Environmental Consequences of Intensively Managed Forest Plantations in the Pacific Northwest

John P. Hayes, Stephen H. Schoenholtz, Mitschka J. Hartley, Glen Murphy, Robert F. Powers, Dean Berg, and Steven R. Radosevich

ABSTRACT

Environmental consequences of intensively managed forest plantations (IMFP) are manifested primarily through influences on biodiversity, soils, and water resources. These consequences may be positive, neutral, or negative, depending on the spatial and temporal context and site-specific details. Many aspects of environmental consequences of IMFPs are increasingly understood, but significant gaps in our knowledge remain. Societal environmental goals and objectives of IMFPs remain poorly articulated and fuel a lively, often heated, social dialogue that will likely continue for some time to come.

Keywords: environmental consequences; forest plantations; Pacific Northwest; snags; soil; water; wildlife

For the past 30 years, people living in the Pacific Northwest (PNW) have been embroiled in a polarizing debate over how their forest resources are being used. One reason that forest management issues have been so contentious in the PNW is that management decisions interact with many fundamental aspects of the region's economy, ecology, and quality of life, including social values, levels of commodity production, stability of human communities, biodiversity, environmental health, recreational opportunities, viewsheds, and esthetics. Concerns over the environmental consequences of intensively managed forest plantations (IMFP) have been central to the debate over forest management practices in the PNW and much of the world.

Generalizing the environmental consequences of IMFPs is challenging for several reasons, including the following:

IMFP practices vary with ownership and location.

Consequences of management practices are sometimes site- or species-specific.

Research on some aspects of the environmental consequences of IMFPs is minimal or nonexistent.

The combined influences of these factors result in uncertainty concerning many environmental consequences, and what may be true in one location or under one set of conditions may not be true in others. Assessing the environmental consequences of IMFPs is further complicated because the consequences sometimes vary, depending on the spatial and temporal scale from which the issues are viewed.

Societies demand diverse outputs from forests, including wood products, clean water, biodiversity, scenery, and recreation. It is only possible to manage efficiently for all of these amenities when forests are viewed from a landscape perspective. Even when considered at broad spatial scales, however, forest use can be allocated several ways to achieve society's goals. One approach is to zone forest lands for different amenities and values in an attempt to optimize yield of one or two outputs (such as wildlife habitat or wood fiber) in selected zones. Application of this concept would allow increased focus on many environmental outputs in some zones and reduced concern about some environmental considerations in IMFP zones. An alternative model is to lower output of any single resource on all parcels of land but to allow for some (albeit reduced) output of many values on all lands. A central issue regarding the environmental consequences of IMFPs thus concerns how impacts of intensively managing forest lands to maximize production of wood fiber on a relatively small area compare with a strategy of dispersing less intensive management and fiber production over larger areas and longer time frames. Clearly, some values are not compatible and cannot be provided on the same piece of land simultaneously (e.g., wilderness and intensive production of wood products), and strategies that mix these approaches often may be optimal. However, these two contrasting approaches present a useful template for examining the environmental consequences of IMFPs.

In this article, we review the environmental consequences of IMFPs, emphasizing influences on biodiversity, soils, and water resources. Our review focuses on highly intensive management practices and should not be construed as an assessment of planta-

Figure 1. In this clearcut a few live trees and created snags were left standing to promote wildlife habitat. Photo courtesy of Tom Adams.

tion forestry in general. We highlight aspects that we believe reflect trends typical over broad areas, recognizing that these generalities may not hold in all locations or situations and that evaluation of every possible environmental consequence is beyond the scope of this article. Our intent is neither to criticize IMFP practices nor to defend their use, but rather to overview some of the major environmental consequences of their use. Inevitably, environmental consequences of IMFPs are merely one of many factors that drive the social acceptability of IMFPs.

Environmental Consequences of IMFPs at Local and Stand Scales

Although forest planning is increasingly done at large spatial scales, forest management is typically implemented in forest stands or management units of 15 to 30 ha or smaller. Similarly, many of the environmental consequences of IMFPs can be observed and measured at the stand scale.

Truncation of Stand Development. In management of IMFPs, stand development is truncated on both ends, strongly influencing the biodiversity of the area. Although IMFPs are generally perceived to provide early successional habitat for species, characteristics of recent clearcuts and very young plantations under intensive management differ significantly from those in early successional stands resulting from natural disturbance. A key difference is that large amounts of dead wood typically occur in stands following natural disturbances, but relatively little dead wood generally remains following harvest of IMFPs. In addition, the length of time that stands are in early stages of development (including the grass-forb and shrub-seedling phases) is greatly reduced in IMFPs. As a result, although IMFPs in the early stages of development do provide habitat for some species associated with open conditions, habitat for many species that are associated with early-seral conditions is not present, is reduced in quality, or only exists for a limited period. Short rotations typical of IMFPs also eliminate later stages of stand development. Consequently, species that are closely associated with later stages of forest development or structural characteristics of stands that are typical of older forests (such as large-diameter trees, snags, and logs) typically occur in very low densities or are absent from IMFPs.

Soil Disturbance. Management of IMFPs often involves use of land-based machinery that can disturb and compact forest soils. In many soil types, compaction impacts site productivity through degradation of the physical properties of soil, including increased bulk density and soil strength, decreased aeration porosity, and diminished capacity for water infiltration and gas exchange. The impacts of soil compaction often are minimized in IMFPs through use of practices such as designated skid trails. In contrast, on droughty sites with coarse-textured soils, soil compaction sometimes has little or no effect on productivity, and in some cases may enhance growth and yield by altering distribution of pores in the soil and improving capacity for water retention (e.g., Gomez et al. 2002; Heninger et al. 2002). Evaluating effects of compaction on forest productivity in skid trails and areas of concentrated ground-based traffic can be confounded by reduction of competing vegetation in traffic corridors; studies are often unable to separate these different effects on tree growth.

Hydrology and Water Quality. Many aspects of IMFPs influence hydrology and water quality at the site scale, although the consequences of IMFPs on water resources are highly variable and often site-specific. As water enters and cycles through a forest, it is influenced by the character of the vegetation and soil through which it passes. Magnitude, timing, and duration of peak and low water flows can be modified by manipulations of vegetation and by alterations of the soil surface. Thus, IMFPs influence the dynamics of water movement through soil, streamflow, and localized groundwater fluxes as water cycles through the managed forest plantation system.

Management activities that expose mineral soil often decrease infiltration capacity. Water movement along roads and skid trails also increases the likelihood of accelerated soil erosion. Loss of surface soil by erosion can decrease site productivity and be detrimental to water quality if sediment is exported to streams, rivers, or lakes. In addition, potential increases in stream temperature and levels of dissolved nutrients (especially nitrate after fertilization) and contamination by pesticides continue to be concerns associated with IMFPs.

Dead Wood and Organic Matter. Decisions concerning management of dead wood and organic matter can influence site productivity in two ways. First, the productive capacity of soils could be degraded when removal of nutrient and organic matter from a site exceeds the replacement capacity provided by mineral weathering and atmospheric inputs of nutrients. Intensive utilization of fiber by whole-tree harvesting, piling of logging slash, and prescribed burning can decrease organic matter and increase nutrient losses. Concerns about net loss of nutrients from intensively managed forests were first raised in the 18th century in European forests that were subject to frequent litter raking. Similar concerns have arisen more recently in response to the potential for declining productivity with successive harvest rotations when intensive forestry practices are used (Fox 2000). There are few examples, however, of declining productivity in subsequent rotations that are directly attributable to net nutrient loss, and productivity without fertilization is generally at least as high in subsequent rotations as in earlier rotations (Nambiar 1996; Powers 1999). In cases where productivity may be reduced because of nutrient deficiencies, fertilization generally can be used to overcome nutrient limitations and maintain forest productivity.

Decisions concerning management and retention of dead wood also have consequences for biodiversity, as quantity and characteristics of dead wood are key determinants of the suitability and quality of a site for many species (Figure 1). Amount and quality of dead wood in IMFPs typically are limited by short rotations, salvage activities, and removal of snags (standing dead wood) for safety concerns or to reduce fuel loads. Snags can be up to five times less abundant in managed forests under typical management prescriptions than in unmanaged forests, and large snags may be as much as one hundred times less abundant (Wilhere 2003). Between 25 and 30 percent of the forest-dwelling vertebrates occurring in most forest types in the Pacific Northwest use cavities in snags for reproduction or roosting (Bunnell et al. 1999). Relationships between dead wood and habitat suitability are best documented for cavity-nesting birds; strong relationships between bird abundance and snag density are well documented, particularly at low snag densities. Snags also are critical habitat components for arboreal mammals, bats, and several species of arthropods, fungi, lichens, and bryophytes. Although not as well documented, several species are closely associated with downed dead wood as well. Habitat value of snags and downed wood is a function of the size and stage of decay of the wood and general condition of the stand in which they occur. Large-diameter material is of particularly high value for a number of species, and the most severe impacts of reduced densities of downed wood on biodiversity will most likely be seen only after remaining legacy structures are lost from IMFPs.

Within-Stand Vertical and Horizontal Heterogeneity. In combination, vertical (amount and type of vegetation in different vertical strata) and horizontal (variation in plant community composition and cover in a stand) heterogeneity reflect the distribution of vegetation in forest stands in three-dimensional space. Vertical and horizontal heterogeneity are thus direct measures of stand structure and strongly influence biodiversity at the stand scale. Of particular importance to many species are the amount and characteristics of understory vegetation. Vertebrates and invertebrates feed on understory foliage, and shrubs provide cover and nesting sites for many species. Moreover, shrubs are important for some species that are associated with the very early stages of stand development. In conifer-dominated forests, presence of hardwoods influences diversity of animals and nonvascular plants; hardwoods provide key substrates for lichens, cavities for cavity-dependent species, and forage for invertebrates. Increased horizontal heterogeneity also results in greater variation of resource and niche availability, both of which may be contributors to species diversity. Management of IMFPs influences vertical and horizontal heterogeneity by using short rotations, planting crop species at high stocking densities, cultivating monocultures, and controlling competing vegetation; the combination of these practices generates structurally simple stands.

Maintenance or Establishment of Forest Cover. Throughout the world, one of the most significant forest conservation issues is loss of forest cover. In the PNW, roughly 100,000 acres per year of forestland has been converted to other uses over the past three and a half decades (Alig et al. 2003). Management of IMFPs generally results in maintenance of a significant portion of an area as forest over most of the rotation. Simply maintaining a substantial amount of a landscape in forest cover benefits many forest-dwelling species. Although some species of forest wildlife are in low abundance, rare, or absent from IMFPs, many maintain healthy populations in IMFPs. Even species that prefer forests with more complex structure for breeding or foraging often use IMFPs when moving among habitat patches and during dispersal or migration. In cases where forest cover has been lost, such as through mining or conversion to agriculture, establishing new forests and IMFPs (through afforestation and ecological restoration) on these disturbed lands often results in improved soil and water quality, as well as enhanced habitat for wildlife.

Environmental Consequences of IMFPs at Landscape and Watershed Scales

Many of the stand-level consequences of IMFPs simply increase additively as IMFPs increase on the landscape. Accumulation of activities conducted at small spatial scales is sometimes manifested in unique ways at larger spatial scales, however, and some patterns and processes exhibit emergent properties at large spatial scales. Consequently, considering environmental consequences of IMFPs at broad spatial scales is important.

Roads and Transportation Networks. Roads and transportation networks are often of concern when considering environmental consequences of forestland use at the landscape scale. A well-planned and adequately maintained transportation network is essential for several aspects of forest management, including access for logging, transportation of logs, and fire management. Road systems have been implicated as contributing to increased sediment production, risk of landslides, and spread of invasive species (Gucinski et al. 2001). Despite the potential importance of environmental consequences of road systems at the landscape scale, relatively little work has addressed this issue. Recent work suggests that, at least in some situations, roads in concentrated, intensive management scenarios produce less sediment than do road networks under less intensive, more dispersed forest management strategies (G. Murphy and M. Wing, unpublished). Given the potential importance of environmental consequences of road and transportation networks, consideration of the implications of the interactions between forest management strategies, road networks, and environmental consequences would benefit from implementation of well-designed, replicated studies.

Watersheds. Although outcomes, either positive or negative, of IMFPs on water quality and regimen at the individual stand level may be insignificant or benign, the potential for cumulative effects, both spatially and temporally, within larger watershed scales should be considered when assessing environmental consequences of IMFPs. Accurately evaluating effects of repeated management activities over time or across multiple locations within a watershed has not frequently been accomplished, however, and there is no generally agreed-on methodology for analyzing influences of large-scale land transformation to IMFPs. Because of the relatively long-term nature of IMFPs, coupled with complex biophysical interactions over large temporal and spatial scales, effects of repeated management practices that occur infrequently during each rotation or that occur in multiple locations in a large watershed are challenging to estimate. This suggests that modeling that incorporates current understanding of relevant hydrologic processes and responses can be valuable.

Biodiversity. At the landscape scale, many of the impacts of IMFPs on biodiversity are quantitative (resulting in changes in *abundance* of species) rather than qualitative (resulting in changes in community composition and *presence* of species). The continued persistence of some species exhibiting quantitative changes in intensively managed landscapes could depend on maintenance of refugia or "source populations" in unmanaged or less intensively managed areas. This is likely to be especially true for rare species, habitat specialists, and species associated with forest interiors. Although this idea has strong conceptual and theoretical foundations, few empirical studies have actually demonstrated this relationship.

Throughout the world, considerable attention has been given to potential impacts of forest fragmentation on biodiversity. Negative effects of forest fragmentation have been observed in regions and forest types as diverse as eastern deciduous forests of North America, neotropical rainforests, and Australian eucalypt forests. Although there have been few studies of fragmentation effects in the PNW, the results of those studies indicate landscape composition (the amount and types of habitat patches in a landscape) is an important consideration for many species, but landscape configuration (the spatial distribution of habitat patches) tends to be important only for selected species, particularly those with low vagility. Thus, fragmentation tends to be less important to many species in the PNW than has been documented elsewhere. The observed responses to landscape characteristics in the PNW have been hypothesized to result from the fact that forest management activities create a shifting mosaic of habitat types that have some similar attributes (forest stands of different ages) as opposed to a static landscape of highly contrasting patch types (such as often occurs in woodlots fragmented by urban or agricultural development). Moreover, patterns of disturbance resulting from forest management are more similar to natural disturbance regimes (e.g., fire) than are disturbances (e.g., long-term deforestation) that predominate in landscapes where fragmentation is a more serious issue (McGarigal and McComb 1995). Few studies of fragmentation have been conducted in the PNW, however, and the extent to which large expanses of IMFPs impact distributions and movements of many species remains an open question.

As with water and soil issues, cumulative effects on biodiversity are likely to increase at the landscape scale over time in intensively managed landscapes (Thompson et al. 2003) as reduced vegetative species diversity, reduced density of dead wood (especially in larger size classes), and high-disturbance frequency occur over large geographic areas. Threshold values of such impacts likely exist, but the magnitude of these thresholds is unclear.

Environmental Consequences of IMFPs at Regional and Global Scales

It has been proposed that IMFPs can play an important positive role in conservation of biodiversity regionally and globally because the potential to meet timber demands on a relatively small land base can allow for greater protection and conservation of natural forests (Sedjo and Botkin 1997). Under this hypothesis, use of IMFPs could result in increased acreage of unharvested natural forests, longer rotation lengths for natural forests that are harvested, and increased retention of biological legacies on surrounding natural forests after harvest. Similarly, according to this hypothesis, use of IMFPs in more developed countries in temperate zones could benefit biodiversity globally by helping meet regional timber demands and reducing use of unsustainable practices in more sensitive areas, such as primary tropical forests. This would result in significant conservation benefits because high levels of endemism and species richness in the tropical forests make them among the highest global conservation priorities (Hunter 1996). In addition, concentrating timber production in temperate forests is likely to result in fewer negative environmental consequences because government and nongovernment organization infrastructure, regulations, and consumer awareness tend to be greater in temperate than tropical regions (Berlik et al. 2002), and as a consequence forest management practices are often more environmentally sensitive.

Although the premise that efficient fiber production in plantations translates into greater concessions for biological diversity elsewhere in the landscape, region, or world is logical, it does not necessarily do so (Hartley 2002). Increased timber production from IMFPs has been accompanied by protection of native forests in some places, such as New Zealand, but has not resulted in strong forest protection in other places, such as Chile. The contribution of IMFPs to native forest conservation, then, depends largely on other factors in force at a given location, such as the ratio of IMFPs to natural forests, local forest policies, and land use regulations, which ultimately drive the tradeoffs chosen between operational costs, rotation times, mill capacity, profitability, and amount of forestland taken out of production.

Conclusions

Our review of environmental consequences of IMFPs reveals both certainties and knowledge gaps. Influences of forest management practices in IMFPs are often site-specific, and there are substantial uncertainties concerning some environmental consequences of IMFP practices. However, due to the complexity and scale of the issues involved, it is difficult to assess the full suite of environmental consequences of IMFPs in any given landscape, and many of the regional environmental ramifications of use of IMFPs on only a portion of the land remain unclear. In addition, as many environmental consequences are only expressed over long-time frames, implications of management actions often are not evident for long periods of time. Given this, it would be beneficial to implement long-term monitoring and management experiments to assess the environmental consequences of IMFPs and integrate them into a management framework. We are aware that a number of such efforts have begun, some of which have been initiated by or in close cooperation with the forest industry, and we encourage the establishment of others.

The list of potentially negative consequences of IMFPs that we have generated is considerable. In assessment of the social acceptability of these consequences, the standards used in their evaluation are key in determining the importance of these consequences. From a global perspective, PNW forest owners are increasingly subject to economic competition from timber producers in areas with less stringent environmental regulations and from manufacturers of other, less environmentally benign, construction materials (e.g., steel and concrete; Lippke et al. 2004). In this regard, it may be most appropriate to contrast environmental consequences of IMFPs to alternatives in which forested land is converted to other uses or natural wood products are substituted for other construction materials.

Contemporary management practices in IMFPs in the PNW, shaped by forest practice regulations designed in part to protect soil, water quality, and biological diversity, have successfully promoted many aspects of sound forest management. These practices also have achieved several environmental goals. But as a society, many of the environmental expectations and objectives for IMFPs remain poorly articulated. Until these expectations are better articulated, appropriate standards of evaluation of the environmental consequences of IMFPs are agreed on, and the most appropriate spatial and temporal scales for evaluation of the environmental consequences of IMFPs are resolved, there will likely continue to be a lively and often heated social dialogue for some time to come.

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John P. Hayes (john.hayes@orst.edu) is professor, Department of Forest Science, Oregon State University, Corvallis, OR 97331-5752, Stephen Schoenholtz (stephen.schoenholtz@orst.edu) is associate professor, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331-5706, Mitshka (Mitch) Hartley (mitch_hartley@fws.gov) is assistant coordinator (North Atlantic), Atlantic Coast Joint Venture, US Fish & Wildlife Service, Turners Falls, MA 01376, Glen Murphy (glen.murphy@orst.edu) is professor, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331-5706, Robert Powers (rpowers@c-zone.net) is principal silviculturist and science team leader, USDA Forest Service, Pacific Southwest Research Station, Redding, CA 96001, Dean Berg (dean@wolfenet.com) is private consultant, Silvicultural Engineering, Edmonds, WA 98026, and Steven R. Radosevich (Steve.radosevich@oregonstate.edu) is professor, Department of Forest Science, Oregon State University, Corvallis, OR 97331-5752.