GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 2, NO. 1, 2004: 91-99
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EVOLVING AN EMPIRICAL METHODOLOGY DOR DETERMINING APPROPRIATE INTERVAL FOR REMOTE SENSING OF A FOREST ENVIRONMENT

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ABSTRACT

The phenomenon of deforestation has been an environmental threat, and some concerted efforts have been made by researchers to tackle the problem. These generally include mapping of the areas affected, using remote sensing and GIS to display information on the spatial and temporal distributions of the processes. It is however, observed that little or no attempt has been made on the conceptualization of deforestation for better understanding of the problem scenario which can be applied to any forest for effective planning and management. It is in this light that the paper attempted to evolve an innovative mathematical model for establishing appropriate interval for remote sensing of a forest environment, using Afaka Forest Reserve as a case study.

The methodology consists of conceptualizing Afaka Forest Reserve as a tightly stretched string under tension of human - induced deforestation; deriving a mathematical model; and testing it with the assumed error free values of the rate of deforestation computed in each period, using remote sensing imageries of 1962 aerial photographs (B-W); Landsat MSS (1970); Landsat TM (1987); and SPOT (XS) of 1994. The results show that the proper interval for mapping is eight years under ideal condition, followed by nine years interval, irrespective of imageries used.

The uniqueness of this approach, is that it can be applied to any forest or dynamic feature on the earth, and can enjoy universal application as well.

KEYWORDS: Evolving empirical methodology, innovative mathematical model, appropriate interval, remote sensing, forest environment planning and management.

INTRODUCTION

Deforestation has been acknowledged to be one of the great environmental challenges of the late 20th century, and forest clearance, therefore, must generally be tackled by reducing the rate of deforestation rather than drastic solutions such as population transfer and giant, futile reafforestation schemes (Soussan and Millington, 1992).

The environmental functions of forests as well as their economic values make a strong case for more effective action to reduce the rates of, especially tropical deforestation (Nwadialor, 2001). As a result, many authors have investigated this phenomenon, aimed at reducing its occurrences. Chandga et al (1991), conducted a real time satellite monitoring of Daxinan Lin forest fire condition and post-conflagration changes in China using NOAA (AVHRR) and Landsat TM. More than 40 scenes of the AVHRR and 7 of Landsat TM images were processed and analyzed. They provided the timely grasp of fire condition including precise locations of the scenes and spreading directions of flames, effectiveness for various fire - suppressing measures and other information important for decision making. An affliction degree map was drawn accordingly which is the basic document for damage estimation and reconstruction planning. They observed that natural rejuvenescence of the areas affected was almost impossible, and therefore, recommended the need for artificial afforestation, and further monitoring approach.

Vibulsresth and Murai (1991), studied the mapping of mangrove forest resources following drastic conversion of the mangrove to shrimp farms and other uses. Mangroves are salt - tolerant forest ecosystems of intertidal regions along tropical and sub-tropical coastlines. Landsat MSS of 1975, and Landsat TM of 1988 were used to map the forest and the images compared. The authors found out that a very greater percentage of the mangroves had been converted to fisheries farms, and warned that Asian people should note that mangrove is a tropical treasure to conserve.

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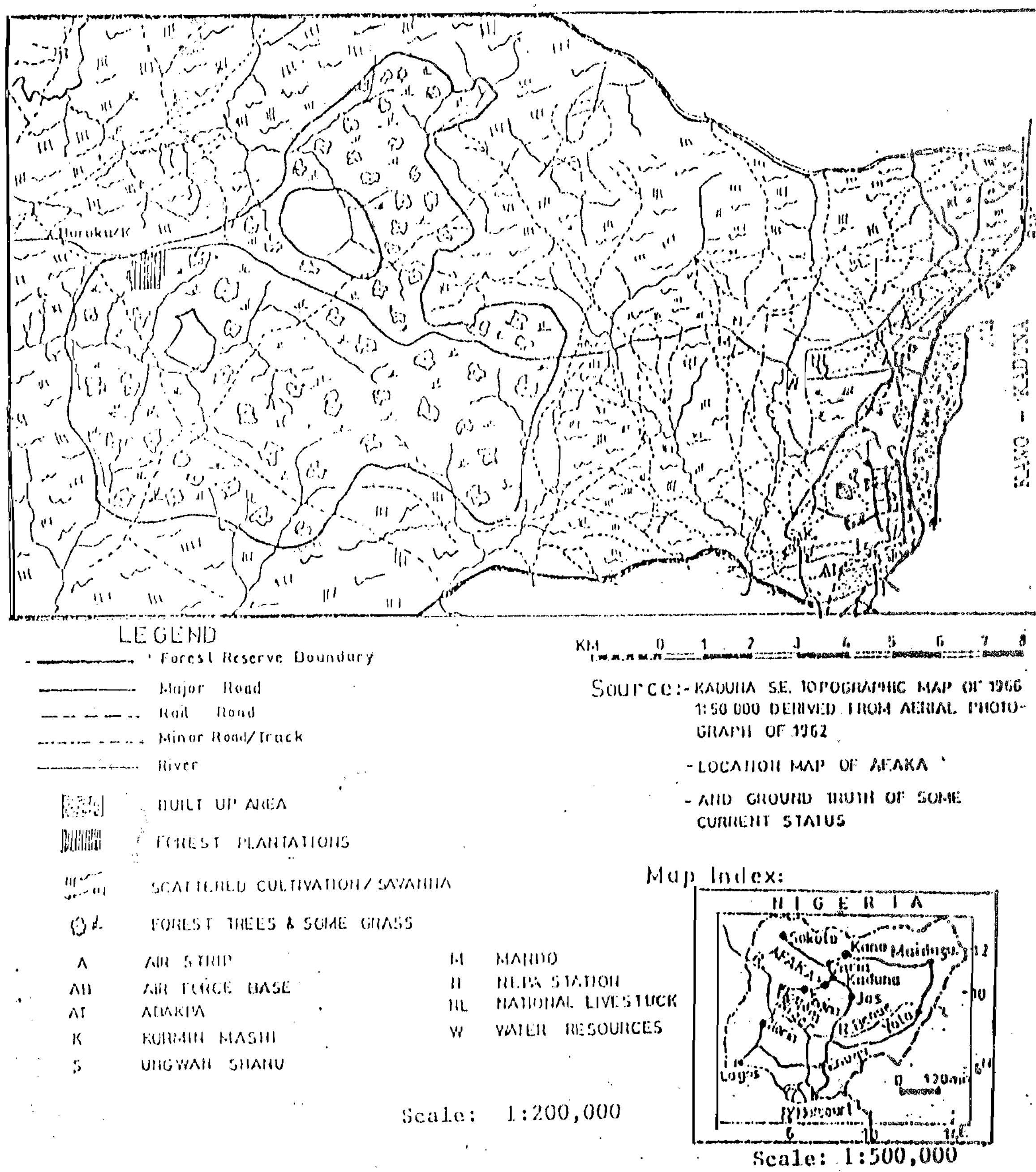

Figure 1:1 LOCATION OF STUDY AREA

Osterlund (1992); produced deforestation and change images for the Chiang Rai Province in Northern Thailand Forest area cover, and rate of change was estimated with the use of sampling design from 1977, 1984, and 1990 Landsat imageries of the same season. Annual rate of deforestation was found to be more than 2% per year between 1977 and 1984. This, the author observed, doubled to 4% within the period of 1984 to 1990. Forest decreased by 64% within a period of 13 years.

Olsson and Ardo (1992), studied deforestation in African dry - lands, using Western Sudan as a case study. They used Landsat imageries of 1973, 1979, and 1987. Wood resources were quantified and manual stratification was used to delineate areas of irrigated and mechanized rainfed agriculture, resulting in classification into; open woodlands, rainfed forest, irrigated agriculture, mechanized rainfed agriculture and others (unhabited areas). The results showed that land use had changed drastically during the study period, but the conclusion reached was that woodlands and forest resources came from the expansion of rainfed mechanized agriculture. About 1.1 million hectares was transformed into agricultural land from 1973 to 1987.

Most authors, Benoit and Eric (1999); Kressler and Steinnocher, (1999); Stamm and Briggs (1999); Foody and Curran (1994); and Souza and Barreto (2000), have also studied deforestation using different approaches. However, this paper attempts to evolve an empirical methodology for establishing an appropriate interval for mapping of forest environments as further contribution to solving the problem of deforestation.

STUDY AREA LOCATION

Afaka Forest Reserve is situated some 30km N - W of Kaduna township, along Kaduna Lagos Express Highway road, and is about 12,243.76 hectares in areal extent (Fig. 1). It is geographically located between latitudes 10^0 33' N and 10^0 42' N; Longitudes 7^0 13' E and 7^0 24' E.

The vegetation cover classes consist of mainly native species of *Isoberlinia doka* and abundance of exotic plantation of mostly eucalyptus and pinus species. This Reserve had been known in the past for its potentials in biodiversity of flora, as well as being an Experimental plantation site for the improvement of the productivity of forests in the semi-arid zone of the Northern Guinea Savannah of Nigeria. This has influenced our choice of location for study.

MATERIALS AND METHODS

The following materials were procured and used to quantitatively map Afaka Forest Reserve to detect and measure deforestation, which was later used to test the validity of the mathematical model derived for determining appropriate interval of remote sensing mapping of forests. These are: aerial photographs (B - W) of 1962 (1 : 40000); Landsat MSS of 1970 (resolution = 50m); Landsat TM of 1987 (resolution = 28.5m); SPOT (XS) of 1994 (20m pixel resolution); topographic map of 1966 at scale (1:50,000); soil map of 1968 at scale (1 : 40,000 and 1 : 25,000).

The ARCINFO and ERDAS IMAGINE software packages were used for the processing of the images. The methods employed for the mapping include the following sequences:

(i) Aerial photographs of 1962 were visually interpreted and later digitized to form the basic information input to the computer.
(ii) Changes in the land use/forest disturbance classes were detected using the three satellite images.
(iii) Interpretation was carried out no-line on the images.
(iv) Digitizing of the interpreted overlay was also carried out.
(v) Digital analyses were performed on the four sets of data (1962, 1970, 1987, and 1994) to produce among other things, areas for the different land use/forest disturbance classes.

The deforestation variables identified and quantitatively measured are: Exotic vegetation (EXO,); Erosion Sites (ERO.); area Under Cultivation (AUC.); and Roads (RD.). These were used to derive the values for the natural forest left in each period for use in model testing for rate of deforestation. The next step was the derivation of a mathematical model for determining appropriate interval for remote sensing mapping of Afaka/any Forest Reserve; based on the conceptualization of Afaka Forest Reserve as a stretched string under tension of human - induced deforestation.

DERIVATION OF A MATHEMATICAL MODEL FOR AFAKA FOREST RESERVE

In the effort to evolve a model for appropriate interval for mapping, the effects of human interference between two periods on Afaka (or any Forest Reserve) were represented through the conceptualization of Afaka Forest Reserve as a sag of a tightly stretched string using the diagram (Fig. 2) below with its associated/derived model equation.

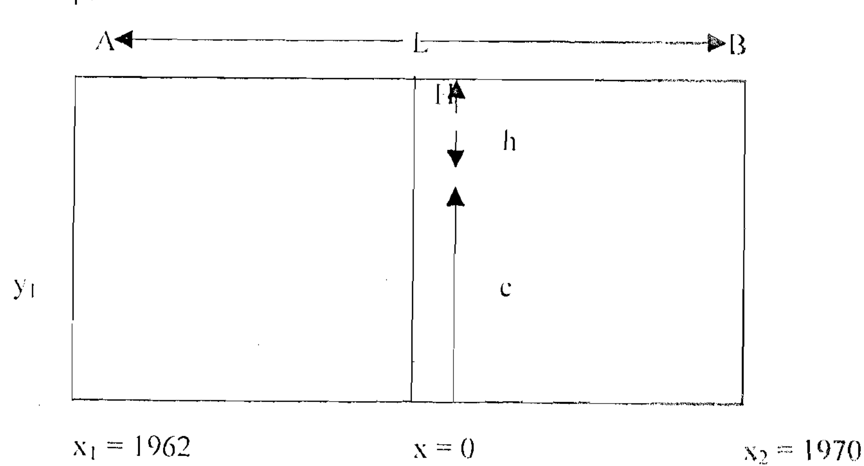

Fig. 2 Model conceptualization of human deforestation of Afaka Forest Reserve. (Source: Author's concept

In deriving the equation for the sag (h) whose reciprocal (h^{-1}) represents rate of deforestation, a trigonometric series expansion was used to find an approximate expansion for the sag of a tightly stretched string. Such a string, suspended between two fixed points, a distance L apart, is shown above in Fig. 2. The elevation of both suspension points is the same. The string is shown hanging loosely in order to show the parameters representing the sag (h), the height of the support (y_1) above the horizontal axis, and the "catenary parameter" (c). The equation of the catenary (that is, the form the string takes) with the vertex at x = 0 and y = c is

$$y = c \cosh \frac{x}{c} \qquad \text{Equation (1)}$$

Referring to Fig. 2, we can write the sag (h) as

$$h = y_1 - c \qquad \text{Equation (2)}$$

Where, $y_1 = c \cosh \frac{L}{2c}$ Equation (3)

Since $x = \frac{L}{2}$ at the point of support.

Expanding the hyperbolic cosine in equation (3) using a trigonometric series, then:

$$h = c \cosh \frac{L}{2} - c = c\left(1 + \frac{1}{2!}\frac{L^2}{4c^2} + \frac{1}{4!}\frac{L^4}{16c^4} + \text{------------------} - 1\right) \qquad \text{Equation (4)}$$

When the string is tightly stretched (i.e no deforestation) (h) becomes very small and (c) is very large. Thus, power of $\frac{L}{c}$ higher than the second can be neglected; leaving the sag as:

$$h = \frac{L^2}{8c} = \text{deforestation tension sag.} \qquad \text{Equation (5)}$$

$$\therefore h^{-1} = \frac{8c}{L^2} \qquad \text{Equation (6)}$$

Where, h^{-1} = rate of deforestation (ha/year).
L = distance between the tape ends = time period between two image sequences.
c = catenary parameter = deforestation over the time interval.
y_1 = forest cover left in each period.

RESULTS AND DISCUSSIONS

The results of the quantitative image interpretation are shown below, indicating that Afaka Forest Reserve is under serious threats of deforestation.

TABLE 1. AREA (IN HECTARES) OF EACH CLASS MAPPED/VALUES OF LAND USE/FOREST COVER CLASSES

Imagery	Decades	Area Under Cultivation (AUC)	Road (RD)	Exotic Vegetation (EXO)	Erosion Site (ERO)	Natural Forest (NAT).
Photos	1962	445.280	17.137	29.307	0.00	11,752.034
L.MSS	1970	670.146	17.137	250.883	110.400	11,204.142
L.TM	1987	676.574	33.536	970.562	242.628	10,320.460
Spot (XS)	1994	591.689	33.536	2998.323	1034.173	7586.036

Source: image interpretation by the author.

The rates of deforestation between each of the two period; that is, from 1962 to 1970; 1970 to 1987; and 1987 to 1994, were calculated from the table above and used to validate the results obtained from the model on the rate of deforestation, $h^{-1} = \frac{8c}{L^2}$ of equation 6 to determine the appropriate interval of mapping.

From imagery, for example, between 1962 and 1970, L = 8 years. Rate of deforestation computed from the values for natural forest in the table above,

$$= \frac{(11{,}752.034 - 11{,}204.142)\text{ha.}}{8 \text{ years}} = \frac{547.892}{8} = 68.50 \text{ ha/yr}$$

These imagery values are assumed error - free and form the bases for testing the values derived from model equation 6 in each case. Substituting in the model:

$$h^{-1} = \frac{8c}{L^2} = \frac{8 \times 547.892}{8 \times 8} \text{ ha} = 68.50 \text{ ha/year}$$

The two values of rate of deforestation are equal for the mapping interval of 8 years. This shows that 8 years interval is the most ideal for mapping since the image and model values of the rate of deforestation are equal, with model error estimate being zero percent. The model is tested for other periods and discussed below as well

Between 1970 and 1987 (L = 17 years). The value of deforestation between the two periods which amounts to about 883.682 ha., gives rise to a yearly deforestation of 24.46ha per year as computed from the model. It is observed that this result is very much at variance with the observed value from the imageries of (1970 and 1987) which is 51.981ha. per year, as the model error estimate is 52.94%; implying that taking remote sensing imageries at 17 years interval, does not give good results of determining the rate of deforestation. The large interval of time does not make for effective and purposeful monitoring of the forest cover as many changes might have taken place which may not augur well for realistic planning.

The model equation was further tested using the value of rate of deforestation computed from the 1987 and 1994 imageries. The period between 1987 and 1994, gives L = 7 years and shows that deforestation is about 2734.424 ha., giving a deforestation rate of about 390.632 per year. Substituting in the modl equation, gives a rate of deforestation of about 446.436 per year. This results in an error of estimate by the model of about 14.29 per cent which is more acceptable than the period 1970 - 1987.

The model was further tested with varying intervals of time by simulation of years, ranging from 1 ----- 20 years, but none returned better values of rate of deforestation than the 8 years period of mapping. It is therefore established that taking remote sensing imageries at 8 years intervals is the ideal as the rates of deforestation of the observed imageries and model values are exactly equal. This is followed by mapping at 9,7,10,11, etc years intervals as the deviations of the deforestation rates at these periods from the 8 year interval (base period), are smaller than other years intervals (see table in the appendix). This implies that using a 9 year mapping interval is an alternative, but approximate if 8 years interval is not possible due to unavoidable circumstances.

On the other hand, mapping at intervals of 1 to 6 years is not economically advisable because of the short periods involved. Mapping at intervals from 12 years and above, is also not advisable because of the lengthy period which may have given rise to many changes that may have caused disaster to the ecosystem. The advantage of this model is that its errors of estimate for each corresponding year for each period mapped, are the same irrespective of the type of imagery used.

CONCLUSION AND RECOMMENDATIONS

The mathematical model derived has indicated that the proper interval for mapping under ideal condition, is eight years. The advantage of this novel model is that it can be applied to any dimensioned or designated forest as well as dynamic features on the earth that are undergoing changes; either through man-made or natural processes. However, since the frequency and time interval between mapping surveys depends on the rate of change in each area, one may suggest that for stable ecosystems, a representative time interval between monitoring surveys would be eight years as given by model; in moderately dynamic ecosystems. 5 to 7 years; in ecosystems at risk, 3 to 4 years; in ecosystems heading to crisis, 1 to 2 years; and in ecosystems heading for disaster, every one year. This suggestion had been subjectively applied by Vinogradov (1995) in his study of aerospace monitoring of desertification dynamics. Afaka Forest Reserve falls in the category of ecosystems at risk, and a monitoring period of 3 to 4 years is therefore recommended as one of its management strategies.

Further development of similar innovative models that would assist in deeper understanding of the information on the anthropogenic/natural influences on the planet earth are needed for the planning and management of our natural resources.

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APPENDIX A

Recall equation 6 above: $h^{-1} = \frac{8e}{L^2}$ = rate of deforestation

For 1962 to 1970, L = 8 years

Observed Deforestation, e = 547.892 ha.

Observed rate of deforestation = $\frac{e}{8}$ = 68. 487ha/yr

Table A: Simulated years for computing Model values of rate of deforestation

L (Years)	Model Values: (h^{-1}) Rate of deforestation	Deviation from 8 years interval	Model error of estimate (%)
1	4383 . 136 ha/yr	4314 . 649 ha/yr	6300 . 00
2	1095 . 784 ha/yr	1027 . 297 ha/yr	1500 . 00
3	487 . 015 ha/yr	418. 528 ha/yr	611 . 11
4	273 . 946 ha/yr	205 . 459 ha/yr	300 . 00
5	175 . 325 ha/yr	106 . 838 ha/yr	156 . 00
6	121 . 754 ha/yr	53 . 267 ha/yr	77 . 78
7	89 . 452 ha/yr	20 . 965 ha/yr	30 . 61
8	68 . 487 ha/yr	0 . 000 ha/yr	Observed value = Model value (0%)
9	54 . 113 ha/yr	14 . 374 ha/yr	20 . 99
10	43 . 831 ha/yr	24 . 656 ha/yr	36 . 00
11	36 . 224 ha/yr	32 . 263 ha/yr	47 . 11
12	30 . 438 ha/yr	38 . 049 ha/yr	55 . 56
13	25 . 934 ha/yr	42 . 553 ha/yr	62 . 13
14	22 . 363 ha/yr	46 . 124 ha/yr	67 . 35
15	19 . 481 ha/yr	49 . 006 ha/yr	71 . 56
16	17 . 123 ha/yr	51 . 364 ha/yr	75 . 00
17	15 . 167 ha/yr	53 . 320 ha/yr	77 . 85
18	13 . 528 ha/yr	54 . 959 ha/yr	80 . 25
19	12 . 142 ha/yr	56 . 345 ha/yr	82 . 27
20	10. 958 ha/yr	57 . 529 ha/yr	84 . 00

Source: Data simulated by the author.

APPENDIX B

1970 to 1987: L 17 years

Observed deforestation, c = 883. 682 ha.

Table B. *Simulated years for computing Model values of rate of deforestation*

L (Years)	Model Values: (h^{-1}) Rate of deforestation	Deviation from 8 years interval	Model error of estimate (%)
1	7069. 456 ha/yr	6958.996ha/yr	6300.00
2	1767.364 ha/yr	1656.904 ha/yr	1500.00
3	785.495 ha/yr	675.035 ha/yr	611.11
4	441.841 ha/yr	331.381 ha/yr	300.00
5	282.778 ha/yr	172.318 ha/yr	156.00
6	196.374 ha/yr	85.914 ha/yr	77.78
7	144.275 ha/yr	33.815 ha/yr	30.61
8	110.460 ha yr	0.000 ha/yr	Observed value = Model value. (0%)
9	87.277 ha/yr	23.183 ha/yr	20.99
10	70.695 ha/yr	39.765 ha/yr	36.00
11	58.425 ha/yr	52.035 ha/yr	47.11
12	49.093 ha/yr	61.367 ha/yr	55.56
13	41.831 ha/yr	68.629 ha/yr	62.13
14	36.069 ha/yr	74.391 ha/yr	67.35
15	31.420 ha/yr	79.040 ha/yr	71.56
16	27.615 ha/yr	82.845 ha/yr	75.00
17	24.462 ha/yr	85.998 ha/yr	77.85
18	21.819 ha/yr	88.641 ha/yr	80.25
19	19.583 ha/yr	90.877 ha/yr	82.27
20	17.674 ha/yr	92.786 ha/yr	84.00

Source: Data simulated by the author.

APPENDIX C

1987 to 1994; L = 7 years

Observed deforestation, c = 2734. 424 ha.

Table C. Simulated years for computing Model values of rate of deforestation

L (Years)	Model Values: (h^{-1}) Rate of deforestation	Deviation from 8 years interval	Model error of estimate (%)
1	21,875.396 ha/yr	21533.593 ha/yr	6300.00
2	5,468.848 ha/yr	5127.045 ha/yr	1500.00
3	2430.600 ha/yr	2088.797 ha/yr	611.11
4	1367.212 ha/yr	1025.409 ha/yr	300.00
5	875.016 ha/yr	533.213 ha/yr	156.00
6	607.650 ha/yr	265.847 ha/yr	77.78
7	446.436 ha/yr	104.633 ha/yr	30.61
8	341.803 ha/yr	0.000 ha/yr	Observed value = Model value. (0%)
9	270.067 ha/yr	71.736 ha/yr	20.99
10	218.754 ha/yr	123.049 ha/yr	36.00
11	180.788 ha/yr	161.015 ha/yr	47.11
12	151.912 ha/yr	189.891 ha/yr	55.56
13	129.440 ha/yr	212.363 ha/yr	62.13
14	111.609 ha/yr	230.194 ha/yr	67.35
15	97.224 ha/yr	244.579 ha/yr	71.56
16	85.451 ha/yr	256.352 ha/yr	75.00
17	75.693 ha/yr	266.110 ha/yr	77.85
18	67.517 ha/yr	274.286 ha/yr	80.25
19	60.600 ha/yr	281.203 ha/yr	82.27
20	54.688 ha/yr	287.115 ha/yr	84.00

Source: Data simulated by the author.