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Short communication

Standardizing the calculation of the annual rate of deforestation

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Abstract

Different authors utilize different formulae to calculate the annual rate of change of forest cover (or its opposite, the annual rate of deforestation) and use different terms to describe it. This generates confusion. I suggest that the annual rate of change of forest cover should be calculated as: $r = (1/(t_2 - t_1)) \times \ln(A_2/A_1)$. This formula is derived from the Compound Interest Law. It is also derived from the mean annual rate of change and for this reason, is more intuitive than the formula used by FAO $[q = ((A_2/A_1)^{1/(t_2-t_1)}) - 1]$. The rate r is always higher than q, but in most cases, the difference between the two quantities is lower than the sampling error. The rate r is significantly higher than q only when deforestation is extremely high. To ease comparisons between sites of annual rates of forest change, the forest area, time of measurements and formulae used should be clearly indicated.

Keywords: Annual rate of deforestation; Compound Interest Law; Exponential decay model

Tropical moist forests, which are estimated to contain over half of the global biodiversity, are being destroyed at an alarming rate (Laurance et al., 2001; Myers, 1984, 1986, 1991; Sayer and Whitmore, 1991). Understanding dynamics of forest loss is critical for the management and conservation of biodiversity. However, the data needed to estimate deforestation are often flawed: the reported statistics are not always standardized, the identification of the forest types may vary and the results may differ with changing scale of the study (Dirzo and Garcia, 1992; Fearnside, 1993). To add to these major drawbacks, different authors utilize different formulae to calculate the annual rate of change of forest cover (or the annual rate of deforestation, its opposite) and give the rate various names. This generates further confusion, such as: lack of comparability, underestimation of the forest loss and application of inappropriate management practices due to faulty calculations. The objective of this short communication is to propose simple rules to standardize the calculation of the annual rate of change.

Forest loss can be measured using satellite imagery and spatial analyses. The annual rate of change is calculated by comparing the area under forest cover in the same region at two different times. According to the FAO (1995), the annual rate of forest change is derived from the Compound Interest Law and should be calculated as

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1 \quad (1)$$

where A_1 and A_2 are the forest cover at time t_1 and t_2, respectively (the unit: per year or percentage per year). The annual rate of change is simpler to use than the annual rate of deforestation because its sign is the

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same as the sign of $A_2 - A_1$. The first formula being counter intuitive, it is necessary to look at its connection with the Compound Interest Law.

In finance, the capital, C at a future time is calculated from the initial principal, P with a fixed annual rate of interest rate, q and time, t in years, t being an integer

$$C = P(1+q)^t \tag{2}$$

When t is continuous, the interest should be added continuously. The year is divided into m equal periods. The equivalent rate is q/m over each period and the capital after t years is

$$C = P\left(1+\frac{q}{m}\right)^{mt}$$

When m tends to infinity,

$$C = P\left(\lim_{m\to\infty}\left(1+\frac{q}{m}\right)^{mt}\right)$$

Which is equivalent to

$$C = P\,\mathrm{e}^{rt} \tag{3}$$

Eq. (3) is the Compound Interest Law or the exponential decay model when r is negative. The parameter, r is the 'continuous rate of change' or the 'natural rate of increase' of population biologists. With C replaced by A (forest cover) and P by A_0 (the constant of the equation) in the Eq. (2), we find the general expression of q of which Eq. (1) is a particular expression.

Since,

$$q = \mathrm{e}^r - 1$$

the exponential decay model with q is as follows

$$A = A_0(1+q)^t = A_0\,\mathrm{e}^{rt} \tag{4}$$

The relationship between q and the Compound Interest Law is obvious but not straightforward. With a more intuitive formula, the rate of forest change can be calculated as

$$\bar{r} = \frac{A_2 - A_1}{t_2 - t_1}\frac{2}{A_1 + A_2} \tag{5}$$

When $t_2 - t_1$ becomes infinitesimal, A_1 and A_2 tend towards A, the forest cover at this instant. Then, Eq. (5) becomes

$$r = \frac{\mathrm{d}A}{\mathrm{d}t}\frac{1}{A}$$

After integration

$$r = \frac{1}{t}\ln\frac{A}{A_0} \tag{6}$$

For practical calculations

$$r = \frac{1}{t_2 - t_1}\ln\frac{A_2}{A_1} \tag{7}$$

The expressions (4) and (6) are two forms of the exponential decay model and obviously, r is the rate of the Compound Interest Law and not q.

It is not clear why q has been preferred to r in the expression of the annual rate of forest change. Maybe because q is called 'annual rate' in economics and was adapted as such to forestry. However, it is not annual per se, this quality being only related to the time unit chosen. It also presents a deceptive property: its value cannot be lower than -100% per year. Of course, it is not possible to destroy more than 100% of a given forest cover in a year. But a rate is a relative parameter and given a short time interval and some forest destruction, it is possible to imagine that in some places, an annual rate of change lower than -100% per year could occur. Actually, investors would admit willingly rates superior to 100% per year. Both for mathematical reasons as well as because of its explicit biological meaning, r should be preferred to q to calculate the annual rate of forest change.

Comparing the changes of these two parameters, it is useful to fix either the time interval $\Delta t = t_2 - t_1$ or the ratio A_2/A_1. In Fig. 1a, the remaining forest area, A_2 has been arbitrarily chosen at 50% of the original area and Δt varies freely. In Fig. 1b, Δt has been chosen arbitrarily to be three years and the ratio A_2/A_1 varies between 0 and 100%. Whatever the situation, the absolute value of r remains superior to that of q. This difference is negligible when the time interval is long and when the ratio A_2/A_1 is small, i.e. when the deforestation is not pronounced. However, when the deforestation is heavy, the difference might become significant.

According to the FAO (1995), the annual rate of change, for the tropics was -0.8% per year in 1990 (Table 1). At this rate, the difference between the different r and q is below the empirical uncertainty in the measurement of $A_1 - A_2$.

Deforestation is a non-homogeneous process and it is of interest to focus on the worst affected area in

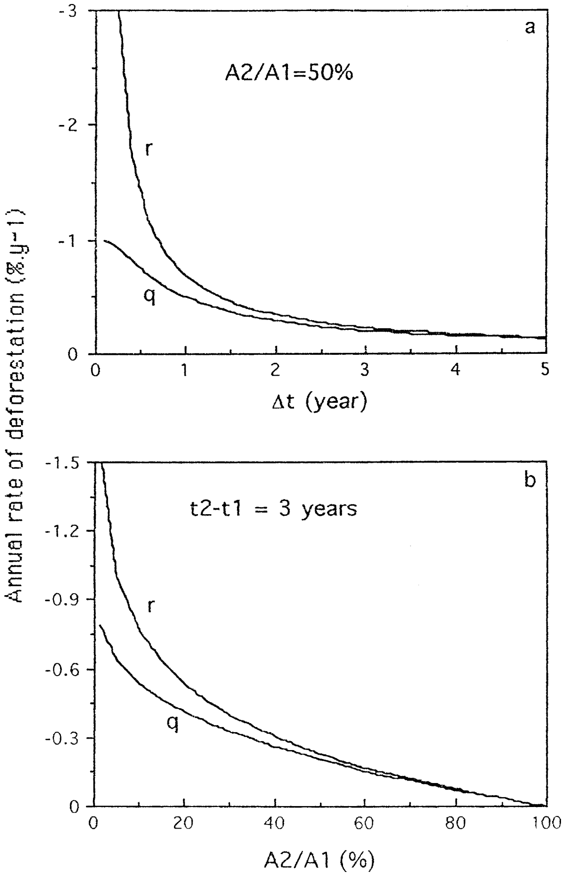

Fig. 1. The annual rate of deforestation with r and q set (a) with increasing time intervals (b) with decreasing deforestation.

order to understand and predict its dynamics and correlate it to socio-economic trends at different scales (Lambin, 1994). At the local level, the annual rate of change can be much higher than the global average because of the unprotected status of the forest or due to economic or legal reasons (Ramesh et al., 1997). Country-wise calculations show that q underestimates r by almost 5% in the worst case (Table 1). Locally, the underestimation might be significant on individual satellite images over a large scale.

The measures $\bar{r}$ and r are close to each other when the time interval measuring forest cover is short. When the time interval is long, $\bar{r}$ can be interpreted as the average of t_1 and t_2. It does not imply any underlying assumptions on the dynamics of deforestation. But r has an advantage over the average: it is supposed to be unique at any point in between two measurements.

Sometimes, the formula

$$R = \frac{A_1 - A_2}{t_2 - t_1} \tag{8}$$

is called the 'annual rate of deforestation' (Fearnside, 1993; Liu et al., 1993). Eq. (8) gives basic information since it is the average speed at which the forest is being cut and it is expressed in unit area per year. Strictly speaking, the term 'rate' is appropriate since it is a numerical proportion between a function and its variable. Nevertheless, the term 'annual' is explicit and R can be simply called 'annual deforestation' or 'annual change' (WRI, 1995, FAO, 1995) in order to avoid any confusion with the annual rate of change.

The annual rate of deforestation is also calculated according to Menon and Bawa (1997), Ramesh et al. (1997), Narendra Prasad (1998) and WRI (1995)

$$P = \frac{1}{t_2 - t_1}\frac{A_2 - A_1}{A_1} \tag{9}$$

It is known under a variety of terms, such as 'rate of deforestation', 'annual deforestation (%)' and 'percent annual change'. The deforested area is arbitrarily compared to the original area and P is not valid

Table 1
The annual rate of change calculated according to q and r.

A_1 (km^2)	A_2 (km^2)	Δt (year)	q (% per year)	r (% per year)	$(r - q)/r$ (%)	Place
39520530	38616050	10	−0.23	−0.23	0.0	World
7025420	6499040	10	−0.78	−0.78	0.0	Africa
22870	19390	10	−1.64	−1.65	0.6	Sri Lanka
19450	13280	10	−3.74	−3.82	2.1	Niger
1580	880	10	−5.68	−5.85	2.9	Haiti
2410	940	10	−8.99	−9.42	4.6	Burundi

Results from the Food and Agriculture Organization of the United Nations (FAO). Global Forest Resources Assessment 2000 (FRA 2000). Results as of 19 January 2001 (http://www.fao.org/).

because of this bias. By comparison, $\bar{r}$ is more objective. As a consequence P, which underestimates the annual rate of deforestation, should be discarded.

When the deforestation is low, r and q are almost equivalent. They can be interchanged to calculate the annual rate of change of forest cover. The rate r is more meaningful to biologists and gives higher values than q when the deforestation is high. Unfortunately, q is more commonly used. To avoid confusion, simple rules should be followed: whatever the algorithm chosen for calculation (r or q) and whatever its name, the formula should be clearly stated. It happens that forest areas and rates of deforestation are calculated for seemingly different years (WRI, 1995, pp. 306–309) without justification. For comparisons, the forest area, time of measurement and rates should be given systematically to allow comparison or recalculation.

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