1. **Project Title**
   **Quantifying Trade-offs and Synergies Between Ecosystem Services in Intensively Managed Forests**

2. **List of principal investigators and other key personnel names and affiliations**



| Role | Name (Last, First) | Affiliation |
|---|---|---|
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| CoPI | Stokely, Thomas | CoF, OSU |
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| CoPI | Phalan, Ben | CoF, OSU & U. Cambridge |
| CoPI | Rivers, Jim | CoF, OSU |
| CoPI | Fitzgerald, Steve | CoF, OSU |
| CoPI | Hatten, Jeff | CoF, OSU |



3. **Project starting and ending date**

| | |
|---|---|
| Start Date | Oct. 1, 2015 |
| End Date | Sept. 30, 2018 |
| Duration (months) | 36 |

4. **Total Project Costs**

| Year 1 | Year 2 | Year 3 | Total |
|---|---|---|---|
| 8,887 | 159,279 | 81,764 | 249,930 |

5. **Summary Abstract**


Global demand for wood resources is expected to increase by up to 40% over the next 15 years, requiring approaches that maximize timber production on a limited land base. Intensive forest management (IFM), which relies on chemical control of non-commercial species and tree planting has been proposed as a solution to increasing demands for wood. However, correlative evidence indicates that IFM can have negative impacts on biodiversity and ecosystem services. Despite such studies, changes to management actions have been slow to occur. This is likely for several reasons: (1) previous studies have been correlative rather experimental so scientific inference has been weak, (2) there appears to be the perception among managers and the public that any biodiversity gain must come at the cost of timber production and jobs (i.e., there is a direct and linear tradeoff), and (3) the benefits of biodiversity in terms of the ecosystem services they provide have not been thoroughly quantified in forest systems. This proposal will address these issues by using a long-term, large-scale manipulative experiment to: (1) quantify the effect of IFM on biodiversity, (2) determine how IFM and biodiversity interact to affect ecosystem services (i.e., timber production, carbon sequestration, pollination), (3) model stand and landscape-scale relationships between IFM and multiple biodiversity components and ecosystem services, and (4) examine public opinions and tradeoffs among IFM, biodiversity, and ecosystem services, and also test whether scientific information influences these perceptions. Throughout this research, we will also implement an extensive extension outreach program that is integrated with our four objectives.

## B. Project Description

### 1. Introduction and justification

Global demand for wood resources is expected to increase by up to 40% over the next 15 years, requiring approaches that maximize timber production on a limited land base (FAO 2009). Intensive forest management (IFM), which relies on such practices as mechanical site preparation and control of non-commercial species using herbicides, has become ubiquitous worldwide because these practices can reduce rotation age and generate a high internal rate of return on investments. In addition to economic benefits, intensive plantation forests sequester carbon, and have received increased focus as a source of biofuel feedstock. It has also been proposed that IFM is beneficial to regional conservation goals because it can reduce the overall amount of area needed to produce the same amount of wood fiber, thus allowing larger areas to be set aside as ecological reserves (Hartman et al. 2010). Despite these benefits, some recent evidence indicates that IFM can have negative impacts on biodiversity and ecosystem services (Brokeroff et al. 2008, Betts et al. 2013), and management actions to address potential problems have been slow to occur. This should not be surprising because the required scientific information for sound decision-making has been mostly unavailable to managers who are responsible for implementing landscape-scale conservation decisions. In particular, five main knowledge gaps exist, which will be addressed by this study:

**(a) How does IFM influence biodiversity?** Although past studies have examined the influence of IFM on biodiversity, most suffer from three important weaknesses. First, most have been conducted at small spatial scales that provide limited guidance for determining how much IFM can occur within management units, at stand and landscape scales, before ecological processes are negatively affected (Brokeroff et al. 2008). Second, many studies that have found significant impacts are correlative and cannot provide strong conclusions about underlying causes. Finally, the few manipulative studies have tended to be short-term, ignoring potential changes in biodiversity and ecosystem process responses that occur as stands develop over the long term.

**(b) To what extent does biodiversity contribute to ecosystem services in managed forests?** Consensus is emerging that loss of biodiversity reduces the efficiency by which ecological communities produce biomass, decompose, and recycle nutrients. However, studies reporting these results are usually based on model systems (e.g., microcosms, artificial plant communities) that are unlikely to reflect ecosystem behavior of managed forests. As a result, great uncertainty remains regarding the magnitude and direction of how biodiversity contributes to ecosystem services within managed forests.

**(c) Are ecosystem services affected by forest management intensity?** Research in agroecosystems indicates that management intensity plays a strong role in structuring ecosystems and the quality of services provided. For example, intensified use of pesticides can increase crop yields in the short term, but may also reduce natural regulation of pests, inflating long-term expenditures on pest control (Crowder et al. 2010). Thus, data are urgently needed regarding the ‘optimal’ amounts of IFM that result in efficient and sustainable timber production.

**(d) What are the trade-offs and synergies between ecosystem services in managed forest landscapes?** One of the most significant challenges in applied ecology is the question of how to close the “implementation gap” between research results and improvement to management (Knight et al. 2008) – particularly in the realm of biodiversity conservation. Quantification of benefits of ecosystem services has been proposed as an approach to provide incentive for landowners and policy makers to conserve elements of biodiversity and ecosystem function (Power 2010). Fortunately, great strides have recently been made in this area with development of spatial models of ecosystem service flows that serve as decision support tools for policy makers (Goldstein et al. 2012). Previous studies have rarely addressed relationships between more than one or two ecosystem services (e.g., biodiversity conservation, carbon sequestration) and therefore provide little guidance for managers seeking to optimize across the broad suite of ecosystem services. There is a need to quantify functional relationships and interactions among multiple services and the ways in which such relationships are influenced by different management practices. Without empirical data in these areas – particularly responses of biodiversity and ecosystem services to IFM – potential services will be ignored by policy makers and result in status quo management approaches that do not apply a broad, integrated view of landscape planning.

**(e) How does the public perceive intensive forest management, biodiversity, ecosystem services and interrelationships among these issues?** Research has examined public opinions and perceptions associated with forest management practices (e.g., Howe et al. 2005, McFarlane et al. 2011). Many of these human dimensions / social science studies describe public responses to individual forest treatments and management approaches (e.g., road building, clearcuts, dispersed vs. aggregated harvesting). Comparatively little research, however, has examined the complex multi-attribute tradeoffs that the public makes among scenarios representing forest management practices, biodiversity outputs, and other ecosystem services attributes (e.g., economic benefits from forest growth, ecological benefits from carbon storage, social benefits from human wellbeing; Kozak et al., 2008; Maness & Farrell, 2004). These tradeoffs reflect some of the most important forest management decisions currently facing state, federal, and private land managers. In addition, scientists assume that production of high-quality science will ultimately influence these decisions and public perceptions of forestry issues, but to what extent is this the case? Limited data exist on the extent that science in managed forests influences public tradeoffs and, potentially, policy. Understanding these tradeoffs is also important because a broad spectrum of the public now demands and expects involvement in decisions regarding natural resource management on both public and private lands. Groups may resort to administrative appeals, court cases, or ballot initiatives if they perceive that their concerns are not being heard and addressed. Management actions lacking public support may also be ineffective or difficult to implement (Manfredo et al., 2004). It is important, therefore, to understand public opinions and tradeoffs associated with IFM, biodiversity, and ecosystem services.

## Objectives

Objective 1: **Expand a large-scale manipulative experiment to determine how biodiversity and ecosystem processes are influenced by IFM.**

Objective 2: **Experimentally determine the role of biodiversity components (i.e., birds, deer, elk abundance) in driving four ecosystem services at stand scale (above- and below-ground carbon storage, soil productivity, pollinator populations, timber production).**

Objective 3: **Build timber-yield and ecosystem service models parameterized with empirical data to project timber yields and other ecosystem services under different management scenarios. We will then project yields and services over the next 100 years to assess tradeoffs and synergies between timber growth and ecosystem services at stand and landscape scales.**

Objective 4: **Evaluate public perceptions and tradeoffs regarding IFM, biodiversity outputs, and ecosystem services.**

**Project Goals.** The long-term goal of our research is to develop and disseminate information about how biodiversity and ecosystem services are influenced by IFM. We seek publically acceptable methods that allow critical biological processes to be maintained simultaneously with high levels of timber production in managed forest landscapes. Our previous research indicates that IFM can have substantial impacts on biodiversity in the first three years following herbicide control of competing vegetation (Betts et al.

2013). With funding from IWFL, we plan to expand the large-scale manipulative study currently funded by the USDA (AFRI) to address the four objectives above. Specifically, we will examine how biodiversity is influenced by IFM over the longer term (0-8 years) and test how changes to biodiversity lead to alterations of four critical ecosystem services: (i) above and below-ground carbon storage, (ii) soil productivity, (iii) pollination, and (iv) timber production (Fig. 1). We will take the results from these experimental, empirical studies to parameterize stand and landscape-scale models (on Oregon Dept. of Forestry land) that allow for examination of resource and social tradeoffs among the different ecosystem services. This decision-support tool will be used in conjunction with spatial landcover data and social science data to provide recommendations regarding management practices necessary to achieve different scenarios and mixes of ecosystem services at landscape scales that are within public tolerance limits.

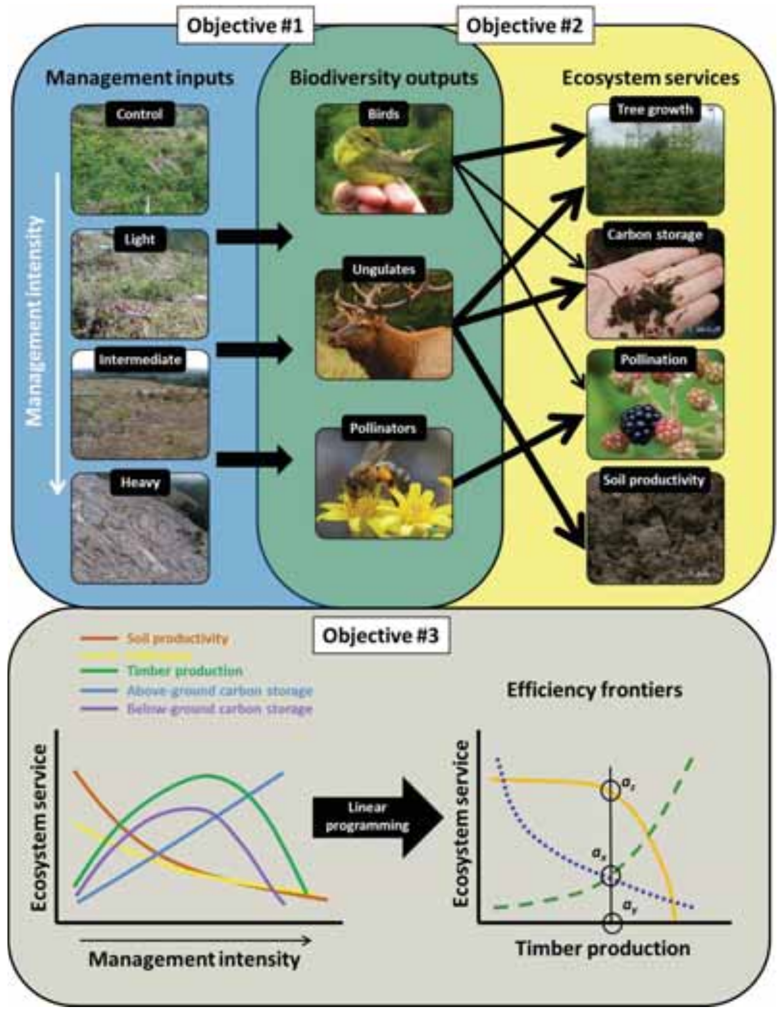


**Fig.1. Conceptual diagram of proposed research.** In Objective, 1, we apply a gradient of 4 levels of forest management intensity to 32 unique stands (blue panel) and then measure how these management inputs lead to changes in 3 biodiversity outputs (green panel). In Objective 2, we assess how changes in biodiversity outputs arising from management lead to alterations of 4 key ecosystem services (yellow panel; arrow thickness is linked to hypothesized strength of relationship). In Objective 3, we use data obtained from Objectives 1 and 2, and input them into linear programing models to develop tradeoffs and efficiency frontiers among multiple ecosystem services. In Objective 4 (not shown) we will present study findings on effects of IFM on biodiversity and ecosystem services to the public via (a) field tours, and (b) representative surveys to measure public tradeoffs and test whether scientific information influences public perceptions of management.

## 2. Research location and methods

***Experimental Design for Manipulative Intensive Forest Management Study.*** We have established 32 study stands (12-16 ha each) clustered into 8 distinct blocks spanning a 100 km (north-south) portion of the northern Coast Range Mountains of western Oregon (http://blogs.oregonstate.edu/intensiveforestmanagement/). All stands were clearcut in fall 2009/winter 2010 and were planted in spring 2011 with Douglas-fir (*Pseudotsuga menziesii*), the major commercial species in the region. We designed our study so that each block contains 4 stands; all stands within a given block are separated by at least 1 km to avoid influence from adjacent treatments, yet are no further apart than 5 km to reduce within-block variation. We established stands within each block to represent each of four treatments across a full gradient in IFM: (1) Heavy (removal of all competing shrub species), (2) Moderate (a heavier operational standard), (3) Light (a lighter operational standard), and (4) Control (no herbicide application; Fig. 2). We used a randomized, complete-block design where we randomly applied each treatment to one of the four stands within each of the eight blocks. All herbicides were applied with consistent timing across stands from 2010-2012. We applied the same amount and type of chemicals for each treatment across all blocks in the study because our objective was to test the combined effects of the suite of herbicides and surfactants used in typical operations, rather than to examine the effect of a particular chemical. Stands are located on timberland representing all major industrial landowners of the Pacific Northwest region (Weyerhaeuser, Plum Creek, Hancock) and Oregon Department of Forestry. Landowners have cooperated to standardize treatments and will provide logistical support for our research. To our knowledge, this is the most extensive experimental IFM study in terms of replication, spatial scale, and breadth of taxa considered.


**Fig. 2. Representative stands demonstrating the range of intensive forest management treatments used in this study.** Treatments include (A) Heavy, (B) Moderate, and (C) Light Herbicide as well as (D) No-Spray Control. Photos were taken 2012, the second year after herbicides application was initiated.

***Biodiversity Data Methods (Objective 1).*** In each stand, we will use standard methods to collect detailed abundance and diversity data for: (1) herbaceous and woody plants, (2) forest birds, (3) arthropods, (4) cervids (deer and elk) (for detailed methods see Betts et al. 2013, Stokely 2014), (5) pollinators (Stephen and Rao 2005). We will analyze response data collected for each of the four key biodiversity components using both categorical (i.e., herbicide treatment) and continuous (e.g., shrub, grass cover) representations of the manipulated gradient of management intensity. Using vegetation composition and structure as predictors will enable us to test for thresholds (i.e., non-linearities) in the response of biodiversity components to management intensity. As in our previous work, we propose that such thresholds may be adopted as useful management targets for maintaining particular vegetation features (i.e., hardwood shrub cover; Ellis and Betts 2011). In all analyses, we will use generalized mixed models (GLMM) or their Bayesian equivalents to account for the hierarchical nature of our study design (i.e., treatments nested within blocks); 'block' will be the random effect. In cases where continuous data from within stands are used as predictors, 'stand' will also be specified as a random effect. Ultimately, testing how IFM influences all four biodiversity components will enable us to determine whether impacts are consistent or different across taxa, and the degree that putative thresholds coincide.

***Biodiversity Effects on Ecosystem Services Methods (Objective 2).*** Our previous work strongly supports the hypothesis that several key biodiversity components decline with increasing IFM, at least in the early stages of stand regeneration following clearcut harvest (Ellis and Betts 2011). Similarly, cervids are expected to avoid intensively managed stands due to the lower abundance of high-quality forage in these stands (ODFW 2008, Stokely 2014). Effects of IFM on birds, cervids, and pollinators raises the question of whether declines in these species could, in turn, negatively influence tree growth, carbon sequestration, soil productivity, and pollination in intensively managed plantations. We will test a suite of hypotheses related to the potential for top-down effects of birds and cervids on timber production. Importantly, we will examine the degree to which these top-down effects interact with IFM.

**Top-down effects of birds.** We hypothesize that birds increase timber production and above ground carbon sequestration by reducing the abundance of herbivorous insects. If IFM reduces bird abundance and diversity, the most intensively managed stands should exhibit the highest rates of tree herbivory. If true, IFM should have indirect negative effects on conifer growth and carbon sequestration by enhancing insect herbivory. We predict that trees in bird exclusion plots will: (i) exhibit greater arthropod density, (ii) show higher rates of insect herbivory, and (iii) have slower growth rates, relative to open controls where birds are allowed access. An alternative hypothesis is that if birds primarily consume arthropod herbivores that consume vegetation that competes with Douglas fir (broadleaf shrubs), this may result in slower tree growth rates due to increased competitive domination by shrubs.

Birds are known to consume not only insect herbivores but also detritivores (primarily beetles) in our system (Hagar et al. 2007). It is therefore possible that birds may indirectly decrease decomposition rates by limiting decomposer populations. Furthermore, by controlling herbivore populations, birds may increase the amount of biomass returning to the soil as litterfall. We hypothesize that birds have top-down control over the rate at which carbon and nutrients cycle through the soil.

**Top-down effects of cervids.** We hypothesize that if cervids are excluded from early seral plantations, tree growth rates and carbon storage will be reduced due to increased competition by crop trees with early seral broadleaf shrubs (the 'Cervid Ecosystem Service Hypothesis'). Alternatively, with reduced browse due to intensive forest management, ungulates may be less selective in their foraging and will damage crop trees thereby reducing tree growth rates and above-ground carbon storage (the 'Cervid Ecosystem Dis-service Hypothesis'). Our pilot data provide preliminary support for the 'Cervid Ecosystem Service' Hypothesis (H3). Cervids exert strong top-down control on tree survival and regenerating shrubs, but this effect is only prevalent in the two intermediate-intensity treatments (GLMM $F$=5.8, $P$=0.02, Fig. 3).

Cervids have previously been shown to affect soil carbon by reducing aboveground inputs thereby slightly reducing mineral soil carbon pools (e.g., Pastor et al. 1993), but potentially increasing its resistance to loss as a result of disturbance (e.g., climate change; Frank et al. 2011). To our knowledge, the interactive effect of cervids and intensive forestry on soil carbon and productivity has not yet been investigated.

To test these hypotheses, we have already established bird and ungulate exclosures in 28 of 32 stands (7 blocks) representing the full gradient in management intensity. This experimental design will enable testing the hypotheses that the strength of ecosystem services is mediated by management intensity. In each stand, we established three experimental plots (each 225 $m^2$): (1) ungulate exclosure only, (2) bird + ungulate exclosure, (3) complete wildlife access ($N$=84 plots total). In each exclosure and associated control, we will collect data on: tree seedling survival and growth, cervid browse damage, arthropod damage, arthropod abundance, plant community composition, soil mineralization rates, and soil carbon.

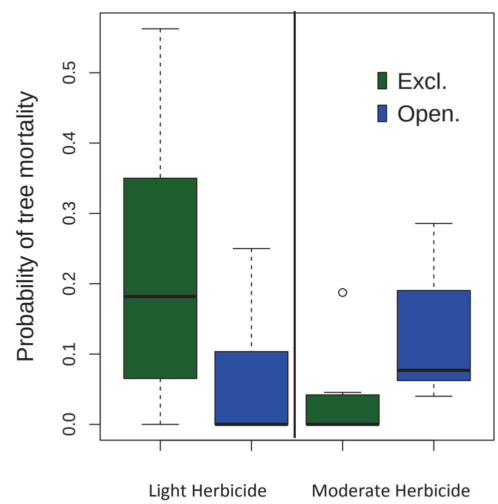


**Fig. 3. Preliminary evidence that cervids control competing vegetation, thereby decreasing tree mortality rates (an ecosystem service).** However, this effect is only prevalent when herbicides are light. In more intensive treatments, a shortage of high-quality forage results in cervid consumption of crop trees, increasing their mortality.

### *Timber-yield and Ecosystem Service Modeling Methods (Objective 3).*

Empirical evaluation of timber yield and ecosystem services interaction requires a representative location with appropriate data. For this study we propose to utilize the Oregon Department of Forestry's (ODF) Forest Grove district. Data for the 115,000 acre forest on the eastern slopes of the Coast Range Mountains will be provided by ODF. We will then work with ODF analysts through the two primary steps associated with this objective; development of stand-scale inventory and yield estimates and then landscape-scale optimization.

**Development of Stand-Scale Inventory and Yield Estimates.** The generation of stand-level data for parameterization of the landscape modeling will require close coordination between OSU researchers and ODF forest analysts. We will provide early stand development (0-10 years) data and then transfer those data to ODF who will project stand development over the remainder of the rotation. For each case, we will provide functions that relate particular intensive management practices and their associated biodiversity effects, to a subset of the ecosystem services (i.e., timber production, carbon storage, pollination, biodiversity [in this case bird species abundance]). **Timber yield:** For young stand development we will use the CIPS variant of the young stand growth model, 'CONIFERS', to project the early (0-10 years) influence of competing vegetation on conifer growth by plot and by treatment. This variant was developed by the Center for Intensive Planted-forest Silviculture (CIPS) in collaboration with Martin Ritchie of the USDA-FS Pacific Southwest Research Station and is based on data from virtually all of the available research data on competing vegetation field trials. The current form of the CONIFERS height growth equation will be calibrated to the early height growth data from the IFM vegetation plots by treatment, with indicator variables added to account for broader differences between these operational sites and the research installations comprising the CONIFERS dataset. Tree lists and vegetation cover from the year 6 measurements will be projected for 4 years (year 6-10) with CONIFERS. The tree lists for each of our vegetative management will then be passed to ODF where they will use the UDSA Forest Service's Forest Vegetation Simulator (FVS) stand projection system (Dixon 2002) to project growth and wood production to 100 years for each plot and treatment. **Carbon Storage:** For each stand, carbon storage will be quantified in six pools: merchantable live tree, non-merchantable live tree, below ground live, below ground dead, standing and downed woody debris, and forest floor shrubs, herbs, litter and duff carbon, using the Fire and Fuel Extension of FVS (Rebain, 2010). **Pollinators and Birds:** Our pollinator and bird sampling will enable us to determine the abundance of species across our four experimental treatments. Given that our sampling funded by the current proposal will only provide data until 8 years following stand initiation, we will supplement our experimental data with chronosequence studies on pollinator (Rivers and Betts unpublished data) and bird abundance (Ellis and Betts 2011, Betts et al. 2010) as a function of age-class degree of forest management. We will use generalized linear models and N-mixture models (Betts et al. 2013) to estimate the relationship for pollinator and bird abundance, respectively, as a function of stand age and management intensity. We acknowledge that the best approach to parameterizing biodiversity components in our simulation models would be to wait until experimental data are available across the entire rotation age (~40 years; 2051). However, in the interest of informing policy over shorter terms, integrating existing non-experimental data into models will be necessary. To reflect the uncertainty associated with this approach, we will: (1) conduct sensitivity analysis around all key model inputs (e.g., bird responses to treatments), (2) maintain a fully transparent approach to modeling (inputs will be clear and easily changed), (3) clearly state uncertainties and assumptions in publications arising from modeling efforts.

Although the growth model does not attempt to represent variation around the projected estimates, uncertainty can be assessed during this analysis by introducing a stochastic element generated as a random draw from a normal distribution. This normal distribution will have a mean of zero and variance defined by the regression MSE and the values for the covariates for each prediction (Draper and Smith 1981). Yield effects of the four experimental treatments will be assessed in several ways. First, the time gain will be determined for each 5-yr growth period, where time gain is defined as the reduction in years required for a given treatment to reach the same timber volume as control plots (no competing vegetation control). Yield gains will also be computed for each 5-yr growth period, expressed as the difference between the treatment yield and control yield at the same age. Present net worth and financial rotation age, as measures of economic performance, will be determined based on costs of reforestation and chemical release, value of timber at different ages, and three discount rates (4, 8, 12%) that reflect the range typically used by large private landowners.

**Optimization of Biodiversity and Ecosystem Services at the Landscape Scale.** We will input production functions into a linearized non-linear programming model developed previously by Co-PI Latta (PNW-RM [Pacific Northwest Regional Model], Latta et al. 2013). The PNW-RM employs a dynamic market equilibrium structure to explain harvest decisions from forest lands (log supply) and log processing decisions at mills or milling centers (log demand) over a pre-specified projection period. Characteristics of log supply and forest resource conditions come from US Forest Service FIA plot data and growth and yield is conducted at the individual tree level. Characteristics of log demand at mills are developed from empirical models of production behavior. This optimization model is well suited to multi-objective problems. Structurally, an optimization model solves the multi-objective management problem with constraints and variables that express management restrictions, goals, actions and/or decisions, respectively. In close collaboration with key project stakeholders (industry, Oregon Dept. of Forestry, US Forest Service) we will implement various flow quantities of ecosystem services incentives in the models' 'objective functions' and other policy targets for ecosystem services as 'constraints' to evaluate the potential tradeoffs among services. For instance, we will be able to quantify the consequence of a "maximize timber production" scenario on long-term (e.g., 100 year) carbon stores, or landscape-scale abundance of pollinators. This will enable us to calculate "efficiency frontiers"; *sensu* (Polasky et al. 2008) for the full suite of ecosystem services considered.

***Public Opinion on Science and IFM Methods (Objective 4).*** We will administer scientifically representative and rigorous survey instruments to the Oregon public measuring their tradeoffs among the different levels of IFM, biodiversity outputs, and ecosystem services attributes discussed above. Orthogonal fractional factorial designs will be used for selecting statistically representative scenarios depicting combinations of these factors and attributes. These scenarios will be embedded in the survey instruments, and stated preference modeling (e.g., discrete choice, conjoint analysis) will empirically measure tradeoffs among these scenarios. These analytical techniques are consistent with random utility theory, thus offering a powerful tool for understanding the complexity of tradeoffs. Respondents' other cognitions (e.g., value orientations, attitudes, intentions, emotions, trust, perceptions) associated with aspects of IFM, biodiversity, and ecosystem services will also be examined.

In addition, efficacy of providing scientific information to influence and change these perceptions and attitudes will be tested using an experimental approach. For a randomly selected subset of survey respondents (treatment group), one survey version will experimentally introduce scientific information in a within-survey pre-post design (e.g., measure attitudes, then have respondents read scientific information, then measure attitudes again) to examine the extent that this information influences cognitions and tradeoffs. Results from this treatment group will be compared to a second survey version that would not present any scientific information (control group). **To improve validity and ensure maximum transparency, stakeholders (e.g., forest industry, other scientists, agencies) will provide input and feedback on development of these survey instruments.**

The sample population will be stratified by rural and urban areas within the main population region of Oregon (between the Coast and Cascade ranges), and proportionate random samples of residents within these areas will be drawn from postal records. Consistent with well-established methods in human dimensions / social science (Dillman et al. 2014), data collection will proceed in multiple phases to ensure acceptable response rates (e.g., postcard with invitation to complete survey instruments online, full mailing, postcard reminder, full mailing). The sample size will be large enough for results to be representative of and generalizable to the target population at the 95% confidence level with a margin of error of less than 5% (e.g., $N$ = 300 urban, $N$ = 300 rural), which is the conventional accepted standard for research of this nature. A non-response bias check and comparisons with the most recent Census data will also be conducted to ensure representativeness and generalizability. Univariate (e.g., percentages, potential for conflict index), bivariate (e.g., analysis of variance, t-tests, chi-square), and multivariate inferential statistics (e.g., multiple and logistic regression, conjoint, cluster analysis, structural equation modeling) will be used for analyzing the data.

In addition, we will engage in a parallel process where, in addition to providing written information on our research findings, we involve individuals in field trips to our study sites. These field visits will be organized by Steve Fitzgerald (Co-PI) with possible continued collaboration from the Oregon Forest Resources Institute (OFRI). Similar to the case of providing written information in the surveys (discussed above), participating individuals (approximate total *N*=100 [4 field trips x 25]) will be given pre- and post-information surveys to assess the degree that scientific information influences their attitudes, perceptions, and decision making about tradeoffs.

## 3. Anticipated outcomes

**Objective 1, Effects of IFM on Biodiversity.** Previous studies have tested influences of IFM on biodiversity but, to our knowledge, this is the first study to examine longer-term responses (>3 years) at spatial scales relevant to management for multiple indicators of biodiversity (plants, insects, birds, cervids, pollinators). Our results will therefore contribute to the scientific literature on IFM and biodiversity. More importantly, our results are highly likely to have substantial movement and policy implications for forest management in the Northwestern U.S. Recently, "complex early seral forest" has been deemed the scarcest forest type in the region (Swanson et al. 2011) and the Northwest Forest Plan may soon be revised to address this on Federal lands. The degree that private lands are 'sources' for early seral biodiversity will have great bearing on such new policy. Furthermore, our ongoing extension efforts with industrial, small private, and State managers may increase the palatability of managing plantations with biodiversity conservation in mind. Finally, the public debate about herbicide use in Oregon has increased in recent years http://www.oregonlive.com/environment/index.ssf/2015/04/how_average_oregonians_challen.html#incart_river). Empirical data on biodiversity responses to herbicide use will help inform this debate.

**Objective 2, Effects of biodiversity on ecosystem services.** A key question in forest and wildlife management is, '*How much habitat is enough'* (MacLean et al. 2009)? For instance, do all landscapes need to be managed to maintain populations of early seral songbirds, pollinators, and cervids? The answer to this question is dependent on whether such species serve important ecosystem services at local scales (i.e., 'functional' biodiversity). For example, if birds play an important role in controlling populations of herbivorous insects, it will be important to maintain relatively evenly distributed populations of certain species across stands and landscapes. Similarly, if cervids are important in controlling competing vegetation and reduce the need for herbicide, populations of these animals should be maintained at landscape-scales. Thus, biodiversity may be utilized to generate a broader set of ecosystem services. By calculating opportunity costs associated with reduced herbicide use and increased tree growth rates, we will quantify in economic terms the importance of biodiversity. Our results therefore have the potential to provide non-altruistic incentive for managers to conserve biodiversity.

**Objective 3**, **Landscape-scale Ecosystem Services Models.** Our project will result in the first landscape-scale decision support model to quantify ecosystem service tradeoffs and synergies in plantation forests. These will be available for use by Oregon Dept. of Forestry in future plan revisions (see Pew letter of support), but may also be of use to other landowners as decision support tools. Such models will allow for better integration of wood production goals and other ecosystem services, thereby achieving important biodiversity conservation objectives while also generating reasonable economic returns.

**Objective 4, Evaluate public opinions and tradeoffs associated with IFM, biodiversity, and ecosystem services.** We anticipate that the general public will have opinions and attitudes about IFM, biodiversity, and ecosystems services, but low levels of knowledge about relationships among these factors. Our research will also be the first to empirically document tradeoffs that the public makes among these factors, which is important for reflecting the complexity of management decision making. We will also document drivers of these attitudes, knowledge, and tradeoffs (e.g., demographics, value orientations, emotions), allowing managers to understand where these cognitions are coming from and how amenable they are to change through educational information. Our research will also show the role that scientific information plays in individual decision making and attitudes toward IFM, biodiversity and ecosystem services, and the extent that exposure to new scientific information can change these attitudes and tradeoffs.

**Anticipated Scientific Outputs**: In addition to the policy and management-relevant results above, we anticipate substantial peer-reviewed scientific productivity from the proposed work. We have already amassed 4 years of empirical data, so are poised to analyze data on additional temporal responses by biodiversity and ecosystem services to IFM. Research from prior work on this project has resulted in 11 peer-reviewed publications (3 more to be submitted by December 2015) to top-tier journals in the field of forest ecology and management (e.g., *Ecology*, *Ecological Applications*, *Forest Ecology and Management*). This work examined the effects of IFM on bird abundance and diversity (Betts et al. 2013), bird demography (Ellis et al. 2012, Rivers et al. 2012), arthropod biomass and moth diversity (Root et al. In Prep), and ungulate habitat use (Stokely 2014).

## 4. Outreach activities

In prior work on this project, the PI, Co-PIs, and their students delivered 49 public or scientific seminars detailing project findings. Our work has resulted in 9 organized field tours for managers from private and governmental institutions, and small private landowners. We organized a major symposium on the topic of IFM at the 2012 meeting of *The Wildlife Society* (total attendance >100). Recently, we collaborated with the OFRI to organize a major conference (fall 2014) to translate our scientific results into management recommendations for forest managers throughout the Pacific Northwest.

Our continued formal and informal extension activities will be coordinated through OSU CoF (Steve Fitzgerald). Efforts will be designed to maximize the likelihood that our results will be received by forest managers and policy makers, thereby enhancing the likelihood of implementation. Formal extension activities will include: (1) at least one major field tour/ year designed for forest managers, policy makers, and the public, (2) a major conference on ecosystem services in managed forest landscapes to share our work with the broader scientific community development, (3) a collaborative workshop with ODF forest planning staff on implementation of the simulation model developed in Objective #3, (4) continuation of a website on the IFM project: http://blogs.oregonstate.edu/intensiveforestmanagement/, and (5) the social science component of our study will be tightly linked to the field tour / outreach activities. As noted above, we will test the degree that participation in field tours influences prior attitudes about IFM and its relationships to biodiversity and ecosystem services. For the survey component, stakeholders (e.g., forest industry, other scientists, agencies) will provide input and feedback on development of these survey instruments.

**5. Timeline.** *Hiring field crews*: March 2016 & 2017; *Field work and empirical data collection*: April 2016 – August 2017; *Entry of data into relational databases*: Fall 2016 & 2017; *Field tours of experimental sites for forest managers and policy makers*: Summer 2015-2017; *Publication of results*: 2015 - 2017; *Organization of conference workshop*: Winter 2017; *Development of Ecosystem Services Models*: Oct. 2017-Dec. 2018.

**6. Integration with IWFL Themes.** Our proposal is directly relevant to two of the four thematic areas addressed by the IWFL program: **Intensively Managed Forests** and **Resilient Ecosystems**. It also addresses two of the key opportunities identified: (1) "**Enhancing Ecosystem Health with a Landscape Approach**"; one of the key objectives of the Institute is to "conduct fundamental research to increase our understanding of ecosystem dynamics, and applied research to refine, validate, and scale a suite of adaptive management techniques". By implementing a long-term research experiment that cuts across landownerships, our project is well positioned to address this objective. (2) **Increasing Public Trust in Active Management of Public & Private Lands**; our social science survey research and field tours will assess knowledge, attitudes, tradeoffs, and trust associated with management approaches that are *most commonly* used on State lands, as well as large and small private ownerships. We will also assess the degree that scientific knowledge and first-hand experience can influence these attributes.

**5. Partner linkages and support.** Our effort depends critically on the following partners:
**(i) Landowners**: Our empirical data collection will occur across four major landownerships (Plum Creek, Hancock, Weyerhaeuser, ODF). These landowners have consistently supported our research via: (a) forgoing the opportunity cost of maintaining unsprayed controls over the course of the study, (b) in-kind time and support of biologists and foresters who consistently collaborate on study design (site layout, sampling efforts), and (c) implementation of forest management treatments that are atypical in normal forestry operations (e.g., 4 successive years of spring herbaceous spray). **(ii) Oregon Dept. of Forestry Planning:** As noted above, the modeling component of our study will rely heavily on ODF forest inventory data and yields. ODF is also contributing in-kind support by encouraging their forest modelers to collaborate with our team. (iii) A substantial portion of our empirical field data collection is already supported by a grant from **USDA-AFRI** (1 year of pollinator surveys, 1 year of arthropod data).

**6. Interaction with IWFL Board members.** This proposal has benefited from the suggestions and advice of the following IWFL board members:
(1) **Liz Dent** (and Jeff Brandt), ODF. Liz and the team at ODF have encouraged our efforts to scale up our empirical data to provide a landscape-scale biodiversity and ecosystem services model.
(2) **Jeff Light**, Plum Creek. Jeff is one of the original industry representatives involved with the IFM project. Jeff has supported the need for continued empirical data collection on our study sites and will continue to provide constructive input on the social science survey component of the research.
(3) **Greg Johnson**, Weyerhaeuser. Greg has provided useful advice on how best to implement the soil productivity and carbon storage components of the study. Based on his input that inter-site variation across our system is likely to be very high (thus obscuring ecological effects of herbicide), we will focus primarily on the role that birds and ungulates play in influencing soil properties.
(4) **Tom Spies**, USFS. Tom provided input on the best sorts of models to accomplish broad-scale tests of ecosystem service tradeoffs. He suggested that a state and transition model applied at fine temporal resolutions (1 year) would be the most efficient for the purposes of our research in early seral systems.
(5) **Jake Verschuyl**, NCASI. Jake has been a major collaborator on the IFM project since just after its inception. He will continue to have a major role in directing research and developing research and extension products.

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