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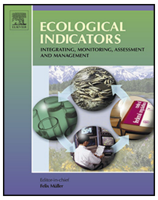

Planning horizons and end conditions for sustained yield studies in continuous cover forests

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ABSTRACT

The contemporary forestry preoccupation with non-declining even-flow during yield simulations detracts from more important questions about the constraints that should bind the end of a simulation. Whilst long simulations help to convey a sense of sustainability, they are inferior to stronger indicators such as the optimal state and binding conditions at the end of a simulation. Rigorous definitions of sustainability that constrain the terminal state should allow flexibility in the planning horizon and relaxation of non-declining even-flow, allowing both greater economic efficiency and better environmental outcomes. Suitable definitions cannot be divorced from forest type and management objectives, but should embrace concepts that ensure the anticipated value of the next harvest, the continuity of growing stock, and in the case of uneven-aged management, the adequacy of regeneration.

1. Introduction

What planning horizon is appropriate in simulation and optimization studies to establish claims of sustainable forestry? This question is vexed enough for even-aged plantations, but becomes even more complex for continuous cover forests managed through natural regeneration (Pommerening and Murphy, 2004). Given the attention paid to the broader issue of sustainable forestry since 1992 (e.g., Aplet et al., 1993; Maser 1994; Oliver 2003; Higman et al., 2004; Espach 2006), and to the technical aspects of simulation modelling and operational research (e.g., Bettinger and Chung, 2004; Pretzsch et al., 2006; Weintraub and Romero, 2006; Bettinger et al., 2010; Weiskittel et al., 2011), it is surprising that this question about the length of the planning horizon has not been examined more closely, and that there is not more agreement amongst researchers and practitioners. This review examines current norms, and seeks to establish guidelines for further research on planning horizons and aspects affecting yield prediction and planning of forest estates, particularly those practicing continuous cover forestry.

How can one resolve an appropriate length of simulation study to establish that a proposed harvest is sustainable? The answer to this question depends in part on the applicable definition of sustainability and whether a constraint for non-declining even flow is required. A more helpful interpretation of sustainability arises from Hartig (1795) who argued that foresters should utilize forests fully, in a way that future generations will have at least as much benefit as the present generation. This is effectively the same as Bruntland (1987) who expressed the same concept as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Both these views can be simplified in a forestry context as an objective to maximize current harvests (and services), without impairing future options. Curiously, the contemporary forestry practice to maintain a non-declining even flow seeks neither of these long established goals, hampers the ability to maximize current utility (e.g., to increase harvesting during buoyant markets and to defer harvests during recessions), and does not explicitly seek to avoid impairing the future options (e.g., may not preclude depletion of standing capital). The more simple case of the optimal even-aged rotation has been well studied (e.g., Newman, 2002), but the more complex question of the sufficient simulation to demonstrate sustainability warrants further attention.

2. Historical precedents

Evelyn (1664) recorded (Chapter 32, paragraph 13) that " . . . in Germany and France . . . the King's Commissioners divide the woods and forests into eighty partitions, every year felling one of the divisions, so as no wood is felled in less than fourscore years. And when any one partition is to be cut down . . . every twenty foot leave a good, fair, sound and fruitful oak standing . . . the acorns which take root in a short time furnish all the wood again . . . ". In this ideal situation, where the site is homogeneous

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and the climate unchanging, where regeneration is adequate, and the forest is in a steady-state condition, then a one-year simulation is sufficient to prescribe a steady-state harvest. A one-year simulation suffices in this case, because this hypothetical forest is already in a steady-state condition, and because the end condition is precisely defined (as "eighty partitions, every year felling one of the divisions, so as no wood is felled in less than fourscore years"). The real world is rarely so convenient, and it is more common to find forests far from steady-state, and to find the identification of steady-state capricious. Thus it is useful to consider a simple theoretical case to shed some light on the way forward.

3. Theoretical construct

Consider a simple case, such as unicellular algae in a jar of water, and assume that its state (e.g., biomass) can be measured with a univariate indicator, S. We expect S to follow a characteristic sigmoidal yield curve, and its first derivative, the growth rate, to have a simple maximum such as a quadratic curve (Fig. 1). If the system remains at the optimum (S^*) then the net growth S' can be harvested in perpetuity, and a single-cycle simulation may be sufficient to demonstrate sustainability. If the system is overstocked ($S_0 > S^*$), then some harvesting in excess of S' will return the stand to the optimal state, and a simulation of a few cycles may be warranted to demonstrate the return to the optimal state. If the stand is understocked ($S_0 < S^*$), any harvest may need to be deferred or reduced to allow the system to recover to the optimal state, which may require a longer simulation to illustrate convincingly. This theoretical example is overly simple, but helps to indicate that the length of simulation cannot be divorced from the state of the system. This simple example forms the basis for the successful educational game FishBanks (Meadows, 1992) which is well respected for teaching sustainability (e.g., Ruiz-Pérez et al., 2011).

The corresponding analysis for a real world system quickly becomes more complex than the simple theory above. Even eighty partitions of even-aged oak forest (Evelyn, 1664) add much complication: for instance average age is insufficient as an estate-level state indicator (S), and mean annual increment (S/n) rather than the current annual increment (S') should be used as the indicator of volume growth (Assman, 1970). In addition, because forestry usually involves periodic substantial harvests rather than small annual harvests at any particular site, the optimal post-harvest stand will not coincide exactly with peak production S'. And because management objectives for most forests are more complex than the simple goals of Evelyn's example (e.g., Westoby, 1987; McKinnell et al., 1991; Lawrence and Stewart, 2011), the optimal state (S^*) should not be viewed purely as a timber goal, but in terms of the productive potential of all the goods and services desired from the forest. Despite this complexity, the enduring principle is the use of simulation studies to assist in maximizing current harvests, without impairing future options. And these simple examples help to illustrate that a short simulation is sufficient for forests close to steady-state, whereas a long simulation is warranted for forests far from steady-state, or for which an optimal state S^* cannot be defined. However, researchers need to be mindful that long simulations are helpful only if they predict and report appropriate indicators: a long simulation displaying only timber yields and omitting other considerations such as biodiversity indicators is unlikely to inform debate about broader aspects of sustainability, particularly if they are unable to offer evidence that the forest remains unimpaired at the end of the simulation.

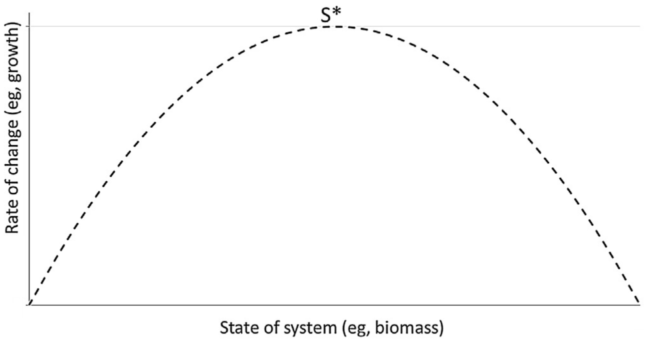

Fig. 1. Hypothetical response curve typical of many natural resources, indicating how production varies with state of the system, and how an optimal state can be identified.

It seems appropriate to suggest that the appropriate planning horizon is the shortest possible that demonstrates the attainment either of steady-state S^*, or of an improved future condition $S_0 < S_n \leq S^*$ (or equivalently, in the case of an overstocked system, $S_0 > S_n > S^*$). It is entirely possible that steady-state may not be reached within a reasonable (say 100-year) simulation, that it is impractical to adequately define a steady state condition, or even that the desired end condition S_n may not be attainable from the current condition S_0. In such cases, a suitable compromise may be to demonstrate that the end condition S_n is not inferior to the starting condition (thus, $S_0 < S_n \leq S^*$), retains the same production potential, and forecloses no management options.

In theory, it is possible to assert that forest managers should strive for $S_0 < S_n \leq S^*$ when a system is understocked, and $S_0 > S_n > S^*$ when a system is overstocked, the latter with an inequality because $S_n \equiv S^*$ is likely to be unstable given the variable conditions experienced naturally by most forests. In practice, forest management is more complex because of the challenges of defining, measuring and monitoring forest systems. A few industrial plantation monocultures may have narrow commercial goals that can be monitored adequately using simple indicators such as stand basal area, but most forests have more complex objectives that require multi-criteria management goals not easily reduced to a single univariate state variable. Thus although it is useful to conceptualize and seek an optimal forest condition, the reality is that in practice, both the indicators and optima are fuzzy variables that reflect directions for, rather than destinations in forest management.

4. Empirical examples of planning horizons

A survey of the literature reveals a wide range in the length of simulation chosen to investigate the sustainability or consequences of timber harvesting (excluding studies of species succession), and reveals few explanations for the length chosen. Hoogstra and Schanz (2009) suggested that 15 years is the most distant horizon that is realistic for most foresters, and Ferguson (2013) argued that planning horizons beyond 50 years stretch credulity, a contrast to earlier suggestions (e.g., Botkin, 1993) that 400-year studies may be needed to infer sustainability. It is common for the planning horizons of yield forecasts to span 60 (e.g., Howard and Valerio, 1996; Harper et al., 2007) to 100 years (e.g., McKenney 1990; Vanclay 1994; Rohweder et al., 2000; Baskent and Keles, 2005) or 2–3 harvesting cycles (e.g., Preston and Vanclay, 1988; Weintraub et al., 1994; Vanclay, 1996), while some studies in tropical forests may deal with intervals as long as 400–500 years (e.g., Huth and Ditzer, 2001; Sebbenn et al., 2008). Few authors document the reasons for selecting a particular planning horizon other than to denote that their choice is consistent with established practice.

Unfortunately, it is even less common to explicitly compare the terminal condition at the end of the simulation with the initial