areas still depend on access to land, the contribution of land concentration to the explanation of total income inequality has declined over time. Income inequalities within communities are higher than resource inequalities (GONZALES de OLARTE, 1994). Average family incomes in a modern region can be four to five times higher than those in a traditional region (COTLEAR, 1989) and educational achievement is the most important source of income differences (Van GINKEL *et al.*, 2002).

Modern holdings (private ownership, artificial irrigation, mechanization, and use of chemicals) are commonly located in the lowlands; they influence and coexist with the highland traditional ones (common property, native crops, rotation, and long fallows). Their integration through flows of energy, materials and investment is asymmetric. Highland communities give more importance to landholding conflicts, whereas middle and lowland communities give more importance to difficulties in acquiring chemicals (fertilizers and pesticides).

A source of inequality in farm size is demographic differentiation. As households begin, grow, and mature over the course of their life cycles, changes in land holding reflect fluctuations in the demand for land associated with each stage (CHAYANOV, 1996). A young household forms and expands, acquiring land to meet its growing needs. Later, as children mature and leave the household, pressures decline and land holdings may contract. Increasing population, combined with bilateral inheritance, results in successive subdivision of land at the death of the owner. Extreme fragmentation creates difficulties for technological innovation since many of their packages are inadequate in small properties. Technological change facilitates the evolution of land use systems and at the same time, this evolution facilitates the diffusion of technical change. Since AU with less than 2 ha cannot sustain a family with 5-6 members, peasants approach the use of resources through cooperation.

Interviews with 44 family heads and 11 groups of farmers showed that a common concern is the decrease of land productivity and availability. Farmers recognize that a plot that produced around 20 bags of potatoes actually only yields four. However, that perception is not as acute as chronic cash shortages (MAYER, 2002). The cost of soil recovery ranges from US$ 777~962/ha/year (SANTOS-GRANERO and BARCLAY, 1998).

Land Use Systems

Land, water, grazing territories, and labor were neither bought nor sold in pre-Columbian times (MAYER, 2002). Changes in field systems reflected adaptations to changing environments and socio economic demographic conditions, based either on innovation or diffusion (DENEVAN, 2000). Peasants still manage multiple farms at the same time to maximize human labor and get advantage from the ecological variability. In a dual decision making system, the household is the producing unit, while at a higher level the community administers a vast territory. The difficulties of supplying and scheduling labor limit the total size that a family can farm.

The land can be divided into three concentric circles around each town. The nearest one is under intensive use, privatized, and generally irrigated. The parcels located in the outer circle are of common use, mainly for grass, and are located above 4,000 masl, or constitute areas without drainage. In "modern" communities, communal rotation has disappeared, and the privatization of land has expanded. This process is faster in communities situated at low and intermediate altitudes (DENEVAN, 2000). The system of cropping and the property rights are different in each circle. Within the agricultural belt, abandoned fields and non-cultivatable land are referred to as *tierra eriaza*; which are not irrigated and are communally controlled and open to residents of the village for grazing and the collection of herbs and firewood. The most common form of access to land is inheritance (GUILLET, 1995), followed by purchase, sharecropping, and to a lesser extent, renting and acquisition of land as collateral for a loan (*anticresis*). Agricultural plots are the basis of a land market in which prices are regulated by supply and demand, and there are no restrictions on sales to outsiders (*forasteros*).

Table 4 Correlation matrix between main parameters (total of districts)

	A	B	C	D	E	F	G	H	I	J
A. Area (%)	1.00	-0.04	-0.13	-0.35	-0.22	-0.17	-0.24	0.64	0.61	0.00
B. Population	-0.04	1.00	-0.51	0.33	0.51	-0.39	-0.30	-0.08	0.25	-0.27
C. Altitude (masl)	-0.13	-0.51	1.00	-0.17	-0.21	0.25	-0.14	-0.16	-0.56	0.91
D. Agric. Land (ha)	-0.35	0.33	-0.17	1.00	0.92	0.07	0.31	-0.39	-0.23	-0.12
E. Irrigated area (ha)	-0.22	0.51	-0.21	0.92	1.00	-0.07	-0.02	-0.20	-0.07	-0.13
F. Grassland (ha)	-0.17	-0.39	0.25	0.07	-0.07	1.00	0.27	-0.29	-0.32	-0.04
G. Forest land (ha)	-0.24	-0.30	-0.14	0.31	-0.02	0.27	1.00	-0.30	-0.23	-0.18
H. Total AU	0.64	-0.08	-0.16	-0.39	-0.20	-0.29	-0.30	1.00	0.78	0.04
I. Entitled Properties	0.61	0.25	-0.56	-0.23	-0.07	-0.32	-0.23	0.78	1.00	-0.33
J. Common Properties	0.00	-0.27	0.91	-0.12	-0.13	-0.04	-0.18	0.04	-0.33	1.00

Factors Interrelation and Statistics of Land Use per District

The correlation between the total AU and entitled AU with district area are positive (R=0.64 and 0.61 respectively), the same with the irrigated area and population (R=0.51), total and entitled AU (R=0.78), and altitude and AU under common property (R=0.91). Variables with non significant correlation are the total of AU with the number of AU under common property (R=0.04), the area of grasslands with the number of AU under common property (R=-0.04), population and total of AU (R=-0.08), irrigated and forested areas (R=-0.02) and irrigated and grassland areas (R=-0.07) (Table 4). Santos-Granero and Barclay (1998) add that the length of occupation is correlated with greater land fragmentation and that the relation between the proportion of perennial crops and the proportion of fallow land is negative.

While in Amarilis, Cayran and Yarumayo the rates of irrigated fields are 97, 86 and 65%; in Chaulan, Quisquis, Chinchao and Margos they are 39, 38, 29 and 10% respectively (Fig. 3), meaning that in the last four districts more than half of fields depend on rains. Accessibility is a main factor to access irrigation infrastructure; Amarilis and Cayran are next to the city of Huanuco. The 32,723.3ha of irrigated plots in Amarilis constitute 58% of the total irrigated area in the province. The distribution of irrigated areas in the province is heterogeneous. Irrigation influences the crop structure, the type of tillage, and the level of fragmentation of the agricultural unit (Gonzales de Olarte *et al.*, 1987). The irrigation canals are built by communal labor, anyone wishing to have land allotted in the new area must participate in their construction.

Margos has two communities and 8,538 AU under common use (Table 3, Fig. 5) while in Churubamba there are seven peasant communities and only 1,119 AU under common use. Production zones with higher productivity (lowlands) accelerate the degree of privatization (Mayer, 2002). Effectively, in Churubamba half of the total AU has only one patch while in Margos only 17% (Fig. 4). Communities do not necessarily control common land, individual herders can share

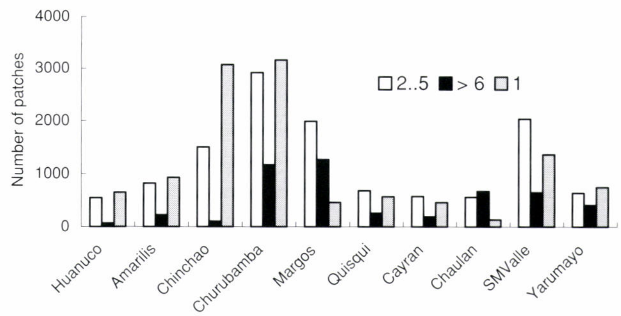

Fig. 4 Number of patches per agricultural unit. (INEI, 1996)

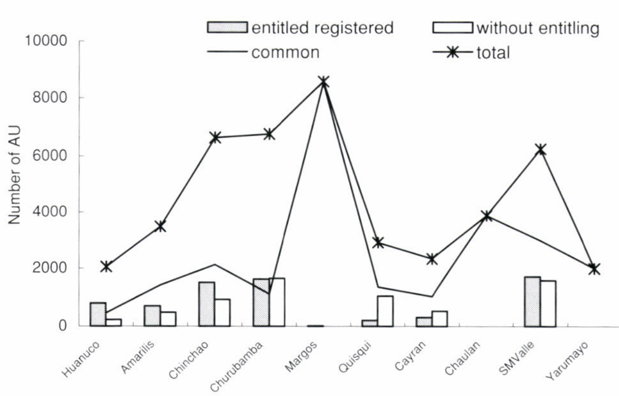

Fig. 5 Land tenure condition per district (status of agricultural units per district) (INEI, 1996)

common grasslands. There are more patches per AU in highland than lowland areas (parallel use of diverse production zones). In Churubamba 122 AU comprise between 11 and 15 patches of land. In Chaulan it is 35, and in Yarumayo it is 65. In Margos, 5 patches compose 223 AU and 318 AU by 6 to 10 dispersed patches, the higher values for those ranked. The proportion of AU with only one patch ranks from 14% (Chaulan) and 16% (Margos) to 54% (Huanuco) and 67% (Chinchao). In half of the total districts, more than half of AU posses only one patch (Huanuco, Amarilis, Chinchao, Churubamba, and Yarumayo) (Fig. 4).

The number of entitlements in each district depends on its accessibility and distance to the capital. In Margos and Yarumayo it is less than 1%, while in the Huanuco district it is 39%. The proportion of AU under common property in each district is 100% in Margos, 98% in Chaulan, and 100% in Yarumayo (Fig. 5); in contrast, it is 23% in Huanuco and 17% in Churubamba (their territory extends from lowlands to highlands). An owner is recognized as one who is holding a land title even though it is still not registered in the official records; an owner without a title is simply denominated "land holder".

Change in Land Use

The comparison of aerial photographs from 1962 and 1995 in an area of 7.30km^2 enclosing the 4/5 of Huanuco city, indicates that croplands converted to urban areas at a rate of 2.6% per year. As there are no easy routes to change the status of land tenure, farmers in state cooperatives and other agricultural societies illegally subdivide the common land into private plots, and few have valid titles over them (De Soto, 2000).

In 10 observations, a higher correlation exists between the forest areas of the real and ideal condition maps (R=0.6364) than in the case of agriculture (R=0.463) or grassland areas (R=0.2242), explained by the overlapping in time and space of grazing and agricultural areas. In the real situation, there is no conservation or protection class as such; it is intermingled within the forest and grassland classes. Moreover, the regional census did not consider that land category. Data for the ideal condition was obtained according to the methodology; since they are types of physiographical characteristics at small scale, it is assumed that will not change substantially over time.

The extent of farms established in areas with other suitability was delineated on the ideal map (Fig. 6). The total of pixels (smallest units on the map) for each case were converted to percentage of ground area considering that 1 pixel equals 0.704km^2. In the current situation (Fig. 7) agriculture occupies over 50% of the total area in most of the districts, while in an optimal situation (Fig. 8) it is restricted to some areas and land dedicated to other uses are better distributed. The results are shown in Figs. 7 and 8. The cropped areas in Amarilis, Churubamba, Huanuco, and SMValle are properly located (78.6, 80.5, 64.7, and 77.1%, respectively, of the total area cultivated in each district). However, in the same districts, the proportion of cropped areas suitable for forestry are 21.4, 19.5, 35.3, and 18.3%, respectively. In Quisqui this use reaches 72.3%. In Chinchao, primarily, and in Quisqui, Margos, and Chaulan, the proportion of cultivated plots to areas suitable for only conservation are 34.3, 10.7, 7.57, and 3.6%. The rates of cropped plots on areas suitable for grazing are high in

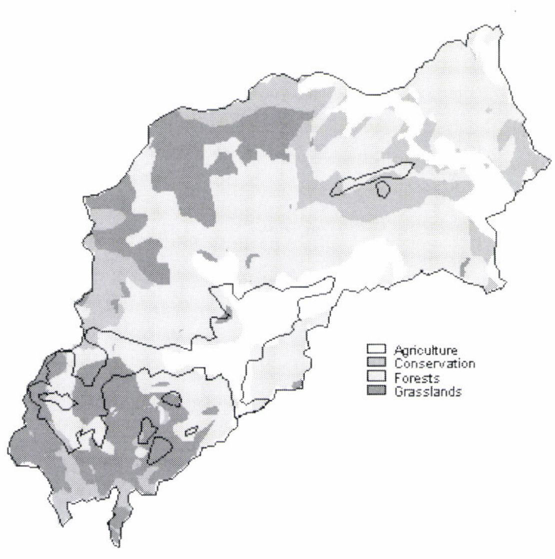

Fig. 6 Map of suitable land use with demarcation of cultivated areas

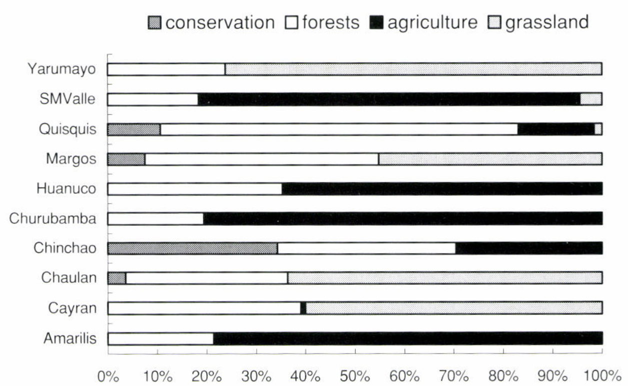

Fig. 7 Rates of crop areas established on areas with other suitability (current situation)

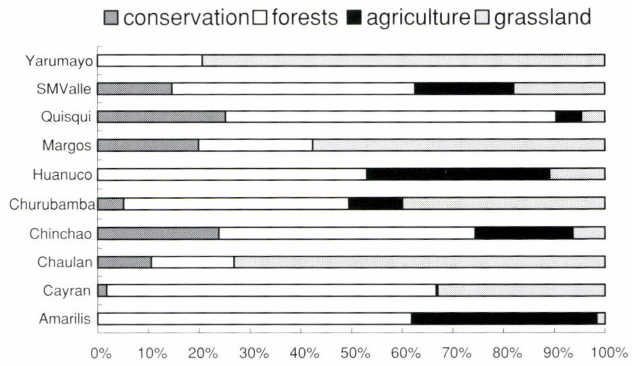

Fig. 8. Area rates per category of land use in an ideal condition

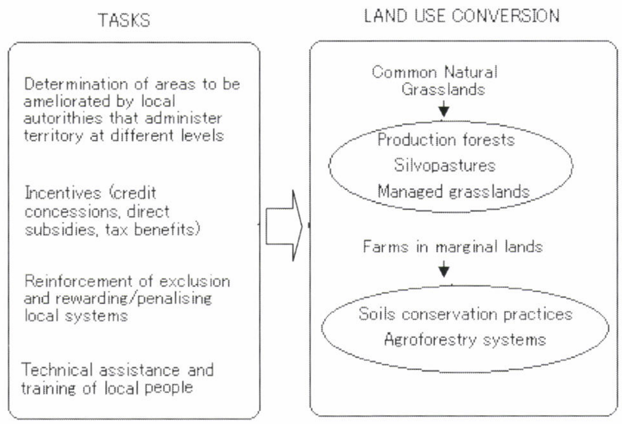

Fig. 9 Proposed scheme to increase land value

Yarumayo (76.2%), Chaulan (63.6%), Cayran (59.74%), and Margos (45.2%). It is notable the overuse of land for agriculture in Amarilis (31,291.7ha) and Margos (8,118.8ha), for grasslands in Chinchao (8,320.8ha), Quisquis (5,538.5ha) and SMValle (29,971.5ha) and the sub use of areas suitable for forests in Chinchao (14,762.52ha), Quisquis (5,670.7ha) and SMValle (9,822.5ha).

Fig. 9 is a proposed scheme to achieve a sustainable use of land in the central Andes of Peru. Common natural grasslands and agricultural holdings in marginal lands comprehend the majority of area under use; their progressive conversion to widespread recommended measures (encircled) with permanent and higher output values can be achieved through the actions described in the right box, failure in any of them will not assure success. Local institutions (diverse systems of cooperative work, sharecropping, regulated use of productive resources and control of diverse production zones at different altitudes) and incentive alternatives should be negotiated with the local communities. Technical assistance and training might enhance the managerial skills of the locals, adapt new methods of land use and reconsider good practices of traditional knowledge.

DISCUSSION AND CONCLUSIONS

Areas under agricultural, grazing, and forest use changed broadly from 1972 to 1996 in all districts, and are far from matching the most suitable land use. A farmer changes cultivation practices both from year to year and from field to field for reasons that may be spatial, environmental, economic, informational, demographic or idiosyncratic. Land use is heterogeneous among the districts. Pressure on land varies from district to district and is the main force that conduces to institutional change. Policy shifts from collectivism to market oriented solutions and back to heterodoxy created uncertainties and deepened rural divisions. The paradox of an ideology of egalitarian resource distribution alongside differentiation continues to provoke tensions in Andean communities (HARDEN, 1996). Land reforms as were traditionally conceived are no longer needed since do not solve social infrastructural problems. Even though management systems are similar, there are differences regarding intensity, areas, and type of land use. The average patch area/owner is 5ha, with exceptions in Chinchao (less than 0.5ha) and Churubamba (10ha). This can hinder technological innovation since studies in other realms confirm that larger farms are more open to it (NEIL and TYKKYLAINEN, 1998); and that households with more land have higher levels of income from non agricultural employment (ECHEVARRIA, 2001). Inequality has to be confronted by reducing economic instability and through programs that improve the access by the poor to productive assets. The number of patch/owner is inversely proportional to the patch size in all cases, meaning that while large holders are prone to technological change, smallholders diversify their production in multiple cycles to divert risk. Accessibility is a main factor for the diffusion of infrastructure and property formalization. Development policies for each district will differ. In Chinchao rehabilitation measures have to focus on forest resources while in SMValle on grasslands management. In Huanuco and Churubamba the main actors are small holders while in Chaulan and Yarumayo most of the productive resources are under common use. The local social institutions have the potentiality to enable a sustainable use of land if they are duly recognized by state policies and receive an external stimulus from agencies of development. The success of this effort will depend on action within the sector (institutions, policy, technology) as well as outside the sector (economical and political stability, education, transportation, communication). Traditional land tenure in the Andes is not well described by artificial categories such as private or communal, both are complementary and intermingled. The point is not who has the right over land, but who has the right to use determined area for a specific purpose. Although the existence of production zones as a production system is not exclusive (MAYER, 2002), the inclusion of people and institutions with different objectives and interests but with the ability to cooperate in the coordination, creation and exploitation of them, is exceptional in the Andes; and forms the basis on which of land use policy must rely. Agriculture in steep areas suitable for other uses has been traditionally inherited but the customary institutions that regulated land use are diminishing because of modernization. The environmental consequences can be unexpected since peasant communities control more than 30 percent of the fragile lands (COTLEAR, 1989). The evidence that privatizing cooperative property does not automatically led to sustainable investment must be pondered; it is of interest only if individual management is highly profited (RIDDELL, 2000). Agricultural output would rise, but the impact on employment will depend on the technologies used on the new consolidated holdings. A policy risk is that smallholders who sell their lands may move to the forested areas. Moreover, given the high ecological diversity in the Andes, it is unlikely that a land market is going to develop for second or third quality land. Andean genetic diversity is a case where common access leads to an increase in biological diversity rather than a reduction (MAYER, 2002).

People self organize in response to change (SILBERSTEIN and MASER, 2000), creating new instruments and institutional forms capable of responding to restructuring pressures (NEIL and TYKKYLAINEN, 1998). They spontaneously organize into extralegal independent groups until the government is able to create a unique system of legal property. Entitling farmers and deregulating agricultural prices can slow emigration. If the farmer has a legal right to his land, he will also invest more in its conservation. Together with a well-designed land information system it would create the needed social capital for sustainable land use. The emergence, implementation and effectiveness of local policies depend upon the complex of economic, social and political conditions found within and beyond the locality. The changes are slow and continuous, a "green revolution" has not occurred. The growing tendency towards external linkages offers new potentialities, but also new risks for the local people. Markets tend to reinforce the extractive activities, conduces resources outside the rural realm and is indifferent to processes of environmental degradation (NEIL and TYKKYLAINEN, 1998).

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Article

A Vegetation Similarity Index Driven by Distance-dependent Spatial Information

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ABSTRACT

A vegetation similarity index (*VSI*), developed to describe the similarity of nearby vegetation conditions to each forest patch (*i*), is presented as a new method for visualizing landscape heterogeneity. All forested patches within a certain distance (*M*) of each patch *i* are examined, and a value is developed to describe the similarity. These values are then weighted by an inverse distance method, and aggregated to produce a single value for each patch *i*. The distance *M* examined can vary, and visual representations can be subsequently developed to assist biologists, planners, and policy makers in their understanding of vegetation similarity as viewed by various animal species. The *VSI* assesses the spatial configuration of vegetation conditions, and although it does not measure habitat loss due to particular natural or human-caused disturbances, it provides a new perspective on landscape vegetation similarity.

Keywords: landscape assessment, spatial analysis, fragmentation

INTRODUCTION

Forest fragmentation is one of the most hotly debated conservation issues facing land managers today because landscape disturbances are a noticeable consequence of landscape change (McIntyre, 1995), and the heterogeneity of landscapes has been shown to influence human perceptions (Geoghegan *et al.*, 1997). Fragmentation has been described as a process that spatially segregates those entities that would normally belong together in order to optimally function (Carsjens and van Lier, 2002), and has been used as a process to describe the loss of certain habitat conditions (e.g., Li *et al.*, 2001). Forest fragmentation has also been described as a state of a landscape wherein elements of it have ecological characteristics that are very distinct from other elements, disrupting ecological connections between them and producing barriers to animal dispersion (Forman, 1995; Jaeger, 2000). Fragmentation of late-seral forests may result in smaller patch sizes than normally found in natural areas, an increased distance between patches containing similar forest structural conditions, and thus increased amounts of forest edge (D'Eon, 2002), and isolation of original habitat (Carsjens and van Lier, 2002).

The main impacts of fragmentation are on wildlife species that are dependent on the size and configuration of interior habitat, however defined, thus fragmentation may result in local extinctions and losses of biodiversity (Baillie and Groombridge, 1996; Kouki *et al.*, 2001). The effects of fragmentation, however, vary depending on the patterns and processes under investigation (Robinson *et al.*, 1995; Donovan *et al.*, 1997). For example, increased fragmentation across a landscape has been found to reduce the diversity of bird species, increase the number of edge species present, and reduce the number of species requiring interior forest habitat (McIntyre, 1995), although landscape heterogeneity has also been shown to be positively associated with bird abundance (McGarigal and McComb, 1995). The impacts of forest fragmentation have been postulated as complex and site-specific (Lynch and Whigham, 1984), yet a landscape-scale perspective is important. For example, on a site-specific basis, forests fragmented by agriculture have been shown to result in a higher level of bird nest destruction than forests fragmented by logging, yet areas severely fragmented by logging and closer in proximity to human activity may show different results (Bayne and Hobson, 1997). However, a negative correlation has been found between the amount of edge at the landscape scale and the level of nest parasitization and predation (Robinson *et al.*, 1995; Donovan *et al.*, 1997), thus generalist bird predators typical of fragmented landscapes seem to react more to landscape composition than to local

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fragment characteristics, as do certain medium-sized carnivores (OEHLER and LITVAITIS, 1996, DONAVAN *et al.*, 1997). Few studies have examined the effects of fragmentation on managed forest landscapes, where older forests are surrounded by regenerating patches (ENOKSSON *et al.*, 1995; MCGARIGAL and MCCOMB, 1995; HAGAN *et al.*, 1996). Most fragmentation studies, in fact, have been undertaken to test the hypothesis that habitat loss is important to the existence and persistence of specific wildlife species (OPDAM 1991, WICKHAM *et al.*, 1997), usually late-seral forest-dependent species. Further, DONOVAN *et al.* (1997) suggest that the first approximation to predicting the impact of edges on songbird reproductive success is to assess habitat characteristics at the landscape scale.

While the spatial patterning of landscape elements may be functionally linked to ecological processes occurring on the landscape (TURNER, 1989), human development processes also have an effect on landscape elements, and thus ecological processes. Forest edges generally have been described as sharp boundaries between contrasting environments (DONOVAN *et al.*, 1997), and edge effects can be considered either beneficial or detrimental, depending on the species or context under consideration (KREMSATER and BUNNELL, 1999). Fragmentation need not always involve distinctly different habitats or sharp edges, since it can occur within a forest (ENOKSSON *et al.*, 1995), via irregular gaps created by forest operations. These gaps usually have less long-term effect than more permanent changes in the landscape, such as gaps created by agriculture (DROLET *et al.*, 1999), since forested landscapes fragmented by harvesting operations retain some forest structural conditions and tend to prevent invasion by generalist predators that can adapt to human-dominated landscapes (ANDRÉN, 1994). In forested landscapes fragmented by forestry operations late-seral forests might become separated by the introduction of younger forests of varying ages, and one might view the spatial and temporal location of late-seral forest as dynamic (MCGARIGAL and MCCOMB, 1995).

Area-related edge effects in managed forests, such as the reduction in habitat quality due to changes in vegetation types, or competition by species able to better utilize a patchy landscape, require consideration of spatial and temporal changes in remnant patches of certain forest types and changes in edge effects (SCHMIEGELOW *et al.*, 1997). Thus simplified concepts, such as the area of certain habitat patches, are not adequate when considering dynamic landscape mosaics (HAILA *et al.*, 1989).

At any given location in a landscape, forest patterns will be influenced by soil, topography, ownership, and management history, as well as urban pressure (WICKHAM *et al.*, 2000). In terms of forest bird communities, fragmentation seems to result in more pest predation than in contiguous forested areas (ROBINSON *et al.*, 1995), however the effects of fragmentation are mixed, since research shows that various measures of fragmentation send conflicting signals. For example, HOBSON and BAYNE (2000) found bird species richness to be higher in fragmented landscapes than in contiguous forests, yet this mainly occurred because the fragmented landscapes contained several bird species that are normally associated with edge habitats, while the contiguous landscape did not. FREEMARK and MERRIAM (1986) also indicate that larger forests are more important for increasing the number of forest-interior species, yet to maintain a diverse forest avifauna, they suggest that maximization of both forest size and habitat heterogeneity is important. The area of larger forest may, however, not be linearly related to the population size of some bird species, since forest remnants sufficiently large to include the size of a typical territory, may still be considered too small from a species' perspective (DROLET *et al.*, 1999). SCHMIEGELOW *et al.* (1997) point out that the size of older forests is important to the reproductive success of some bird species, and the availability of these patches over time and space should be considered in managed forests. Further, size differences in forested patches create forest habitat islands, and species composition in these islands is fairly predictable, whereas certain groups of species may be regularly absent from smaller patches (AMBUEL and TEMPLE, 1983). DROLET *et al.* (1999) suggest that travel patterns may also be disrupted by clearcuts, affecting the establishment or dispersal of some species across and landscape. Thus in dynamic landscapes, a simplified approach to measuring fragmentation may not be adequate.

The objective of this research is to develop a vegetation similarity index (VSI) which seeks to describe the similarity of the vegetative conditions across a landscape, yet leaves the interpretation of the ecological effects of vegetation similarity to biologists, planners, and policy makers. For example, the VSI indicates the level of similarity (or conversely, contrast) within certain distances (M) from each patch on the landscape. This measure may be useful in characterizing landscape structure (KÜCHLER, 1973). Forests can be considered homogenous in structure if forest conditions vary only a little across the landscape. However, boundaries between patches of vegetation may be either abrupt or gradual, and the level of heterogeneity may affect (positively or negatively) certain wildlife species. Heterogeneity, of course, depends on the scale at which it is measured (FORMAN and GODRON, 1986). Heterogeneity generally increases when the scale being viewed is broadened, and it reaches its highest level when viewed very closely. How wildlife perceive a landscape's vegetative condition is important for both active forest management and future policy analysis. For example, within a relatively homogeneous vegetative landscape, average air temperatures will vary little from one place to the next. If abrupt edges exist, indicating a more heterogeneous vegetative landscape, air temperature may be perceived as inhospitable to the movement of certain wildlife species with small home ranges. If predators of these species also concentrate within the different patches of vegetation, movement through or around these patches will be slow and hazardous (FORMAN and GODRON, 1986). Since wildlife use different landscape features for different purposes, understanding how the vegetation may be perceived at different scales can be important for forest management, research, and policy. Thus the interpretation of the ecological effects correlated with different VSI levels will vary from one wildlife species to the next, and be a function of the scale at which they perceive the environment. The VSI index is useful to biologists, planners, and policy makers in that it allows one to think spatially about landscape heterogeneity, since an index is computed for each unit of the landscape. Thus the VSI technique is unique in that it allows one to see where the areas of high (or low) vegetative similarity are on the landscape. Once mapped, the index can facilitate an evaluation of current or historical conditions as well as provide a basis for comparing future conditions projected by alternative landscape management plans.

The context of this research is somewhat different than that used in previous forest fragmentation research, in that large areas of homogenous landscapes may be more important for certain species of wildlife regardless of the structural condition. Similarly, heterogeneous landscapes are important for other species, and it is the delineation of the level of vegetation similarity across the landscape that is important. Thus the research focuses on vegetation similarity, not fragmentation, since it is similarity that is measured, not a deviation from a target forest structure (e.g., late-seral forest structure). While HERZOG *et al.* (2001) describe a set of metrics that may be used to describe landscape structure, and categorize them into metrics that relate to patch area, shape, diversity, and configuration, the metric described here combines the features of patch area, diversity, and configuration to provide a different view of the similarity of vegetation across a landscape.

METHODS

Measures of spatial structure generally include aspects related to the composition, configuration, and connectivity of resources. Several landscape metrics, in fact, can adequately quantify the major structural properties of a landscape (HERZOG *et al.*, 2001), although landscape indices encountered in the literature have rarely undergone the scrutiny of assessing the correlation of the resulting measures with the success of foraging, reproduction, and dispersal of species of interest (SCHUMAKER, 1996). Some of the most common landscape metrics related to the quantification of fragmentation or vegetative conditions described in the literature include assessments of the number of patches, patch area, core area, patch perimeter (edge), nearest-neighbor distance, contagion, fractal dimension, perimeter-area ratio, shape, and patch cohesion (SCHUMAKER, 1996). HARGIS *et al.* (1998) examined the behavior of several commonly used metrics of forest fragmentation: edge density, contagion, mean nearest neighbor distance, mean proximity distance, perimeter-area fractal dimension, and mass fractal dimension, and note that none of these measures is able to differentiate between dispersed or aggregated spatial patterns. While the quantification of landscape structure is a prerequisite to studies of landscape function and change (LI *et al.*, 2001; MCGARIGAL and MCCOMB, 1995), there is no evidence that landscape metrics have generic application for the conservation of large sets of species, although they are useful in the quantification of landscape pattern from a human perspective (LINDENMAYER *et al.*, 2002).

The application of fragmentation indices to landscapes should include a discussion about which landscape elements are being assessed, and should focus on the system property of interest (LI and REYNOLDS, 1995). The VSI developed here focuses only on forest stand age as a surrogate of vegetation similarity, an element which many ecologists, managers, and policy makers frequently use to describe the contiguity of a landscape. Other measures, such as tree species composition or forest structural condition (e.g., number of large trees or snags per unit area) could also be used as long as the differences between different conditions can be adequately quantified.

Perimeter, or edge, density is typically described as the total length of patch edge per unit area in a landscape (MCGARIGAL and MARKS, 1995), and it is sensitive to map resolution (HARGIS *et al.*, 1998). Edge density is not sensitive to landscape pattern, however (HARGIS *et al.*, 1998). Contagion describes the extent to which patches are aggregated. Contagion is calculated using the proportional representation of a certain cover type on a landscape, and the conditional probability that given a certain patch of land is cover type i, that a neighboring patch of land is cover type j (MCGARIGAL and MARKS, 1995; LI and REYNOLDS, 1993). Contagion is insensitive to landscape patterns in which patches are either widely dispersed or tightly clustered (HARGIS *et al.*, 1998). Nearest-neighbor distance, or proximity, measures the isolation of a patch within a complex of patches, given a certain search radius (HARGIS *et al.*, 1998), and is the ratio of the sum of the patch size to the nearest neighbor edge-to-edge distance (MCGARIGAL and MARKS, 1995). Mean nearest neighbor distance defines the average distance between patches, yet does not adequately describe the spatial distribution of patches across a landscape (HARGIS *et al.*, 1998). Perimeter-area ratio and fractal dimension both provide information on the irregularity of patch edges on a landscape. These measures generally provide a patch-level statistic that makes comparing landscapes somewhat difficult if all patches exhibit similar irregularity. Patch cohesion is a relatively new concept that normalizes perimeter-area ratio by a shape index (SHUMAKER, 1996).

As one may have gathered, landscape metrics can be categorized as describing patch-scale characteristics or landscape-scale characteristics of resources. Patch-scale characteristics examine the conditions in the immediate vicinity of each patch. Landscape-scale characteristics look beyond the immediate vicinity of each patch, and include measures such as the distance to the nearest similar patch, the density of similar patches on a landscape, and other computations aggregated to a single measure to describe a large area (BAILEY *et al.*, 2002).

Measuring Vegetation Similarity

The *VSI* proposed here attempts to measure the spatial configuration of classes of forest vegetation across a landscape. Stand age is used as the surrogate variable used to discriminate between vegetation classes. The *VSI* model is applied to a large landscape in western Oregon, composed mainly of coniferous tree species. Since forest structure generally changes as the age of coniferous stands increases, it seems intuitive that older forests generally contain taller trees than younger forests on similar sites with a similar composition of tree species. In fact, ISHII and MCDOWELL (2002) note that tree crown development in older forests is much different than crown development in younger forests. And, ROBBINS (1980) suggests that canopy height and forest isolation are the most consistently important predictors of the abundance of some bird species. For example, neotropical migrants may be more abundant in forests where the trees are tall, although other factors such as plant diversity are also important (LYNCH and WHIGHAM, 1984).

There are a number of quantitative approaches for measuring the similarity between adjacent patches on a landscape. It is essential that landscape metrics provide unique contributions to the understanding of landscape structure or fragmentation. Correlation among metrics may be expected as they all tend to use similar basic parameters, such as patch size, patch shape, and interpatch distance (HARGIS *et al.*, 1998). At a regional scale, WICKHAM *et al.* (1999) suggest graphing the proportion of forest area in the largest patch versus the proportion of area in anthropogenic cover to assess the degree of fragmentation. At this scale, however, distinctions between age groupings of forests are generally lost, and thus the discussion of edge and edge influences in specific species becomes fuzzy. Some landscape metrics can be used to calculate the proportion of similar (or dissimilar) area within a neighborhood around each patch. WICKHAM *et al.* (2000) illustrate the use of percolation thresholds, although these metrics do not necessarily measure the dispersion of similar or dissimilar patches, only the percent of area that is similar or dissimilar. At smaller landscape scales, other measures, such as the Shannon's diversity index (MCGARIGAL and MARKS, 1995) can be used:

$$H' = -\sum p_i (\ln p_i)$$

Where:

p_i = the proportional area of cover type i on a landscape.

FREEMARK and MERRIAM (1986) used a similar measure, the Shannon information function, to describe habitat heterogeneity in a study of bird use of temperate forest fragments. While these metrics can be used to evaluate fragmentation or landscape similarity, they require no spatial information other than knowing that a landscape condition is, or is not, present.

Defining Edge

MATLACK (1993) defines three edge types, recent, closed, and embedded. Recent edges are those where the side canopy of the residual forest has not closed, and diagonal beam radiation can enter. Closed edges are characterized by intact side canopies consisting of continuous vegetation from low shrubs to the tree crowns, thus little radiation enters the forest. Embedded edges are where young forests abut older forests, yet the tree heights are not exactly the same. In these cases, however, the crown canopies may be unbroken but there are differences in the underlying stand structures. All of these characterizations of edge can be related to age differences in forest stands. Edge, as defined here, represents simply a difference in the age of vegetation in adjacent patches (patches that share an edge).

Inverse Distance Weighting of Differences in Stand Age

Inverse distance weighting is based on the notion that differences in edge (stand age differences) nearby are more significant than differences more distant from a patch (WATSON and PHILIP, 1985). Inverse distance calculations for points across a landscape can be computed with the following process:

$$G(x, y) = \sum_{i=1}^{U} f(x_i, y_i)\, w_i$$

with the weights (w_i) equal to:

$$w_i = d_i^{-p} \Big/ \sum_{j=1}^{U} d_j^{-p}$$

Where:

$G(x, y)$ = an estimated value for point x, y

U = the set of points to be examined as neighbors of point (x, y)

$f(x_i, y_i)$ = the observed value at point x_i, y_i

d_i = the distance from (x, y) to (x_i, y_i)

p = an arbitrary positive real number

The inverse distance weighting concept utilizes spatial data to estimate values on a landscape, thus the structure of the spatial data either inherently facilitates the computations (raster data), or the computations require ancillary adjacency

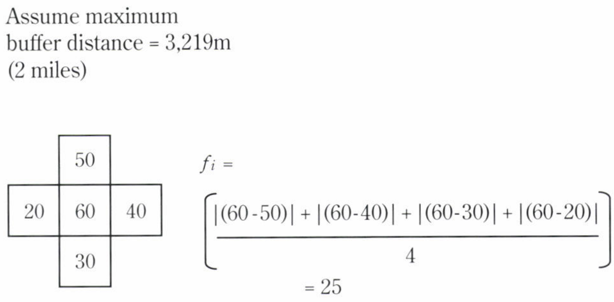

Fig. 1 Calculation of vegetation similarity (using stand age as a surrogate for forest structure) between a focal patch (age 60) and other patches that share an edge with the focal patch.

data (vector data). By changing the value of p, the distribution of weights can be changed from being highly biased in favor of the nearest data points ($p > 1$), to being nearly equal for all nearby data points ($p \leq 1$).

Within the VSI computations, the average absolute difference in forest patch age (f_i) between each patch i and the set (U_i) of adjacent patches to a patch i is first evaluated (Fig. 1).

$$f_i = \left[\frac{\sum_{j}^{U_i} \left| Age_i - Age_j \right|}{u} \right]$$

Where:

U_i = the set of adjacent patches to patch i
u = the total number of adjacent patches to patch i

Thus if the ages of adjacent patches are all similar, the average age difference will be low. The average age difference will be high if the age of the adjacent patches is very diverse. There are some advantages and some drawbacks to this process. If the focal patch is mature forest, and the surrounding forest is all mature, yet one adjacent patch consists of young forest, the average age difference will be relatively low. If the focal patch is a young forest, and the surrounding forest is all mature, the average age difference will be high. While this may be important from the perspective of an organism currently in the focal patch, it may not adequately describe the larger condition of fragmentation across the landscape.

One alternative of this method may be to incorporate the length of the edges among adjacent patches, then weight the age differences by edge length as it relates to total edge length. Another alternative may be to use another metric other than age to describe the differences among patches. These considerations are left for future work, however. In order to weight each difference between patch i and each neighboring patch a distance (d_{ij}) from patch i to each patch j in set U_i is first determined:

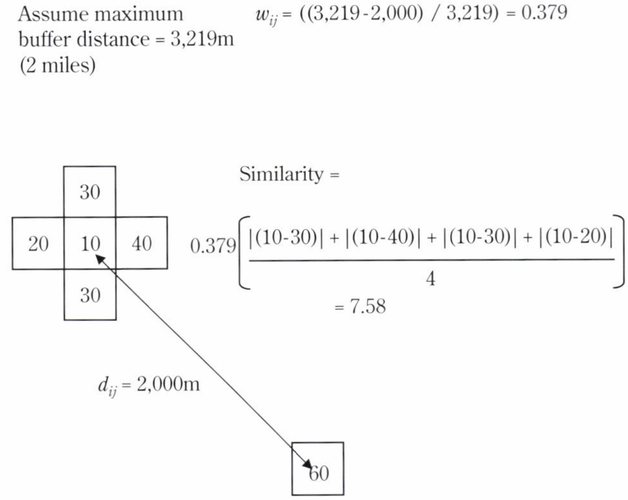

Fig. 2 Calculation of vegetation similarity (using stand age as a surrogate for forest structure) between a focal patch (age 60) and another patch that is within a certain distance (3,219 m) of the focal patch.

$$d_{ij} = \left[\left| x_i - x_j \right|^2 + \left| y_i - y_j \right|^2 \right]^{0.5}$$

The weights applied to the vegetation similarity computations for each patch j in the set U_i are then assigned using the critical distance around each patch (M) within which similarity is assessed:

$$w_{ij} = \left[(M - d_{ij}) / M \right] \quad \forall j \in U_i$$

The sum of the weights (Z_i) from patch i to all patches j in the set U_i is also calculated:

$$Z_i = 1 + \sum_{j=1}^{U_i} w_{ij}$$

Vegetation similarity (Fig. 2) is then evaluated for each patch i:

$$VSI_i = \left[\frac{f_i + \sum_{j=1}^{U_i} (f_j \, w_{ij})}{Z_i} \right]$$

All patches in U_i are evaluated, including the vegetation similarity around unit i, where d_{ij} is be equal to 1.0, thus placing emphasis on the vegetation similarity around patch i. Patches in U_i which are furthest from patch i have less influence on VSI_i. Low VSI scores indicate very similar vegetation exists nearby each patch i, and conversely, high VSI scores indicate dissimilar vegetation exists nearby each patch i.

The VSI was applied to a large landscape in western Oregon (USA) (Fig. 3), where forest patches were defined by a process associated with the COASTAL LANDSCAPE ANALYSIS and MODELING STUDY (2002). The proportion of land area by vegetation age class shows a vast majority of land area is in vegetation age classes less than 40 years old (Table. 1), while a significant amount (21.2%) is in the very old (80+ years) age class.

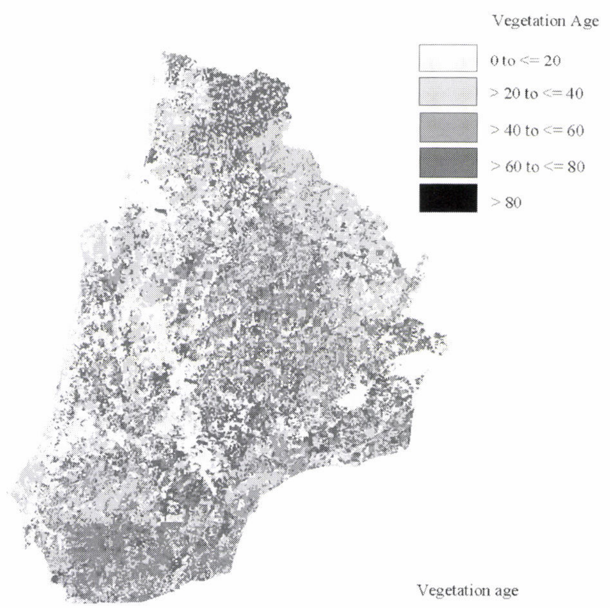

Fig. 3 Age class distribution of vegetation across a 589,512 ha land area on the coast of Oregon (USA).

Table. 1 Land area by vegetation age class for a large land area on the coast of Oregon (USA).

Range of age classes	Land area (ha)
0 to ≤ 20	147,285
> 20 to ≤ 40	208,889
> 40 to ≤ 60	48,615
> 60 to ≤ 80	60,444
> 80	124,279
Total	589,512

RESULTS

For purposes of illustration, *VSI* scores were assessed for each patch *i* using five different maximum distance (*M*) thresholds: 0m, 805m (0.5 miles), 1,609m (1 mile), 2,414m (1.5 miles), and 3,219m (2 miles). The amount of land area within five *VSI* classes was then summarized: 0-20.00, 20.01-40.00, 40.01-60.00, 60.01-80.00, and 80.01+. The total amount of land area that fell into five *VSI* classes shows a convergence from two sides of the scale (Table. 2). First, the amount of land area in the 0-20.00 *VSI* class seems to move upward into the 20.01-40.00 *VSI* class as the maximum distance threshold (*M*) increases. This indicates that similar vegetation classes may be initially grouped close together, yet when viewed from a broader perspective, the similarity of vegetation decreases (*VSI* increases). Second, the amount of land area in the 40.01+ *VSI* classes generally decreases as *M* increases, indicating that there is some heterogeneity of vegetation age classes present when viewed at a fine scale, yet when viewed from a broader landscape perspective, the similarity increases (*VSI* decreases). When viewed from the broadest perspective (3,219m buffer), the landscape vegetation is quite similar, with most of the land area (84.6%) in the 20.01-40.00 *VSI* class.

Graphical descriptions of the *VSI* scores when a maximum distance threshold *M* of 0m was used (Fig. 4) are somewhat reflective of the initial age class distribution, and with a few exceptions reflect the heterogeneity of vegetation age classes inherent in the initial landscape. Areas on the northern portion of the landscape, for instance, have high levels of *VSI* due to the high degree of interspersion of older and younger forested areas. However, areas such as the most southern portion of the landscape, where a significant amount of older vegetation exist in the initial landscape, and interspersion of older and younger vegetation age classes is low, are portrayed as having low *VSI* scores, since many of the older forest patches are adjacent to one another. When *M* is 0m, in fact, *VSI* is calculated using only the adjacent patches touching each patch *i*, thus presenting a very fine-scale picture of vegetation similarity.

Table. 2 Land area by VSI class for a large land area on the coast of Oregon (USA).

Range of VSI classes	Maximum distance threshold (*M*)				
	0 m	805 m	1,609 m	2,414 m	3,219 m
	Land area (ha)				
0 to ≤ 20	244,960	138,725	87,390	59,149	43,189
> 20 to ≤ 40	202,266	327,883	423,593	472,275	498,965
> 40 to ≤ 60	96,899	116,671	77,529	58,078	47,358
> 60 to ≤ 80	33,805	5,775	995	10	0
> 80	11,582	458	5	0	0

When M is increased to 805m (Fig. 5), the fine-scale delineation of *VSI* classes begins to dissipate, and broader groupings of similar and dissimilar vegetation begin to appear.

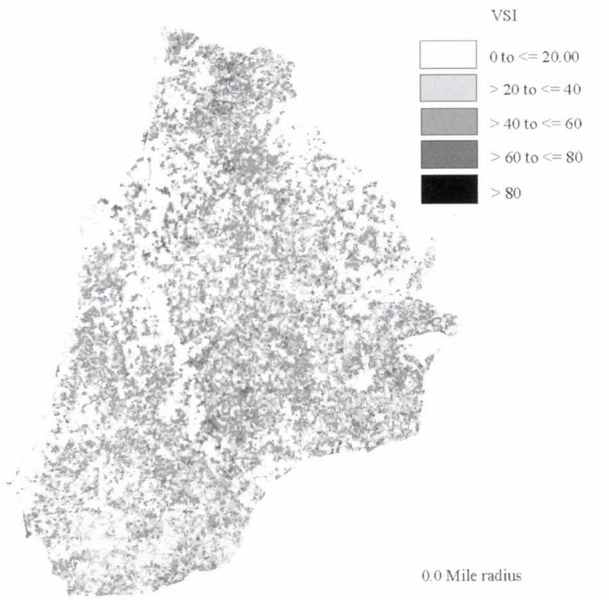

Fig. 4 VSI classes for all patches across a 589,512 ha landscape when the maximum distance threshold for calculating VSI is 0 m.

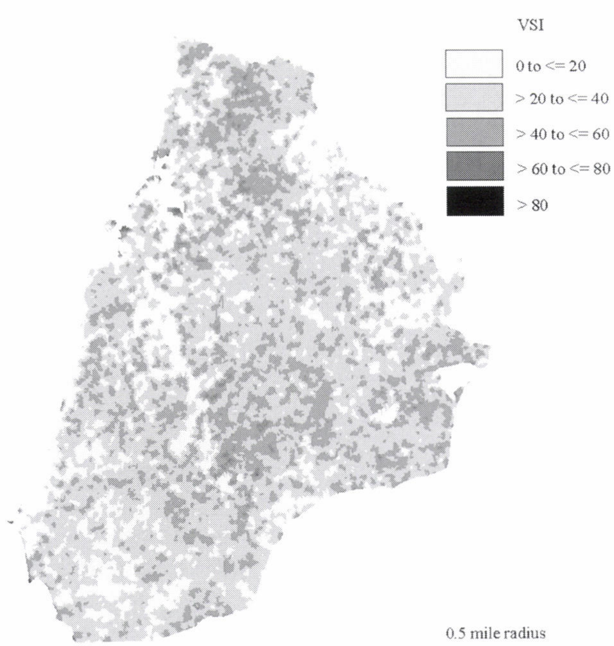

Fig. 5 VSI classes for all patches across a 589,512 ha landscape when the maximum distance threshold for calculating VSI is 805 m.

As M is increased to 1,609m (Fig. 6), 2,414m (Fig. 7), and 3,219m (Fig. 8), one can begin to view how differences in vegetation condition might be viewed at broader landscape

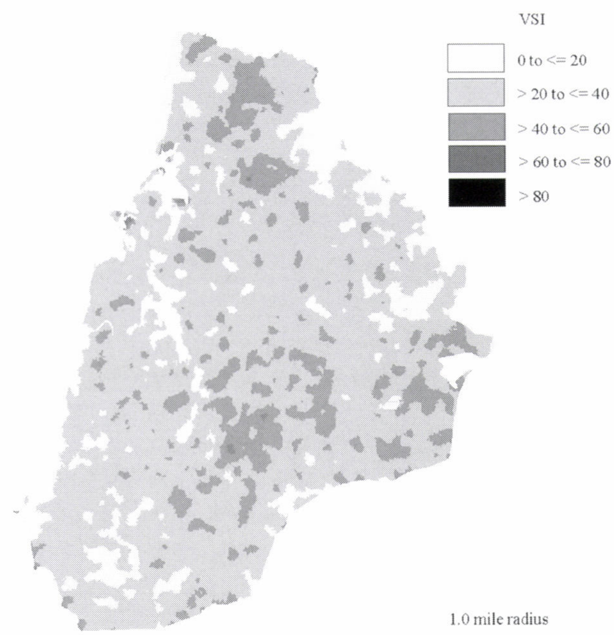

Fig. 6 VSI classes for all patches across a 589,512 ha landscape when the maximum distance threshold for calculating VSI is 1,609 m.

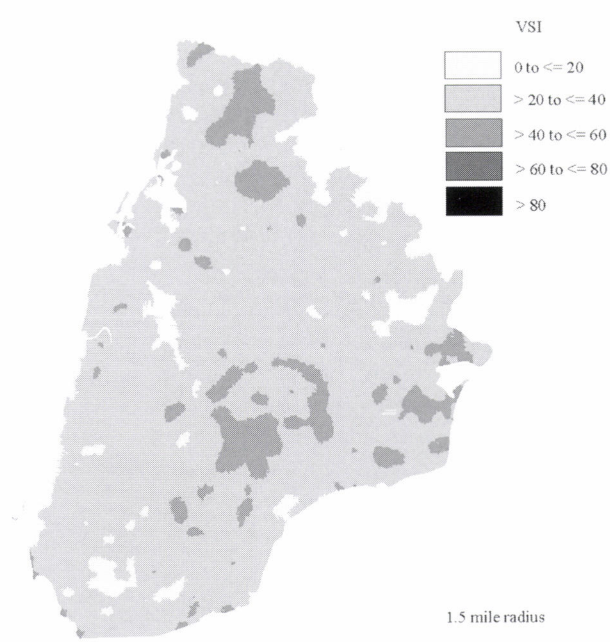

Fig. 7 VSI classes for all patches across a 589,512 ha landscape when the maximum distance threshold for calculating VSI is 2,414 m.

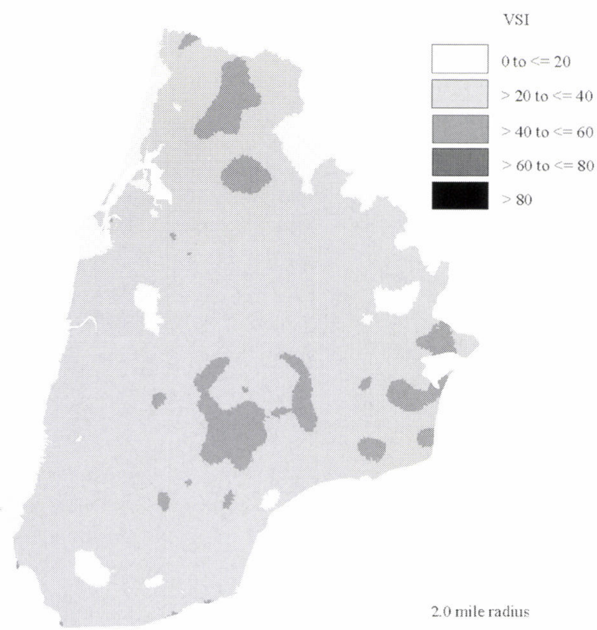

Fig. 8 VSI classes for all patches across a 589,512 ha landscape when the maximum distance threshold for calculating VSI is 3,219 m.

scales. The areas of high interspersion of different vegetation classes thus become quite evident at these scales.

DISCUSSION

Landscape metrics probably do not have generic applicability for the conservation of large numbers of species, but may be useful where the aim of management is to quantify landscape patterns from a human perspective, or to measure the change that is occurring across a landscape (LINDENMAYER *et al.*, 2002). The objective in the development of this spatial *VSI* has been to evaluate the differences in vegetation condition across a landscape, with condition defined as the age of the vegetation in a patch. The technique described here may be complementary to others presented in the literature (e.g., patch size, shape, edge, nearest-neighbor, diversity, contagion, interspersion, patch cohesion). The dynamics of landscape change have not been evaluated, yet with a time-series of historical or projected landscape conditions, one can analyze the differences in vegetation similarity with overlay functions contained within a geographic information system program.

Habitat configuration and subdivision undoubtedly play a role in regulating population abundance, distribution, and dynamics, but the magnitude of this may vary over space and time in relation to changes in regional habitat conditions (MCGARIGAL and MCCOMB, 1995). Almost every patch within a given forested landscape is habitat for some biotic species. If conservation strategies (e.g., THOMAS *et al.*, 1990) suggest that amounts of certain habitat conditions must be retained in certain spatial configurations, then the *VSI* may allow the quantitative evaluation of how similar habitat conditions (as defined by forest age class) are within and among the current or projected conditions of a landscape.

The need to be cognizant of the scale at which landscape metrics are applied has been noted as important (CALE and HOBBS, 1994). For example, landscape metrics do not capture the structural attributes at a fine scale (the tree or smaller) that may be important for estimating the distribution or abundance of certain species. The *VSI* described here obviously ignores fine-scale differences in vegetation, such as patches of trees less than 10ha that may be important nesting, roosting or foraging habitat for certain species of wildlife, for example, as these conditions are aggregated into larger patches. Spatial heterogeneity at a small scale is associated with higher species richness, because the differentiation of vegetation prevents exclusion by a single superior species (OLFF and RITCHIE, 2002). Smaller levels of *VSI* may therefore shed light into where these areas might be located, given an assumption that age differences in forested areas imply habitat differences due to the presence of different structural conditions. The critical scale at which the positive effects of landscape heterogeneity switch to negative effects increases with the size and mobility of the species under consideration (O'NEILL *et al.*, 1989; OLFF and RITCHIE, 2002).

JAEGER (2000) discusses several desirable features of fragmentation indices: consistent behavior among the various stages of fragmentation (perforation, incision, dissection, dissipation, shrinkage, and attrition), intuitive interpretation, insensitivity to omission or addition of small residual areas, low data requirements, and mathematical simplicity. Although the *VSI* (which can be classed as a subset of fragmentation indices) described here does not adhere to all of these characteristics, it does have the following five features. First, the behavior is consistent with the various stages of fragmentation. Fragmentation is considered highest during the dissipation stage, where there is a thorough mixture of patches with distinctly different characteristics, and it is lowest in the perforation and attrition stages, since these are seen as being similarly fragmented (e.g., either mostly older forest, or mostly younger forest). Thus the view from which fragmentation is made depends on the state the landscape currently occupies. For example, a landscape with mostly younger forest may not be ecologically desirable for some species, yet it is for other species, thus fragmentation of a younger forest landscape (allowing urban areas to encroach, or setting aside certain patches to grow into older forest conditions) may also occur. Second, the intuitive appeal of the *VSI* model described here is evident: the differences among adjacent forest stands is measured, and the spatial heterogeneity of the landscape within a certain distance of each patch is taken into account. Third, the addition of small areas or other landscape elements have little effect on the calculations. Fourth, the data requirements are moderate: a geographic information system database of the landscape is required, some knowledge of the spatial relationship of landscape elements is required, as is some knowledge of the condition of each patch. Fifth, and finally, the index described here is not mathematically simple. JAEGER (2000) emphasizes that only simple measures will be used in practice, yet FRAGSTATS (MCGARIGAL and MARKS, 1995) is widely used, and contains some very complex measures, such as proximity, contagion and interspersion and juxtaposition indices.

The *VSI* may also provide a different perspective on the effects of landscape change. Not from the perspective traditionally taken by landscape ecologist, that fragmentation of a landscape is some change from an older forested state, but rather the *VSI* illustrates how different a landscape is perceived from the perspective of various species that have a distinct spatial home range. It is similar to a diversity index, yet calculated for each patch on the landscape, and what is meaningful are maps describing concentrations of very dissimilar vegetation. Since ecologists are interested in the spatial distribution of patches (HARGIS *et al*., 1998), and policy makers are increasingly becoming interested in spatial representations of proposed forest policies, a landscape metric that quantifies spatial arrangement seems to be increasingly important.

A number of issues related to the application of the *VSI* remain to be examined, including the insight a measure such as *VSI* can provide toward the potential for habitat corridors across certain regions of a landscape. It may also facilitate an examination of the effects that gaps in preferred habitat within managed forests have on barriers to species' movement across a landscape.

CONCLUSIONS

This research represents an advance in the area of landscape measures of vegetation similarity, a subset of fragmentation indices, and one of four areas of study encouraged by the International Studygroup on Multiple Use of Land (CARSJENS and van LIER, 2002). Landscape measures of fragmentation have also been noted as one of the key criterion (1.1e) of the Montreal Process (CANADIAN FOREST SERVICE, 2000) for guiding the conservation of species biodiversity within managed forests, and this research presents a tool that characterizes the spatial configuration of vegetation across a landscape, as opposed to the composition or connectivity of habitat. It is assumed here that patch vegetation age is a surrogate for forest structural condition, and is in direct correlation with forest tree height across a landscape, although certainly differences in site index from stand to stand cloud the issue. Any other type of forest structural condition (e.g., number of large trees or snags per unit area) could be used to describe the differences in vegetation, however. Management units (patches) represented by vector polygons, were used to conduct the analysis, and the distance weighting procedure was based on the centroid of each. Groups of residual leave trees (legacy trees) within management units are therefore ignored, since a patch was defined by a single vegetation age. The objective was to measure vegetation similarity and to provide biologists, foresters, and decision-makers with a metric that will allow them to make inferences about the effect of different management policies on the relative fragmentation of a forested landscape, as defined by the spatial arrangement of different types of forest structure.

Estimates of vegetation similarity using the spatially explicit model are sensitive to the assumption regarding the distance around a focal patch to which similarity is evaluated. Other patterns represented by rates of forest conversion to agriculture, urbanization pressures, and changes in management behavior of forest management organizations also affect fragmentation and vegetation similarity measures, although these hypotheses were not tested. Although the *VSI* does not measure the habitat loss due to particular disturbances (natural or human-caused), it provides insight into the similarity of vegetation classes across a broad landscape. The logical next steps in this research would be to examine the correlation and synergy of this technique with other established techniques, and to attempt to correlate species behavior (foraging, reproduction, dispersal), presence, or abundance to *VSI* levels to determine the landscape requirements for various species, and how sensitive species characteristics are to various *VSI* levels.

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Article

Allometric Equations for Estimating Root Systems of Mizunara Oak (*Quercus crispula*) in Secondary Forests

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ABSTRACT

Root biomass can represent a significant proportion of the total ecosystem biomass, although the difficulty in extracting the roots is often a limiting factor when estimating the belowground biomass. The objective of this study is to create equations to estimate the root variables from other tree variables for mizunara oak (*Quercus crispula* BLUME) in broad-leaved secondary forests. First, experimental plots were established in secondary forests dominated by mizunara oak and sample oak trees were felled just outside the plots. The biomass of each tree organ was measured and other root variables such as root length, area and volume were also measured. Then, allocation of the four root variables by root diameter classes was described. Regression equations by power function were created between the four root variables and root diameter to estimate the missing root parts by root diameter classes and for the total root system. Root variables for missing parts were estimated from the diameter of broken root ends with regression equations between the four root variables and root diameter for total root system. Finally, allometric regressions between root variables and other tree variables were analyzed both by root diameter classes and for the total root system. Diameter at beast height (DBH) proved to be a good predictor of root variables for different root classes and for the total root system. Diameter at stump height (DSH) can be a useful estimator if branching starts at DBH as it also shows high correlation with root systems.

Keywords: missing root, root area, root biomass, root length, root volume

INTRODUCTION

Forests play an important role in regional and global carbon cycles because they store large quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, are sources of atmospheric carbon when they are disturbed by human or natural causes, become atmospheric carbon sinks during regrowth after disturbance, and can be managed to sequester or conserve significant quantities of carbon on the land (BROWN *et al.*, 1996). With a changing global climate, the role forests play in the uptake and release of carbon may alter. Because of their importance in the global carbon cycle, there is an increasing need to improve the accuracy of estimates of the amount of carbon the forests contain (BROWN *et al.*, 1999). Forest biomass that represents the potential amount of carbon is a useful measure for assessing changes in forest structure and for comparing structural and functional attributes of forest ecosystems across a wide range of environmental conditions (BROWN *et al.*, 1999). The biomass is composed of aboveground and belowground components. While aboveground tree biomass is often surveyed, information on belowground biomass is scarce.

Since root biomass can represent a significant proportion of the total ecosystem biomass (BÖHM, 1979), and since a large proportion of annual photosynthetic production is allocated to the belowground biomass component, some methods need to be developed for estimating root biomass and production in the model (KURZ *et al.*, 1996). Root area, the area of root surface, has seldom been determined in ecological research, although this parameter seems to be one of the best in experiments on water or nutrient uptake (BÖHM, 1979). Because it is difficult to classify roots in the same way as to classify the aboveground parts, KARIZUMI (1974a) attempted to classify roots mechanically into six parts and BÖHM (1979) reported that the common practice of dividing tree roots into classes with different diameters is on aid to obtain information on the amount of fine, small, medium, and large roots in a root system. Furthermore, VOGT (1989) suggested that root systems could be divided into several diameter classes based on their function in the support, storage, transport and uptake

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for field monitoring purposes. BÖHM (1979) gave details of methods for studying roots. The roots < 0.2 cm in diameter are usually called fine roots and those 0.2-0.5cm are called small roots (BÖHM, 1979; KARIZUMI, 1974a). The primary (parent) root and primary laterals are the major structural supports of the tree (VOGT, 1989).

The extraction of roots is a difficult and time-consuming process that can be a limiting factor when estimating the belowground biomass. Regression equations of root systems based on calculation from easily observable measures such as diameter at beast height (DBH) (KONOPKA *et al.*, 2000; TER-MIKAELIAN and KORZUKHIN, 1997; DREXHAGE and COLIN, 2001; SANTANTONIO *et al.*, 1977) might be useful as a simple input variable for growth models and carbon storage assessment. This relationship is based on the hypothesis that the growth of structural roots depends on stem diameter and that the above- and below-stump development of trees maintains an allometric balance (LACOINTE, 2000). SANTANTONIO *et al.* (1977) compiled allometric regressions of root biomass on DBH for a large number of tree species. Such relationships might be very useful for predicting root system biomass as they rely on easily obtainable above-stump parameters (BARTELINK, 1998; DREXHAGE and GRUBER, 1999; MILLIKIN and BLEDSOE, 1999; LE GOFF and OTTORINI, 2001). Regression equations of root biomass on DBH derived from other studies might be useful for applications in forestry and as a simple variable for growth models (DREXHAGE and COLIN, 2001 and TER-MIKAELIAN and KORZUKHIN, 1997). However, the fundamental question is whether allometric equations constructed for a stand growing under certain conditions are suitable also for stands in other conditions (KONOPKA *et al.*, 2000; FULTS, 2001).

The objective of this study is to create equations between root variables and other tree variables in order to estimate carbon storage and uptake by growth of tree biomass in broad-leaved secondary forests or to estimate root variables in growth models for broad-leaved secondary forests. The subject of this study was a secondary forest dominated by mizunara oak (*Quercus crispula* BLUME). Not only root biomass but also root length, area and volume were analyzed as root variables. Roots were classified into root diameter classes and the four root variables were analyzed not only for total root systems but also by root diameter classes. Allometric regressions between root variables and other tree variables were analyzed after missing root parts were estimated.

STUDY SITE AND METHODOLOGY

Study Site

The study was conducted inside and outside of Niigata University Forest in Sado Island (hereafter called Sado Forest) located in the northern part of Sado Island (Latitude 38°12'N; Longitude 138°26'E) (Fig. 1). Altitude ranged from 250m - 970m above sea level. According to weather survey point

Fig. 1 Location of the study site

installed in Sado Forest, the mean annual temperature was 8.9°C and the mean annual precipitation was 1,312mm. This study site was located in the cool-temperate zone of Japan. The topography is mountainous and the parent material is andesite and basalt. The site is basically covered with a secondary forest consisting of deciduous broad-leaved trees, such as mizunara oak, konara oak (*Quercus serrata* MURRAY), maple species, and wingnut (*Pterocarya rhoifolia* SIEB. et ZUCC.). Whereas sugi (*Cryptomeria japonica* D. DON) grows mainly in a region of 700 or more above sea level, hiba arbour-vitae (*Thujopsis dolabrata* SIEB. et ZUCC.) grows in a region of 600m or less.

Ground Investigation

By considering the distribution of mizunara oak, experimental plots, Plots 1 to 4, were established in Sado Forest (TATSUHARA *et al.*, 2002) and Plot 3 was selected from the four plots for this study. Moreover, Plot 5 was set up outside Sado Forest. A summary of these plots is shown in Table 1. Standing trees with girth at breast height of 15cm or more in each plot were measured.

According to the record on each tree, four or more sample trees outside the plot were selected in order to cover the whole range of diameter. In other words, dominant, co-dominant, intermediate, and suppressed tree should be represented so that stand estimation might not be overestimated. In Plot 5, we chose mizunara oak with the mean DBH and subtracted or added variance of DBH (σ or

Table 1 Summary of Plot 3 and Plot 5

Plot	3			5		
	Total	Broad-leaf	Conifer	Total	Broad-leaf	Conifer
Altitude (m)	555			613		
Plot size (m^2)	300			625		
Average DBH (cm)	11.81	11.87	8.91	11.14	11.23	8.23
Average height (m)	9.80	9.82	9.00	8.13	8.15	7.49
Density (Trees/ha)	3,333	3,267	67	2,224	2,160	64
Basal area (m^2/ha)	41.02	40.60	0.42	29.18	28.82	0.36

Table 2 Summary of sample trees

Plot	No.	Crown class	DBH (cm)	Height (m)
5	Tree 1	Codominant	15.80	10.2
	Tree 2	Intermediate	12.40	8.2
	Tree 3	Intermediate	9.40	8.9
	Tree 4	Suppressed	7.10	7.0
3	Tree 5	Suppressed	6.11	6.6
	Tree 6	Intermediate	8.55	8.6
	Tree 7	Intermediate	11.30	10.6
	Tree 8	Codominant	14.07	12.3
	Tree 9	Dominant	17.06	13.8

2σ) from or to it. In Plot 3, we arranged the measured DBH in ascending order, categorized the values into 5 groups, and calculated the mean in each group. We chose mizunara oak with the mean from each group. We felled one dominant, one co-dominant, two intermediate and one suppressed tree in Plot 3; and one co-dominant, two intermediate and one suppressed tree in Plot 5. In Plot 3, there was no dominant tree that was accessible for a tractor. Table 2 shows a summary of the selected trees.

Selected mizunara oaks were felled leaving a 0.3 m-high stump. Tree height, diameter at 0.3m, that is, diameter at stump height (DSH), bole height and crown were measured. The north site of each tree was marked at the ground level. Trees were separated into stem, branch and foliage and their fresh weight were measured using spring balances according to each stratum, i.e., 0.3, 1.3, 3.3 and then every 2m. If the last stratum was less than 3 meters, it was cut to the closest 1-meter last of all. Disc of stem in each stratum was cut at the bottom per stratum. Then, a sample of stem, branch, and foliage of each stratum was taken for further processing in the laboratory.

We excavated the four sample trees of mizunara oak with a power tractor in Plot 5. On the other hand, we excavated the five sample trees in Plot 3 with tools by hand tool. Then, the root systems were brought to the laboratory where they were washed to remove soil particles and exposed to the open air to dry. All soil was removed from the root plate with a high-pressure jet water stream, and the stem was cut from the root plate at the root collar. Nevertheless fresh weights of roots with a diameter >5.0cm for Trees 7, 8, and 9 were measured in the field without washing them, as they were too heavy to be brought to the nearest road.

Subsequently, root systems were placed upside down on a flat surface desk for measurement processing. We weighed the root biomass and recorded the root length and diameter of root cross-sectional area at both ends according to diameter classes of < 0.2cm, 0.2 - 0.5cm, 0.5 - 2.0cm, 2.0 - 5.0cm and >5.0cm, at precisions of 1.0g and 1cm, respectively. The length of roots with a diameter under 0.2cm was not measured, as they were fragile and their branches were difficult to spread out. Many roots were broken during excavation and remained in the soil. The diameters of broken root ends were measured outside the bark in two perpendicular directions for Trees 1 to 4 in Plot 5 and Tree 5 in Plot 3.

Data Analysis

Measurement of samples

Stem analysis consisted of counting of annual rings and measuring of diameter on stem cross sections lying at each stratum. The annual rings were measured from centre to outside the bark at one-year intervals across the radius in four directions and perpendicular to each other. Stem volume was calculated from measured data.

Samples of foliage were dried at temperature of 96°C for 48 hours. Samples from roots of different diameter classes together with samples from stem and branch were dried to a constant weight at a temperature of 105°C to determine conversion factors from fresh weight to dry weight.

Estimation of root variables

The diameter at the broken ends was tallied and a regression equation was applied to correct these losses of roots. To create the regression equation to determine missing roots, first of all cross-sectional diameters and length of unbroken root ends were sampled and measured on each root branching or every 25cm if a distance between branches was greater than 25cm. Second, root volume, biomass and area were calculated. As the sample of unbroken end of roots was weighed in total, the fraction of biomass was calculated by employing the ratio of root volume. Third, they were summed according to the branching in order to determine the proportion of loss of roots. Finally, regression equations of cross-sectional diameters of unbroken root ends versus root biomass, volume, area and length were developed for root diameter classes 0.2 - 0.5cm and 0.5 - 2.0cm and for total root systems. The frustum of cone formulae used to calculate root area and volume were as follows:

$$\text{Root area} = \frac{\pi}{2}\left(d_1 + d_2\right)\sqrt{\left(\frac{d_1 - d_2}{2}\right)^2 + l^2}\,, \tag{1}$$

$$\text{Root volume} = \frac{\pi}{12}\, l\left(d_1^2 + d_1 d_2 + d_2^2\right), \tag{2}$$

where d_1 and d_2 were diameters of section and l was length. Only regression equations for roots with a diameter of 0.2 - 0.5cm and 0.5 - 2.0cm were developed because roots with a diameter under 0.2cm were fragile and their branches were difficult to spread out.

Allometric equations with regard to roots

Allometric equations of root biomass, volume, area and length versus other tree variables were developed for the two root diameter classes and for the total root system, in order to predict root systems from other tree variables such as DBH. In the equations, the tree variables were used as the independent variable x in a simple regression of the root system as dependent variable y (Drexhage and Colin, 2001; Canadell and Roda, 1991):

$$y = ax^b, \tag{3}$$

where a and b were parameters. The parameters were estimated separately from roots investigated in Plot 5 and Plot 3 using a logarithmic transformation of Eq. (3), because they were located in a different stand and excavated in different ways. Regression equations of root biomass versus other tree variables were developed to estimate root stand biomass for each plot.

RESULTS

Measured Root Systems

The results of measured root systems are described in Fig. 2. Root diameter classes <0.2, 0.2 - 0.5, 0.5 - 2.0, 2.0 - 5.0, and >5.0cm were named root classes 1, 2, 3, 4, and 5, respectively.

Root class 5 formed about three fifths of the root biomass and the other classes two fifths. Root class 5 in Plot 3 (67%) accounted for a higher percentage of root biomass than that in Plot 5 (53%). Otherwise, root class 3 in Plot 3 (14%) contributed a smaller percentage of root biomass than that in Plot 5 (22%). Root class 2 distributed roughly 14% for all trees excluding Tree 1. Tree 4 had the smallest percentage of root class 5 (43%) but it had the highest percentage of root class 3 (29%). Root class 5 in Trees 5, 7, 8 and 9 contributed about 69% of root biomass in Plot 3. Although root class 5 in Tree 6 had lowest percentage of root biomass (59%), root class 3 had the highest percentage of root biomass (19%) among the trees in Plot 3. Trees 2 and 3 in Plot 5 accounted for a similar percentage of biomass in each root diameter class.

Root classes 5, 4, 3, 2 and 1 roughly accounted for 1.5, 4.3, 34.8, and 59.3 % of the root length. The root length percentage of root class 3 in Plot 3 (36.3%) was greater than that in Plot 5 (33.0%). By contrast, the root length percentage of root class 2 in Plot 3 (57.2%) was smaller than that in Plot 5 (61.8%). Root class 2 represented as much as 59.3% of the total root length, although only 3.6% of the root biomass. On the other hand, root class 5 constituted as much as 61.0% of the root biomass, and only 1.5% of their total length.

The root area percentage of root class 4 (15.9) and 5 (16.2) in Plot 3 was greater than that in Plot 5 (13.5 and 13.6 in that order). By contrast, the root area percentage of root class 2 (42.6) and root class 3 (25.2) in Plot 3 was smaller than that (45.5 and 27.3, respectively) in Plot 5. Root class 3 contributed the highest portion of root area (43.9 %). Then, root classes 2, 4, and 5 constituted 26.2%, 15.1%, and 14.9%, respectively. Although Trees 2 to 6 might have a similar percentage of root area, other trees might create a different root class pattern. Root class 2 represented 26.2% of the root area, but as much as 59.3% of the total root length. On the other hand, root class 3 constituted as much as 43.9% of the root area, and 34.8% of the total root length. Furthermore, root class 5 constituted as much as 61.0% of the root biomass, and only 14.9% of the total root area.

Tree 1 gave the highest value of root volume, unlike the other root variables for which Tree 9 always dominated other sample trees. As did root biomass (61.0%), root class 5 dominated the percentage of root volume (55.4%). Root class 5 represented 55.4% of the root volume, but as much as 1.5% of

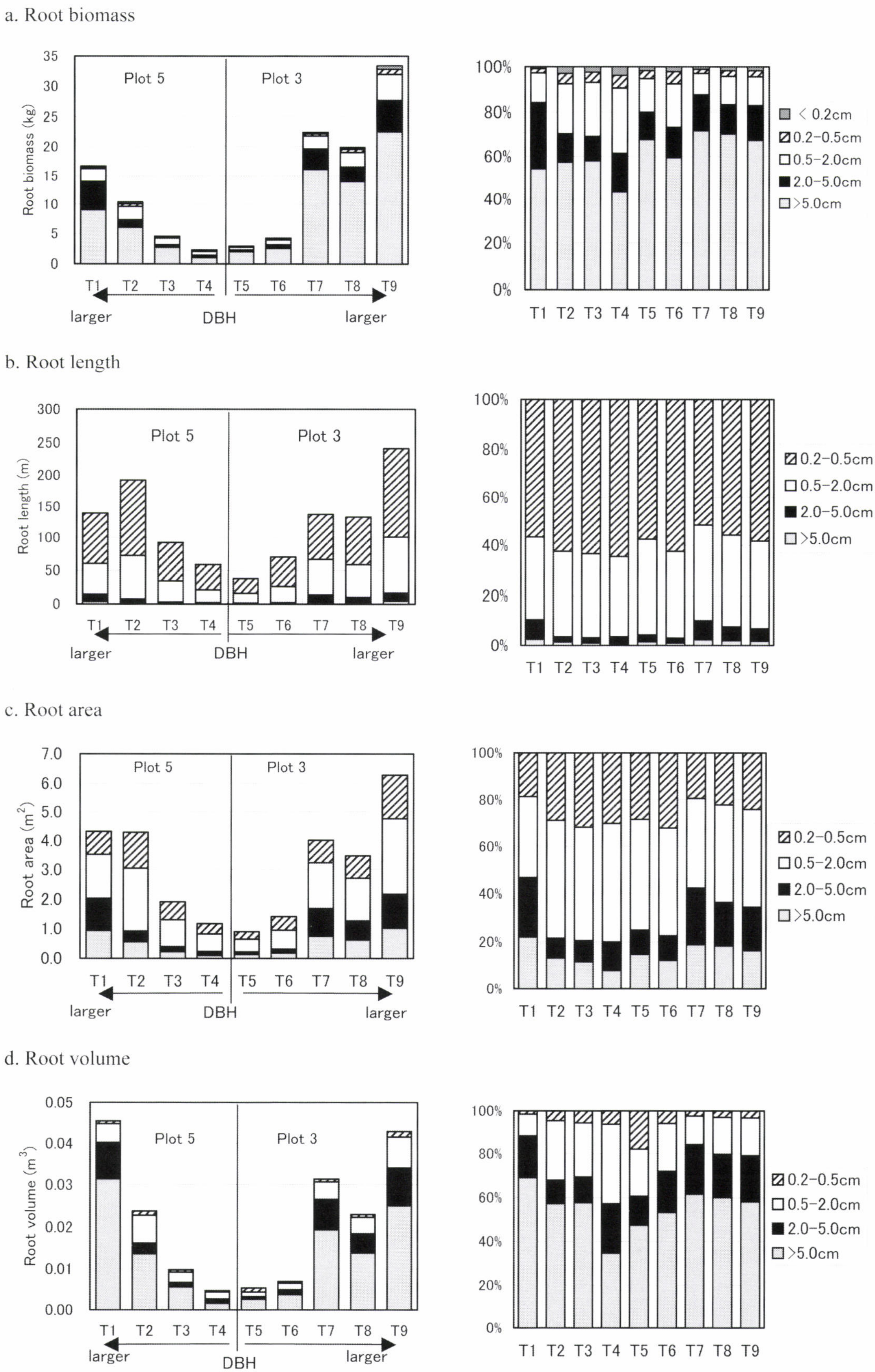

Fig. 2 Root variables and their percentage by root diameter classes

the total root length and 14.9% of the total root area. On the other hand, root class 2 constituted as much as 59.3% of the root length, and only 5.6% of the total root volume. In general, the percentage distributions of root biomass and root volume were quite similar.

Missing Roots

The coefficient of determination of regression equations by power function for root biomass, volume, length or area and root diameter by root diameter classes or for total root system are shown in Table 3. Although the correlation for root biomass and root class 2 was 0.13, that for root biomass and root class 3 was 0.77 in Plot 5. On the other hand, the correlation for both root diameter classes in Plot 3 had a value of about 0.50. The same applied to root area where root class 3 had a better correlation than the other root classes. Also, the correlation for both root diameter classes in Plot 3 had a value of about 0.37. By contrast, root length had a low correlation for both root classes in both plots ($R^2 < 0.37$). In general, root class 3 had a much higher coefficient correlation than root class 2 in Plot 5, but was only slightly different in Plot 3. Regression equations by power function for the total root system are also shown in Table 3. While root biomass, volume and area were highly correlated with root diameter, root length had the lowest correlation ($R^2 < 0.64$). In general, missing roots in Plot 5 had a higher correlation coefficient with root diameter than that in Plot 3. The parameters of regression equations by

Table 3 Correlation between missing root system variables and root diameter by root diameter classes and for total root system

Root system	Root class	Plot 5 No. of samples	Plot 5 R^2	Plot 3 No. of samples	Plot 3 R^2
Root biomass	2	10	0.135	162	0.546**
	3	23	0.779**	91	0.501**
	Total	40	0.914**	255	0.823**
Root volume	2	10	0.135	162	0.597**
	3	23	0.779**	91	0.501**
	Total	40	0.914**	255	0.841**
Root area	2	10	0.000	162	0.386**
	3	23	0.631**	91	0.360**
	Total	40	0.836**	255	0.748**
Root length	2	10	0.116	162	0.136**
	3	23	0.366**	91	0.263**
	Total	40	0.644**	255	0.593**

*, significant (at 5% level); **, highly significant (at 1% level)

Table 4 The parameters of regression equations between total missing root system variables and root diameter

	Plot 5 *a*	Plot 5 *b*	Plot 3 *a*	Plot 3 *b*
Root biomass (g)	0.0360	2.3681	0.0238	2.5727
Root volume (mm^3)	79.7902	2.3681	47.3459	2.6184
Root area (mm^2)	242.0080	1.6715	171.8005	1.9094
Root length (mm)	45.4515	1.1531	42.2094	1.3874

Table 5 Estimated missing root biomass, volume, length and area in each sample tree

		Plot 5 (digging by tractor)				Plot 3 (digging by hand tool)				
		Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	Tree 7	Tree 8	Tree 9
Root biomass (kg)	Missing	0.33	0.19	0.09	0.10	0.04	0.05	0.29	0.26	0.44
	Measured	16.66	10.39	4.54	2.27	2.83	4.19	22.41	19.87	33.39
Root volume (m^3)	Missing	7.3×10^{-4}	4.2×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	7.9×10^{-5}	1.0×10^{-4}	4.6×10^{-4}	3.4×10^{-4}	6.3×10^{-4}
	Measured	0.0455	0.0238	0.0097	0.0047	0.0054	0.0069	0.0314	0.0230	0.0430
Root length (m)	Missing	21.07	11.72	9.39	8.14	9.05	17.03	33.38	32.19	58.68
	Measured	138.85	192.06	92.24	58.62	37.15	69.89	136.98	132.10	240.81
Root area (m^2)	Missing	0.39	0.22	0.14	0.14	0.09	0.15	0.42	0.36	0.66
	Measured	4.33	4.28	1.91	1.19	0.91	1.55	4.39	3.81	6.88

power function between total missing roots and root diameter are shown in Table 4. In general, parameter a in Plot 5 was greater than that in Plot 3, but parameter b was smaller in Plot 5 than in Plot 3.

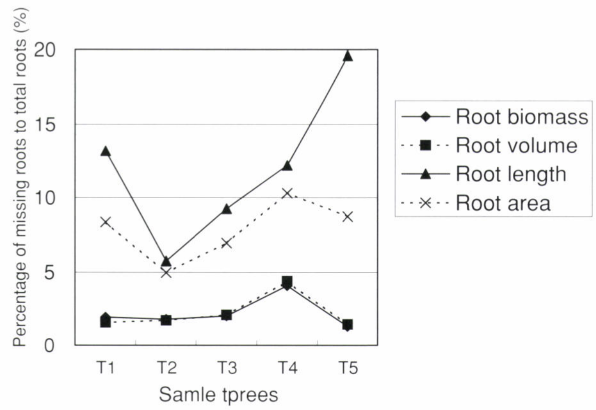

Fig. 3 Percentage of missing root biomass, volume, length and area

Estimated missing roots and their percentages are shown in Table 5 and Fig. 3, respectively. Missing broken root ends were not measured in Trees 6, 7, 8, and 9, so they were assumed to hold the same missing root percentage as Tree 5 in Plot 3 because the larger tree size such as DBH, the larger missing root part and the missing root percentage was relatively constant for Trees 1 to 4 in Plot 5. The missing percentage for root volume and biomass was approximately similar. The percentage of missing root biomass was quite low compared to measured roots. Digging roots with tools by hand resulted in a smaller loss of roots than that by tractor for root biomass and volume, comparing Tree 4 with Tree 5. Percentage of missing root length and area were much larger than those of root biomass and volume.

Allometric Equations between Root Variables and Other Tree Variables

By root diameter class

The relationships between root system and tree variables were analyzed by power function. The length of roots with a

Table 6 Coefficients of determination of regression equations for root variables and tree variables by root diameter classes

Tree variable	Root variable	Plot 5					Plot 3				
		Class1	Class2	Class3	Class4	Class5	Class1	Class2	Class3	Class4	Class5
		<0.2	0.2-0.5	0.5-2.0	2.0-5.0	>5.0	<0.2	0.2-0.5	0.5-2.0	2.0-5.0	>5.0
DBH(cm)	Biomass	0.421	0.699	0.899	0.905*	0.981**	0.975**	0.988**	0.977**	0.885*	0.870*
	Length		0.631	0.710	0.937	0.967*		0.958**	0.945**	0.832*	0.869*
	Area		0.636	0.732	0.901	0.994**		0.950**	0.940**	0.853*	0.872*
DSH(cm)	Biomass	0.413	0.728	0.899	0.779	0.985**	0.982**	0.967**	0.984**	0.921**	0.919*
	Length		0.671	0.747	0.828	0.915*		0.930**	0.947**	0.887*	0.912*
	Area		0.691	0.744	0.776	0.968*		0.923**	0.946**	0.899*	0.915*
Leaf area(m^2)	Biomass	0.548	0.846	0.907*	0.546	0.915*	0.955**	0.910*	0.933**	0.846*	0.868*
	Length		0.820	0.867	0.604	0.825		0.863*	0.875*	0.813*	0.869*
	Area		0.849	0.838	0.538	0.866		0.869*	0.892*	0.818*	0.859*
Volume(m^3)	Biomass	0.408	0.706	0.899	0.858	0.989**	0.936**	0.983**	0.943**	0.825*	0.802*
	Length		0.642	0.721	0.898	0.947*		0.947**	0.908*	0.763	0.800*
	Area		0.654	0.732	0.854	0.989**		0.929**	0.894*	0.788*	0.805*
Stem biomass(kg)	Biomass	0.383	0.684	0.883	0.861	0.983**	0.969**	0.997**	0.977**	0.886*	0.859*
	Length		0.619	0.700	0.901	0.937*		0.977**	0.956**	0.826*	0.860*
	Area		0.632	0.710	0.859	0.983**		0.967**	0.945**	0.852*	0.865*
Branch biomass(kg)	Biomass	0.351	0.633	0.851	0.922*	0.962*	0.857*	0.849*	0.844*	0.731	0.759
	Length		0.562	0.645	0.952*	0.938*		0.763	0.761	0.705	0.744
	Area		0.568	0.666	0.921*	0.977*		0.745	0.764	0.706	0.740
Foliage biomass(kg)	Biomass	0.334	0.657	0.751	0.466	0.827	0.950**	0.893	0.922**	0.839*	0.865*
	Length		0.632	0.687	0.529	0.683		0.849*	0.864*	0.808*	0.869*
	Area		0.674	0.643	0.466	0.766		0.859*	0.886*	0.811*	0.856*
Aboveground biomass(kg)	Biomass	0.377	0.678	0.879	0.862	0.982	0.968**	0.989**	0.972**	0.875*	0.858*
	Length		0.613	0.694	0.902	0.934*		0.958**	0.940**	0.821*	0.857*
	Area		0.626	0.704	0.860	0.982**		0.947**	0.932**	0.843*	0.860*

*, for significant (at 5% level); **, for highly significant (at 1% level)

diameter under 0.2cm was not measured, as they were fragile and their branches were difficult to spread out. Coefficients of determination of root biomass, length and area versus tree variables by root diameter classes are shown in Table 6.

In general, the greater the root diameter, the greater was the coefficient correlation for Plot 5, but in Plot 3 it was the opposite. A high correlation ($R^2 > 0.85$) was recorded between root biomass and other tree variables for root class 1 in Plot 3, but there was a low correlation ($R^2 < 0.55$) in Plot 5. A statistically significant correlation (average of $R^2 = 0.90$ for Plot 5 and 0.85 for Plot 3) existed in root biomass, length or area and other tree variables. Also, a relatively close correlation was seen between root biomass, length or area and other tree variables for each root class in both plots.

In Plot 5, regression of DBH versus root biomass, length and area for root class 5 had the highest correlation with R^2 of 0.98, 0.96, and 0.99, respectively, followed by 0.70, 0.63 and 0.64, respectively, for root class 2. On the other hand, R^2 was 0.99, 0.96 and 0.95, respectively, for root class 2 in Plot 3, but only R^2 of about 0.87 was obtained with all the three root variables for root class 5. Furthermore, coefficients of determination between root biomass and DBH for root class 1 in Plots 5 and 3 were 0.42 and 0.94, respectively.

The DSH-root biomass correlation was comparable to DBH-root biomass correlation. A similar correlation also existed between DBH and DSH in terms of root length and area. A statistically significant correlation ($R^2 > 0.81$) existed between root biomass, length or area and leaf area in Plot 3. A high correlation ($R^2 > 0.84$) was found in root biomass, length or area and height in Plot 3, but there was a low correlation ($R^2 < 0.70$) in Plot 5.

The greater the root diameter, the greater was the coefficient correlation of root biomass, length and area versus aboveground biomass, stem, branch and foliage in Plot 5, but it was the opposite in Plot 3.

For total root system

Correlations of root variables versus tree variables for total root system are shown in Table 7. Coefficients of determination of DBH with root biomass, length, area and volume in Plot 5 were 0.99, 0.78, 0.93 and 1.00, respectively, and 0.90, 0.96, 0.92 and 0.86, respectively, in Plot 3. In other words, the correlation between DBH and root length was lower in Plot 5 than in Plot 3. Correlation of DSH with root biomass, length, area or volume had coefficients comparable to those for the correlation to DBH.

Stem biomass and aboveground biomass were relatively closely correlated to root biomass, length, area and volume with R^2 of 0.98, 0.76, 0.90 and 0.98, respectively, in Plot 5 and 0,89, 0.96, 0.92 and 0.84, respectively, in Plot 3. Approximately linear correlations were seen between stem biomass or aboveground biomass and root biomass in both plots. A high correlation ($R^2 = 0.89$) was found between branch biomass and root system in Plot 5, but the correlation was relatively low ($R^2 = 0.75$) in Plot 3. On the other hand, the correlation between foliage biomass and root system was relatively low ($R^2 = 0.72$) in Plot 5, but as high as 0.86 in Plot 3.

Table 7 Coefficients of determination of regression equations for root variables and tree variables for total root system

Tree variables	Root variables	Plot 5	Plot 3	Tree variables	Root variables	Plot 5	Plot 3
DBH	Biomass	0.994**	0.897*	DBH	Biomass	0.958*	0.937**
(cm)	Length	0.777	0.956**	(cm)	Length	0.795	0.946**
	Area	0.931*	0.923**		Area	0.902*	0.940**
	Volume	0.998**	0.855*		Volume	0.950*	0.893*
Volume	Biomass	0.984**	0.836*	Leaf area	Biomass	0.848	0.880*
(m^3)	Length	0.781	0.929**	(m^2)	Length	0.877	0.873*
	Area	0.919*	0.878*		Area	0.867	0.874*
	Volume	0.984**	0.786*		Volume	0.813	0.832*
Stem	Biomass	0.979*	0.890*	Branch	Biomass	0.978*	0.773*
biomass	Length	0.760	0.970**	biomass	Length	0.715	0.766
(kg)	Area	0.905*	0.928**	(kg)	Area	0.890	0.750
	Volume	0.980*	0.854*		Volume	0.989**	0.696
Foliage	Biomass	0.742	0.875*	Above	Biomass	0.977*	0.886*
biomass	Length	0.695	0.860*	ground	Length	0.755	0.952**
(kg)	Area	0.709	0.867*	biomass	Area	0.901	0.915*
	Volume	0.717	0.830*	(kg)	Volume	0.980*	0.843*

*, for significant (at 5% level) ; **, for highly significant (at 1% level)

DISCUSSION

Part of the root system was lost during the excavation the root systems of the sampled mizunara oak trees. The fit of the regression is highly dependent on the root extraction technique (DREXHAGE and COLIN, 2001). Root system equations established from samples of seemingly unbroken root ends might allow the estimation of missing parts of the root systems. The regression equations by power function for the entire root system were applied to determine the missing root parts because of the high correlation, while the regression equations between root diameter classes and root system variables had lower correlation (Table 3). Missing root parts represented between 1 and 5% of the measured root biomass. LE GOFF and OTTORINI (2001) estimated that missing roots of beech represented between 10 to 20% of the measured value, where regression equation for estimating root class 1 was included. However, the biomass of missing fine roots should represent a very small part of the total root system biomass (LE GOFF and OTTORINI, 2001). The estimation of the biomass of missing root parts appears essential when the root system is excavated by hand (LE GOFF and OTTORINI, 2001). The greater the root diameter, the greater was the coefficient of determination in Plot 5, but it was the opposite in Plot 3, probably because the plots were located in different sites. In addition, in root class 5, fresh weight for Trees 7, 8 and 9 was measured in the field without washing them and errors might have increased due to the sticky soil.

The few works available showed data on the relationship between quantity of roots within different diameter groups and aboveground tree variables. The root biomass distribution patterns show that the larger tree had a relatively higher proportion of root class 5 (Fig. 2). This might be related to mechanical constraints, which impose a relatively greater development of structural roots in a larger tree to ensure their stability and anchorage in the soil (STOKES, 1997 in LE GOFF and OTTORINI, 2001). Relating with DBH, the aboveground biomass and root systems showed higher correlations with increasing root diameter class on a logarithmic scale in Plot 5 as shown in Table 6. This might be due to the morphology of the root system which makes up several levels of "hierarchy" starting from the stump-primary ones, secondary ones, tertiary ones, and so on (KONOPKA and TSUKAHARA, 2000).

As tree DBH decreased, the root length per dry weight (Fig. 4) and root area per dry weight tended to increase in each plot. We found that root length and root area per unit root weight for root diameter 0.2 - 0.5cm was higher in Plot 5 (27 cm/g, 27 cm^2/g) than in Plot 3 (18 cm/g, 20 cm^2/g). Roots at a site with a low site index are longer than those at a site with a high site index and the surface of root systems is higher in dry soil than in moist soil (KARIZUMI, 1974b), i.e., Plot 5 has a smaller site index and drier soil than Plot 3. However, the dry weight ratio for root diameter <0.5cm was lower in Plot 5 than in Plot 3 (0.5 and 0.7, respectively). This contradicts with the argument for the root length and root area per unit dry weight, as a higher root dry weight ratio is expected. Generally, the stand soil with a small site index is either dry or heavily wet (KARIZUMI, 1974b).

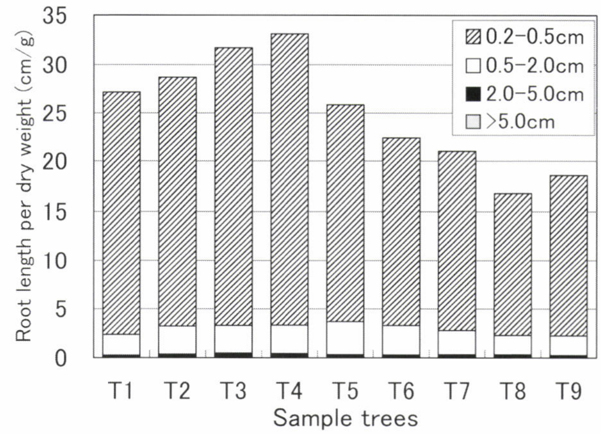

Fig. 4 Root length per dry weight by root diameter classes for each sample tree

The possibility of estimating below-stump biomass by using an easily obtainable above-stump parameter such as DBH has already been tried for various tree species (SANTANTONIA, 1977). Allometric equations are useful for estimating plant biomass by component in forest (SANTANTONIA, 1990 in DREXHAGE and COLIN, 2001). Tree DBH proved to be a good predictor of root systems for different root category and for the entire root system of mizunara-oak in the condition of the experimental stand. This is consistent with already published results on oak species and other species (DREXHAGE *et al.*, 1999; LE GOFF and OTTORINI, 2001; DREXHAGE and COLIN, 2001). This research also reconfirmed that the relationship between root biomass and DBH is generally best fitted by a power function (DREXHAGE and COLIN, 2001; CANADELL and RODA, 1991). The regression equations developed might be useful for estimating root systems from DBH, which is a simple variable to measure. Furthermore, for applications in forestry inventories and as an input variable for entire tree-growth models and carbon storage allocation, the equations might be extremely useful for a simple estimation of root systems without the need to extract them. However, DSH might be a useful estimator as it also has a high correlation to root systems if branching starts at breast height (CANADELL *et al.*, 1988; CANADELL and RODA, 1991; THIES and CUNNINGHAM, 1996). DREXHAGE and COLIN (2001) suggested that researchers should need to agree on whether the stump should be considered as a part of the root system or not. Also, HOFFMAN (2001) highlighted that it is necessary to uniformly define the limits of the root diameter classes and stump biomass whether it is listed separately, or ignored to be able to compare the

Table 8 The parameters and coefficients of determination of regression equations between DBH and coarse-root weight (values in No. 1 to 5 were cited from DREXHAGE and COLIN, 2001)

No.	Species	No of data	*a*	*b*	R^2
1	*F. sylvatica* ,(PELLINEN in (DREXHAGE *et al.*, 2001)	8	-2.00	2.70	0.98
2	*F. sylvatica* ,(LE GOFF and OTTORINI, 2001)	16	-1.66	2.54	0.99
3	*Q.petraea*, (DREXHAGE and COLIN, 2001)	71	-1.56	2.44	0.94
4	*Q.ilex*, (CANADEL and RODA, 1991)	32	-1.05	2.19	0.73
5	*Q.douglasii*, (MILLIKIN *et al.*, 1997)	6	-0.56	1.81	0.89
6	*Q.crispula*, in Plot 5 (this study)	4	-1.75	2.50	0.99
7	*Q.crispula*, in Plot 3 (this study)	5	-1.59	2.57	0.90

results to the other researchers' ones. In addition, VOGT *et al.*, (1998) suggested that a uniform agreement of how root biomass and production should be sampled and calculated is urgent.

The results of quantitative analysis between root biomass and DBH among broad-leaved species (cited from DREXHAGE and COLIN, 2001) is shown in Table 8. Although no statistical comparisons could be made, the present results and those obtained on other broad-leaved species have relatively similar allometric relationships between DBH and root biomass. LE GOFF and OTTORINI (2001) found that total root biomass is closely linked to tree dimension, independent of tree age and site. These results suggest that individual root biomass of oak species was estimated confidently from tree DBH.

CONCLUSION

During the excavation of the root systems of the sampled mizunara oak trees some of the root system was lost. However, the root system equations established from samples of seemingly unbroken root ends might allow the estimation of missing parts of the root system. Root length and root area per unit root dry weight might be possible as a site index indicator.

Allometric equations are a useful tool for estimating the root system by component in forests. Tree DBH proved to be a relatively good predictor of root systems for different root categories and for the entire root system to estimate carbon storage and uptake by growth of tree biomass in broad-leaved secondary forests. Furthermore, for applications in forestry inventories and as an input variable for entire tree-growth models and carbon storage allocation, the equations might be extremely useful for a simple estimation of root systems without the need to extract them. DSH can be a useful estimator as it also has a high correlation to the root system if branching starts at DBH.

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Article

Wood Products' Marketing Functions Carried out by Forest Adjacent Dwellers. Implications for Policy Makers - A Study of Kakamega Forest in Kenya -

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ABSTRACT

This paper reviews functions undertaken in marketing of forest products (poles, posts, timber, firewood and charcoal), policy challenges arising and possible solutions to the problems. The focus is on Kakamega forest found in western Kenya, the activities of the forest adjacent dwellers, and how their activities relate to the current forest law and policy. The approach taken involves looking at individual functions namely; acquisition, or buying, selling, storage, transportation, processing, standardization, financing, risk bearing, and market intelligence. It was realized that each function reveals specific policy challenge(s) and this could be arising due to lack of specific laws on marketing functions in the current law and policy. In addition, negative impacts which include loss of revenue, conflicts, high enforcement cost, and distortion of forest products markets and over extraction are also noted. Mixes of policy options are necessary to overcome the challenges. A review of the current law and policy is necessary if the forest has to continue providing services now and for posterity. Forest policy formulators should move towards creating laws and policies that address specific issues in marketing.
Keywords: Marketing functions, Law and policy, Wood products, Kakamega

INTRODUCTION

Marketing of forest products involves various functions. These functions start with buying or acquisition and end when products reach the final consumer. In the process of marketing, if certain functions are not carried out well, forest resources will not be sustainably utilized. In forestry the presence or absence of the recognition of the importance of laws and policies on marketing is highly likely to have a big impact on resource utilization and conservation. Thus understanding marketing functions can become a pillar on which laws can be based that will ultimately determine the survival of a forest.

The Forests Act chapter 385[1] of the laws of Kenya under subsidiary legislation allows local people to extract certain forest products freely from government forests for home consumption. The act also allows for commercial extraction on payment of a fee. The rights of usage by the local people are covered under subsidiary section, part 3 which states that any bonafide resident of Kakamega and Bungoma[2] Districts may, without any charge or permit, in a Central Forest to which these rules apply - take or collect dead fallen wood for firewood for his own personal domestic use but not for barter; take and collect thatching grass; pick wild berries and fruits for his own consumption; cut and remove creepers and lianas for building purposes; place honey boxes and have free access to them, provided no damage is done to any of the trees; take stock other than goats to such watering places within the Central Forests as are adjacent to grasslands and along recognized stock routes (Government of Kenya, 1992). This act does not cover aspects of marketing even though it recognizes commercial use on payment of a fee.

The forest policy (white paper No.5 of 1957, Sessional Paper No 1 of 1968 and lately Kenya Forest Policy of 1994) does not give guidance on marketing of forest products.

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[1] Kenya's law is divided in to Chapters, of which 385 is the Forests Act

[2] Bungoma is a neighboring district.

Therefore, we would like to argue that the lack of the inclusion of marketing functions in the law and policy has implications for the forest. Kakamega forest is hereby selected for study. Kakamega was chosen because of the unique position it occupies in Kenya's forests. It's the only moist tropical rain forest in Kenya. It's actually the eastern most relic similar to forests found in Central Africa. Kakamega forest though small in area, ranks number three out of 51 forest groups in Kenya when forests are classified in terms of biodiversity value, environmental protection, local forest use and threats. The objectives of this study are: to describe how Forest Adjacent Dwellers (FADs) market wood forest products namely: - timber, poles, posts, firewood and charcoal, find out the policy related problems arising from the marketing activities and recommend policy options that can be used by forestry authorities to minimize negative impacts of the current marketing practices.

Emerton (1991), working under KIFCON[3] collected information on forest utilization in and around Kakamega forest. In her work, she looked at the needs of the households from the forest. One aspect was the use of the forest as a source of income. This implies selling of forest products. She further looked at the perceptions of rights and ownership of the forest. Omolo (1991), also of KIFCON reviewed local markets in wood products with an aim of identifying the source of timber sold in Kakamega town. He also examined the proportion that came from Kakamega forest. Other research has been done by Wachira (1995), who looked at the development of a timber market assessment model for Kakamega district. What was observed in all these cases is that they touch on the issue of marketing without evaluating the various components. In addition, their research does not go far enough in examining issues related to law and policy. Forests have value and value is dependent on laws and policies. Our aim shall not be to describe or discuss the marketing system or practices. The aim is to examine the individual functions that local people engage in carrying out commerce using products from the forest, and how these functions relate to the law. We are thus moving to a much deeper level beyond merely describing the marketing system.

METHODS

In marketing research, a mixture of methods is preferable in order to unearth as much information as possible. We employed this approach in this study. In the case of primary data, this was collected through visits to forest adjacent dwellers living within a five kilometer radius of Kakamega forest. Additional information was obtained through interaction with forestry officials because they are the ones on the ground and therefore have some information that may not be obvious to researchers. For secondary data, literature on Kakamega forest, its utilization, forest law and policy, annual report appendix and forest department annual royalties were examined. Data was collected using a questionnaire (direct interviews), observation and discussion. Issues on buying, selling, storage, transportation, processing, standardization, financing, risk bearing and market intelligence were included in the questionnaire.

After a reconnaissance survey, lists were drawn of the various households in four sub-locations[4] namely Ileho, Virhembe, Kambiri and Mukango. Random sampling was used in selecting the respondents. Data was collected from one area at a time before moving on to the next. A checklist was also prepared and was referred to as data collection progressed. Household heads and in their absence any responsible adult member of the household were interviewed. Four smallest central government administrative units called sub-locations were selected for visits. Interviews were carried out with FADs in these areas.

We faced several challenges in the course of carrying out this work. "Traders" in general are not used to providing information on how they carry out their activities. The fact that people are using free forest products as a source of income makes it hard to extract information. However, confidence was built through the help of local assistants. One hundred and sixty one respondents were interviewed. Four government officers provided further information and clarifications where it was necessary.

STUDY AREA

The forest is located in western province of Kenya. It is currently found in Kakamega, Lugari and Vihiga districts, but for purposes of this report all shall be considered to part of Kakamega district as it is the mother district. According to the District development plan of 1997-2001, published by the Republic of Kenya in 1997, the district lies between longitudes 34 and 35 degrees east and latitudes 0 and 1 degrees north of the equator. The total area of the district is over 3,000 square kilometers. There are five forest stations viz; Lugari, Turbo, Nzoia, Malava and Kakamega. The first three have a total of 12,171.3ha and are mainly composed of industrial plantation planted with Pine, Cypress and Eucalyptus, which mainly supply pulpwood material to Pan African Paper Mills in Webuye town. Malava and Kakamega are covered mainly with indigenous forests with *Croton megalocarpus*, *Caltis duradii*, *Aningeria altissima*, *Ficus exasperata*, *Fantumia clastica* and *Bosqueia phoberos* being dominant species. *Croton macrostachys* and *Olea welwistchii* are of special concern since

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[3] KIFCON: Kenya Indigenous Forest Conservation Project. An ODA (British) financed project

[4] Kenya as a country is divided in to provinces, districts, divisions, locations, and sub-locations as the main administrative units of the central government.

though abundant in the past, they have been overexploited for timber. According to the Kenya Forestry Master plan (1994), Kakamega is one of the forests identified for priority biodiversity conservation. Based on the Annual Report Appendix (1995), by Forestry Department (FD), Kakamega forest covers an area of 24,918.6ha and lies at an altitude of 1,500-1,700m. This part of Kenya receives over 2,000 milliliters of rainfall annually. Its importance derives from the number of species of flora and fauna. Kakamega forest is tropical, and there are over 380 different plant species in this one small area. Among the species of plants are *Milicia excelsa*, *Olea capensis*, and *Markhamia lutea*, which produce high value timber. There are over 330 species of birds recorded from the forest. Many mammals are found in this forest though the numbers are declining. Kakamegas' famous primates include the Black and White colobus monkey and the swamp monkey. Snakes include the forest Cobra and the Kaimosi blind snake endemic to this area. There are lizards, insects and mollusks too (KIFCON, 1994). The foregoing makes the forest an important biodiversity reservoir. Management of the forest is shared between Forestry Department (FD) and Kenya Wild life Service (KWS). However, wood production is the responsibility of the former.

The dominant community living around the forest is the Abaluyia. Apart from small-scale farming[5)] of maize, beans, potatoes and sugarcane, the community is engaged in small scale livestock rearing and other commercial activities. The people living around the forest also grow trees on their own farms. Kakamega district is a high potential area receiving adequate rainfall and has fertile soils for growth of various tree species. The species preferred are multi purpose. Among the many uses to which trees can be put, trees on farm have both social cultural and economic values. It has been argued that trees on farm for many farmers act as bank for the future. They are only cut when large finances are needed such as when paying school fees or meeting medical expenses (LUBANGA, 1990). Otherwise, they are left untouched to grow both in height and in girth. This is truer where an alternative source of wood exists, like in the case of Kakamega forest.

Looking at wood extraction, there are local extractors hereby referred to as Forest Adjacent Dwellers, middlemen, wholesalers and retailers who ensure that products reach consumers. Wood products from the forest are sold locally but have been noted to reach far off places like Nairobi, 500 kilometers away, as passers by also buy wood products. Products coming from the forest include timber, charcoal, firewood, gold, building poles, posts, thatching grass, water and medicinal plants.

There is use of the forest by commercial extractors though this will not be given emphasis in this study. The reason for this is that their activities are well known and the products they sell are easy to track down. A flow chart showing the movement of wood products from Kakamega forest is hereby provided.

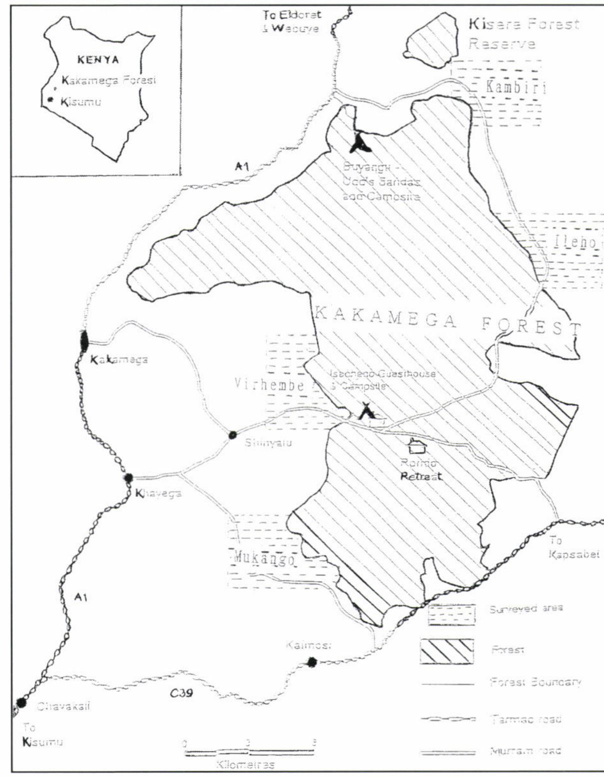

Fig. 1 Location of surveyed areas around Kakamega forest
Source: Modified from KIFCON (1994)

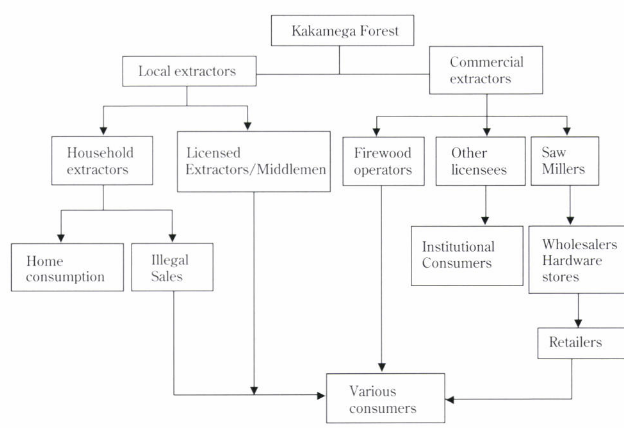

Fig. 2 Flow chart for marketing of wood forest products from Kakamega forest (Source: Field survey)

Of importance to note in Fig. 2, is that products obtained legally and illegally can and do reach consumers. There are licensees who sell in the same market as those that obtain

5) Small-scale farming is for both subsistence and sale.

products legally but sell them illegally. Although not included in the chart above, local people who have products on their farms, can and do sell to consumers.

MARKETING FUNCTIONS FOR FOREST PRODUCTS AND PROBLEMS ARISING

In looking at the functions, we shall specifically concentrate on Kakamega. Other areas of the republic of Kenya do not have similar characteristics to Kakamega. It's therefore not possible to generalize the case of Kakamega for the whole nation. Areas are different socially, economically and even in terms of flora and fauna.

There are at least three major approaches to the analysis of a marketing problem- the functional approach, the institutional approach, and the behavioral systems approach. All these are merely ways of breaking down a complex marketing problem into its parts so that it can be better understood. One method of classifying the activities that occur in the marketing process is breaking the process down into functions. A marketing function may be defined as a major specialized activity performed in accomplishing the marketing process. A widely accepted classification of functions is as follows: Exchange functions (buying or assembling, selling), Physical functions (storage, transportation, processing), Facilitation functions, (standardization, financing, risk bearing, marketing intelligence) (Kohls, 1967). It is these functions that local people engage in marketing their products that we shall examine. This allows an evaluation of each specialized activity on its own rather than focusing on the wider practices or marketing system. If we need to formulate viable policies, then each component of the marketing chain must be examined. Without this, certain valuable information will be left out. We hereby proceed to examine each of the functions.

Acquisition or Buying

For people living around Kakamega forest, alternatives exist as to acquiring wood products. One is buying from the Forestry Department (FD). Those who buy are the so called monthly ticket holders. These people also play the part of middlemen. On one hand they buy products genuinely and sell where markets are. On the other hand, they act as conduit for products and other activities for those who want to sell products illegally. They are thus middlemen.

Another way of getting products is freely under the guise of home consumption or to extract the products illegally either for home use or for sale. Results showed that very few forest adjacent dwellers buy wood products from the local Forestry Department office. Those who buy are the monthly ticket holders for fuel wood and those who supply fuel wood to institutions like schools and hotels. Products once outside the forest can then enter the market chain without any hindrances except charcoal whose marketing has been highly controlled by the government. As products are obtained legally, even if eventually sold, there is no possibility that forestry officers can intervene as this is outside their jurisdiction. The law does not cover different forms of acquisition and disposal. It is equally challenging for anyone to attempt to read the final intentions of those extracting for home consumption.

Selling

Wood products obtained from Kakamega forest are sold mainly in markets near the forest. The forest is located near urban centers and a tarmac road passes through some parts of the forest. Therefore, passers by also buy wood products. These wood products are then transported as far as 500 kilometers away. Thus, a secondary market exists and this market offers even higher prices as passers by are in most cases in cars hence relatively better endowed with financial resources. Local extractors sell firewood, poles, posts and charcoal. Although the law envisaged local use and if possible little selling to local schools and institutions, the sale beyond the catchment's area provides a challenge as better prices encourage more extraction. The cycle is thus repeated. Forestry officers may not know how to deal with this.

Storage

Storage of wood forest products is item dependent. Products that are easily obtained such as firewood are not stored with much care. High value hardwood timber e.g. *Olea welwitschii* and *Fagara macrophylla* is stored in concealed places or in houses. These are considered safe places by extractors. Improper storage means that wood products can and are lost to thieves, termites, and weather elements. Therefore, it follows that more products have to be extracted if the local people have to meet certain financial obligations. High value products like timber are sometimes stored underground, hence prone to termite attack. More timber will be demanded if the timber from the forest is stolen or damaged. From a utilization point of view, this means wastage. From a management point of view, there is misallocation of resources. Policies will thus be needed to redress this.

Transportation

In the case of forest adjacent dwellers, transportation by head, bicycle, cart and even motor vehicle is done where appropriate. Firewood for example, is carried in most cases by bicycle when meant for sale. Although it is not stated anywhere in the forest law, the basic assumption is that wood from Kakamega forest is transported by head when meant for home use, and by bicycle when for sale. Reality on the ground reveals that this is not the case. This therefore calls for a closer examination of the modes transport to differentiate between home and commercial use. In some cases, once wood is outside the forest, its handed over to monthly ticket holders (bicycle transporters or middlemen) who then sell the wood, keep some commission and hand the rest of the money to the extractor. The mode of transport cannot be used as a determinant as to whether wood will be sold or not. This is an issue that forest managers should keep in mind.

Processing

Illegally felled logs are pit sawed to produce timber. This is done in the forest, as the logs are too heavy to take outside the forest. Poles and posts may not need any processing apart from sizing and debarking. Firewood is chopped and split into merchantable sizes and shapes usually inside the forest. In the case of wood taken out as pole wood, splitting and splicing is done. Charcoal is prepared in earth kilns both in and outside the forest. For charcoal prepared outside the forest, the wood is taken out in form of firewood. Problems arise from the mode of processing used. Pit sawing is a wasteful mode of processing, as recovery rates are very low. This means that a lot of round wood is needed to produce a small amount of sawn wood. Preparation of charcoal in kilns is wasteful. There are also associated risks of fire when it is done in the forest. We therefore note that processing has a direct link to recovery, extraction and conservation of the forest. The ability of FADs to convert poles and posts into firewood and charcoal outside the forest is a challenge that requires attention of the local forestry managers.

Standardization

Local people have their own standards based on local knowledge. These standards are item dependent. For example, high-density charcoal is preferred to lower density. This is because high density charcoal burns longer. The Kenya Bureau of Standard and Forestry Department have no set standard of what constitutes poles, posts and firewood. Charcoal has also not been graded. Lack of standards, means that forestry officers cannot give advice if required. Consumers are thus negatively affected. The lack of uniform measurement of quality and quantity will definitely affect the way the forest is used. Consumers may be cheated and hence have to incur extra costs of product replacement in cases where the lifespan is short, especially for wood used in construction. More products are thus extracted, leading to shrinkage of the forest.

Financing

Forest adjacent dwellers have some financing from middlemen who are also members of the local community and partake in the daily activities of the society. Intermediaries are endowed with resources more than the extractors are, thus can, and do offer help when needed. There were cases where it was observed that FADs receive cash and later supply products to the middlemen. Sometimes, middlemen took products from forest adjacent dwellers and paid when the market prices were better. The existence of this system encourages illegal activities. Under the current law and policy, forest managers cannot take action against those involved in such activities.

Risk Bearing

Middlemen undertake risk for forest adjacent dwellers. They take wood from the FADs in lean times with a promise of delivering funds once goods are sold. All middlemen live up to their promise. The fact that risk is covered by middlemen encourages illegal extraction and sale as the extractors are well aware that their effort will be rewarded. The current law does not cover risk aspects in marketing of forestry products.

Market Intelligence

Market intelligence involves collecting, analyzing and disseminating information on the market. In the case of FADs, middlemen provide market intelligence. One clear observation as relates to market intelligence is pricing. Middlemen control the prices. Most FADs cannot set prices as they lack the basis of doing that.

REAL AND POTENTIAL NEGATIVE IMPACTS OF THE ILLEGAL USE OF THE FOREST AS A SOURCE OF INCOME

The Kakamega District forestry office stands to be affected by activities that go on in Kakamega Forest. Illegal use of the forest has implications. Among them are loss of revenue, conflicts, high enforcement costs, distortion of markets and over-extraction.

Loss of Revenue

This is one of the most important and serious impacts of the use of the forest as an illegal source of income. In the case of Kakamega forest, an attempt will be made to estimate the revenue lost by forestry office because of the illegal sale of wood products. Losses are through the value of products on which FD does not collect revenue and taxes. Showing revenue loss estimates is one of the best ways of drawing policy makers' attention to a problem in forestry. As people obtain products freely, the FD does not collect revenue. The following section explains the losses made by Forestry Department and how it compares to revenue earned over a year's period from legally harvested products. Revenue losses calculated here do not show exact values but only estimates. This is because there must be year-to-year variations in extraction as conditions cannot be the same year in year out.

Table 1 Estimated revenue loss

ITEM	QUANTITY	UNIT	ESTIMATED VALUE 1998 (Kshs) [6]
Trade license fees	2,435	No	1,217,500
Poles	130,478	No	521,912
Posts	290,956	No	1,745,736
Timber	16,839	M^3	97,430,582
Firewood	2,435	No	14,610,000
Charcoal	369,277	No	12,186,141
Total			127,711,871

Source: From survey data

In fact, in the case of Kakamega forest, and based on the economic factors on the ground, illegal activities should increase with time. Estimated revenue lost in Kenya shillings (Kshs) is given in Table 1. The losses are based on annual values. This will help us compare this to revenue used by the forestry office in managing the forest.

In the financial year 1997/98 10,062,632 Kenya shillings was spent by the forestry office for recurrent and development expenses. In the same year, 606,309 Kenya shillings was the total revenue earned from minor and major products. The estimated annual loss is 127,711,871 Kenya shillings. This is far way above the revenue generated and spent. Even without this, the expenses are much higher than the annual revenue. This can only be justified if the forest is managed for mainly for bio conservation purposes or if it's still young. This is not the case for Kakamega forest. To capture leaked revenue, there must be policies that address some if not all of the issues that have been seen in the marketing functions.

Resource Use as a Source of Conflict

Conflicts arising can be grouped into two. One, are conflicts between government agencies and the local people. The other is between the local people themselves. In the first case, due to the nature of activities that forest adjacent dwellers are engaged in, the forestry officers may try to intervene. If they do this, there is a likely hood of conflicts as the people are used to free products from the forest.

In the second case, we refer specifically to intra-communal conflicts. There are two possible sources of conflict. One is where products coming from the forest are so cheap as to out-compete farmers who produce the same products. It was noted that about 40% of the land area outside the forest is under trees. The trees that farmers grow are mainly for cash when the need arises. If they cannot sell these trees due to products coming from the forest, there is bound to be conflict.

The other possible source of conflict is where there are law-abiding citizens who report cases of theft to the authorities. When this happens, there may be quarrels and hence conflicts. In the case of Kakamega, this reality has been experienced.

Enforcement Costs

Illegal use of the forest requires that management take steps to control it. This means that resources that could be channeled to other uses have to be used for patrols and the like. Arresting offenders, taking them to court and related activities cost money. Further, with the realization that there is illegal use, more patrols have to be done. With scarce resources, this becomes expensive and the FD may not afford.

Distortion of Markets

As earlier mentioned, there will definitely be differences in pricing between products obtained free of charge and those that are produced on farm. If markets are distorted prices are definitely affected. If this is the case, then market failure, which results in misallocation of resources, will be felt. This is not good for forest conservation. Bridging the price gap is a challenge that needs addressing if forest products should have a realistic market price.

Over Extraction

The forest act allows people living around the forest to use the forest freely for certain products. However, if these products feed other markets and these markets grow beyond the available supply, then there will be problems. As businesses grow and demand grows, there will be increased threats to the forest. This means that eventually the forest will not be able to supply quality and quantity. This is the beginning of the extinction of the forest. A clear statement

[6] Estimated value is calculated as quantity multiplied by price. For license fees, it's the estimated number of evaders multiplied by the gazetted annual license fees by the Forestry department.

made by the forestry authorities in Kakamega at the time, is that most high value hard wood timber species have been poached. This has led to a situation where low timber value (low quality) species are being exploited. This means furniture or buildings made from these low quality trees cannot last for long. Replacement is frequent; hence, more forest products are required for the replacement jobs. As such, it causes a spiral effect, as more products will be needed over short periods. Consequently, biodiversity of the forest suffers.

POLICY OPTIONS TO ADDRESSTHE CHALLENGES

In this section an attempt is made to look at each function independently and recommend appropriate policy options. These policy options should specifically cater for the marketing of forest products. They should be explicit and focused. There are cases where some options cut across a number of functions. Overall, however before any policy options are changed, there is the need to change the law so that activities that people carry out are recognized. It would be futile to change certain policies when the overall law is against forest utilization for commercial purposes. There is need to recognize use of the forest as a source of income for rural households. Once this is done, then other aspects of the marketing practices can be tackled.

Acquisition/Buying

Challenges observed here could be overcome through several policy options, namely forestry focused education, more research and development, and command and control. Forestry focused education should be provided to area residents so that they appreciate the forest and the need sustainable utilization. Schools in areas near forests should incorporate forestry training in their curriculum. The curriculum should include the multipurpose role of trees. Rural afforestation and extension services should be enhanced to provide information to FADs. Research and development will go along way in creating either alternative ways and means for local people to survive or understanding why they do what they do. Action research is thus recommended.

Selling

Selling results in loss of revenue by FD as earlier explained. It could also be a catalyst for community stress. Information should be provided so that those who want to engage in trade have all the information they need. There is need to create a transparent market. There should be incentives to help people plant trees on farm so that reliance on the forest is reduced. Incentives may include guaranteed minimum returns for their tree products. Command and control may also be used to stop those who sell illegally.

Storage

To avoid wastage through pest damage, there is need for education on proper storage methods. This combined with other products specific information should be clearly stated out in the forestry products marketing policy. This will go along way in limiting wastage. This has a positive impact on forest conservation.

Transportation

Transportation of wood products is not mentioned in the law and policy. Issues that can address the policy challenges arising from this are negotiation and education. The local householders should know the importance of not selling the products they extract for home consumption. Education should be provided at all levels of society concerning sustainable use of forest resources. Transportation of large quantities of wood under the guise of home consumption should be discouraged. If possible, rationing should be used to reduce overexploitation by large families.

Processing

With proper technical information provided through extension, recovery rates should improve. Information should be provided at all times to ensure that recovery rates are high and that processing is of the highest order. This will minimize wastage. If recovery rates can rise beyond the current estimated 40-50%, this will help reduce excessive timber extraction assuming constant demand.

Standardization

Forestry is one area that lags behind in terms of standards. Efforts should be made to ensure that institutions like the Kenya Bureau of Standards (KBS) play their part in grading timber or providing guidance on the same. KBS should also prepare quality guidelines on other wood products as this is currently lacking. This will ensure that only high quality products reach the market. High quality products will last longer and this has a direct positive impact on the forest. Research is also needed so that standards are based on scientific data. This calls for NGOs, Energy Department and Kenya Forestry Research Institute to intensify research efforts that will lead to formulation of standards for all forest products. As situations may change, the policy should be for continuous review of standards and not a one off thing.

Financing

Financing of forestry activities especially on farm should be given priority through institutions such as Agricultural Finance Cooperation (AFC). Education should also take center stage in policy that is formulated to overcome shortcomings in the area. Proper education in financial management can help mould forestry into an enterprise that rural people can rely on. Financing provided by middlemen should be eliminated. It is a part of the black market that fuels illegal extraction.

Risk Bearing

Education stands out as the best policy option to overcome risks observed in the marketing by forest adjacent dwellers. Thus, all necessary information and knowledge should be imparted to communities living around the forest. This can be done through school education and rural afforestation and extension services.

Market Intelligence

The forest policy should emphasize the importance of a market information system. This should be area focused and clearly spelt out for each aspect of the marketing functions. If this is done and one is created, it will be easier to operate a proper market for products from the forest and those from farms. This will go along way in encouraging tree planting for income. It will reduce exploitation by middlemen. The policy may also encourage the presence of middlemen if they contribute to the forest and community positively.

CONCLUSION

Although mentioned in general management terms, the lack of clear policy statements on specific functions in the marketing of forest products presents problems for forest managers. For Kakamega, it means that a forestry officer is at dilemma as to how to deal with issues not covered by the act and policy. There are no other laws to guide him or her. Lack of definition of what constitutes fuel wood is one of the things that are lacking in the law and policy. This makes it easy for all sizes of wood to be extracted; they are then used outside the forest as poles, posts, and for charcoal making.

The law does not cover charcoal making outside the forest for illegally extracted wood. This means that forestry officers cannot take legal action against the perpetrators of this activity. It is our thinking that these lapses in law need to be carefully addressed and amendments made in the forest law and policy.

This paper has examined the marketing functions for timber poles, posts, firewood and charcoal by forest adjacent dwellers. They are engaged in exchange functions, physical functions and facilitation functions. The functions reveal differences from the normal businesses as products obtained without charge are sold. The way functions are carried out, and looking at the forest act and policy, led us to finding various policy challenges. In order to correct the situation, policy options need to be taken into account. Among them are provision of education, conducting research and development programs, ensuring proper tenure rights, negotiation with local extractors on better forest use and command and control where it's felt necessary that all other avenues have been refused. If this is done, there is likelihood that the forest will be better managed for posterity. If policies are developed to address specific marketing functions, this will go along way in helping in forestry conservation. The need for a more focused and comprehensive forest policy is thus emphasized.

Since each forest has its own unique socio-cultural and economic situations surrounding it, it would be appropriate to suggest that policies need be developed to address these situations. The government thus needs to come up with policies that address specific forest areas and specific marketing functions. In our view, there should be a specific act on marketing of wood forest products. In addition, there is need to develop a forest products marketing policy. The two should be developed by forestry policy makers who face challenges in the absence of the policies.

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