Chapter 6. EXECUTIVE SUMMARIES OF TEAM RESOURCE-SPECIFIC FINDINGS

Introduction

This chapter compiles the executive summaries from all the individual team chapters (Appendices A-F), including each team's resource-specific findings and management recommendations.

Fire and Forest Ecosystem Health

The 2004 Amendment to the Sierra Nevada Forest Plan identified a coordinated system of fuel treatments distributed across the landscape as the preferred management alternative. The goals of this approach, defined as strategically placed land area treatments (SPLATs), were to modify dangerous fire behavior and improve forest health in the National Forests in the Sierra Nevada region of California. The 2004 amendment also introduced the concept of fireshed management. Firesheds are analogous to watersheds in concept, but are topographic units based on the behavior of a problem fire – a fire that has the greatest potential impact based on the local topography, weather, and fire history. We tested the performance of SPLATs as designed and implemented by US Forest Service in two firesheds, Last Chance in the Tahoe National Forest and Sugar Pine in the Sierra National Forest. We conducted detailed field measurements before and after treatments in order to quantify changes in forest structure and fuel loads resulting from SPLATs. To account for potential changes unrelated to forest management, a control fireshed was paired with the treated fireshed at each site. Data from the field measurements were used to parameterize fire and forest growth models. These models were then used to simulate wildfire effects on fire behavior and to explore the responses of tree growth efficiency (a measure of tree vigor) to the treatments. At Last Chance, fuel treatments distributed across 18% of the landscape reduced the percentage of the forest exposed to damaging flame lengths from 33% (no SPLATs) to 22% (with SPLATs). The impact of SPLATs on fire behavior was less at Sugar Pine. Fire simulations for Sugar Pine showed that SPLATs completed on 29% of the area, reduced exposure to damaging flame lengths from 29% of the landscape to 25% – a minimal decline of 4 percentage points. In contrast, trees in the treated fireshed at Sugar Pine nearly doubled their growth efficiency in the ten years following SPLATs while there were only minor improvements in growth efficiency following treatments at Last Chance. This dichotomy in the response to SPLATs was related to differences in the extent and intensity of the treatments applied at the two sites as well as ecological and land use variations. The treated fireshed at Sugar Pine supported a mixed conifer forest that was more crowded with bigger trees but exposed to a lower initial fire hazard. Nevertheless, in aggregate our results support the promise of SPLATs. Coordinated treatments across part of the landscape can help minimize the hazards posed by severe fires and at the same time meet forest health objectives.

Spatial

The SNAMP Spatial Team was formed to provide support for the other SNAMP science teams through spatial data acquisition and analysis. The objectives of the SNAMP Spatial Team were: (1) to provide base spatial data; (2) to create quality and accurate mapped products of use to other SNAMP science teams; (3) to explore and develop novel algorithms and methods for Lidar data analysis; and (4) to contribute to science and technology outreach involving mapping and Lidar analysis for SNAMP participants. The SNAMP Spatial Team has focused on the use of Lidar – Light Detection and Ranging, an active remote sensing technology that has the ability to map forest structure.

Lidar data were collected for Sugar Pine (117km^2) in September 2007 (pre-treatment), and Nov 2012 (post-treatment); and for Last Chance (107km^2) on September 2008 (pre-treatment) and November 2012 and August 2013 (post-treatment). Field data were collected at each site according to an augmented protocol based on the Fire and Forest Ecosystem Health (FFEH) Team plot method. From the Lidar data, field data and aerial imagery (for some of the products), a range of map products were created, including: canopy height model, digital surface model and digital terrain model; topographic products (digital elevation model, slope, aspect); forest structure products (mean height, max height, diameter at breast height (DBH), height to live canopy base (HTLCB), canopy cover, leaf area index (LAI), and map of individual trees); fire behavior modeling products (max canopy height, mean canopy height, canopy cover, canopy base height, canopy bulk density, basal area, shrub cover, shrub height, combined fuel loads, and fuel bed depth), as well as a map of individual trees, and a detailed vegetation map of each site. Lidar data have been used successfully in the SNAMP project in a number of ways: to capture forest structure; to map individual trees in forests and critical wildlife habitat characteristics; to predict forest volume and biomass; to develop inputs for forest fire behavior modeling, and to map forest topography. The SNAMP Spatial Team also explored several avenues of research with Lidar data that resulted in eleven peer-reviewed publications, listed in Appendix B2. Our research has been significant over a range of areas.

Technical advances from the SNAMP Spatial Team

In a comprehensive evaluation of interpolation methods, we found simple interpolation models are more efficient and faster in creating DEMs from Lidar data, but more complex interpolation models are more accurate, and slower (Guo et al. 2010 SNAMP Publication #4). The Lidar point cloud (as distinct from the canopy height model) can be mined to identify and map key ecological components of the forest. For example, we mapped individual trees with high accuracy in complex forests (Li et al. 2012 SNAMP Publication #6 and Jakubowski et al. 2013c SNAMP Publication #24), and downed logs on the forest floor (Blanchard et al. 2011 SNAMP Publication #7). We investigated the critical tradeoffs between Lidar density and accuracy and found that low-density Lidar data may be capable of estimating plot-level forest structure metrics reliably in some situations, but canopy cover, tree density and shrub cover were more sensitive to changes in pulse density (Jakubowski et al. 2013b SNAMP Publication #18).

Lidar data used to map wildlife habitat

Lidar can be used to map elements of the forest that are critical for wildlife species. We used our data to map large residual trees and canopy cover – two key elements of forests used by California spotted owl (*Strix occidentalis occidentalis*) for nesting habitat (Garcia-Feced et al. 2012 SNAMP Publication #5). Lidar also proved useful for characterizing the forest habitat conditions surrounding trees and snags used by the Pacific fisher (*Pekania* [*Martes*] *pennanti*) for denning activity. Large trees and snags used by fishers as denning structures were associated with forested areas with relatively high canopy cover, large trees, and high levels of vertical structural diversity. Den structures were also located on steeper slopes, potentially associated with drainages with streams or access to water (Zhao et al. 2012b SNAMP Publication #16).

Lidar products used in fire behavior modeling

Forest fire behavior models need a variety of spatial data layers in order to accurately predict forest fire behavior, including elevation, slope, aspect, canopy height, canopy cover, crown base height, crown bulk density, as well as a layer describing the types of fuel found in the forest (called the "fuel model"). These spatial data layers are not often developed using Lidar (light detection and ranging) data for this purpose (fire ecologists typically use field-sampled data), and so we explored the use of Lidar data to describe each of the forest-related variables. We found that stand structure metrics (canopy height, canopy cover, shrub cover, etc.) can be mapped with Lidar data, although the accuracy of the product decreases with canopy penetration. General fuel types, important for fire behavior modeling, were predicted well with Lidar, but specific fuel types were not predicted well with Lidar (Jakubowski et al. 2013a SNAMP Publication #13).

Use of Lidar for biomass estimation

Accurate estimation of forest above ground biomass (AGB) (all aboveground vegetation components including leaves/needles) has become increasingly important for a wide range of end-users. Lidar data can be used to map biomass in forests. However, the availability of, and uncertainty in, allometric equations used to estimate tree volume influences the accuracy with which Lidar data can predict biomass from Lidar-derived volume metrics (Zhao et al. 2012a SNAMP Publication #14). Many Lidar metrics, including those derived from individual tree mapping are useful in estimating biomass volume. We found that biomass can be accurately estimated with regression equations that include tree crown volume and that include an explicit understanding of the overlapping nature of tree crowns (Tao et al. 2014 SNAMP Publication #29). Satellite remote sensing has provided abundant observations to monitor forest coverage. Validation of coarse-resolution above ground biomass derived from satellite observations is difficult because of the scale mismatch between the footprints of satellite observations and field measurements. Lidar data when fused with course scale, fine temporal resolution imagery such as MODIS, can be used to estimate regional scale above ground forest biomass (Li et al. 2015 SNAMP Publication #37).

Management implications

Our work has several management implications. Lidar will continue to play an increasingly important role for forest managers interested in mapping forests at fine detail. Understanding the structure of forests – tree density, volume and height characteristics - is critical for management, fire prediction, biomass estimation, and wildlife assessment. Optical remote sensors such as Landsat, despite their synoptic and timely views, do not provide sufficiently detailed depictions of forest structure for all forest management needs. We provide management implications in four areas:

1. Lidar maps and products

- Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone.
- Lidar software packages are not yet as easy to use as the typical desktop GIS software.
- There are known limitations with the use of discrete Lidar for forest mapping - in particular, smaller trees and understory are difficult to map reliably.
- Discrete Lidar can be used to map the extent of forest fuel treatments; treatment methods cannot be detected using discrete Lidar, but waveform Lidar might be alternative choice to map understory change.

2. Wildlife

- Lidar is an effective tool for mapping important forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.
- Lidar will increasingly be used by wildlife managers, but there remain numerous technical and software barriers to widespread adoption. Efforts are still needed to link Lidar data, metrics and products to measures more commonly used by managers such as CWHR habitat classes.

3. Fire behavior modeling

- Lidar data are not yet operationally included into common fire behavior models, and more work should be done to understand error and uncertainty produced by Lidar analysis.

4. Forest management

- There is a trade-off between detail, coverage and cost with Lidar. The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data.
- Standard Lidar products do not yet operationally meet the requirements of many US forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. More work is needed to translate between the remote sensing community and the forest management community in some areas of the US to ensure that Lidar products are useful to and used by forest managers.
- The fusion of hyperspectral imagery with Lidar data may be very useful to create detailed and accurate forest species maps.

The future of Lidar for forest applications will depend on a number of considerations. These include: 1) costs, which have been declining; 2) new developments to address limitations with discrete Lidar, such as the use of waveform data; 3) new analytical methods and more easy-to-use software to deal with increasing data sizes, particularly with regard to Lidar and optical imagery fusion; and 4) the ability to train forest managers and scientists in Lidar data workflow and appropriate software.

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Wildlife: California Spotted Owl

We conducted a two-part analysis to assess the effects of SPLATs on California spotted owls (*Strix occidentalis occidentalis*). First, we performed a retrospective analysis using 20 years of demographic data collected at 74 spotted owl territories that included the Last Chance Study Area (LCSA) and the nearby Eldorado Study Area (ESA). This approach deviated from our original plan to directly estimate the effects of SPLATs on spotted owls at Last Chance using a Before-After Control-Impact experimental design, similar to the approach used by some of the other SNAMP Science Teams. The revised approach was necessary because too few owls were present on the LCSA and the delay in implementing the Last Chance fuels-reduction project resulted in only one year of post-treatment data collection. As a result, we needed to spatially and temporally expand the retrospective analysis to achieve sufficient power to detect changes in owl demographic parameters (Popescu et al. 2012). The drawback to our revised approach was that we could no longer specifically estimate the effects of SPLATs on owls because many different types of timber harvest, as well as wildfire and forest succession, occurred within owl territories during our study period (1993-2012). Second, we performed a prospective analysis (30 years into the future) of the effects of SPLATs and wildfire on spotted owl habitat and demography within the LCSA only. This analysis represented our integration effort with the research conducted by the Fire and Forest Ecosystem Health [FFEH] and Spatial teams.

The retrospective analysis has been published in a peer-reviewed journal (Tempel et al. 2014), and we have reproduced this paper in the first section of this appendix. We assessed the effects of forest conditions, timber harvest, and wildfire on spotted owl reproduction, non-juvenile survival, and territory occupancy using the previously mentioned 20-year data set. All habitat and timber harvest variables that we extracted from our vegetation maps were time-varying and could change annually because of natural disturbance, timber harvest, or regrowth. We categorized timber harvest into three broad categories for analytical purposes—low-intensity, medium-intensity, and high-intensity. The classification scheme was based on the expected change in forest structure and was developed after consultation with three local forest managers who were naïve to the objectives of our study. SPLATs and other U.S. Forest Service treatments conducted prior to the adoption of SPLATs were considered to be medium-intensity harvests. Adult survival and territory colonization were relatively high, while territory extinction was relatively low, in territories that had greater amounts of high-canopy-cover forest (≥70% canopy cover, dominated by trees ≥12” [30.5 cm] diameter at breast height). Reproductive success was negatively associated with the area of medium-intensity timber harvests characteristic of SPLATs. Our results also suggested that the amount of edge between older forests and shrub/sapling vegetation and increased habitat heterogeneity may result in higher spotted owl demographic rates. We found some evidence that high-severity fire was correlated with a reduced likelihood of territory colonization, but the standard error was unestimable for the parameter coefficient, suggesting that we lacked a sufficient sample size of burned territories to draw definitive conclusions. Despite correlations between owl demographic rates and several habitat variables, life-stage simulation (sensitivity) analyses indicated that the amount of high-canopy forest was the primary driver of population growth and equilibrium occupancy at the territory scale. Greater than 90% of medium-intensity harvests converted high-canopy forests into lower-canopy vegetation classes, suggesting that landscape-scale fuel treatments in such stands could have short-term negative impacts on California spotted owl populations. Moreover, high-canopy forests declined by an average of 7.4% across territories during our study, suggesting that habitat loss could have contributed to declines in abundance and territory occupancy detected in a previous study of this population. Thus, we recommend that managers consider the existing amount and spatial distribution of high-canopy-cover forest before implementing SPLATs and that SPLATs be accompanied by a rigorous monitoring program within an adaptive management framework.

We present the prospective analysis in the second section of this appendix. For this analysis, the FFEH Team simulated forest growth 30 years into the future under four combinations of modeled wildfire and treatment (i.e., Last Chance fuels-reduction project): treated with fire, untreated with fire, treated without fire, and untreated without fire. We compared spotted owl habitat on the LCSA under the four scenarios using a habitat suitability index developed from canopy cover and large-tree measurements at nest sites on the ESA. In addition, we compared population growth rate and equilibrium occupancy at four spotted owl territories within the LCSA for each scenario using the statistical relationships between forest structure and these population parameters that we developed in the retrospective analysis. We found that effects of fuels treatments were contingent on fire occurrence. Treatments had a positive effect on owl nesting habitat and demographic rates up to 30 years after simulated fire, but they had a persistently negative effect throughout the 30-year period in the absence of fire. We conclude that SPLATs may provide long-term benefits to spotted owls if fire occurs under escaped wildfire conditions, but can have long-term negative effects on owls if fire does not occur. However, we only simulated one fire under the treated and untreated scenarios and therefore had no measures of associated uncertainty. In addition, the net benefits of fuels treatments on spotted owl habitat and demography will depend on the future probability that fire will occur under similar weather and ignition conditions, and such probabilities remain difficult to quantify. Therefore, we recommend adopting a landscape approach that restricts timber harvest within territory core areas of use (~125 ha in size) that contain critical owl nesting and roosting habitat (Berigan et al. 2012) and locates fuels treatments in the surrounding areas to reduce the potential for hazardous fire to spread into PACs.

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Wildlife: Pacific Fisher

Fishers (*Pekania pennanti*) are a medium-sized mammalian carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). Ecologically, fishers are a mature or old forest-obligate species (Zielinski et al. 2005), and in central to eastern Canada and the northeastern United States their numbers were reduced historically by the combination of intensive trapping and loss of forest habitats (Powell 1993, Powell and Zielinski 1994). The species is uncommon to rare in the western United States. It is listed as a sensitive species by the Oregon Department of Fish and Wildlife and endangered by Washington State. In July 2015, the California Fish and Game Commission voted to list the southern Sierra Nevada fisher population as threatened, and the species is currently a candidate for listing under the US Endangered Species Act. In advance of federal and state listing decisions, conservation planning has been underway in California since 2013 to develop an approach to maintaining viable populations of fishers in both northwestern California and in the southern Sierra Nevada. Information from the SNAMP Fisher Project (published manuscripts, submitted manuscripts, and unpublished data) described herein has been included in a Southern Sierra Nevada Fisher Conservation Assessment developed by the Conservation Biology Institute, with input from a team of 13 fisher researchers and scientists.

The SNAMP Fisher Project was initiated by the UC Science Team in fall 2007, in association with multiple other SNAMP research programs, to provide an independent evaluation of how vegetation management, prescribed by the 2004 Sierra Nevada Forest Plan Amendment, affects fire risk, wildlife, forest health and water. A major goal of the SNAMP Fisher Project was to determine whether current rates of survival and reproduction will allow fishers to persist in the Sierra Nevada in the context of active forest management to reduce fuels and the risk of catastrophic wildfire. Our approach for assessing how fishers would respond to Strategically Placed Landscape Area Treatments (SPLATs) was designed to be multifaceted including (1) life history responses to fuels reduction (changes in survival, reproduction/fecundity, lifespan), (2) changes in local scale habitat use within individual home ranges, and (3) shifts or changes in habitat use at the home range scale of animal resource use/resource selection.

A range of standard methods were used in the study to live-trap, radiocollar and monitor survival status of individual fishers. Monitoring was accomplished almost entirely by fixed-wing aerial radiotelemetry, supported by an “in house” aviation program developed specifically for SNAMP Fisher and administered by the Forest Service. Ground-based radiotelemetry was used to monitor female fishers during denning seasons, and to recover carcasses of deceased fishers. Cameras were systematically placed throughout the study area at the center points of 1-km^2 grid cells. Grid cells within the SNAMP study area and the key watershed region were surveyed annually, while grid cells outside these areas were surveyed opportunistically. We used the camera survey data to support an occupancy analysis, investigating the impacts of different forest management actions on fisher occupancy, persistence, and extinction.

A total 110 individual fishers were captured and radiocollared from Dec 2007 to Dec 2013 (62 females, 48 males). Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males. On average 10.5 radiocollared fishers died in each population year over the course of the study, and the most common cause of death was predation by felid carnivores (bobcats, *Lynx rufus,* and mountain lions, *Puma concolor*). Two radiocollared fisher deaths were roadkills on Highway 41, and five others were directly linked to anticoagulant rodenticides being used in association with illegal marijuana grow sites in the Sierra National Forest.

Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit. Among the 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of adult female fishers for which reproductive status was known produced at least 1 weaned kit. We were able to determine litter size for 48 of 59 denning females. A total of 73 kits were known produced, with an average litter size of 1.5.

Fisher population sizes ranged from 48 in 2010 to 62 in 2012, whereas mean population density ranged between 0.072 fishers/km^2 in 2010 and 0.093 fishers/km^2 in 2012. Lambda across all years was 0.90, which was suggestive of general population decline, however, the annual and cumulative 95% confidence intervals all overlapped with 1.0.

Camera surveys were completed in 905 unique 1-km^2 grid cells throughout the overall study area, including 56 grid cells within the southern region of Yosemite National Park. Fishers were detected in 448 of the unique grid cells surveyed, which helped to identify that fishers in this part of the southern Sierra Nevada were most common between 4500 and 6500 feet elevation (1372 and 1981 m elevation). Occupancy estimates for multi-year surveyed grid cells corrected for imperfect detection < 1.0 ranged from 0.62 to 0.80.

Occupancy modelling indicated that fishers reduced their use of forest patches exposed to higher levels of restorative fuel reduction; i.e. persistence of occupancy declined with additional acreage treated for fire resiliency. However, neither restorative nor extractive (i.e., commercial thinning) fuel reduction was related to either initial probability of occupancy or local extinction. We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However, they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0.

The combination of an overall negative population growth rate and the relatively small abundance estimate (*n* = 93, range 80-107), warrants concern for the long term viability of the fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g., forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 individuals (Spencer et al. 2015), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The estimated population growth rate in the SNAMP Fisher study area reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2015), especially wildfires that are likely to increase in frequency and intensity with climate change. Moreover, the SNAMP Fisher study spanned a limited period of six years during which multiple novel threats to fisher survival within the study area were identified, and three large wildfires significantly reduced availability of suitable habitat for fishers immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. Development of ways to mitigate for major threats to fisher survival and fisher habitats and population viability analyses are necessary for evaluating the long-term prospects for fishers in the southern Sierra Nevada. Data from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the north margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

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Water Quantity and Quality

Part I of Appendix E addresses water quantity measurement and modeling to determine the impacts of forest fuel treatments and wildfire on hydrologic fluxes. For this study, a spatially explicit hydro-ecologic model, based on observed data, was used to scale from small to large catchments. The Regional Hydro-Ecologic Simulation System (RHESSys) was calibrated using headwater catchment observations of climate, snow, soil moisture, and stream discharge for the three pre-treatment water years (2010-2012), which encompassed wet, average, and dry precipitation conditions. The successful headwater calibrations were then transferred to the fireshed scale, based on geologic similarities between catchments. Changes in forest structure were determined by differences in Leaf Area Index (LAI), overstory canopy cover, and understory shrub cover.

Implementation of Strategically Placed Landscape Treatments (SPLATs) at Last Chance resulted in a vegetation decrease of 8% leading to runoff increases of at least 12% for the initial 20 years, falling to 9.8% by year 30, when compared to the no treatment scenario. Predicted vegetation growth following SPLATs showed the reduced biomass densities only lasted for about 10 years; after 10 years runoff decreased to pre-treatment levels. Two other modeled scenarios were also assessed: fire without SPLATs reduced vegetation by 49.8% while fire with SPLATs reduced vegetation by 38.1%, increasing runoff respectively by 66.7% and 54.9%.

SPLAT implementation at Sugar Pine resulted in a 7.5% decrease in vegetation, but increases in runoff were less than 3% compared to the no treatment scenario over 30 years. Predicted vegetation growth following SPLATs again showed the reduced biomass densities only lasted for about 10 years. Fire without SPLATs reduced vegetation by 42.5% while fire with SPLATs reduced vegetation by 39.5%, increasing runoff by 15.2% and 13.1% respectively.

Implementing SPLATs, both with and without wildfire, had a greater effect on annual runoff in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration rates, suggesting the forest is more water-limited than at Last Chance, where changes in evapotranspiration were more closely linked to forest density. This response can be illustrated using the scenario of greatest vegetation change, wildfire without SPLATs, where a 42.5% reduction in Sugar Pine vegetation led to a 2.9% decrease in evapotranspiration. The 49.8% reduction in Last Chance vegetation resulted in a 22.8% decrease in evapotranspiration. Although the high-intensity fires can result in greater vegetation reductions and lead to increased runoff, these results did not specifically address water quality issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

Management implications of this work include the need for more spatially distributed measurements of the water balance components (particularly snow depth and soil moisture). Having a model calibrated with multiple variables allowed us to upscale from a headwater basin to an ungauged basin to capture fireshed responses to forest treatments. In our study, the most effective areas for forest treatments, with the goal of increasing water yield, are forests without significant water limitations.

Part II of Appendix E addresses water quality measurements that were made to determine potential effects of treatments on water quality which could impact aquatic life and downstream water resources. Stream water temperature, conductivity, turbidity, and dissolved oxygen were recorded at 15-minute intervals using continuous recoding sensors from water year 2010 to water year 2013 in all four watersheds. Additional grab samples were collected and analyzed on a bi-weekly to bi-monthly basis for major ion chemistry and stable isotope chemistry. Movement of channel bed material was measuring using load cell pressure sensors and also recorded at 15-minute intervals for water years 2012-2014.

Water temperature, conductivity, and major ion concentrations were found to be higher in the 2012 and 2013 concurrent- and post-treatment water years respectively (referred hereafter in this chapter as the post-treatment period), however, these years were dry years and these patterns are typical of drought conditions. Dissolved oxygen remained fairly stable throughout the years of the study. Water chemistry parameters were found to all be within healthy ranges for aquatic life with the exception of low dissolve oxygen values during very low flows of dry years when stream flow was intermittent.

Much of the water quality measurement effort was focused on turbidity and bedload movement due to the healthy ranges for other water quality parameters and a lack of sources for chemical pollutants in these headwater systems. The observed timing of turbidity verses discharge event peaks indicates that sediment is coming from localized in-channel sources that are easily transported (Martin et al. 2014). Data trends are indicative of accumulation and depletion periods tied to high and low flows. Because SPLATs were light and set far back from stream channels we hypothesized that any changes in water quality (namely turbidity) due to treatments would be due to changes in stream discharge. Mean peak turbidity values were compared for pre- and post- treatment periods in the treatment watersheds but no significant difference was found. This may have been due in part to small sample sizes and large standard deviations caused by the infrequent and episodic nature of sediment movement in these streams. Channel bed movement data trends are indicative of the channel bed acting as temporary storage for sediment, but that it remains stable over the long term. The treatments as implemented were not intensive enough to show an increase in discharge during a low precipitation year and SPLATS as implemented in SNAMP had no detectable effect on turbidity.

Management implications of the water quality study point to the heterogeneity of flowpaths in these headwater catchments. Parameters from one headwater catchment may not translate to a nearby catchment. To capture this heterogeneity, spatially explicit measurements are necessary.

Martin, S.E., M.H. Conklin, and R.C. Bales. 2014. Seasonal accumulation and depletion of localized sediment stores of four headwater catchments. Water 6(7): 2144-2163.

Participation

Appendix F is a report on the diverse activities carried out by the Participation Team to assess participation in SNAMP, improve our methods of outreach, and contribute to the integrated chapters (chapters 3, 4 and 5 of this report).

The Sierra Nevada Adaptive Management Project (SNAMP) was developed to incorporate stakeholders into an adaptive management framework where the University of California (UC) used scientific experiments to assess the impacts of Forest Service fuels reduction projects. The first pillar of the UC 2007 SNAMP workplan was that adaptive management involved “deliberate experimentation” and this dictated the way the UC Science Team structured the science conducted in SNAMP (in addition to the Participation Team, SNAMP teams studied the following subjects: fire and forest ecosystem health, Pacific fisher, California spotted owl, and water quality and quantity, and spatial analysis). The workplan’s second pillar was “...that adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long term relationship grounded in shared learning about the ecosystem and society.” We considered the Participation Team role to be two-fold: a demonstration of a model of participatory, or collaborative, adaptive management and an analysis of the participant experience in SNAMP. While the primary mode of stakeholder interaction with scientists and the Forest Service was necessarily consultative rather than the power-sharing of a full collaboration, the participatory adaptive management process used by SNAMP was defined for the project as “collaborative adaptive management” or CAM. For this reason, the participatory process as implemented in SNAMP has the following stated definition of collaborative adaptive management (CAM):

> CAM is a science-driven, stakeholder-based process for decision-making while dealing with the scientific unknowns inherent in many physical and biological systems. In the SNAMP process, adaptive management incorporates stakeholder participation in order to improve the amount and breadth of information for decision-making, create meaningful engagement and build mutual understanding, learning, and trust.

Over the last century, the Forest Service has shifted from an emphasis on management based solely on technical expertise to models using more participatory methods. Increasing litigation in the 1980s reflected continued frustrations and conflict as stakeholders demanded more input into the decision-making process. The third party model that SNAMP used, in which an agency, the public and an outside science and outreach provider in a sense act as checks and balances to each other was derived out of the concept of shared, multi-party, or joint monitoring, and to some extent, citizen science. Both increase the participation of stakeholders in the science that drives management decisions. As true co-management, where power is shared equally, is not legally possible for the Forest Service or for scientists adhering to strict experimental protocols, projects like SNAMP can be seen to allow for more transparency in the decision-making process by opening up the science and planning processes, and providing additional pathways for input and feedback. An unforeseen benefit was the stakeholder enthusiasm for increased participation in and understanding of the science that became apparent in the course of the project. SNAMP provided some direct communication channels between scientists and the public, and this turned out to be one of the most appreciated aspects of SNAMP.

To address our focal question and engage stakeholders in the adaptive management process, the Participation Team conducted outreach based on long evolved University of California Cooperative Extension principles, and produced extensive assessments of the participant experience in SNAMP. We developed a participation process and analysis framework based on our best practices for collaboration expertise as well as an extensive review of the literature. The five core elements of our effort were inclusivity, transparency, learning, relationship building and effectiveness. We collected input from both SNAMP participants and non-participants with regard to these core elements in SNAMP via written surveys immediately at the end of meetings as well as through two online email surveys of the SNAMP listserv and three separate rounds of in-depth interviews. Our Team employed the following varied outreach methods to address these elements.

The Team focused on both in-person events and presentations as well as at-a-distance methods that were web-based. Each type of participation event had its advantages and limitations and each allowed certain kinds of learning to occur or relationships to be fostered (Tables F3 and F4 in Appendix F). Face-to-face interactions with scientists and managers were a focal point of the in-person outreach program. Our large public meetings gave broad access to the project, though with little time for details, and provided a forum for interest group positions to be shared. The smaller technical integration team meetings were focused on individual topics. These provided in depth data sharing with advanced discussions and were incredible learning opportunities based on the presentations of the lecturers but also as participants learned from each other's less formal questions and comments. Field trips, where participants could "kick the dirt" together and actually see the forest, were touted as most valuable for learning about management context, scientific methods and findings as well as for building relationships through intimate and casual conversations. Subject matter workshops, which conveyed all the most relevant science on managing a resource including findings beyond the scope of SNAMP, were highly appreciated by managers. Taking SNAMP to targeted audiences by going to their meetings and events proved to be a powerful way to spread the scientific outcomes of SNAMP as well increase project inclusiveness and transparency.

The project's at-a-distance methods such as the website and its document archive, science briefs, newsletters, and blogs provided the basis for all other SNAMP contacts because of their accessibility and transparency. The email list was invaluable for getting information out to interested parties though it is not particularly interactive. Webinars were found to be useful at the end of the project (they saved time and money), but none of the online interactions could replace the importance of face-to-face connections with scientists, managers, or other stakeholders. We observed that our webinars were mainly successful because they occurred at the end of the project when relationships were solidified and there was a group comfort level that could overcome the impersonal nature of the webinar.

To transfer the SNAMP collaborative lessons and to train stakeholders and the agencies to conduct or participate in future collaborative adaptive management projects, we created and implemented a multi-day workshop curriculum and companion workbook. Participants in these trainings gained a clearer understanding of adaptive management and how to include the public in the process, how and when to use an independent third party, and how participants can utilize facilitation tools to help defuse conflict. Evidence from the post-workshop surveys suggests that these trainings increased participant commitment to collaboration and it is these key stakeholders and agency participants that could help ultimately complete the SNAMP adaptive management cycle.

A review of our participation model by core element starts with the two most basic and primary elements: transparency and inclusivity. We attempted to attract and reach out to the broadest extent possible by varying our events, presenting at other groups' events and extending our contact through online and traditional media. Our goal was to include as many voices and perspectives as possible to foster the strongest buy-in for the final results as well as input during the process. Transparency was a focal point from the beginning, starting with the SNAMP website. Within its contractual constraints, SNAMP strove to be as open and transparent in its processes and decision-making as it could be. Our surveys showed that the strong effort put in by the UC Science Team to focus on inclusivity and transparency was recognized by participants.

Learning was the next goal of the SNAMP Participation Team and was also the overall purpose of SNAMP, as reflected in the title of the project: "Learning how to apply adaptive management…" Each of the science teams produced copious amounts of novel data with regard to their subjects and presented these findings to the public multiple times a year. We found that learning in these kinds of social settings helped SNAMP produce shared understandings about basic biological and ecological conditions as well as larger concepts about forest health and adaptive management.

The other crucial outcome of shared learning and understandings was new and improved relationships between the participants in SNAMP. Our results show that over the long life of the project, in which there were many and varied opportunities to interact or observe other participants, relationships improved even among those historically opposed to each other such as environmental and forest products groups. Unfortunately, some relationships in the project were strained not because of the shared learning experience but due to limitations of the project such as funding. Though not an explicit goal of SNAMP, participants also learned about the Forest Service and the constraints faced in Sierran forest management that could help improve collaboration with the agency in the future. The shared scientific understandings and the hybrid culture they fostered, combined with the improved relationships between participants and familiarity with the Forest Service, could be the foundation for more productive and continued collaborations in the future. The Forest Service will need to continue to engage intensely with the public in order for the positive trends to continue.

We interpreted our goal of effectiveness as encompassing the collaboration's process or structure as well as the project's ability to accomplish the goals that the literature suggested and participants felt were important for the project to be interpreted as successful. Much of the basic communication structure of the project worked well: the project invested in trained outreach and facilitation staff, meetings were set up to encourage productive discussions, events were evaluated and continually adapted to meet participant suggestions, and a large variety of outreach strategies were implemented and supported for the duration of the project. In addition, the Forest Service treatments were implemented, the academic experiments were completed and this report was drafted, reviewed by peers and the public, and published; those were milestones that were not always assured of completion during the project and now can also be considered examples of SNAMP's effectiveness.

Ultimately, participants in collaborations like SNAMP intend for the project to have far-reaching and broader impacts past the study areas, timeframes, and agencies involved. One agency participant suggested that the most important goal of SNAMP was to create a group of stakeholders prepared to collaborate with the Forest Service and reduce conflict around forest management in the Sierra. The Participation Team worked to exemplify a model process for conducting collaborative adaptive management and training that could be implemented by agencies to hopefully reduce conflict. Though there was almost complete turnover of the Forest Service participants in SNAMP, many of the public, environmental group, forest products, and other agency representatives were able to stick with the project all the way through. A group of stakeholders had formed at the end of the project who had developed long-term relationships with each other, shared common understandings about the resources, and had similar expectations about the process of adaptive management. This modeling and training, combined with the shared understandings and improved relationships between participants, bodes well for future collaboration in the Sierra.

But was SNAMP effective at reducing conflict? A large majority of our email survey participants felt that SNAMP increased trust within the three party model. Yet both email survey respondents and interviewee participants were ambivalent as to the project's ability to reduce conflict over forest management in the Sierra. The dominant sentiment was that appeals and litigation were inevitable because they are driven by the entrenched philosophies and agendas of interest groups. The two solutions offered by email survey respondents were the cornerstones of the SNAMP three party effort: independent science and increased stakeholder participation.

SNAMP's three party model structure was effective in a most critical aspect – the university and its science were seen as independent, unbiased, and responsive to stakeholder input. But with this new model came miscommunications and disappointed expectations. The two biggest issues were the separation between management and science, and financial constraints. Initially, there were disagreements as to what subjects would be studied in SNAMP. Next, some stakeholders and managers hoped that SNAMP would bring university experts into the Forest Service's planning processes, but this was the opposite of what the UC Science Team imagined due to their interpretation of how to conduct a controlled experiment. A related misinterpretation was connected to definitions of monitoring. Some stakeholders expected the university to "blow the whistle" on the Forest Service if it implemented the treatments differently than planned. This too was not the role of the university as interpreted by the UC Science Team. A Neutrality Agreement was created by the UC Science Team to clarify some of these concerns.

The financial structure of the project was a serious challenge to our effectiveness, though not surprising given the dollar amounts and years of commitment. For large scale adaptive management projects, sizeable and consistent funding over many years is vital yet very difficult to achieve (Gregory et al. 2006). The difficulties of carrying out long term projects with federal agencies under an annual funding regime have been well documented (Nelson 1995). In addition, the recession that started in August of 2008, just a few years into the project, caused havoc with state and federal budgets and threw the project into years of financial stress and uncertainty. Throughout the interviews, there were many comments about the tensions within the MOU Partner funding agencies with regard to how much each contributed, staff turnover, as well as a perception that the university did not understand the financial constraints and had unrealistic expectations. Eventually, the project was completed but with less funding and over a longer period of time than originally planned.

In 2015, UC completed its role in SNAMP. It is left to the Forest Service to work directly with stakeholders to use SNAMP's products, results and recommendations, and to adapt them to future needs. How and whether UC Science Team results and public input are used in the next and future forest treatment plans will determine how SNAMP's effectiveness is ultimately seen. Throughout this project, we have considered this a crucial step that is outside of the funded and UC Science Team part of SNAMP (Figure F1 in Appendix F). The SNAMP collaborative adaptive management workshop teachings offer tools for both the public and the agencies to improve their communication to complete the cycle of adaptive management and begin the next cycle of learning.

Participants from all three sides of the three party model concluded the project with positive aspirations for the future. The third party science provider model was well demonstrated and should be transferable in parts or in whole to other situations or places given adequate attention and funding. It is now up to the Forest Service to close the adaptive management loop and for all of us to use the lessons learned from SNAMP to improve collaboration and management of the forests of the Sierra.

> "… we are the beneficiaries of the work and I think that the investments that we made, no one has groused about them. That wasn't the motivator for us. Benefits to the landscape over the long term and over the entire Sierra landscape were our motivators." MOU Partner 2014

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Nelson, R.H. 1995. Public lands and private rights: The failure of scientific management. Landham, MD: Rowman & Littlefield Publishers.