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Assessing the sustainability of timber harvests from natural forests: Limitations of indices based on successive harvests.

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Abstract

The concepts of sustainable original harvest (SOH) and sustainable disturbance harvest (SDH), and simple indices such as the ratio of successive harvests do not provide a reliable indication of the sustainability of a harvest. Some limitations of these concepts are illustrated in the context of selection harvesting of timber from natural forests. Four models are used to demonstrate that maintaining an SOH or SDH indicates little about the long term sustainability of a timber harvest. The concepts may offer greater utility in even-aged systems harvested by clear-felling, but still suffer the limitation that many factors may mask any change in site productivity. Any measure of sustainability should include an appraisal of the condition and vitality of the residual resource. Simple indices based on successive harvests do not consider the residual stand, and can be misleading.

Introduction

Although it is usually easy to see when timber harvesting causes problems which may render an operation unsustainable, it is difficult to ascertain if an apparently good harvesting operation is in fact, sustainable in the long term. Thus, it would be convenient to have a simple index indicating sustainability. Unfortunately, there is no such simple index, and it may be unrealistic to expect one. However, the search for a convenient index has led many to compare successive harvests from the same site, and introduce the concepts of a sustainable original harvest (SOH in which all harvests are the same as the first) and sustainable disturbance harvest (SDH in which subsequent harvests are the same as the second, e.g. Botkin and Talbot 1992, p.62). This may be misguided as there are many problems. Some are fundamental and relate to the comparability of successive harvests, as many factors may change and mask site changes (e.g., genotype, silviculture, atmospheric deposition, etc.). Others are technical and concern the reliability of long-term record-keeping and the comparability of forest measurements (e.g., Peterken and Backmeroff 1988). Consistent records spanning several decades may be required even in the simplest three-cycle case that reduces SOH and SDH to the ratios V_2:V_1 and V_3:V_2 respectively (where V_i is the volume harvested in the i^{th} harvest). Although the use of three cycles has become customary in many such studies, it does not provide a good basis for estimating sustainable yields. Botkin (1993, p. 212) warned that "reliance on three harvests can be deceptive as a way to determine whether a harvesting practice is sustainable", and suggested that 400-year studies may be necessary to infer sustainability.

These problems apply to both plantation (e.g., Powers et al. 1990) and natural forest systems, but the latter pose some additional fundamental problems with the concept of SOH and SDH. Here, I illustrate some problems with appraisals of sustainability based on ratios of successive harvests, by focusing very narrowly on the volume of timber produced; just one small component of sustainability (e.g., Aplet *et al*. 1993). This narrow focus in no way implies that other aspects are unimportant, but merely shows that simple indices can be invalidated even within simplistic and partial concepts of sustainability.

The dripping tap

A dripping tap provides a convenient analogy to illustrate some problems in assessing the sustainablity of harvesting a renewable resource. If we have a tap that drips constantly at one cupful per minute, then it is clear that the sustainable harvest will be one cup/min, provided there is no wastage. The analogy with forest harvesting, which is usually oriented at the compartment or concession level, is enhanced by assuming a T-junction with, say 4 openings, so that water drips equally into four different cups. Each cup will fill in 4 minutes and the sustainable harvest remains unchanged. If we start with a new resource so that the 4 cups are full, it is clear that we can harvest (i.e. drink) one cupful every minute in perpetuity − provided that there are no losses (i.e. time taken to empty the cup is negligible and we replace it immediately). But full cups overflow, so during the first three minutes some water is lost. This analogy is valid in many forestry situations, as many unmanaged (i.e., "virgin", old-growth, etc.) forests may exhibit lower nett growth than equivalent managed stands.

If we drink two cups during the first minute and the third and fourth cups during the second and third minutes, then by the fourth minute there will be no full cup, and we will have to make do with a cup three quarters full. After that, we can again drink one cup every minute in perpetuity. This strategy has gained us an extra cupful during the first minute, and deprived us of quarter of a cup during the fourth minute. Thus we have a nett gain of 3/4 of a cup. This is the rationale offered to justify why initial exploitation of previously unmanaged forests may exceed the long-term sustainable harvest. It is clear from this analogy that the rationale is valid (in the narrow context of volume of timber produced), provided that the productive capacity of the system is not impaired.

A few experiments reveal other good strategies. The sequence 2, 2, ½, ¾, ¾, 1, 1, ... gives us an extra cupful, and the sequence 3, 1, ½, ¾, 1, 1, ... gains an extra 1¼ cups. The sequence 4, ¼, ½, ¾, 1, 1, ... netts an extra 1½ cups, but departs a long way from even-flow. All these harvests are sustainable and tend towards even-flow, but simple indices based on successive harvests do little to reveal this, because they do not discriminate between stock reduction and natural accretion (i.e. drips or forest growth). It is necessary to harvest some stock to attain a non-zero accretion (otherwise the cups overflow, and tree growth may be offset by mortality), but this reduction of stock may distort simple indices during the first few cycles, detracting from the real trend (e.g. see number sequences above). Any of the above sequences could be sustained, provided that the source is not depleted, the tap remains unblocked and the cups remain unbroken. Clearly, sustainability has more to do with the health of the system than with the relative sizes of successive harvests.

The analogy is useful, but is rather limited, and it is informative to study some aspects of forest dynamics in more detail. I illustrate these aspects using three forest growth models. There is nothing special about these models; they are typical of many used in yield prediction and forest planning (e.g., Vanclay 1994a), and are chosen only because I am intimately familiar with them and the forests they represent.

A stand level model

One difference between the forest and the dripping tap is that growth (cf. the drips) may depend on the state of the forest as well as the condition of the site. Forest production depends on the composition and structure of the forest, and timber production may decrease as stand density diverges from the optimal range. Unmanaged forests may have negligible nett production as any growth may be offset by mortality. Similarly, production may be reduced following heavy thinning or clearfelling.

Such a growth response is evident in many stand growth equations. One example is an equation for stand basal area increment in cypress pine (*Callitris columellaris*) in southern Queensland (Vanclay 1988):

$$\Delta G = e^{-3.071+1.094\ln G+(0.007402S-0.2258)G}$$

where ΔG is stand basal area increment (m²/ha/yr), G is stand basal area (m²/ha), S is an index of site quality (Vanclay and Henry 1988), and ln is the natural logarithm to base e. This equation predicts gross increment (i.e. no allowance is made for the death of trees). Here we are concerned with nett increment, so I make a subjective and approximate allowance for density-dependent mortality (Figure 1):

$$\Delta G = e^{-3.071+1.094\ln G+(0.007402S-0.2258)G} - 10^{-5} G^3 \qquad \textbf{(1)}$$

From Figure 1, it is clear that production will be optimized if the stand basal area is maintained in the vicinity of 10 m²/ha. Typically, stands not previously exploited may have much higher stand density (e.g. about 15 m²/ha for stands with S=17 in south east Queensland, depending on their fire and disturbance history, see Beetson *et al*. 1992), so the first harvest may be much larger than harvests obtained from stands managed at optimal density. If we assume a harvesting cycle of 40 years (i.e., stands are harvested once every 40 years), then the optimal regime is to reduce the stand to around 7 m²/ha during harvesting, and allow it grow to about 14 m²/ha before the next harvest. This is consistent with the silvicultural characteristics of the species (Johnston 1975), and yields a non-declining even harvest of about 7 m²/ha in the second and every subsequent harvest. The size of the first harvest will depend on the initial state of the resource.

To follow the dripping tap analogy, consider a forest divided into four blocks so that one block is harvested in years 0, 40, 80, ..., another is harvested in years 10, 50, 90, ..., the third is harvested in years 20, 60, 100, ..., and the last is harvested in years 30, 70, 110. Assuming that the harvest reduces the forest to a stand basal area of 7m²/ha, damages few trees and causes no site changes (i.e., a near-optimal regime), we can show (from Equation 1) that the initial harvest depends on the initial state of the resource (Figure 2), and subsequent harvests are equal at about 7.7 m²/ha of basal area. Clearly, the ratio of initial to subsequent harvests does not provide a good basis for evaluating sustainability. We should not infer from this example that the ratio of harvests 2 and 3 may provide a valid index, as this model does not take account of the individual trees which account for many characteristics of a timber harvest.

A size-class model

Forests and harvests comprise trees, and when we take the species and sizes of individual trees into account, the picture becomes more complex. Not all the growth of the forest accrues to commercial trees, and much of the growth may be in the form of smaller trees or non-commercial species, so it is necessary to examine the implications of stand structure and dynamics. One convenient way to do this is to use a size-class model, which takes species groups and tree sizes into account (Vanclay 1994a). There are many such modelling approaches which may be used and here we will briefly examine a case study involving teak forests in Myanmar (Burma).

The Pegu Yoma region of central Myanmar contains extensive areas of indigenous teak (*Tectona grandis*) forest, much of which has been managed under a consistent silviculture since the mid 1856 (Anon 1991, Brandis 1896). Some of these forests have yielded four successive commercial timber harvests of similar magnitude, and remain in a productive condition. A simple density-dependent size-class model (Vanclay 1994b) has been used to examine some implications of continued management of these forests. The model considers two stand fractions, teak and other species. For both fractions, growth and recruitment are density dependent, but simple average mortality rates are assumed. Consistent with forest management practices in Myanmar, timber is harvested from both fractions in separate operations with an interval of several years. In this analysis, we consider only the yields of the more valuable species, teak.

Four different management strategies were investigated, and are summarized in Figure 3 and Table 1. These strategies differ only in the girth limit for harvesting and in the percentage of trees removed, and the initial harvests are similar in volume, but the predicted long-term implications differ markedly (Figure 3). Neither the initial harvest, nor the ratio of the first two (or second and third) harvests give any real indication of the long term trend, which may take up to five cycles to emerge, even in these managed forests. The only reliable way to gauge the nature of future harvests is to study the residual stand and consider both the ecology and dynamics of the species involved, and the condition and nutrient status of the site.

One concern with an analysis of this type is whether the model is adequate, so that results reflect forest and harvest dynamics rather than characteristics of the model. A comparison of predictions from simple and sophisticated models of tropical rainforest suggest that simple models may provide reasonable results (e.g. Figure 4), and that the greatest limitation may be the assumptions of a fixed harvest cycle and a homogeneous stand structure.

A single-tree model

My final example concerns the rainforests of north Queensland. These forests are particularly pertinent to this paper since several studies reported that timber harvesting operations in these forests were ecologically sustainable (e.g. Poore 1989, Prabhu *et al*. 1993, Vanclay 1990).

Timber had been harvested from these forests for about 100 years, but ceased in 1988 following their inclusion on the World Heritage List (Vanclay 1995). However, the area remains of interest to modellers because an extensive system of permanent plots has been maintained for as long as 40 years (Vanclay *et al.*1991), and reliable records of the harvest are available for much of the period of exploitation (e.g. Vanclay 1995). Three growth models have been constructed from these data, and vary greatly in their sophistication (Higgins 1977, Vanclay 1989, 1994c).

The two more recent models provide rather similar results when simple fixed-cycle harvesting is assumed (i.e. cutting cycle analysis, see e.g. Vanclay 1994a,c). The more sophisticated model (Vanclay 1994c) provides detailed information not available from the more simple model, but aggregate predictions are rather similar (Figure 4). Both models reveal that harvesting during the 40 years prior to 1988 was about double what could be expected during a subsequent cycle (if the same silvicultural and harvesting practices are followed), but that timber production could be expected to increase again in the longer term. However, this is subject to the assumption of a fixed cutting cycle and some other assumptions inherent in the method of cutting cycle analysis (Vanclay 1994a,c), and a more realistic forecast involving dynamic yield scheduling suggests that 60,000 m^3/yr may be the maximum sustainable harvest that could have been sustained during the decades following 1988 (Vanclay 1994c). Here again, ratios of successive harvests (actual or predicted) provide no real indication of sustainability (Figure 4).

In a previous study (Vanclay 1990), I attempted to assess the sustainability of harvesting by examining growth rates of individual trees, adjusted for tree size and stand density. The method is demanding of data (requires long-term permanent sample plot data), but indicated that existing management practices probably were sustainable, and provided statistical evidence to support the assertion that any productivity decline could not exceed six percent per harvest. Unfortunately, the method does not provide a convenient index, and is not comparable with the SDH/SOH concept.

Discussion

I have used a series of rather simple models to demonstrate limitations of the utility of indices based on ratios of successive harvests as indicators of sustainability. These simple models assume *status quo* (e.g. no major changes in genotype, silviculture, atmospheric deposition, climate, etc.), and examine only the timber harvest (a very small component of sustainability), but even this simplest possible case reveals limitations in the concepts of sustainable original harvest (SOH) and sustainable disturbance harvest (SDH). Any changes in site productivity (soil erosion or compaction, loss of organic matter or nutrients, etc.) or other environmental conditions may further compound the limitations of these indices.

Ratios of successive harvests offer some appeal because they can be estimated comparatively easily (although the precision is rarely stated). However, we should not be distracted by this convenience, as concepts such as the SOH and SDH may be misleading and irrelevant. The critical issues for sustainability are not the relative size of successive timber harvests, but involve soils, species composition, stand structure and dynamics, ecological processes, etc. in the residual stand, and of course people and their aspirations.

Work is underway to devise more realistic indicators of sustainability. Much of this research addresses indicators at a broader scale than is considered here (e.g. Anon 1995), but some focuses on the forest level. Preliminary results from this work suggests that such indices will be more complex, and embrace many more elements, than simple ratios of successive harvests (Prabhu, pers. comm.).

Conclusion

The simplistic concepts of sustainable original harvest and sustainable disturbance do not provide a useful paradigm for sustainable harvesting. They may be influenced by the initial state of the forest, by the silvicultural and harvesting procedures adopted, and by assumptions made in yield calculations and simulation models.

Sustainability cannot be inferred from simple indices based on estimates of successive harvests. The sustainability or otherwise of the harvest of timber and other natural resources can only be gauged if the nature of the residual (post-harvest) resource, its entire ecosystem and its ecological and human dynamics are also considered.

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Table 1. Alternative harvesting strategies simulated for Myanmar teak forests, and the resulting ratios of successive harvests.

Harvesting cycle	Volume harvested under strategy † (m^3/ha/cycle)			
	A	B	C	D
1	3.66	3.66	3.66	5.67
2	4.37	4.18	4.61	4.10
3	4.72	4.38	5.83	4.01
4	3.62	3.49	11.80	7.32
5	4.48	2.24	21.91	12.53
6	6.88	1.19	28.59	8.18
7	7.05	0.54	30.89	22.20
8	4.90	0.21	30.60	14.72
9	3.23	0.07	29.58	14.75
Ratio 2:1 †	1.19	1.14	1.26	0.72
Ratio 3:2	1.08	1.05	1.26	0.98

† The starting condition for all four strategies represents the average stand table for forests in the Pegu Yoma of Myanmar. These forests have been managed for over 100 years, so the true sustainable original harvest cannot be estimated.

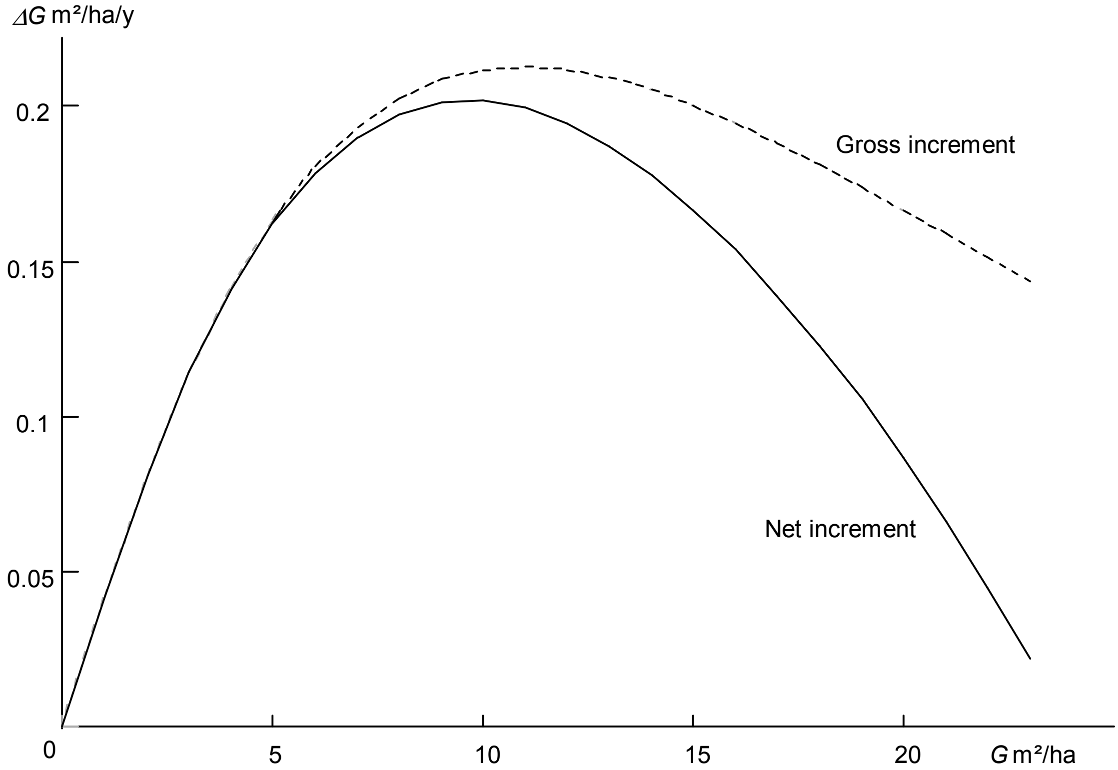

Figure 1. Stand basal area increment function for cypress pine (assuming $S = 17$ m), drawn from Equation 1.

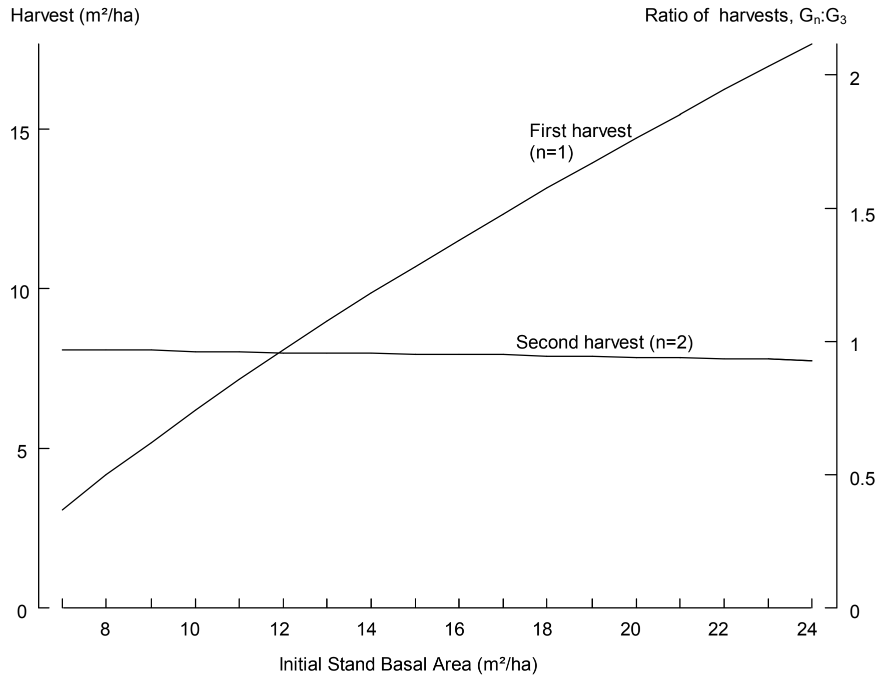

Figure 2. Initial state of a forest resource and the ratio of successive harvests (G_n/G_3 , with G expressed as basal area in m^2/ha), assuming a 40-year cycle and harvesting to a residual basal area of 7 m^2/ha (derived from Equation 1).

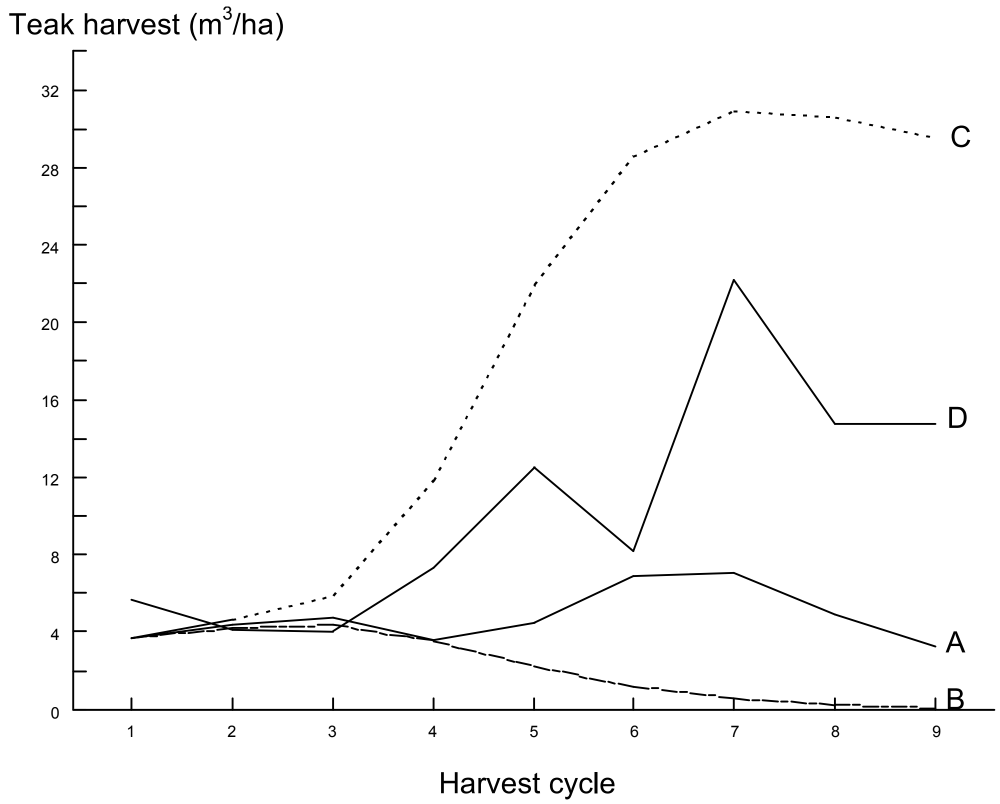

Figure 3. Simulations of long-term yields under four different harvesting strategies. Notice that the trend evident in successive early harvests is not a reliable indicator of the long term trend (Table 1).

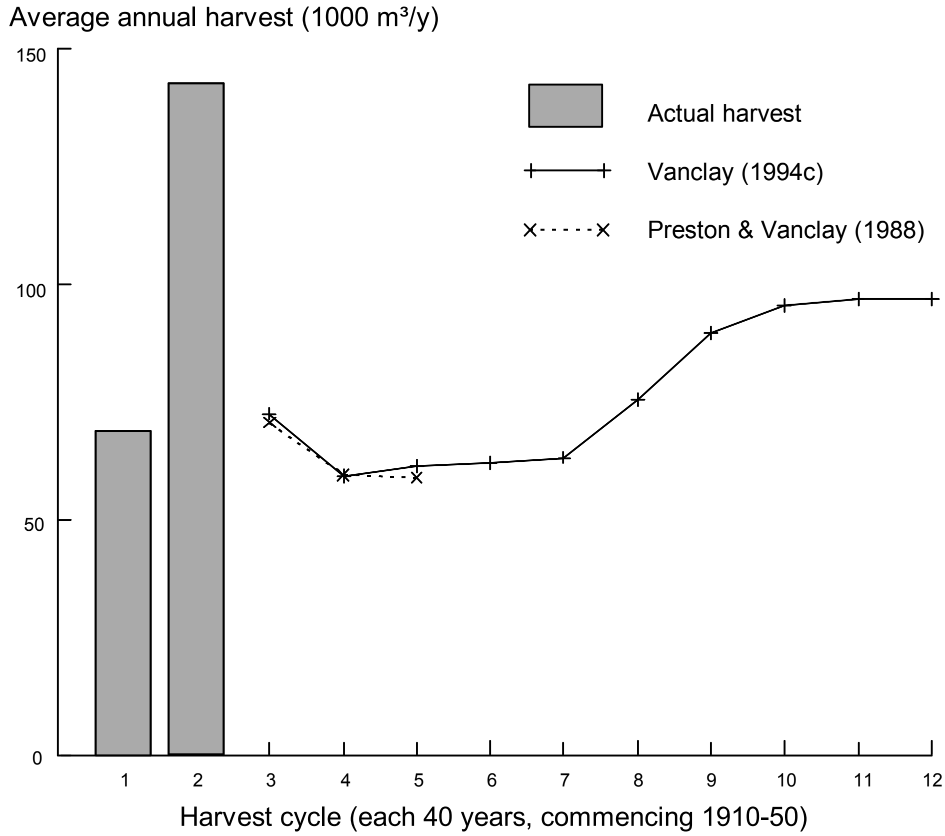

Figure 4.. Actual and projected harvests from north Queensland rainforests. Note that the area available for harvesting varied during the first two cycles. New areas became available as access improved, while some logged-over areas were converted to other uses. These data relate only to timber production from rainforest on crown (public) lands, and exclude harvests from plantations and private lands.