

Would spatial yield models be more relevant for forestry operations in the tropics?

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Photograph 1. Low-impact logging system using the Logfisher, a type of swing-yarder.
Photograph H. Bigsby.

RÉSUMÉ

LE MODÈLE SPATIAL DE RENDEMENT EST-IL UNE SOLUTION PLUS PERTINENTE POUR L'EXPLOITATION DES FORÊTS TROPICALES ?

L'expérience de sociétés forestières pratiquant l'abattage sélectif d'arbres individuels au Sarawak montre que leurs opérations ne sont encadrées en général que par une réglementation de base concernant par exemple le diamètre minimum d'abattage, les dimensions maximales des trouées ou les essences autorisées. En général, les aspects sylvicoles ne sont, au mieux, pris en compte qu'implicitement dans les règlements sur l'abattage, et non explicitement dans la planification et les opérations d'abattage. Les sociétés forestières tendent de plus en plus à pratiquer un comptage à 100 % des arbres, associé à une cartographie par GPS, dans le cadre de systèmes d'exploitation à impact faible ou réduit. L'utilisation de systèmes GPS permet d'élaborer des bases de données spatialisées et des descripteurs clés des arbres. Ceux-ci pourraient servir d'appui à la planification d'activités futures basées sur des modèles de croissance et de rendement permettant de prendre en compte des paramètres forestiers importants, comme le DBH et les essences présentes, et de cartographier la position des arbres. Cela aiderait les gestionnaires des récoltes et les arpenteurs forestiers à passer d'une optique purement opérationnelle à une optique sylvicole, en prenant en compte des paramètres tels que l'espacement, le recrutement et les tiges d'avenir lors de la planification des opérations d'abattage. L'absence de ce type de planification parmi les sociétés forestières est principalement due au fait que les modèles d'exploitation forestière en milieu tropical sont généralement basés sur des paramètres de zonage (modèles à l'échelle des peuplements ou selon les classes de dimension) qui ne sont pertinents que par rapport aux besoins de la planification à grande échelle. Ces modèles n'intègrent généralement pas les données spatiales générées par la planification, ils nécessitent des données beaucoup plus nombreuses et différentes de celles utilisées pour planifier les opérations d'abattage et ne produisent pas de résultats utiles à la planification opérationnelle des récoltes. Il est plus utile de se servir de modèles par arbre qui intègrent des données spatiales et produisent des résultats pertinents au plan opérationnel, comme les diamètres, les essences et la position des arbres. Cet article rappelle les contraintes opérationnelles de l'exploitation forestière à impact faible ou réduit, et préconise des approches pour la modélisation des rendements compatibles avec ces systèmes.

Mots-clés : planification de l'exploitation forestière en milieu tropical, modélisation par arbre, exploitation forestière à impact réduit.

ABSTRACT

WOULD SPATIAL YIELD MODELS BE MORE RELEVANT FOR FORESTRY OPERATIONS IN THE TROPICS?

Experience with companies, using single-tree selection systems for logging in Sarawak, shows that they are generally guided only by basic statutory harvesting rules like minimum diameter limits, maximum gap size and permitted species. At best, silvicultural considerations are typically only implied in the harvesting rules, rather than being explicitly considered in harvest planning and operations. Increasingly, companies are moving towards 100 percent enumeration of trees and tree mapping using GPS as part of reduced or low-impact logging systems. Use of GPS results in a spatial database of trees and key descriptors that could be used to plan future activities by modeling growth and yield to forecast key forest parameters, such as DBH and species, and to map the location of trees. Doing this would help to shift the focus of harvest planners and surveyors from operational to silvicultural considerations such as spacing, recruitment, and future crop trees, when planning harvesting. The main reason why companies are not doing this type of planning now is that the common tropical forest models use area-based parameters (whole stand models, size class models) that are only relevant to large scale planning. Typically these models do not make use of the spatial data that is generated in logging planning, require significantly more and different data than what is used in planning logging operations, and do not produce outputs that are relevant to operational harvest planning. What would be more useful are single-tree models that make use of spatial data, and that produce output that is operationally relevant, including diameter, species, and location of trees. The paper outlines operational requirements of reduced and low-impact logging systems and recommends yield modelling approaches that would work with these systems.

Keywords: tropical forest planning, single tree model, reduced impact logging.

RESUMEN

¿ES ACASO MODELO ESPACIAL DE RENDIMIENTO UNA SOLUCIÓN MÁS ADECUADA PARA LAS OPERACIONES FORESTALES EN BOSQUES TROPICALES?

La experiencia de empresas madereras que practican la tala selectiva de árboles individuales en Sarawak muestra que, por lo general, sus operaciones sólo se guían por reglas básicas como, por ejemplo, el diámetro mínimo de corta, las dimensiones máximas de los claros o las especies autorizadas. En general, como mucho, los aspectos silvícolas sólo se toman en cuenta de forma implícita en las normas de aprovechamiento, y no explícitamente en la planificación y operaciones de corta. Las empresas madereras tienden cada vez más a practicar un conteo del 100% de los árboles, asociado a una cartografía por GPS, en el marco de sistemas de aprovechamiento de impacto bajo o reducido. La utilización de sistemas de GPS permite elaborar bases de datos espaciales y descriptores clave de los árboles que podrían ser utilizados para planificar actividades futuras, basándose en modelos de crecimiento y rendimiento que integren importantes parámetros forestales, como el DAP y las especies presentes, y permitan cartografiar la ubicación de los árboles. Esto ayudará a planificadores de cosechas y agrimensores forestales a pasar de una perspectiva puramente operativa a una perspectiva silvícola que tome en cuenta aspectos como el espacio, el reclutamiento y los árboles de futura cosecha en la planificación de las operaciones de aprovechamiento. La ausencia de este tipo de planificación entre las empresas madereras se debe principalmente a que los modelos de aprovechamiento forestal en entornos tropicales suelen basarse en parámetros zonales (modelos a escala del rodal o por clase de tamaño) que sólo son adecuados para la planificación a gran escala. Estos modelos normalmente no integran los datos espaciales generados por la planificación, requieren datos mucho más numerosos y distintos de los que se emplean para planificar las operaciones de corta y no producen resultados útiles para la planificación operativa de las cosechas. Sería más útil utilizar modelos por árbol que integren los datos espaciales y produzcan resultados relevantes a nivel operativo, tales como el diámetro, la especie y la ubicación de los árboles. En este artículo se describen los requisitos operativos del aprovechamiento forestal de impacto bajo o reducido, y se recomiendan métodos para la modelización del rendimiento compatibles con estos sistemas.

Palabras clave: planificación del aprovechamiento forestal tropical, modelización por árbol, aprovechamiento forestal de impacto reducido.

Introduction

In recent years a great deal of effort has been directed at the logging industry in Sarawak to bring about sustainable forestry practices. These efforts can broadly be categorized in terms of regulations that govern what will be harvested, changes to harvesting systems, and the development of forest planning models. Regulations refer to what are generally prescriptive guidelines that determine what is considered to be a harvestable tree. Changes to harvesting systems refers to modifications to how harvesting is planned and carried out. Forest planning models refer to models of growth and yield that are relevant to mix-aged, mixed species forests, and that aid in planning by forecasting the effects of harvesting decisions on future stand structure and yield.

There is concern that to some extent these efforts, while potentially having significant effects on sustainable forest practices when taken individually, together are not well coordinated and thus lead to less than optimal outcomes. The purpose of this paper is to examine yield models in the context of the regulatory environment that governs harvesting in Sarawak and the move to new harvesting systems.

Forest Management in Sarawak

Similar to most parts of the tropics, Sarawak practices a selection harvest system that uses a simple set of operational rules based on a Minimum Diameter Cutting Limit (MDCL) and a specified re-entry period or cutting cycle length. In Sarawak, this is a modification of the Malaysian Uniform System (MUS) (LEE, 1982). Under the modified MUS in Sarawak the MDCL is 60 cm for dipterocarp species and 45 cm for non-dipterocarp species, and the cutting cycle is 25 years (LEE & LAI, 1977). From a regulatory and administration perspective, the advantage of this system is that it requires basic training to use, and is very simple to administer and enforce. An important feature of selection harvest system used in Sarawak is that has an implicit, rather than explicit, link to sustained yield. Underpinning the use of the selection harvest rules is a notional concept that over the cutting cycle, the Mean Annual Increment (MAI) and recruitment for a mixed dipterocarp forest will be sufficient to replenish the forest structure and volume that was removed during harvest. In essence, the assumption is that if the rules are followed, then a crop will be there for the next cycle.

However the experience in Sarawak, as with most other parts of the tropics, is that conventional tractor logging using selection harvesting rules alone is not sufficient to ensure regeneration of the forest (FORSHED *et al.*, 2008; PUTZ *et al.*, 2008; SIST, 2001, 2003; SIST *et al.*, 2003; VALLE *et al.*, 2007; ZIMMERMAN & KORMOS, 2012). The single most important characteristic of conventional logging is that it is largely unplanned. As usually practiced, a feller goes through a block finding trees and cutting them down, and after that the skidder creates trails to extract logs. The result of this unplanned logging is that the number, length and

impact of skid trails, is significant. Crawler tractors were designed for road building rather than harvesting and the impact of building skid trails is significant due to blading of topsoil and compaction of the ground. There also ends up being a large number skid trails. As a result, 10 to 30% of the forest area ends up being compacted by skid trails, roads and landings (FORSHED, 2006; AHMAD & KAMARUZAMAN, 2003). In addition, there is a significant level of damage to the residual crop (FORSHED, 2006; AHMAD & KAMARUZAMAN, 2003). Conventional logging damages or destroys up to 60% of the residual crop (FORSHED, 2006).

The problems associated with conventional tractor logging have led a change in the focus of logging management to controlling the impacts of harvesting through Reduced Impact Logging (RIL) and Low Impact Logging (LIL). RIL applies to conventional tractor logging and involves modifying the way tractors are used in logging operations to reduce stand damage. LIL applies to the use of new harvesting technology rather than crawler tractors to minimise the effects of logging. Examples of LIL are the Logfisher (photograph 1) and helicopters (photograph 2).

One of the most important changes to logging with RIL and LIL is to plan harvesting before the felling and extraction take place. One of the most important elements of planning harvesting is a 100% enumeration done as part of pre-harvest planning. The 100% enumeration is used to identify trees to be harvested, and then to plan felling and extraction so that the number and length of skids trails is reduced and stand damage is minimised. Although called a 100% enumeration, the inventory is generally limited to a proportion of the tree population. In Sarawak, only trees that are more than 30 cm for diameter breast height (DBH) are generally included in the 100% enumeration. During the inventory, data is collected on species, DBH, GPS location and status as potential crop, protected or mother tree. It is important to note that this inventory is generally done by experienced



Photograph 2.
Low-impact logging system using helicopter.
Photograph H. Bigsby.

Waypoint List

Map Name : Fmu (coupe 3) bk 27.bmp
 Map File : E:\a) SFM Map\Coupe 3A\Block 27\BK 27 contour\FMU (Coupe 3) Bk 27.map

Datum : Timbalai 1948

Waypoint File : E:\a) SFM Map\Coupe 3A\Block 27\27.13 all.wpt

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Num	Name	Latitude	Longitude	Alt(ft)	Description
1	174	1 28.9124	113 40.4438	1044	10-FEB-09 A2193 PLIS 54.3 FT (Felling)
2	175	1 28.9166	113 40.4492	1167	10-FEB-09 A2792 MRTX 42.3 PCT (Potential Commercial tree)
3	176	1 28.9106	113 40.4654	1172	10-FEB-09 A0406 DURM 43.3 FRT (Fruit tree)
4	177	1 28.9160	113 40.4570	1237	10-FEB-09 A2195 NYTO 49.5 FT
5	178	1 28.9148	113 40.4678	1184	10-FEB-09 A2196 PLIS 58.6 FT
6	179	1 28.9106	113 40.4894	1352	10-FEB-09 A2793 MRTX 49.4 PCT
7	180	1 28.8896	113 40.4996	1179	10-FEB-09 A2794 MRTX 30.0 PCT
8	181	1 28.9064	113 40.5290	1344	10-FEB-09 A2795 MRTX 47.5 PCT

Figure 1.
100% Enumeration Data.

surveyors rather than trained foresters. This means that no silvicultural decisions or observations are recorded or assessed. The 100% enumeration results in a database of trees included in the inventory (figure 1) that can be transferred to a GIS database and map (figure 2).

At present the data from 100% enumeration in figure 2 is used only for pre-planned extraction of logs. This includes identifying crop trees, skid trail alignment and directional felling. Pre-planned extraction based on 100% enumeration has been successful in reducing residual stand damage, erosion, and the area lost to skid trails where applied appropriately. However, there are still a number of issues related to strict adherence to MDCL rules even with pre-planned extraction (SIST, 2001, 2003; SIST *et al.*, 2003). In mixed dipterocarp forests, MDCL leads to high felling intensities (10-20 or more trees per hectare), high stand damage (greater than 50% of remaining trees), and can

mean that there is little difference between the effects of Reduced Impact Logging (RIL) and conventional logging (SIST *et al.*, 2003). As a result, a typical recommendation on top of the other MDCL rules is that no more than 8 stems per hectare be harvested or that felling gaps are less than 500m².

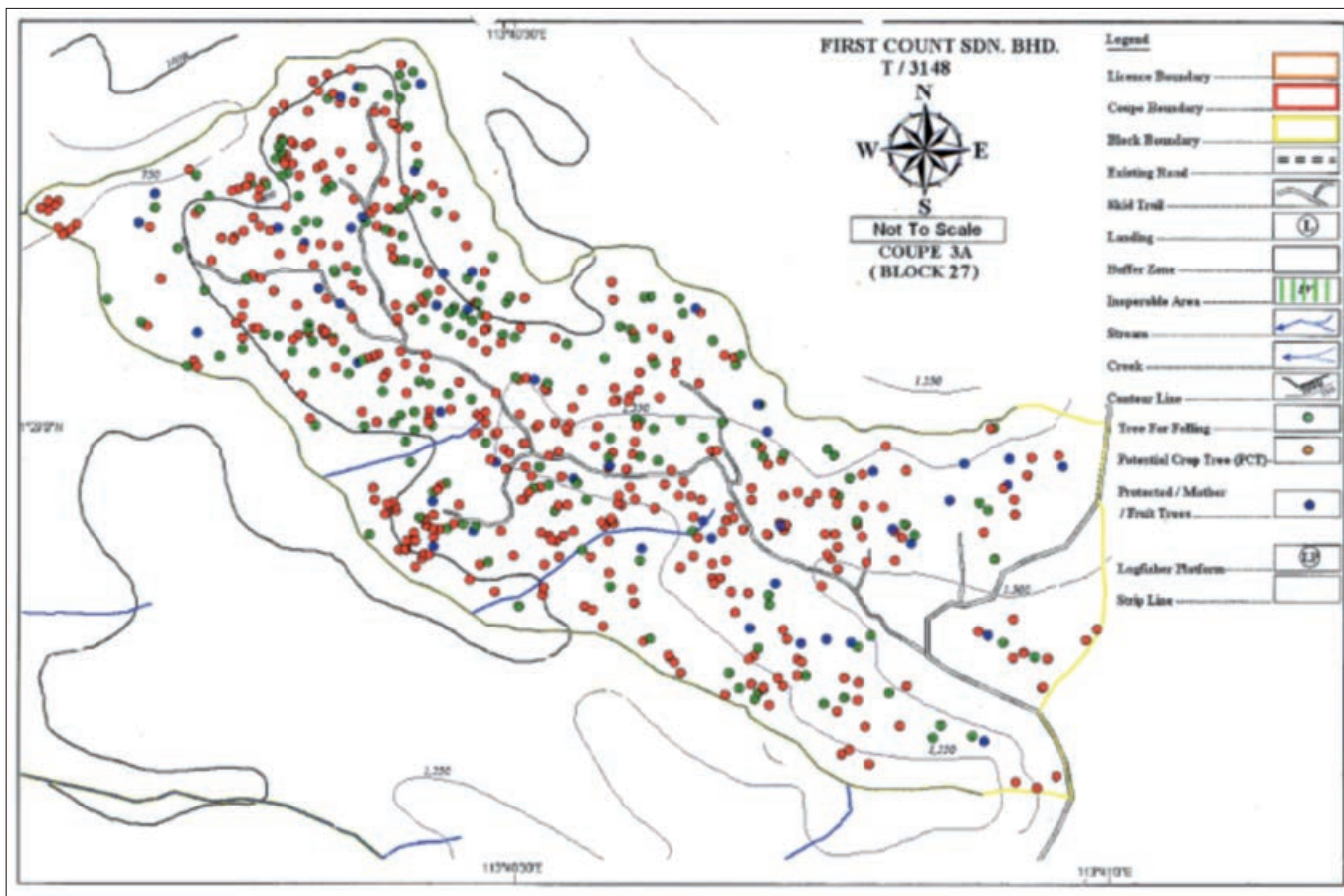


Figure 2.
Logfisher Planning Map from 100% Enumeration.

The need for additional rules to limit the number of stems per hectare or gap size is indicative of the fact that forest managers are still missing an explicit link between harvest planning and future timber availability. The primary factor that contributes to the inability of forest managers to make this link is that harvest planning does not use yield models. As a result, a tropical forest manager is not able to model the effect of different harvest decisions on future harvest possibilities before final harvest decisions are made. The ability to model or simulate forest growth after harvest has become a critical part of the decision process for managers of even age forests and forest plantations, allowing managers to optimise use of resources to meet planning objectives. Managers of uneven age forests need the same ability to model the effects of harvest decisions.

For forest managers planning single-tree selection harvest, there are two important aspects of yield modelling that need to be considered. From a marketing and production planning perspective, a forest manager needs to know the availability of trees with desired characteristics, such as species and diameter at a particular point in time, and to be able to evaluate the effect of harvest decisions on residual trees so that harvesting options can be explored. From an operational perspective, a yield model that produced a spatial projection of trees of known characteristics at a point in time would facilitate the planning of pre-harvest, harvest, and road building activities. Ideally, a forest manager should be able to run a model that maps the location of trees by desired characteristics (DBH, species) at given points in time, based on particular starting conditions. Importantly, a yield model that was able to produce a spatial projection of trees at a point in time would help to shift the focus of forest managers from planning logging operations with only vague connections to future crops, to explicit consideration of silvicultural factors such as spacing, recruitment, and future crop trees.

The spatial database of trees from the 100% enumeration contains information on tree location, species, and DBH, all of which are potentially useful parameters for yield model of uneven age forests that is able to meet all these requirements. While the potential for the use yield models in tropical forest planning is evident, the reality is that there is essentially no use of yield models in forest planning in Sarawak. The question is then why yield models are not being used.

Operational Yield Models

The common approach to modelling mixed-age forests is to use area-based parameters. These types of models include whole stand models and size class models (VANCLAY, 1994). Whole stand models are those that use stand-level parameters like basal area, stocking, stand volume or stand diameter distribution to model growth and yield. Size class models use classes of trees rather than whole stands. The term "size class" comes about because tree size (diameter or height) is a common way of classifying trees. Examples of these types of models for Borneo include DIP-SIM (KLEIN, 1999), MYRLIN (REDHAHAR *et al.*, 2003), SYM-

FOR (PHILLIPS *et al.*, 2003; VALLE *et al.*, 2007; VAN GARDINGEN *et al.*, 2001), FORMIX 3-Q (DITZER *et al.*, 2000), and FORMIND (KÖHLER & HUTH, 2004).

Despite the availability of yield models such as these, none are used by forestry companies in Sarawak. One reason for this is that these yield models use more complex or different data than generated by forest operations. Unlike the data collected in a 100% enumeration, yield models use non-spatial, area-based data that can only be acquired by carrying out particular types of inventories (e.g. trees below 30 cm DBH), or require measurements that must be done using specialist equipment and by trained specialists (e.g. leaf area). For example, DIP-SIM requires a systematic terrestrial inventory according to a three-nested plot design with a 0.25 ha L-shaped principal plot and subplots of 0.04 ha (20 x 20 m) and 0.01 ha (10 x 10m), respectively (KLEIN, 1999). FORMIX-3 requires allometry parameters to calculate productivity of the crown foliage of a tree of given size based on a Michaelis-Menten-type light response curve including estimates of photosynthetic capacity, photosynthetic efficiency and a light extinction coefficient (DITZER *et al.*, 2000). This means a forest manager would have to undertake a separate inventory operation to acquire data to do yield modelling. At best, the spatial data that is generated in the 100% enumeration as part of logging planning would contribute to these models only as way of calibrating some parameters.

From an operational perspective, the main problem with these models is that they are not spatial, and model yield on the basis of stands or area. Since the output of the models is also non-spatial, it is also largely not relevant to planning operations. In order to make yield modelling useful to forestry operations and more likely to be used in making decisions, modelling approaches need to adopt a new paradigm that focuses on operationally relevant considerations. In particular, models need to use data generated from operations, which includes GPS data from 100% enumeration and GIS databases. This means that what is more useful is to develop single-tree models that make use of spatial data, and that produce output that is operationally relevant, including diameter, species, and location of trees.

Single-tree models are a variant of the size class model where the size class is an individual tree (VANCLAY, 1994). At the level of the single tree, one important consideration is competition, and the relative location and characteristics of competing trees become important to the modelling process. This leads to a class of single-tree models called spatial models that use information about position and size of neighbouring trees to simulate growth. These models come in deterministic and stochastic forms, but focus on diameter increment with specifications for mortality and recruitment that apply to individual trees (VANCLAY, 1994).

One other important consideration in yield modelling is the time frame of the modelling and the parameters that are most important to that time frame. The models mentioned earlier have all been developed to study long term impacts of harvesting and AAC over many cutting cycles. For this purpose, it is important to be able to model recruitment and mortality as well as growth. From an operational perspective, this level of detail is not necessary since trees of

interest over the next cutting cycle are already growing, and depending on size, have already been measured. It is thus important to distinguish between long term models of tropical forest growth that are ecologically robust, and short term operational models that provide useful planning information. At the same time, it is important to recognise the link between the two types of model in terms of the long term effects of repeated short run decisions and the necessity of having both models being used by forest managers.

At a minimum though, a relatively simple operational yield model would become the first step for tropical logging to be guided by silvicultural considerations. Ideally, an operational individual tree growth model would be used by a forest manager to predict DBH increment, spatial competition, and survival from one planning period to the next for a known spatial distribution of trees based on a harvest scenario. The output of the model would be in two forms, a table of predicted output by species, DBH and volume, and an updated planning map that showed the location of likely harvestable trees by DBH and species (figure 3).

Among the current models that have been developed for Borneo, SYMFOR is the only one that appears to have the potential to be adapted to an operational yield model. It has been developed to be spatially explicit, with coordinates recorded for trees that are used to calculate competition (PHILLIPS *et al.*, 2003). However, it appears that this data is only used as a means of creating a typical area of forest that can be modelled at a stand level rather than preserving the spatial integrity of the data. It also appears that the initial input data is from physical measurement rather than GPS.

Summary

Current yield models that have been developed for Borneo are largely not relevant to forestry operations and as a result are not being used to inform decisions about planning harvesting or silviculture. The lack of relevance arises from the fact that yield models use data that is different from what is generated as part of pre-harvest inventory, and generally produce output that has no application in planning harvesting activities. However, RIL and LIL approaches now being used by forestry companies provide a detailed spatial database of trees through pre-harvest inventory. This provides forest modellers with an opportunity to modify yield modelling approaches to ones that use single trees in a spatial context. The output of this type of modelling is a spatial projection of trees that has operational usefulness. The important outcome of an operational yield model would be that it would allow forest managers to move beyond prescriptive harvesting rules to practicing silviculture by considering the impacts of decisions about skid trail location and harvested trees.

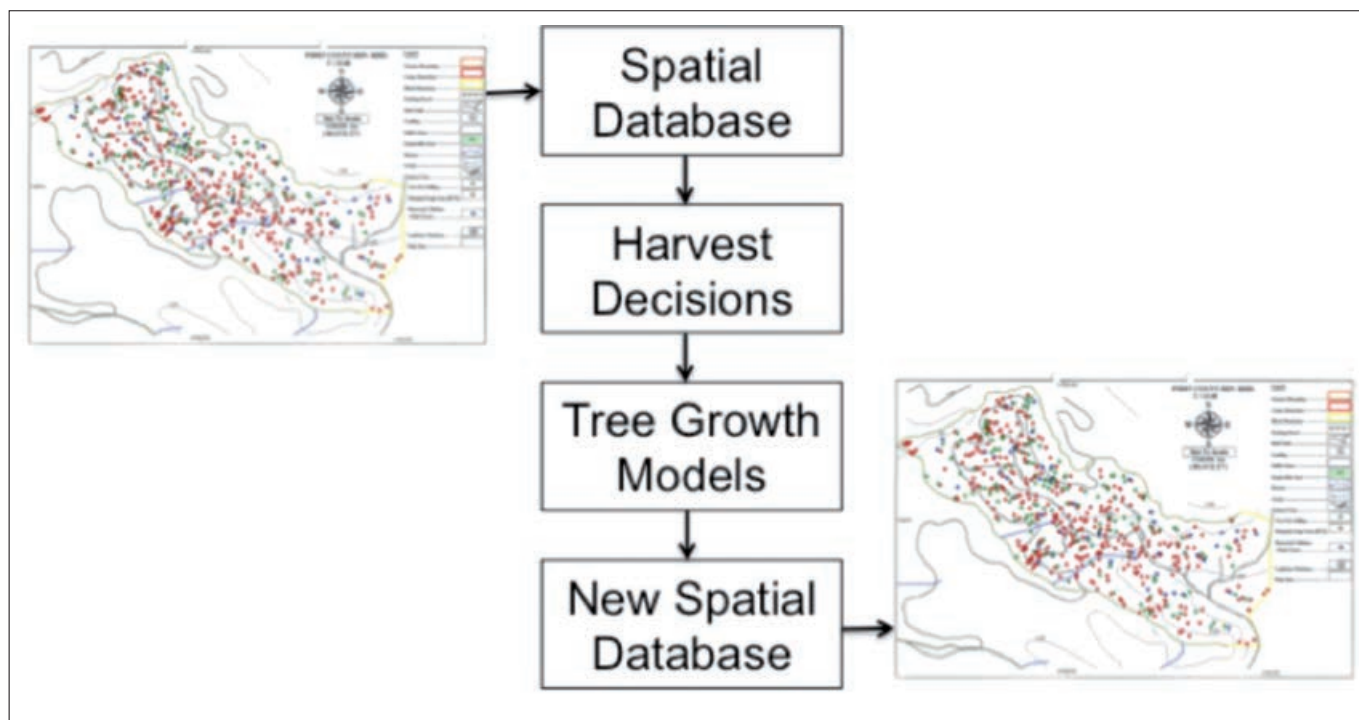


Figure 3.
Planning Process Using Pre-Harvest Inventory Data and a Single-Tree Growth Model.

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