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Entropy as an indicator of fragmented landscape

Human-induced fragmentation in forest landscape involves the substitution of contiguous natural land covers by any natural, semi-natural or anthropogenic types, resulting in disconnected and isolated patches of nature[1]. In simple terms, patches consist of communities surrounded by a matrix with a dissimilar community structure or composition[2]. Fragmentation leads to habitat loss, isolation and edge effects[3,4] and subsequent degradation of ecosystem. It is considered to have the largest impact of all drivers on biodiversity change[5]. The main cause behind this increase is biotic impact in an area.

Fragmentation itself is a matrix easily agreed upon to understand the landscape. It is obvious that fragmentation over a space could be represented using geospatial tools[6]. The problem however is to introduce a quantitative measure of forest fragmentation. An adequate fragmentation matrix is consequently needed for policy development with respect to nature and biodiversity conservation. Developing this analogy, the mathematical representation of degradation and the concept of entropy are close (entropy was often used as a measure of degradation). In this way, information theory can offer an appropriate framework to approach the landscape as a spatial information system[7]. Moreover, it is demonstrated that heterogeneity (pattern) and entropy can be considered as equivalent terms[8]. In the present study, entropy is used as a measure of the fragmentation process, i.e. a measure of disorderness in the forest patches. In order to develop this concept and to demonstrate its applicability to a natural ecosystem, we used Shannon's entropy index to quantify the intrusion of non-forest to forest area (conversion of forest patches into non-forest areas). Analysis of cartographic data or remote sensing imagery to analyse the pattern heterogeneity (entropy) of an entire landscape implies data completeness: the complete landscape or image pattern is always analysed (often using a Geographic Information System (GIS))[8], and is not estimated by use of a sample or subset of the landscape of interest.

The study area, Northeast India, extends from 88–97°E and 22–29°30′N, with a geographical area of about 255,083 km^2. The area consists of 25% of the total forest cover of the country. The altitude in the study area varies from the low-lying plains of Brahmaputra to around 6000 m in parts of Arunachal Pradesh. The climate varies from typical tropical to subalpine. Since last three decades, the area is being affected by intense land-cover changes. The land use practices consist of activities for timber collection, shifting cultivation, mining, permanent agriculture, etc. The practice of shifting cultivation has been found to be the major cause behind forest fragmentation. It results into conversion of dense forests to open forests as well as non-forests including shifting cultivation. About 0.45 million families in the northeastern region annually cultivate 10,000 km^2 of the forests, whereas total area affected by 'jhuming' (shifting cultivation)[9] is about 44,000 km^2. With the phenomenal increase in human population, the 'jhum' cycle has been decreased from 20 to 30 years in the past to about 3–5 years in many areas. Reduction in the 'jhum' cycle due to increase in pressure on land because of population increase has accelerated the process of land degradation, which has further enhanced eco-degradation[10]. Earlier workers have reported a high degree of forest fragmentation in this landscape[6,11–13].

We analysed four historical datasets to relate entropy to the degree of forest fragmentation over a multi-decadal period forest cover estimate of Forest Survey of India (FSI) for the years 1987 (ref. 14), 1989 (ref. 15), 1993 (ref. 16) and 2001 (ref. 17). For maps showing the pattern dynamics of Northeast India, the forest cover and its relation with population has been carried out. The contiguous vegetation in the entire Northeast is fragmented due to shifting cultivation and other forest extraction processes[18]. The dense forest cover has decreased with increase in population. It reflects the impact of biotic factors on forest areas. After 1989, there is stability in dense forest cover, while population has increased with almost the same rate. The rate of decrease in dense forest was slow between the years 1987 and 1993, and dense forest cover increased during the years 1993 and 2001. This is due to regeneration in abandoned shifting cultivation areas and density improvement[17,19]. Also, change in forest policies and interim ban imposed by the apex court on felling in forests has led to increase in dense forest cover. As one-fourth of India's forests is in this fragile location, the region has to be restored and the resources are to be used in a sustainable way. The order has come at a proper time, wherein the region was losing 31,700 ha of forest every year, mostly due to the nexus between the government and traders[20].

Regarding the natural growth rate of population during the period of 1971–2001, all the states in the region have registered higher growth rate than that for the whole country. As a result, the increasing population pressure in this region has given rise to linkages between population dynamics and environmental degradation[21].

Figure 1 shows the dependency of the population on forest for livelihood. It indicates the reverse trend of the forest against the compounding population. Since 1972, dense forest patches in the NE have been reduced by 25% in two decades. Increasing population pressure has been progressively lowering the per capita agriculture resource availability. This creates more pressure on forests to acquire land for cultivation. The population has increased twice in the decadal period 1981–91.

The map sheets prepared by visual interpretation of satellite data at 1 : 250,000 scale were used for the year 1987 (Landsat MSS data of 1981–83), 1989 (Landsat TM data of 1985–87), 1993 (Landsat TM data of 1989–91) and 2001 (IRS 1C/1D LISS III data of 2000). After image-processing (scanning, image enhancement and geometric correction), the database was created in the geographic information domain (ArcGIS) after patch recognition. The dataset was put to spatial analysis.

On analysing the decrease in dense forest and increase in open forest cover, the increase in the number of patches is evident. The number of patches for both dense and open forests was accounted with the change in time. Further, these maps were queried in geospatial domain and were analysed with Shannon's entropy index to quantify the intrusion of non-forest to forest area/conversion of forest patches into non-forest areas. The Shannon's entropy index is given as:

$$H' = -\sum P_i \log_e(P_i),$$

where P_i is the proportion of variable (non-forest) in the ith zone or forest class, and n is the total number of forest classes in the region.

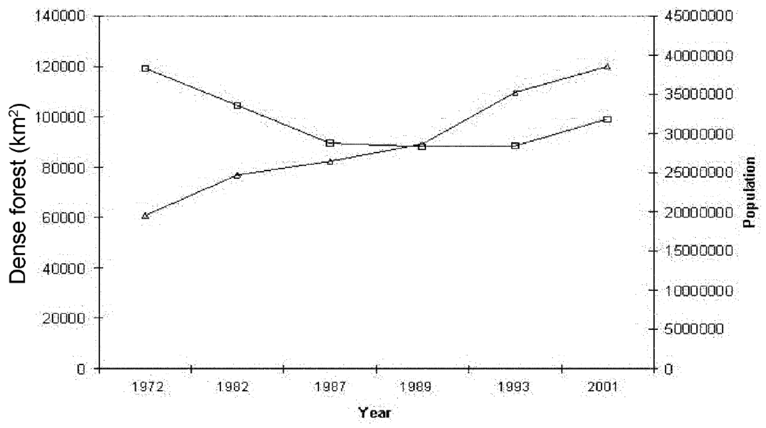

Figure 1. Relation between forest cover and population (Δ, Population; □, Dense forest).

Table 1. Total number of patches and entropy (H') in forest classes

Year	Dense forest		Open forest	
	Number of patches	Entropy	Number of patches	Entropy
1987	2422	1.316	2185	1.039
1989	1790	1.506	2698	1.680
1993	1685	1.386	2553	1.455
2001	2165	1.502	2612	1.724

The entropy for dense and open forest patches is considered in order to quantify forest fragmentation. The entropy is calculated for dense and open forest patches, because in these landscapes forest fragmentation is the result of (i) conversion of dense to open forest patches, (ii) reduction in the size of a forest patch, and (iii) complete loss of a forest patch.

The entropy data indicate an influence of the degree of fragmentation on the forest pattern. The forest area was found more disordered (increase in entropy) with time, due to partitioning of the vegetation into spatially separated patches and due to loss of the original habitat, as evidenced by the number of patches (increasing with time) and habitat area trends (decreasing with time). The trend is not consistent during 1989 to 1993, due to the disappearance of entire patches, which causes a decrease in total habitat area and number of patches at the same time and drastic habitat loss (Table 1).

Calculation of entropy has proved to be useful for the assessment of degree of fragmentation. The number of patches is expressed as a fraction of the highest value observed over the considered time period. Increasing degrees of fragmentation coincide with increasing entropy, increasing number of patches and decreasing habitat area. The landscape heterogeneity is assumed equivalent to uncertainty or entropy[8]. The use of familiar diversity indices like the Shannon and Simpson indices to represent spatial entropy is therefore appealing, although the transfer of concepts or terms like entropy between ecology and the mathematical theory of information can be subjected to debate[23,24]. Some workers have also used it in urban sprawl dynamics[25,26]. The importance of this study lies in the fact that entropy is determined not by means of a sample or hypothetical dataset but on a real landscape, which is facing acute fragmentation. On the other hand, work dealing with a sample or subset has inherent sampling error or sampling variance, which does not represent an interpretation of the natural setup. Hence, in spite of unavoidable errors in the dataset preparation, it represents a reliable estimate. The entropy depends on the total area considered as a drawback, although the discrepancy is negligible for large area. Therefore, the absolute values for entropy should not be compared (they were influenced by the original image extent and the scanning resolution) rather, data should only be interpreted as increasing/decreasing trends for a particular site.

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Reconstruction of the ancient Port, Korkai in Tuttukkudi District of Tamil Nadu

Chronologically, Korkai is the oldest port site of Tamil country possibly since the beginning of the first millennium BC. However, its emergence as a significant emporium may have been only around the fourth and fifth century BC. Korkai (8°40′N; 78°5′E) is recognized by the Periplus of the Erythrean Sea as Colchis and by Ptolemy as Kolkhoi. Correct identification came in 1838. Early archaeological excavations carried out by Caldwell in the Tamiraparani delta in the 19th century, affirmed its present site almost in ruins close to a place called Eral[1]. It was a dual centre of the early Pandya rule, identified with Pandya-Kavada by the *Ramayana* and the *Mahabharat*, and as Kapatapuram in *Kalithogai*. Its reputation is spoken of in *Akananuru* and *Ainkurunuru*. The entire Gulf of Mannar is recognized by the Periplus as the Colchic Gulf, due to pre-eminent status of Korkai. Excavations by Nagaswamy and others have brought to light the early artifacts of the site at Korkai. Stone inscriptions in the Koil of Vetrivelamman and the Pillayar Kovil at Korkai and at Attur across the river on the opposite bank reaffirm that the site is the old port of Korkai. A lone 'Vanni' tree standing in Korkai is about 2000 years old, according to the Tamil Nadu Archaeological Survey.

Upstream of Korkai about 20 km away on the same river valley on the right bank of Tamiraparani is Aditchanallur, the largest megalithic burial urn area in South India[2]. Its proximity and the find of megalithic burial urns at Korkai itself indicate that the valley side was fairly well-populated during megalithic times. Carbon dating of the artifacts in the area indicates an age of 785 BC, while Aditchanallur findings of copper finds including an icon of Mother Goddess of 8th century BC indicate that it was an active settlement, and probably river navigation extended up to it from the delta mouth.

Korkai is sited on an alluvial terrace, above the present-day flood plain of the river. The archaeological finds are about 3 m below the terrace level. Excavations have revealed Mauryan pottery of 2nd and 3rd century BC and the glazed pottery found belong to Northern Black Polished ware. The burial urns lie adjoining a structure built with large bricks. Adjoining on the west end are heaps of pearl oyster shells, and three ring wells. More significantly, the finds of black and red pottery ware with old Tamil Brahmi scripts (two to four letters in a line or two), apart from drawn graffiti of the sun, fish, bow and arrow have been dated to a period between 3rd century BC and 2nd century AD. The occurrence of Roman ware, and rouletted ware indicates their external links. Archeologists have found ruins of chank-cutting factories, centres for split opening