Alternative definitions of growth and removals and implications for forest sustainability

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Summary

Alternative definitions for growth and removals from a forest being monitored over time are discussed. It is shown that the definitions that are used in practice may not be what one would expect and estimates can vary substantially under alternative definitions. This can result in conclusions about forest sustainability that may be misleading. Alternative definitions are applied to selected states using US Department of Agriculture Forest Service inventory data. Standard errors of growth over removals ratios are used to indicate potential sustainability problems for selected forest types.

Introduction

Forest sustainability can be measured by numerous criteria and indicators such as those developed by international working groups, e.g. the Montreal Process or the Helsinki Process (Brand, 1997; Hall, 2001). Forest growth and removals are included as indicators under Montreal Process Criterion 2: *Maintenance of Productive Capacity of Forest Ecosystems*. Similar criteria are applied as part of the forest certification process (Hansen *et al.*, 2006). There is an intuitive appeal to the notion that timber removals should not exceed timber growth in a sustainable forest (Prisley and Malmquist, 2002). The growth over removals ratio (G/R) is an accepted index of sustainability when assessing timber demand and supply scenarios (Cubbage *et al.*, 1995). Ratios less than 1 may be indicative of overcutting, while ratios greater than 1 suggest sustainability.

The value of growth and removals as indicators is due to their relationship to long-term forest sustainability. However, growth and removals estimates apply to a specific time interval that is determined by the inventory data. The G/R estimate from a 10-year periodic survey gives only a partial indication of sustainability. If $G/R < 1$, then the situation is not indefinitely sustainable, but the total amount of inventory may be large enough to continue this trend for decades to come. It is possible for a management plan to legitimately call for a $G/R < 1$ while adjusting the age class structure of the forest. Likewise, $G/R > 1$ could lead to excessive mortality and fuel accumulation that would not be sustainable. Thus, the G/R ratio is a valuable index, but should generally be evaluated as part of a suite of indicators.

There are at least two benefits to looking at ratios. First, G/R eliminates the need to annualize growth or removals estimates from a periodic

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survey, i.e. there is no need to divide by the number of years in the period. Second, it eliminates variance due to uncertain area estimates, since multiplication by area is cancelled by the division and area becomes irrelevant. Annual inventories, such as those conducted by the US Department of Agriculture (USDA) Forest Service Inventory and Analysis (FIA) programme, can potentially give annual *G/R* estimates to show a trend. However, the definitional issues to be discussed here apply to either periodic or annual inventories.

Definition of growth and removals

The value of *G/R* as an indicator of sustainability seems obvious, but one should not overlook the fact that the result depends on definitions for both growth and removals. In particular, definitions must include the time period of interest, the land base and what trees are considered to be contributors.

Defining the time period of interest is step 1. The time period that the computed *G/R* ratio applies to should be clearly specified. For example, periodic inventories provide estimates for the time between plot measurements. Annual surveys can provide estimates for a span of years or a particular year (Roesch, 2007).

Defining the relevant land base is step 2. Assume first that at any given time, land in an area of interest can be divided into two classes, forest and non-forest. Land can change from forest to non-forest (known as a diversion) or from non-forest to forest (known as a reversion) over time. However, assume that our time interval is short enough that only one transition in classification can occur on any particular segment of the land area. This results in four potential classifications of the land base over the interval: forest, non-forest, diversions and reversions. Growth and removals are attributes that are usually defined with respect to forest land. Therefore, these attributes could be estimated from measurements on any sample plot that was on forest land at some point during the specified time period. However, failure to distinguish between a classification change, such as forest to non-forest, and tree growth has led some into illogical definitions of growth, removals and mortality. Roesch (2007) pointed out that further confusion had been entered into the topic by definitions that were sample dependent, rather than strictly population dependent.

Finally, one must define the contributing trees. This involves, for example, getting specific about how the contribution of growth on mortality trees is handled. How the volume and volume growth are counted can have a noticeable impact on the *G/R* ratio. Likewise, should trees that were killed by human activity be counted as removals or mortality?

Once these definitions are clear, it is appropriate to discuss how the sample observations will be used to estimate forest change and growth.

Growth

We will consider two definitions for growth. The first definition corresponds to what FIA defines as net annual growth in its standard tables. The land base includes all land that was forested at time 1. The contributing trees are all growing stock trees in this land base that were merchantable (>5.0 inches diameter at breast height, 12.7 cm) subsequent to time 1. Trees that were merchantable at time 1 but died before time 2 also contribute to net annual growth. The entire time 1 volume of these trees is treated as negative growth (USDA, 2005), because net annual growth is volume at time 2 minus volume at time 1 divided by the number of years. The merchantable volume of a mortality tree is zero, by assumption.

The second definition is identical to the first except that it is limited to trees that are alive at time 2. This avoids double counting some mortality trees. The convention of assuming that merchantable volume is zero for a dead tree places a large penalty on growth if these trees are included in the growth estimate, since the entire time 1 volume is counted as negative growth. The second definition is very close to what FIA analysts define as gross growth (Thompson, 1997) except that growth on mortality and removals subsequent to time 1 is ignored. However, it is not currently possible to estimate gross growth from publicly available FIA data.

Removals

Alternative definitions also exist in practice for removals. The first definition corresponds to the

Table 1: Comparison of average net annual growth of growing stock and average annual removals of growing stock (cubic feet) for selected states

State	FIA			Alternative		
	Growth	Removals	*G/R*	Growth	Removals	*G/R*
Alabama	1511639873	1220881849	1.24	1564271615	1164756977	1.34
Michigan	761209404	333015174	2.29	691373223	321411275	2.15
Minnesota	469693637	293554700	1.60	382133301	257717083	1.48
North Carolina	1287523069	1004191792	1.28	1475950498	1168253712	1.26

Computed by FIA and the alternative method using the same definitions for growth and removals.

FIA definition. The land base includes all land that is forested at time 1. The contributing trees are those that are cut for products and all trees on land that was diverted to non-forest uses. Therefore, trees on land that goes into an urban development are counted as removals. Trees that die due to human actions are also counted as removals.

The second definition includes only trees that were removed from forest land and used for products. This excludes mortality trees and trees on land that was diverted to a non-forest use.

Applications

The first application compares *G/R* estimates that result from the two definitions. There can be definition-caused differences in estimates, but there are also different ways to approach the estimation process that have nothing to do with growth and removals definitions. An alternative estimation approach is used that differs from the standard FIA estimation scheme.

The second application looks at the use of *G/R* ratios to assess the relative sustainability of hardwood versus softwood management practices in Alabama. A *G/R* variance estimator is also suggested.

Comparison of G/R between states

Estimates based on alternative definitions of removals are derived from FIA data for the states of Alabama, Michigan, Minnesota and North Carolina. The general methods used to compute estimates by FIA are described in Bechtold and Patterson (2005). However, an alternative approach (Van Deusen, 2004) is used here. The alternative method is to compute mapped plot means and multiply them by FIA estimates of forest area. FIA is using a more complex approach involving stratification within analysis units and adjustment for denied access plots. A comparison is made between the methods (Table 1) that shows estimates of *G/R* to be within 10 per cent. There does not appear to be any consistent difference between the alternative method and FIA's method.

The time period that these estimates apply to is determined by when the plots having growth and removals data were measured. Alabama has plots measured from 2001 to 2006. For Michigan, plots were measured from 2004 to 2006. Minnesota and North Carolina have plots measured from 2003 to 2006. Generally, the first year for each state has few growth plots, so the estimates are weighted towards the more recent years.

The results for the FIA method come directly from the mapmaker online tool (Miles, 2007). Every effort was made to ensure that both methods used the same plots and trees, but there is no guarantee that this is the case. Differences (Table 1) between the two analysis methods might be due to any of the following reasons: slight differences in the data; not using stratification for the alternative method, not correcting for denied access for the alternative method and to the use of the mapped plot estimators (Van Deusen, 2004) for the alternative method. However, the intent of this paper is to compare alternative definitions for growth and removals, not to reproduce FIA estimates. The comparison of definitions is not effected by failure to reproduce the FIA estimates.

Table 2: Average net annual growth of growing stock and average annual removals of growing stock (cubic feet) for selected states computed with the alternative method under definition 2

State	Definition 2		G/R	
	Growth	Removals	Definition 1	Definition 2
Alabama	1666921961	1120361653	1.34	1.49
Michigan	940693633	292994965	2.15	3.21
Minnesota	599078847	231273455	1.48	2.59
North Carolina	1673280687	952668496	1.26	1.76

G/R ratios are shown for definitions 1 and definition 2 for comparison.

The same estimates are computed for each state using the second definition for growth and removals (Table 2). The alternative estimation method is used. Now growth does not include any trees that are dead at time 2 and removals is based only on trees that were removed and used for products. The *G/R* estimates using the alternative method for definitions 1 and 2 are both shown (Table 2) for easy comparison.

It is revealing to compare *G/R* estimates based on the same data and estimation methods where only the definition of growth and removals has changed (Table 2). For each state, the *G/R* estimate increased under definition 2. This is not surprising because generally growth should increase and removals should decrease for definition 2 relative to definition 1. This is because trees that die between time 1 and time 2 are removed from the growth estimate. The growth contribution on mortality trees is negative according to FIA definitions. Likewise, any trees that died or were on land diverted to non-forest use are eliminated from removals for definition 2.

Comparison of G/R estimates by forest type

The hardwood resource has become increasingly important for paper making processes and for bioenergy. This suggests that it could be important to look at *G/R* ratios by forest type. It would also be useful to have standard error estimates to indicate the confidence interval width around *G/R* estimates.

Standard errors of *G/R* estimates can be estimated with equation (2.46) from Cochran (1977). The finite population correction factor is ignored here, since a very small proportion of the population is being sampled by FIA plots. The standard error estimator is

Table 3: *G/R* estimates for selected forest types in Alabama

Forest type	G/R	s(G/R)	n
Loblolly pine	1.88	0.14	1441
Loblolly pine/hardwood	1.01	0.17	437
Longleaf pine	2.04	0.83	118
White oak/red oak/hickory	2.34	0.55	359
Sweetgum/yellow-poplar	0.84	0.18	249
Mixed upland hardwoods	0.66	0.11	598
Sweetgum/Nuttall oak/willow oak	2.05	0.54	235
Sweetbay/swamp tupelo/red maple	1.43	0.54	170

The table gives standard error estimates and sample sizes (n). Computations are based on definition 2 and the alternative estimation method.

$$s(\widehat{G/R}) = \frac{1}{\sqrt{n}\bar{X}}\sqrt{\frac{\sum(y_i - \widehat{G/R}x_i)^2}{n-1}}, \qquad (1)$$

where n is the sample size, y_i and x_i are the growth and removals values from plot i, and $\bar{X}$ is the mean of the removals values.

The *G/R* estimates for forest types in Alabama that had at least 100 FIA plot measurements with growth and removals data are shown (Table 3). Computations are based on definition 2 and the alternative estimation method. Therefore, these *G/R* estimates are more optimistic than what would result from the usual FIA procedures. The results (Table 3) suggest that the loblolly pine type is being sustainably managed in Alabama, because an approximate 95 per cent confidence interval (±2 standard errors) does not overlap 1.0. However, the upper bound of the mixed upland hardwoods type confidence interval is less than 1.0. This suggests that whatever has been happening with upland hardwoods recently is not sustainable. The loblolly pine/hardwood type and the sweetgum/yellow-poplar type might also be of concern. These results (Table 3) suggest that certain hardwoods are being overutilized in Alabama.

Discussion

It is not surprising that the change due to definitions (Table 1) in G/R estimates is smaller for the southern states (Alabama and North Carolina) than for the Lake States (Michigan and Minnesota). States where G/R is close to 1.0 will tend to have less mortality and larger removals. Thus, the change in growth and removals due to definitions will be less because there is less mortality. Also, the relative size of land diversions will be less relative to removals for products in states where product removals are large. It is well known that the Southern States have significant industrial forest activity and a large portion of US removals for products occurs there.

The changes due to definitions in G/R estimates for the Lake States were significant, especially in Minnesota. The G/R estimate could be interpreted as an indication of how much removals could be increased to result in $G/R = 1.0$. Under definition 1, removals could be increased by a factor of 1.48 in Minnesota. Under definition 2, removals could be increased by a factor of 2.59. This highlights the importance of paying close attention to definitional details. Under definition 2, there appears to be a huge amount of available fibre in Minnesota relative to definition 1. The increase for North Carolina may be even more significant from a practical perspective. The North Carolina G/R estimate for definition 1 indicates little room for increased removals. The definition 2 result is much more optimistic.

The above discussion oversimplifies the issue by lumping all forest types and ownerships together. It is possible that G/R values could indicate overall sustainability at the state level, but there could be subregions or forest types where $G/R < 1.0$. The application to forest types in Alabama demonstrates this (Table 3). The mixed upland hardwood type in Alabama had a G/R estimate with upper 95 per cent confidence limit less than 1.0.

We have not attempted to say what the best definition for growth and removals is. Perhaps this is up to the user. We show that the standard FIA definition may not give the results that users expect. This is not to say that the FIA definition is wrong or should be changed. FIA could continue to offer results based on the traditional definition, but offering results from alternative definitions could be useful. Whatever a users preferred definitions are, it is always a good idea to clearly specify them.

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Conflict of Interest Statement

None declared.

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