Extension Note

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Arrow IFPA Series: Note 6 of 8

Criterion 2: Ecosystem productivity

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Abstract

This extension note is the sixth in a series of eight that describes a set of tools and processes developed to support sustainable forest management (SFM) planning and its pilot application in the Arrow Timber Supply Area (TSA). It describes the criterion and two of the indicators selected to set thresholds and evaluate potential impacts on ecosystem productivity for an SFM scenario for the Lemon Landscape Unit. The note also summarizes the analysis results obtained when an ecosystem-based simulation model (FORECAST) was used to examine the effects of varying rotation length on measures of selected indicators of long-term ecosystem productivity for representative site types.

The analysis considered changes in site index, soil organic matter (SOM), and site nitrogen (N) capital on poor-, medium-, and good-quality sites, and evaluated the utility of these measures in assessing and monitoring the effects of different intensities of stand management (as reflected in harvest rotation length) on ecosystem productivity.

Shortening the rotation lengths increased losses of SOM and site N. The poor site showed smaller relative changes in both of these measures when compared to the good and medium sites. This suggests that different sustainability thresholds may be warranted for locations with different site qualities. Shortened rotation lengths had little effect on stemwood production (a proxy for site index), but the reduction in SOM and site N capital would likely translate into a decrease in ecosystem resiliency. Both SOM and N capital are important indicators for evaluating the sustainability of site productivity under alternative management practices. The model results highlight the value of using a multi-indicator approach when evaluating the sustainability of site productivity under alternative management practices.

KEYWORDS: *criteria and indicators, ecosystem productivity, ecosystem simulation modelling, soil organic matter, site nitrogen, sustainable forest management.*

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Introduction

Maintenance of the long-term productive capacity of forest ecosystems (generally defined as the ability of an ecosystem to produce, grow, or yield products) has been identified as an important criterion for sustainable forest management (SFM) both nationally by the Canadian Council of Forest Ministers (CCFM) (Canadian Council of Forest Ministers 1996) and locally in the Arrow Timber Supply Area (TSA; see sidebar) (Extension Note 3). In this regard, ecosystem productivity is fundamental to the development of an SFM plan. Despite its acknowledged importance, the development of a simple set of indicators for monitoring productivity continues to be problematic, in part because little empirical data exists on which to derive and evaluate indicators. This problem will not be resolved in the near future because measurements are required over long time periods (to establish temporal trends) and broad spatial scales (to encompass the variation in ecosystems). Ecosystem simulation models can provide an interim solution because a broad range of potential indicators can be evaluated quite easily using a computer. The objective of this extension note is to evaluate a selection of indicators and associated measures of ecosystem productivity for their utility in assessing the effect of stand management on long-term forest ecosystem productivity.

The development of a simple set of indicators for monitoring ecosystem productivity continues to be problematic.

Criterion and Indicators

Under the Arrow IFPA Sustainability Project, indicators of SFM are used to measure the effectiveness of forest management practices in meeting broad management goals (criteria) (see Extension Note 2, Table 1, for a list of all criteria and indicators). Criterion 2 of the Arrow IFPA SFM framework states: "The productivity of forests and associated soil resources within the Arrow TSA are sustained" (see Extension Note 2). The indicators associated with this criterion can be evaluated over time to determine success in meeting this objective. Indicators 4 and 5 and their associated measures focus on the maintenance of a productive land base within a defined landscape unit. Indicators 6 and 7 and their associated measures are aspatial in nature and refer to representative stand types within the target landscape unit. Specifically, the measures are designed to assess whether timber production is maintained on representative stand types (I6) and to determine whether

The IFPA Sustainability Project

The Arrow Innovative Forestry Practices Agreement (IFPA) was established as a co-operative effort between the five licensees* in the Arrow Timber Supply Area (see Figure 1, Extension Note 1) and the B.C. Ministry of Forests' Nelson Forest Region. The Sustainability Project was an important initiative of the Arrow IFPA that partnered forest practitioners and academic researchers to develop a comprehensive approach to planning and implementing sustainable forest management.

The result of this work has been the Sustainable Forest Management Framework, which is now being used by Canfor* to guide certification and sustainable forest management planning in their British Columbia operations. For further background, refer to: *http://www.sfmportal.com*

Disclaimer

The ideas presented in this extension note form part of a project (outlined in a series of eight notes) that was initiated to develop a system for evaluating management options under a criteria and indicators framework. These ideas do not represent real management options for the Lemon Landscape Unit, or the Arrow TSA, although they could form the basis of such options.

* The Arrow Forest Licensee Group was comprised of Slocan Forest Products, Kalesnikoff Lumber, Atco Lumber, Riverside Forest Products, and Bell Pole. In 2004, Slocan Forest Products Ltd. was acquired by Canadian Forest Products Ltd.

soil resources associated with the resiliency of site productivity are being maintained (I7).

The complete set of proposed measures for indicators 6 and 7 are listed in Table 1; however, at this early stage in indicator development, only measures 6.1, 7.1, and 7.2 are explicitly addressed in this project. The Site Index Biogeoclimatic Ecosystem Classification (SIBEC) method (*http://www.for.gov.bc.ca/hre/sibec/*) provides a solid ecological foundation for determining site index and is thus useful as a long-term measure of site productivity (measure 6.1). If the observed site index on a managed site drops below the normal range for the associated site type, it can indicate a problem which may need to be addressed through management changes. For indicator 7, soil organic matter (SOM) and nitrogen (N) capital are strongly correlated with long-term site productivity (Prichett and Fisher 1987; Morris *et al.* 1997; Johnson and Curtis 2001). They also play a critical role in maintaining ecosystem resilience (i.e., the capacity of an ecosystem to recover following disturbance) (Kimmins 1974; Johnson 1992).

The key to effective measures of long-term soil productivity lies in establishing appropriate thresholds for the representative ecosystem types. Although empirical studies in the region that could be used to develop thresholds are lacking, the literature provides strong support for the value of soil organic matter as an indicator of site productivity (Doran and Parkin 1994; Morris *et al.* 1997; Prescott *et al.* 2000); therefore, thresholds for the modelling exercise were derived from this work. Specific thresholds for the loss of SOM were calculated to correspond with relative losses of ecosystem productivity of 15, 25, and 40% from the current level in each site type. These values were arbitrarily selected to represent an increasing level of risk to ecosystem productivity. The methodology has now been developed more rigorously with an analysis that includes a combination of field studies, literature reviews, and expert opinion (see Seely 2005).

Applying the Concept: Sustainable Forest Management Pilot Basecase Analysis

The goal of the SFM pilot basecase analysis for the Lemon Landscape Unit was to evaluate initial thresholds developed for multiple indicators under a forest management scenario (see Extension Note 4). As part of the pilot, three measures of ecosystem productivity (see Table 1) were evaluated for their utility in assessing the effect of stand management (i.e., the effect of varying harvest rotation length following a clearcut harvest) on long-term ecosystem productivity for poor-, medium-, and good-quality sites.

TABLE 1. Proposed measures for indicators 6 and 7

Measure[a]	Description	Monitoring
M 6.1	Site index does not significantly decrease below the expected range for a given BEC site series and species (SIBEC)	Field surveys
M 6.2	Use of site preparation and (or) fertilization regimes to increase soil productivity	Long-term site productivity study
M 6.3	Mean annual increment does not significantly decrease below the expected range for specific site and disturbance types	Permanent Sample Plot Network
M 7.1	Soil organic matter pools do not decline below thresholds established for specific site types	Field surveys, projected patterns from modelling exercises
M 7.2	Site N capital (measured after harvest) does not decline below thresholds established for specific site types	Field surveys, projected patterns from modelling exercises
M 7.3	Patterns of coarse woody debris accumulation remain within acceptable range established for selected site types	Field surveys, projected patterns from modelling exercises
M 7.4	Soil bulk density does not increase beyond acceptable range following harvest and site preparation	Field surveys

[a] Measures 6.1, 7.1, and 7.2 are addressed in this extension note.

Methods

The evaluation occurred in two stages. First, the ecologically based stand-level management model FORECAST (Kimmins *et al.* 1999) was calibrated to project the growth and development of a broad range of forest types (analysis units) representative of the Lemon Landscape Unit. FORECAST is able to represent the ecological processes regulating the availability of, and competition for, light and nutrient resources. The analysis units were derived from Predictive Ecosystem Maps (PEM) (see *http://srmwww.gov.bc.ca/ecology/tem/* for further information) and the potential productivity of the associated tree species was determined using the SIBEC database developed by Ketcheson *et al.* (2000).

The hybrid approach used in FORECAST requires a combination of "historical bioassay" data describing how trees have grown on sites of specific quality in the past, and other data related to specific ecosystem processes. The yield tables produced by TASS/TIPSY[1] provide data that are suitable for this purpose and were used in conjunction with the species description and site indices described above.

Calculations of above-ground biomass accumulation in stemwood and bark were produced as a time series for each species using the stand table data output generated from TIPSY in combination with published species-specific allometric biomass equations (Standish *et al.* 1985). Given the paucity of below-ground biomass data available for forest ecosystems, below-ground biomass for each species was estimated using a method based on published structural relationships with above-ground biomass (Kurz *et al.* 1996). Data describing height growth patterns and stand density were also extracted from the yield tables for each species and site quality to be represented in FORECAST.

To calibrate the nutritional aspects of the model, data describing the concentration of nutrients in the various biomass components were obtained from a database (developed at the University of British Columbia) of nutrient concentrations encompassing most British Columbia tree species. Lastly, data describing the rates of decomposition of various litter types and soil organic matter were derived from a broad range of decomposition field studies in forest types throughout British Columbia and across Canada.

In the second stage of the analysis, a simulation experiment was conducted with FORECAST to illustrate the potential effects of shortening rotation length (40, 60, or 80 years) on long-term site productivity (a 240-year simulation) for representative Interior Cedar–Hemlock (ICH) and Engelmann Spruce–Subalpine Fir (ESSF) ecosystem types in the Lemon Landscape Unit. Three different site qualities (poor, medium, and good) were used in the simulation to illustrate the importance of starting ecosystem condition on the outcome of the analysis. In all simulations, a clearcut/plant harvest system was employed with fireweed present in the understorey.

Results

The results of the simulations were evaluated in the context of measures 6.1, 7.1, and 7.2. In the case of measure 6.1, relative wood production over subsequent rotations was used as an analogue for site index.

The relative sustainability of each management combination was evaluated independently for each measure in terms of one of three possible outcomes—sustainable, problematic, or non-sustainable—depending on where each point fell relative to the estimated thresholds. Results are shown for the ICH forest type only because results for the ESSF were very similar.

In general, shortened rotation lengths led to increased losses of SOM (Measure 7.1) and site N capital (Measure 7.2) and were less likely to be classified as "sustainable" (Figures 1 and 2) based on the arbitrary thresholds selected for this demonstration. Lower litter inputs and greater harvest exports associated with the shorter rotation lengths were largely responsible for the decline in both measures. The poor site showed smaller relative changes in both measures as compared to the good and medium sites. This was primarily a function of the lower initial conditions for these variables on the poor site. These results suggest that different sustainability thresholds might be warranted for sites with low initial levels of SOM and low N capital. Note that the results concerning rotation length may vary if different silvicultural practices (e.g., fertilization or partial harvesting) were employed.

In contrast to the results for SOM and site N capital, shortened rotation lengths had little effect on relative

[1] The Tree and Stand Simulator (TASS) is a three-dimensional growth simulator that generates growth and yield information for even-aged stands of pure coniferous species of commercial importance in coastal and interior forests of British Columbia. TIPSY is a growth and yield program that provides electronic access to the managed stand yield tables generated by TASS (B.C. Ministry of Forests and Range 2006).

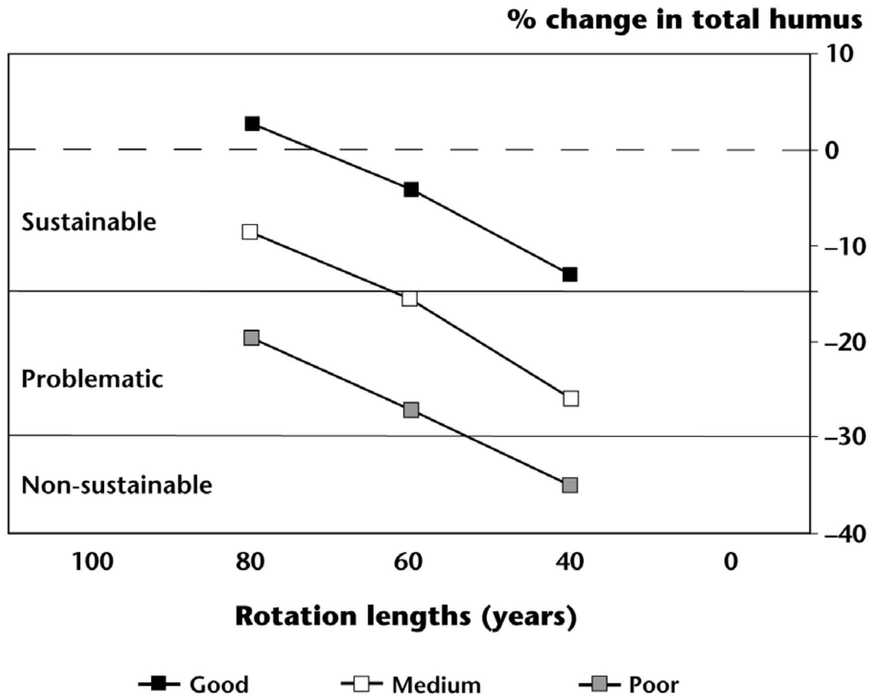

FIGURE 1. The effect of rotation length on the relative change in soil organic matter (represented as total humus) from the initial condition (represented by the dashed line) to the final condition at the end of the 240-year simulation period for poor-, medium-, and good-quality sites. Solid lines represent the boundaries of the sustainability categories.

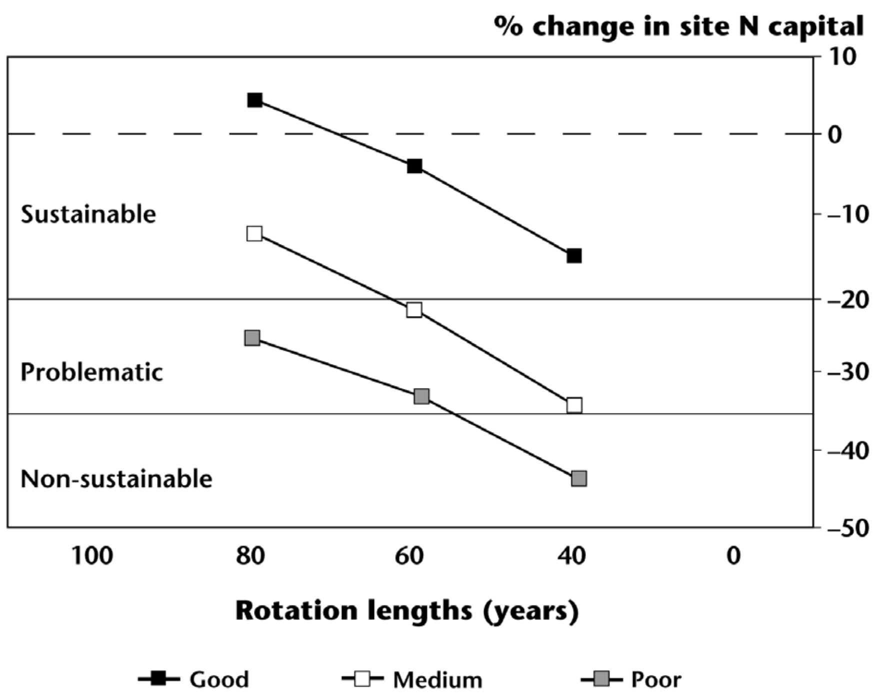

FIGURE 2. The effect of rotation length on the relative change in site N capital from the initial condition (represented by the dashed line) to the final condition at the end of the 240-year simulation period for poor-, medium-, and good-quality sites. Solid lines represent the boundaries of the sustainability categories.

FIGURE 3. The effect of rotation length on the relative change in stemwood production from the first rotation (represented by the dashed line) to the last rotation of the 240-year simulation period for poor-, medium-, and good-quality sites. Solid lines represent the boundaries of the sustainability categories.

wood production (the analogue for Measure 6.1) over subsequent rotations (Figure 3). Even though soil organic matter and site N capital showed significant declines at shorter rotations, model results indicate that sufficient nutrients were still available to sustain wood production at a constant level; however, the reduction in SOM and site N capital under shorter rotations will likely translate into a decrease in ecosystem resiliency. If reserves of SOM and N capital are depleted through management practices, these ecosystems will be less able to absorb further disturbance (either from natural process or harvesting). In this event, reduced productivity (as reflected in measure 6.1) will be a likely outcome.

The results highlight the value of using a multi-indicator approach when evaluating the sustainability of site productivity under alternative management practices.

Given the difference in sensitivity to perturbation, these results highlight the value of using a multi-indicator approach when evaluating the sustainability of site productivity under alternative management practices.

Future Directions

This extension note provides a description of work completed in 2002. The modelling approach and associated indicators described here have recently been refined and substantially modified (see Seely 2005). Work is still required to make the site-level indicators and associated measures more useful in a management context. In this regard, a better understanding of sustainability thresholds for specific site types (e.g., site series or groups of similar site series) is essential in order for forest managers to evaluate the effect of their management strategies on ecosystem productivity. The development of feasible and effective monitoring strategies will be an important aspect of this.

This approach only examines a selection of measures of ecosystem productivity and work is required to evaluate additional measures (e.g., soil bulk density; total nitrogen, phosphorus, and potassium; and coarse woody debris) either in a modelling or field-based context. As such, it would be extremely useful to establish a series of long-term productivity trials to examine the effects of specific treatments on site productivity and to test the efficacy of existing indicators as well as developing new ones.

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Test Your Knowledge . . .

Arrow IFPA Series: Note 6 of 8 – Criterion 2: Ecosystem productivity

How well can you recall some of the main messages in the preceding extension note? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Why is developing credible indicators of ecosystem productivity in managed forests such a challenge?
   - A) Because a lack of sophisticated modelling tools has limited the kinds of predictions that can be made about the effects of forest management scenarios on measures of ecosystem productivity
   - B) Because of the lack of empirical data to derive and evaluate indicators
   - C) Because of a lack of agreement in the scientific community on how to address issues of spatial variability in measures of ecosystem productivity for most British Columbia ecosystems

2. Why was soil organic matter initially selected as a measure of ecosystem productivity?
   - A) The literature shows a strong correlation with long-term site productivity; it also plays a critical role in maintaining ecosystem resilience (i.e., the capacity of an ecosystem to recover following disturbance)
   - B) It is inexpensive to measure
   - C) It demonstrates little temporal variability in managed stands

3. Why should we use multiple measures of ecosystem productivity in assessing the sustainability of managed forests?
   - A) As different measures have different sensitivities to levels of perturbation, the use of a single measure may give us an inaccurate reading of changes in ecosystem productivity under a specific management scenario
   - B) Certification systems require that more than one measure be used for each indicator to assess progress toward sustainable forest management
   - C) Ecosystem simulation models require multiple variables in order to forecast patterns of ecosystem recovery following disturbance

ANSWERS

1. B 2. A 3. A