Oregon State University
College of Forestry

Fish and Wildlife Habitat in Managed Forests Research Program

Progress Reports

Nov 17, 2023

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Fish and Wildlife Habitat in Managed Forests

Final Report

Title: Development of native bee identification keys for the Pacific Northwest

Investigators: James W. Rivers and Lincoln R. Best

Objectives:
The overall objective of this project is to develop user-friendly materials that can be used by non-specialists to quickly and accurately identify wild bees of the Pacific Northwest (PNW, covering Oregon and Washington). Available identification aids used for bees in the PNW are specific to other areas and thus include groups that are irrelevant to this region and confuse identification, rely heavily on arcane taxonomic jargon unfamiliar to novices, and make use of idealized drawings to highlight features that are often unrepresentative of what is observed on real-world specimens. Therefore, our approach is to take existing information regarding bees and create identification materials that leverage ongoing work and expertise from the Oregon Bee Project to develop (1) a generic-level key for bees that are found within the PNW region, and (2) sex-specific species-level keys for all bumble bee (*Bombus*) species that are found within the PNW region.

Summary of Accomplishments toward Objectives:
During the last calendar year we completed study objectives by producing the following products:

1. Key to the bee genera of the PNW; 70 couplets diagnosing 60 genera (Modified from Michener, McGinley, and Danforth 1994. The bee genera of North and Central America).
2. Key to the female *Bombus* species of the PNW; 26 couplets diagnosing 27 species. (Modified from Williams *et al* 2014. Bumble bees of North America: An identification guide)
3. Key to the male *Bombus* species of the PNW; 26 couplets diagnosing 27 species (Modified from Williams *et al* 2014. Bumble bees of North America: An identification guide)

These keys have been vetted by participants in the OSU Master Melittologist program and by participants attending the intermediate and advanced offering of the Oregon Bee School taxonomy courses during the summer and fall of 2023. Language, figures, and key architecture were refined iteratively based on the thoughtful feedback of these students. Additional comments by Dr. Paul Williams (Natural History Museum, London) and other experts improved the overall quality and technical aspects of the resources.

In the course of creating the keys, we have co-produced 292 edited stacked images with Joshua Dunlap at the Oregon Department of Agriculture and August Jackson that are available to teachers, researchers, and extension personnel for use in teaching, research and outreach presentations.

Problems and Barriers:
Complications arising from COVID-19 produced significant barriers that initially impeded progress to our initial timeline. These barriers necessitated a no-cost extension to September 30, 2023, but no additional barriers were experienced in project completion.

List of names and brief overview of graduate and/or undergraduate engagement in project:
No graduate or undergraduate students were directly engaged in the project. However, Ph.D. student Scott Mitchell (Dept. Fisheries, Wildlife, and Conservation Sciences, Oregon State University) will be giving a workshop on pollinator ecology and natural history at for the February 2024 meeting of the Oregon Chapter of The Wildlife Society and will demonstrate use of the keys during his workshop.

List of Presentations, Posters etc.:

1. Best presented an overview of the keys to 30 students in the OSU Master Melittologist program Oregon Bee School intermediate and advanced courses, and to 22 online attendees to the Master Melittologist program monthly Out-of-State Seminar. Additionally, the resources were distributed via the Master Melittologist program listserv to 446 registrants.

2. Rivers is co-organizing a pollinator symposium for the February 2024 meeting of the Oregon Chapter of The Wildlife Society, and he will give a presentation focused on the construction and use of the keys. This will include having hard copies available at the Oregon Forest Resources Institute (OFRI) table, as this group will be helping with distribution of the keys. As noted above, the keys will also be incorporated into a workshop given by Ph.D. student Soctt Mitchell on bee ecology and natural history at the same event.

3. In addition to the 2024 meeting of the Oregon Chapter of The Wildlife Society, collaborators from ORFI will be sharing information about keys and disseminating hard copies at the Oregon Society of American Foresters Annual Meeting in May 2024 and at the Oregon Family Forests Convention in June 2024.

4. Rivers is working with the Society for American Foresters to organize a webinar series regarding bees in managed forests for the 2024 calendar year and he plans to share the keys via that venue.

List of Publications, Thesis Citations:

1. Best, L.R., Dunlap, J., Jackson, A., Rivers, J., & Williams, P.H. (2023). *Bees of the Pacific Northwest: Key to bumble bee (Hymenoptera: Bombus) species for females.* v1.0., October 2023. Fish and Wildlife Habitat in Managed Forests Research Program, Oregon State University, Corvallis, Oregon.

2. Best, L.R., Dunlap, J., Jackson, A., Rivers, J., & Williams, P.H. (2023). *Bees of the Pacific Northwest: Key to bumble bee (Hymenoptera: Bombus) species for males.* v1.0, October 2023. Fish and Wildlife Habitat in Managed Forests Research Program, Oregon State University, Corvallis, Oregon.

3. Best, L.R., Dunlap, J., Jackson, A., & Rivers, J. (2023). *Bees of the Pacific Northwest: Key to Genera (Hymenoptera: Anthophila).* v1.0, October 2023. Fish and Wildlife Habitat in Managed Forests Research Program, Oregon State University, Corvallis, Oregon.

Copies of the identification keys can be accessed via this link.

Fish and Wildlife Habitat in Managed Forests

Final Report

Title: Multi-scale Habitat Value of Slash Piles for Conserving Rare Carnivores

Investigators: Dr. John Bailey and Dr. Katie Moriarty **Master's Student**: Jordan Ellison

Objectives:

1. Document martens and fishers visiting slash piles. Due to the previously documented avoidance of openings by both martens and fishers (Moriarty et al. 2015, Moriarty et al. 2016, Martin et al. 2019), our first goal is to establish whether martens or fishers will enter clear cuts to visit slash piles, and evaluate whether those visits have any relationship to the time since the stand was harvested, how much vegetation cover is present in the stand, or the distance from the forest edge.
2. Generate estimates of small mammal abundance, diversity, and energetic biomass at slash piles and in the surrounding landscape. One possible benefit of slash piles for martens and fishers is the potential for slash piles to increase habitat for small mammals, which constitute a large proportion of marten and fisher diets (Golightly et al. 2006, Slauson and Zielinski 2017, Eriksson et al. 2019, Parsons et al. 2020). If small mammal populations are increased by the presence of slash piles, piles may represent a year-round foraging resource for martens and fishers.
3. Model effects on surface fire behavior with the occurrence of slash piles. Creation and subsequent removal of slash piles is used as a fuel reduction treatment in recently harvested stands. There may be wildlife value in retaining piles, but that value may not be a long-term benefit if piles considerably increase the risk of severe wildfire. We will assess the degree to which pile size, composition, and distribution influence the likelihood of more intense wildlife behavior.

Summary of Accomplishments toward Objectives:

We have surveyed in 69 stands in coastal northern California and 9 stands southern Oregon. Our focal efforts were in northern California because piles were largely not removed over a period of 15 years, allowing us to evaluate both pile size and age. All results presented here are preliminary and subject to change.

Objective 1: Pile detections

During the 2020 and 2021 season, field teams deployed 354 remote cameras in 69 stands in northern California (Figure 1), collecting >1.6 million images. Camera sample units consisted of two sets of cameras: three cameras placed on a single slash pile within the clear-cut, and two cameras placed in the adjacent forest. Fishers were detected either in or adjacent to 59 stands and were detected at the slash pile in 35 of those stands. Martens were detected in eight stands, including one detection at a slash pile. Following the completion of remote camera surveys, we reviewed images using the photo-tagging software *Timelapse*, completed October 2022. We are using a generalized linear mixed modeling

approach using a Binomial distribution with a logit link to evaluate the effect of stand and pile characteristics on the likelihood of detecting a fisher at a slash pile. Using daily detection/non-detection (1/0) of fishers at slash piles as our response, we fit a model with the following covariates used as fixed effects: Distance from nearest forest edge (DistFromOLDF), the age of the pile (PileAge), the approximate volume of the pile (ApproxVol), estimated mean shrub cover in the stand (meancov), season, and a binary variable representing whether a fisher was detected in the adjacent stand.

We fit the GLMM using detections for individual days as the response (1/0), as with a Bernoulli distribution. We used StandID and Date as random effects in the model. StandID serves to group all daily observations within the same stand, and Date groups observations within a single day but across all stands. Martens were not included in analyses due to too few detections, as we cannot assume that martens and fishers would be detected at piles under identical conditions. These analyses are anticipated to be completed within the coming weeks and final results will be available by the end of Fall term.

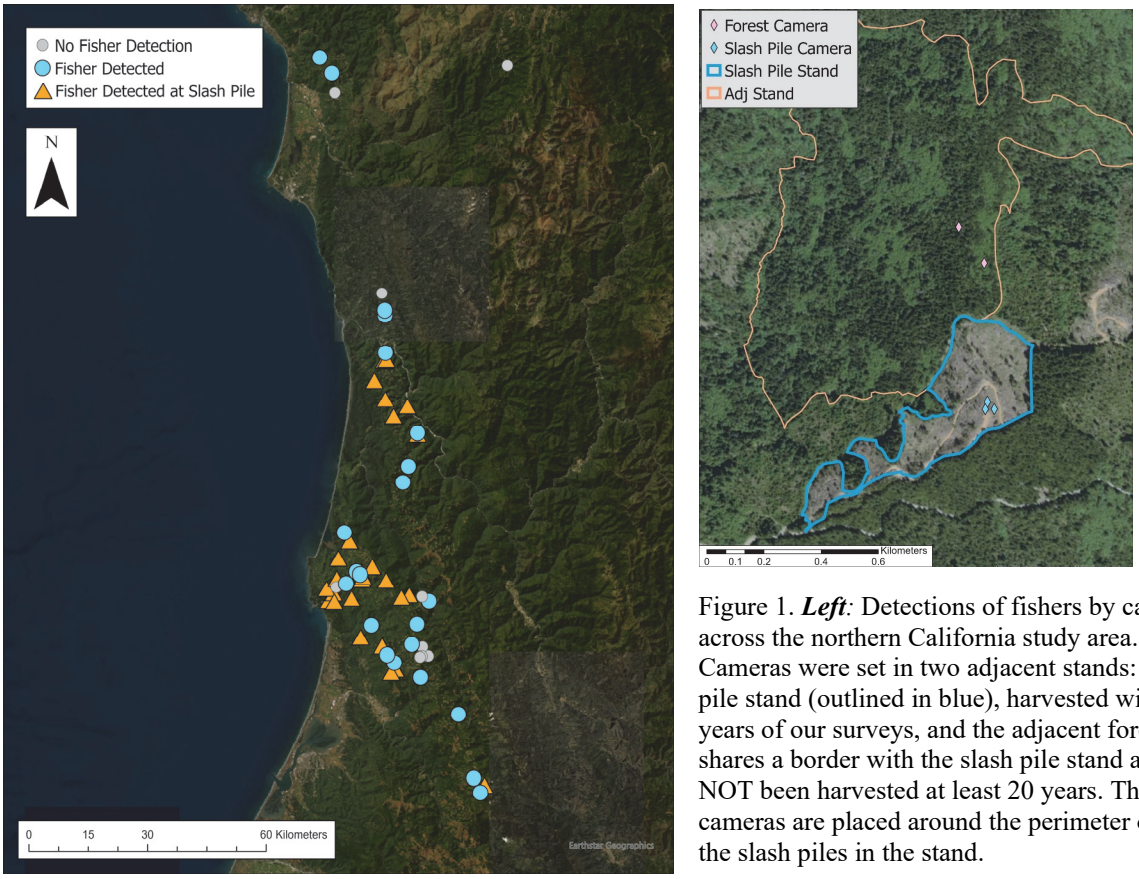

Figure 1. ***Left****:* Detections of fishers by camera across the northern California study area. ***Right****:* Cameras were set in two adjacent stands: the slash pile stand (outlined in blue), harvested within 15 years of our surveys, and the adjacent forest, which shares a border with the slash pile stand and has NOT been harvested at least 20 years. The slash pile cameras are placed around the perimeter of **one** of the slash piles in the stand.

Scat detection dog teams, from Rogue Detection Teams, surveyed 8 stands in southwest Oregon and collected 19 carnivore scat samples, but none were genetically verified as either marten or fisher. In California, teams surveyed 45 stands and collected 144 carnivore scat samples, with 60 samples from 26 stands genetically confirmed as fisher.

Table 1. Mean values and standard deviations of model variables relative to whether or not a fisher was detected at the slash pile.

	All *(mean ± sd)*	**Non-Detections** *(mean ± sd)*	**Detections** *(mean ± sd)*
Mean Shrub Cover (%)	55.77 ± 20.14	55.65 ± 20.16	62.80 ± 17.22
Pile Age (years)	3.96 ± 3.64	3.93 ± 3.63	5.73 ± 4.00
Approx Pile Volume (m^3)	367.33 ± 327.93	368.13 ± 328.18	318.38 ± 309.62
Distance to Forest Edge (m)	28.97 ± 17.42	28.89 ± 17.37	34.06 ± 19.34

Table 2. Total number of survey days and number of unique days with fisher detections, by season

	Total survey days	**Detections**	**Non-detections**	**Proportion** (Detections/Total Days)
Summer *May - Sept 20*	2379	16	2363	0.007
Fall/Winter *Sept 21 - March*	3443	78	3365	0.02

Objective 2: Small mammals

To address the objective of small-mammal use of piles, we conducted 18 trapping replicates with 3 trap 'webs' per replicate, capturing 946 individual small mammals. Our trap webs had an approximately equal number of Sherman, Tomahawk, and Longworth traps with an average of 75 traps per web. A replicate consisted of:

1. A pile stratified by size and age
2. A geographically independent stand without piles or region within the same larger stand away from piles.
3. A forest stand >20 years that shares a border with the stand that contains the slash pile.
4. We are using these data to evaluate potential differences in small mammal abundance, diversity, and/or biomass at slash piles relative to the surrounding landscape (Figure 2).

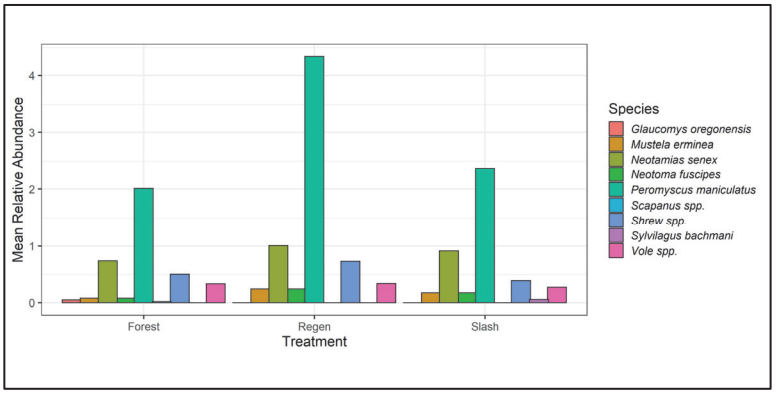

Figure 2. Relative abundances of small mammal species at sampled slash piles, by pile age group.

Objective 3: Fire modeling

We conducted vegetation and woody debris sampling at three randomly selected points in all surveyed stands, with a higher effort in a subset of the surveyed stands in California and southern Oregon (funded by fisher CCAA) for modeling surface fire behavior. Ten piles were randomly selected from aerial imagery. In southern Oregon, we completed vegetation, woody debris, and slash pile sampling in 9 stands on recently harvested private ownerships in the range of both fishers and martens. Fire modeling is being completed using the program Fuel and Fire Tools (FFT). Pile sizes (Table 3) and compositions were highly variable, both within and between stands and across both study areas. High variability between slash piles is likely typical in many places, as slash piles are most often placed based on convenience and some logistical constraints. For instance, piles cannot be created on slopes greater than 40%, so stands that are steeper will generally have fewer piles.

Table 3. Mean pile sizes for stands where higher effort surveys were conducted. Piles estimated as half-ellipsoids.

California Stands

StandID	*n*	*Mean Pile Volume ± sd (m^3)*	*Range*
TRIN-B368	6	557.50 ± 324.51	190.85 - 980.18
TRIN-B378	10	358.74 ± 263.62	120.64 - 945.1
TRIN-B382	10	295.78 ± 218.80	45.96 - 622.04
TRIN-B395	10	269.53 ± 154.78	65.97 - 603.19
TRIN-B412	9	356.63 ± 328.18	14.14 - 963.42
KLAM-B463	10	554.02 ± 496.08	102.1 - 1466.08
BLLK-P322	10	777.78 ± 270.59	452.39 - 1183.86
KLAM-P422	10	964.14 ± 547.79	335.1 - 2019.52
KLAM-P423	1	565.13	565.13
KLAM-P455	4	929.18 ± 981.41	271.43 - 2387.61

Oregon Stands

StandID	*n*	*Mean Pile Volume ± sd (m^3)*	*Range*
Ray15	10	634.03 ± 719.63	49.48 - 2384.47
Ray19	10	500.2 ± 725.16	100.79 - 2526.15
Ray20	10	328.33 ± 368.24	73.3 - 1083.85
Ray22	10	267.44 ± 141.41	85.03 - 571.77
Ray23	10	163.62 ± 124.05	43.98 - 376.99
Ray25	10	368.43 ± 530.17	37.7 - 1806.42
Ray26	10	225.87 ± 118.20	73.72 - 439.82
Ray27	10	171.53 ± 77.92	73.3 - 293.74
Ray28	10	276.83 ± 179.95	70.69 - 604.76

Problems and Barriers:

The *Fuel and Fire* Tools does include an option to incorporate slash piles as a part of a given fuel bed, but outputs for slash piles in this program do not yet include fire behavior metrics. As far as we are aware, there are no other programs that currently provide fire behavior estimates.

Opportunities to survey slash piles within Oregon are limited given that landowners remove piles shortly following a harvest, in some cases within the same year that they were created. This practice is common in Oregon but is a contrast with survey opportunities in our California study area, where piles have largely been retained over time. Due to this difference in practices, we will be unable to examine how slash pile conditions change over time in Oregon.

Additionally, to meet our objectives regarding fisher and marten use, our surveys were limited to within or near to their current known distributions. Much of the area most likely to contain both slash piles and be occupied by martens or fishers in southwest Oregon are on private lands, and thus we were additionally limited by the willingness of landowners to collaborate in the study. We thank Green Diamond Resource Company and Rayonier for their collaboration.

Planned Work:

We expect to complete fire behavior modeling and data analysis in the coming months, and these results will be available following Jordan's MS thesis defense, anticipated by the end of Fall term 2023. Final results for small mammal analyses anticipated during 2024.

List of names and brief overview of graduate and/or undergraduate engagement in project:

Jordan Ellison, MS student in Forest Engineering and Resource Management, will be completing her thesis using the data from this project. We received a scholarship for a Humboldt State undergraduate to intern on the project as a field technician (Shalom Fletcher). Jordan has trained and remotely mentored 6 additional undergraduates (Sandy Diaz, Alanna Garcia, Kelly Johnson, Sabrina Ott, Anna Schwecke, Louis Salas) to process the photographs from the 2020 field season. Two of these individuals (Alanna Garcia and Shalom Fletcher) have completed undergraduate senior theses using these data.

List of Presentations, Posters etc.:

J.L. Ellison, K.M. Moriarty, A. Larsen-Gray, J.D. Bailey. 2021. Conservation value of slash piles for Pacific martens (*Martes caurina*) and Pacific fishers (*Pekania pennanti*). 68th Annual Meeting of the Western Section of The Wildlife Society. Virtual, recorded.

J.L. Ellison, J.D. Bailey, K.M. Moriarty, A. Larsen-Gray. 2021. Investigating the conservation value of slash piles for Pacific martens and fishers. Western Forestry Graduate Research Symposium. College of Forestry.

J.L. Ellison, K.M. Moriarty, A. Larsen-Gray, J.D. Bailey. 2022. A research update investigating the conservation value of slash piles for Pacific martens (*Martes caurina*) and fishers (*Pekania pennanti*). Annual Meeting of the Oregon Chapter of The Wildlife Society. Newport, Oregon.

J.L. Ellison, K.M. Moriarty, A. Larsen-Gray, L.M. Ellsworth, J.D. Bailey. 2022. Conservation value of slash piles for Pacific martens and fishers. Annual Meeting of the Wildlife Society. Spokane, Washington.

List of Publications, Thesis Citations: (December 2023)

Literature cited

Eriksson, C. E., K. M. Moriarty, M. A. Linnell, and T. Levi. 2019. Biotic factors influencing the unexpected distribution of a Humboldt marten (*Martes caurina humboldtensis*) population in a young coastal forest. PLoS One **14**:e0214653.

Golightly, R. T., T. F. Penland, W. J. Zielinksi, and J. M. Higley. 2006. Fisher diet in the Klamath/North Coast bioregion. Humboldt State University, Arcata, CA.

Martin, M. E., K. M. Moriarty, and J. N. Pauli. 2019. Forest structure and snow depth alter the movement patterns and subsequent expenditures of a forest carnivore, the Pacific marten. Oikos **129**:356-366.

Moriarty, K. M., C. W. Epps, M. G. Betts, D. J. Hance, J. D. Bailey, and W. J. Zielinski. 2015. Experimental evidence that simplified forest structure interacts with snow cover to influence functional connectivity for Pacific martens. Landscape Ecology **30**:1865-1877.

Moriarty, K. M., C. W. Epps, and W. J. Zielinski. 2016. Forest thinning changes movement patterns and habitat use by Pacific marten. The Journal of Wildlife Management **80**:621-633.

Parsons, M. A., J. C. Lewis, J. N. Pauli, T. Chestnut, J. I. Ransom, D. O. Werntz, and L. R. Prugh. 2020. Prey of reintroduced fishers and their habitat relationships in the Cascades Range, Washington. Forest Ecology and Management **460**.

Slauson, K. M., and W. J. Zielinski. 2017. Seasonal specialization in diet of the Humboldt marten (*Martes caurina humboldtensis*) in California and the importance of prey size. Journal of Mammalogy **98**:1697-1708.

Fish and Wildlife Habitat in Managed Forests

Final Report

Title: Red Tree Voles in Working Forests

Investigators: John Bailey, Katie Moriarty

Objectives:

- Quantify relative abundance of red tree vole nests across stand ages and distance from old forest
- Quantify detection rates of red tree vole nests across a range of stand ages
- Estimate nest density within stands that differ in age and distance from older forests
- Estimate red tree vole nest status (e.g. old, occupied, recently occupied) and use by other arboreal mammals
- Estimate nest persistence during the study; create framework for long-term evaluation (e.g., 10 years)
- Quantify red tree vole local colonization and extirpation rates across stand age

Summary of Accomplishments toward Objectives:

During the course of the study (from 2019 to 2022) we surveyed a total of 63 stands stratified across varying age classes and distance from the nearest patch of old forest (Table 1). We surveyed 13 stands each year for 4 years, 20 stands each year for 3 years, 12 stands each year for 2 years, and 18 stands for 1 year. We surveyed a total of 6557 trees and 1044 arboreal nests. Of the 1044 nests, 564 were either old or recently occupied tree vole nests.

Table 1: Stand stratification

	Age Class					
	20-29	30-39	40-49	50-59	60-79	80+
0-1km from OF	13	11	6	6	2	9
1-5km from OF	4	4	3	3	2	
Total	**17**	**15**	**9**	**9**	**4**	**9**

We evaluated nest persistence using a known-fate survival model including main covariates for stand age, and nest size Tree vole nest persistence was dependent on both stand age and nest size. Tree vole nests in forests >80yrs exhibited higher probability of persistence year-to-year than tree vole nests in forests <80yrs. Annual persistence probability was also positively correlated with nest volume (Piasecki 2023 Figure 2.6).

We conducted double-sampling in 80 plots across 15 stands to evaluate the detection rates of arboreal nests in young forest. We used a Huggins p and c modeling framework and estimated a detection rate of 84% when implementing ground-based surveys for arboreal nests in young forests (<60yrs). We evaluated detection rates in old forest (>80yrs) through census surveys which we conducted in 9 plots across 3 stands. Using the Lincoln-Peterson estimator, we estimated detection rates in old forest to be 5%.

We used presence/absence data (based on signs of recent tree vole occupancy) from arboreal nests to evaluate tree vole occupancy probability in forests <80yrs across stand age and distance from the nearest old forest. We used a single-season occupancy framework and substituted spatial replicates for temporal replicates. After adjusting for bias, we estimated occupancy probability to be highest in the 20 year age class (0.5, 95% CI 0.01, 0.67), and lowest between the 50 and 80 year age classes (0.0, 95% CI 0.0, 0.4) (Piasecki 2023 Figure 3.9). Our model also suggested that tree vole occupancy probability nears zero in

stands beyond 1425m from the nearest patch of old forest (Piasecki 2023 Figure 3.10).

Using our estimates of detection rates for arboreal nests, which include tree vole nests, we estimated tree vole nest density in 45 stands that were within 1425m from the nearest patch of old forest. We found the density of recently occupied tree vole nests to be locally high in the 30 year age class (1.24 per ha, SD = 0.35) and overall highest in the 80 year age class (53.5 per ha, SD = 14.9) (Piasecki 2023 Table 3.14).

In 2022, which was the year with the highest sample size of both stands (n = 53) and nests surveyed (n = 801), we recorded signs of red tree vole activity (both old and recent) in 40 stands and observed colonization and extirpation of red tree vole nests in 20 stands. Tree vole nests were larger in young forest than in old forest (Kruskal-Wallis Rank Sum $p < 0.001$). Tree vole nest construction also showed significant preference for trees with higher structural complexity (in tree structures per tree) across all age classes except 60yrs (ANOVA $p < 0.01$) (Figure 1). In young forest, tree vole nests were commonly found in association with nests constructed by other arboreal species, 43% of which were originally constructed by Humboldt's flying squirrel. Conversely, 30% of pre-existing tree vole nests were found to be recolonized by Humboldt's flying squirrel, suggesting possible competition for nesting space (Piasecki 2023 Table 2.10). Tree vole nests in old forest (>80yr) were typically small in size, constructed mainly in cavities and under moss mats, and were not found in association with nests of other arboreal species (Figure 2).

Figure 1: Large tree vole nest in a broom defect. Stand age: 27 years

Figure 2: Small tree vole nest under a moss mat. Stand age: 320 years

We successfully implemented our protocol for live capturing and marking red tree voles to determine tree vole density in young forests. We captured 28 voles across 8 stands primarily in the 20 and 30 year age classes with one opportunistic capture in the 80 year age class. We found pregnant females and both pre and post-dispersal juvenile voles at nests in young forest (Figure 4). This suggests tree voles are successfully mating and reproducing although questions surrounding juvenile dispersal remain unanswered. Unique fur clip patterns are used to later identify individuals with nest camera footage (Figure 5).

Figure 4: Juvenile tree vole with fur clip

Figure 5: Nest camera photo of fur clipped adult female tree vole

Problems and Barriers: Because of their dependency on the forest canopy and cryptic nesting behavior, red tree voles are difficult to study and require both ground surveying and tree climbing to confirm tree vole activity. Our work employs multiple survey methodologies to locate, identify, and collect data on red tree vole nests and nests of other arboreal species. Another difficulty lies in capturing colonization events. This is extremely challenging because it is almost impossible to determine when and where a tree vole will build/colonize a nest. Despite this challenge, we have been fortunate enough to capture nest camera footage of red tree voles colonizing pre-existing nests although the amount of effort required is substantial. Of the 111 cameras installed in 2021, only 2 captured tree vole colonization events.

Planned Work:

List of names and brief overview of graduate and/or undergraduate engagement in project: Jason Piasecki – Thesis research

List of Presentations, Posters etc.: Red Tree Vole Working Group 2019, 2020, 2021; TWS-Western Section 2021; WFGRS 2021; TWS-Western Section 2022; TWS-OR 2022; TWS National Conference 2022 (1 talk, 3 posters); TWS-OR 2023; Masters Thesis defended August 7, 2023.

List of Publications, Thesis Citations: Piasecki et al. 2022 – USFWS research report; Piasecki 2023 – Masters Thesis. **Proposed Publications:** Piasecki et al. – The influence of forest age and nest size on red tree vole nest persistence and interspecific nest use, ***Stacks Journal*****;** Piasecki et al. – Detectability and assessing occupancy for an elusive arboreal mammal, ***Forest Ecology and Management***

Fish and Wildlife Habitat in Managed Forests
Progress Report

Title: Where is the most effective to restore streams? Salmon Habitat Restoration using Large Wood: Linking Stream Geomorphic Change and Restoration Effectiveness

Investigators: Madelyn Maffia (PhD. Student), Catalina Segura, FERM (PI), Eric Suring, ODWF (Co-Pi), and Christopher Lorion, ODFW (Co-Pi)

Objectives:

1. Assess the stability/resilience of the fish habitat changes observed 1-yr post Large Wood (LW) restoration to changes observed 6-yrs post restoration.
2. Investigate the geomorphological changes triggered by LW restoration in three reaches based on the comparison of annual topographic surveys conducted 1-yr pre- to 5-yrs post-restoration.
3. Assess the stability of LW structures at the basin scale by comparing wood surveys conducted between 2016 and 2021.
4. Investigate the relationship between local and basin scale habitat/geomorphic metrics and fish population response after the restoration in the context of long-term fish population data.

Summary of Accomplishments toward Objectives:

1. Assess the stability/resilience of the fish habitat changes observed 1-yr post-LW restoration to changes observed 6-yrs post restoration: We have completed the calibration process for all three models and conducted full hydrograph simulations at all three sites. Our next focus is on in-depth analysis of the shear stress data to gain insights into how sediment stability impacts the categorization of habitats as desirable, survivable, or undesirable, particularly in relation to the velocity data. To provide further detail, we have:

- Topographic surveys at a submeter resolution were conducted at each of the three reaches. These surveys were interpolated into surfaces and used as the boundary condition in the hydraulic model.
- Grain patches were identified and estimated for grain size to improve the accuracy of surface roughness for the hydraulic model.
- Stream velocity and stage data were collected during 13 visits to the sites during high-flow events to build rating curves for each of the three sites. Special emphasis has been given to high flows considering we are particularly interested in modeling peak flows. The stage data collected at different flow sizes was used to generate water surface elevation across each reach for the model calibration.
- We have modeled bankfull conditions in Sites 1, 2, and 3 using the Nays2DH, an unsteady quasi-3-dimensional hydraulic model. The modeling has been conducted under the same modeling framework used in the 1-yr post restoration study conducted at the same sites (Bair et al., 2018).
- Findings:
    - Sites 1, 2, and 3 reduced and maintained the amount of undesirable habitat (velocity>1m/s) 6 years after the LW introductions (Figure 1).
    - Although modeled flow was variable between the 2014, 2016, and 2021, the distributions of velocity indicate that the created desirable (velocity<0.5m/s) and survivable (0.5m/s<velocity<1m/s) habitat in 2016 was maintained through 2021 (Figure 1).

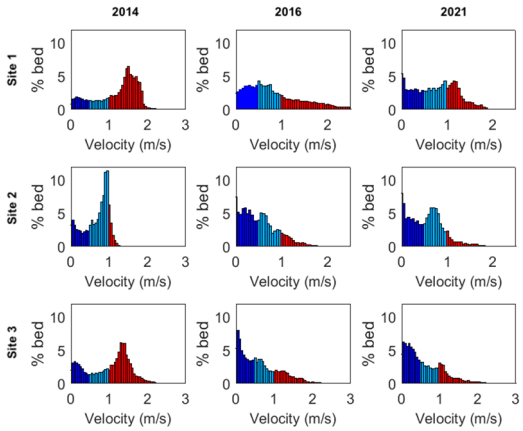

Figure 1. Distribution of velocity values after time for each of the reaches. Colors correspond to thresholds of velocity relevant to the ability of juvenile coho salmon to maintain position in the stream: dark blue: v<v-crit, where v-crit = 0.5m/s, light blues: v-cri<v<v-burst where v-burst = 1 m/s, and red: v>v-burst.

2. Investigate the geomorphological changes triggered by LW restoration in three reaches based on the comparison of annual topographic surveys conducted 1-yr pre- and 5-yrs post-restoration. We have successfully finished the fieldwork and data analysis for this objective and are currently in the advanced stages of manuscript preparation. To elaborate further, we have:

- Completed annual cross-section topographic surveys with a Nikon Total Station within each reach from 2014 to 2021.
- Conducted pebble count surveys at each cross section in all three sites from 2014 to 2021.
- Interpolated annual cross-sectional profiles to quantify annual reach-scale geometric changes in scour, deposition, total change, and net change and site characteristics such as average width, depth, cross-sectional area, and hydraulic radius.
- Analyzed instream changes over time and at variable scales (reach and cross-section scale) to understand how LW restoration efforts in stream of variable characteristics impact geomorphic processes and sediment dynamics.
- Findings:
    - Smaller sites underwent increased changes compared to the larger sites (Figure 2).
    - Locations of increased scouring correlated to LW locations (Figure 2).
    - Locations of increased deposition were often downstream of locations of increased scouring, highlighting the connected interplay of scour and deposition (Figure 3).
    - LW structures that occupy between 35–52% of the stream elicit a maximized amount of scouring.

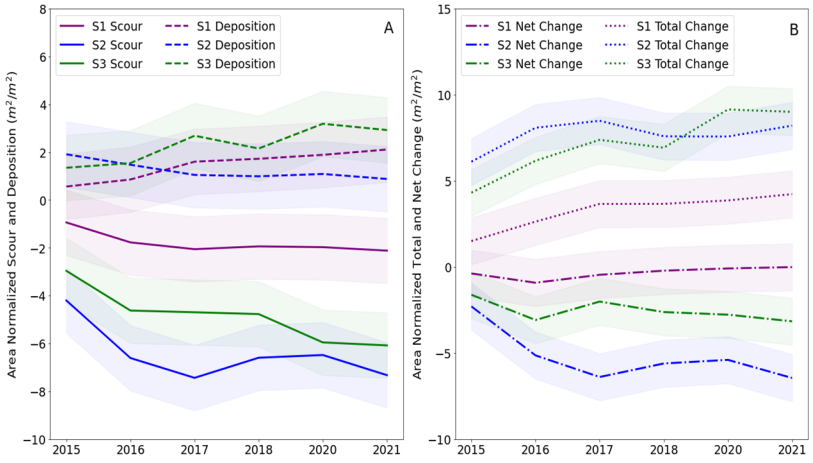

Figure 2. A) Mean reach cross-sectional sediment scour (m^2) and deposition (m^2) normalized by the cross-sectional area (m^2). B) Mean reach sum of cross-sectional net change (m^2) and total change (m^2) normalized by the cross-sectional area (m^2). Error bands represent one standard deviation away from the mean value.

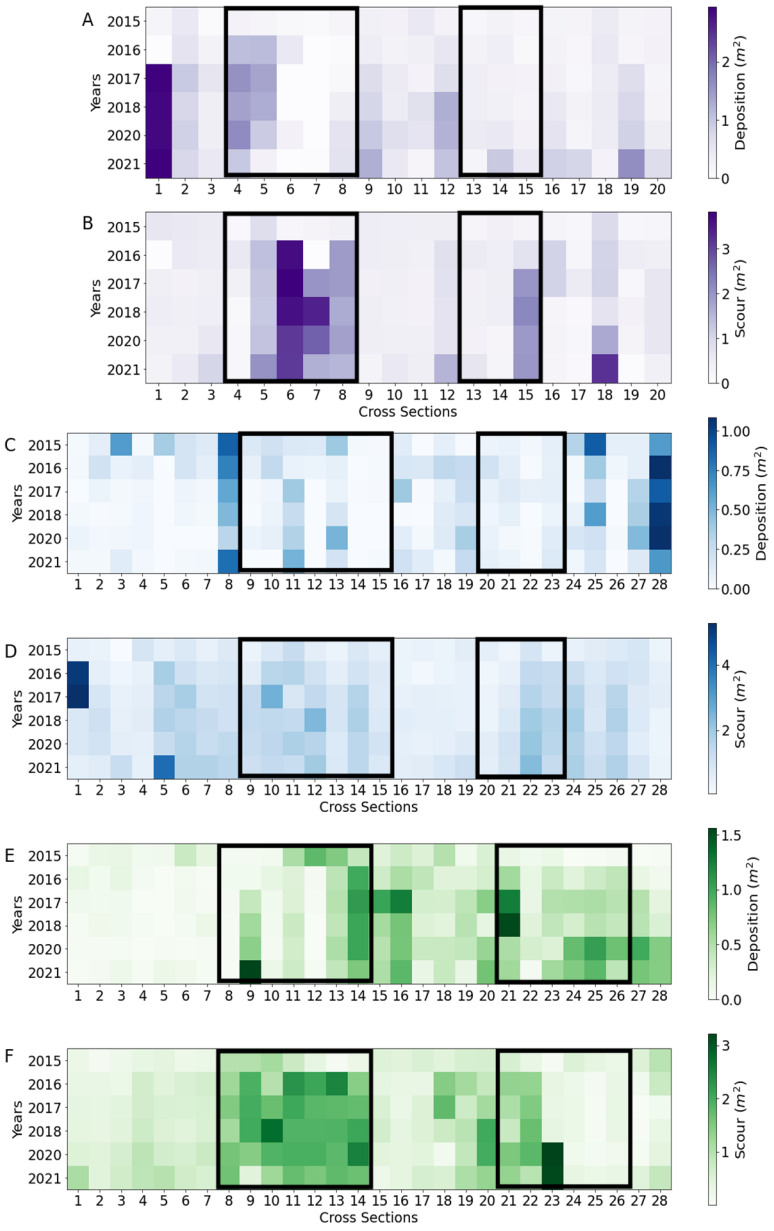

Figure 3. A and B) Annual cross-sectional area-normalized deposition (m^2/m^2) and scour (m^2/m^2) in Site 1 from 2015–2021. C and D) Annual cross-sectional area-normalized deposition (m^2/m^2) and scour (m^2/m^2) in Site 2 from 2015–2021 and E and F) Annual cross-sectional area-normalized deposition (m^2/m^2) and scour (m^2/m^2) in Site 3 from 2015–2021. Black outlines show the locations of the two logjams in each site. Darker colors signify more geomorphic change than lighter colors.

3. Assess the stability of LW structures at the basin scale by comparing wood surveys conducted between 2016 and 2021. Exploring the stability of large wood within each reach provides valuable insights into the longevity of the restoration efforts and the residence time of these structures. We have conducted surveys to track the specific locations of each individual wood piece from 2015 to 2021, offering a comprehensive view of the fate of the jam configurations at the reach scale. Our ongoing efforts to quantify the stability of the LW structures at each site involve:

- Mapped the location of each large wood structure in 2015, 2018, and 2021.
- Examining the relationship between LW movement, stream alterations, and mass wasting events.
- Attempting to extend these efforts to the basin scale.
- Findings:
    - LW structures showed increased stability in the smallest site.
    - LW structures placed in stream bends or places of curvature showed to have the least amount of downstream movement.

4. Investigate the relationship between local and basin scale habitat/geomorphic metrics and fish population response after the restoration in the context of long-term fish population data. We are working with Oregon Department of Fish and Wildlife to investigate the response of native Coho salmon populations. In an effort to satisfy this objective we have complete:

- Assisted in conducting electrofishing surveys with the Oregon Department of Fish and Wildlife (ODFW) in the Mill Creek basin during the 2020 fall season.
- Obtained smolt production data for both the treatment (Mill Creek) and reference (Lobster Creek) basins.
- Findings:
    - Overall, LW introductions appear to improve smolt production by 98% in the Mill Creek Basin relative to the Lobster Creek Basin (Figure 4).

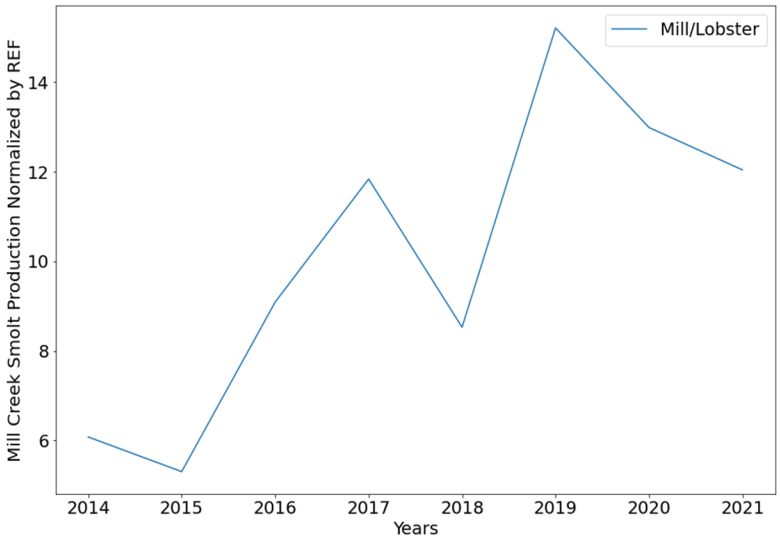

Figure 4. Fish production ratio of restored Mill Creek to unrestored Lobster Creek from 2014 (before the LW introduction) to 2021(6 years after the LW introduction).

Problems and Barriers:

Focusing on peak flow events poses several challenges related to equipment and safety. While we anchor our in-stream equipment to prevent damage or loss, the unpredictable nature and magnitude of storm events can still be a risk. Obtaining the desired peak flow data requires in-stream measurements, which can be hazardous for our students. Safety is a top priority in the Segura Lab, so data collection during large storm events is not always feasible, resulting in missed opportunities to capture higher predictive streamflow values on the rating curves.

Furthermore, the long duration of this research project has introduced unforeseen difficulties. Data collection involving multiple cohorts of students has led to issues with file notation and data organization. We've also encountered challenges in fulfilling the third objective due to data not meeting our desired level of precision. Extrapolating large wood (LW) movement and stability to the basin scale has proven more challenging than expected, mainly because of inadequate documentation of LW locations dating back to 2015.

Additionally, the turnover of personnel and equipment at the Oregon Department of Fish and Wildlife (ODFW) has presented a significant challenge for our fourth objective. Bringing new team members up to speed and dealing with data loss during equipment transitions have required additional training time and caused delays in our efforts.

Planned Work:

For the first objective we need do analyze changes in sediment stability across the three reaches using the shear stress model data. To complete the second objective we need to finalize the manuscript for publication, which is anticipated to be by year-end. For the third objective, we need to scale up the

analysis to the basin scale. And lastly, for the fourth objective we need to continue analyzing data from 2014 to 2021 to identify patterns and explanations for coho salmon population changes.

List of names and brief overview of graduate and/or undergraduate engagement in project: Madelyn Maffia is a third-year PhD student in the Water Resources Science Program, leading this research effort. She has been supported by a team of dedicated field technicians, including Melissa Mauk, Ellen Luedloff, Sydney Anderson, Chris Neihof, and Will Potter, all of whom are pursuing studies under the College of Forestry (CoF) at Oregon State University (OSU). Furthermore, the project received valuable contributions from fellow graduate students Jonah Nicholas, Cedric Piemont, and Jaime Ortega, also from the CoF, who aided in collecting data on peak flow velocity and depth during the Fall of 2021. Michal Tutka, a graduate student in the Department of Biological and Ecological Engineering, advised by Dr. Desiree Tullos, collaborated with the team to investigate the impact of large wood (LW) on flow depth and velocities, particularly in relation to varying log jam orientations at the same research sites. It's worth noting that Michal recently completed his Master's degree after successfully wrapping up his project.

List of Presentations, Posters etc.:

- Maffia, M.M., Segura, C., Suring, E., Longevity of Large Wood Restoration Success to Improve Coho Salmon Habitat: A 2D Modeling Approach. Western Forestry Graduate Research Symposium. April 14, 2023. Corvallis, Oregon.
- Maffia, M.M., Segura, C., Suring, E., Longevity of Large Wood Restoration Success to Improve Coho Salmon Habitat: A 2D Modeling Approach. 14th Annual Pacific Northwest Water Research Symposium. April 20-23, 2023. Corvallis, Oregon.
- Maffia, M.M., Warren, D., Segura, C., Swartz, A. Parsing drought effects of elevated temperature and decreased flow on two apex predators in an Oregon headwater stream. H.J. Andrews Graduate Student Symposium. April 7, 2023. Corvallis, Oregon.
- Maffia, M.M., Segura, C., Suring, E., Longevity of Large Wood Restoration Success to Improve Coho Salmon Habitat: A 2D Modeling Approach. 2022 American Geophysical Union. December 11-16, 2022. Chicago, Illinois.
- Tutka, M., Tullos, D.D., Segura, C., Maffia, M.M. Large wood hydraulics: Using structure from motion to estimate flood depths. 2022 American Geophysical Union. Dec. 11-16, 2022. Chicago, Illinois.
- Maffia, M.M., Segura, C. Restoration Success of Large Wood Introductions on Juvenile Coho Salmon Populations. 2022 ODFW Salmonid Life Cycle Monitoring Symposium. June 8, 2022. Corvallis, Oregon.

List of Publications, Thesis Citations: We anticipate three papers:

- Maffia, Segura, Warren, Suring, Yager, Bair. Restoring Streams with Large Wood: An Analysis of Geomorphic Changes 7 Years Post-Restoration in Streams of Differing Size; to be submitted to Geomorphology or Earth Surface Processes and Landforms in 2023.
- Maffia, Segura, Suring. Longevity of Large Wood Restoration Success to Improve Coho Salmon Habitat: A 2D Modeling Approach; to be submitted to Earth Surface Dynamics in 2024.
- Maffia, Warren, Segura, Lorion, Suring. Basin Response of Coho Population to Large Wood Restoration in the Oregon Coast Range; to be submitted to Journal of Fish Biology in 2025.

Fish and Wildlife Habitat in Managed Forests

Progress Report

Title: Quantifying the Effects of Wildfire on Water Quantity, Water Quality, and Fish: The Hinkle Creek Watershed Study Revisited

Investigators: Kevin Bladon, Dana Warren, and David Roon

Objectives: Our research is addressing the following objectives:

O1. Quantify the effects of wildfire on bioavailable nutrient concentrations and relate these to primary productivity, fish, and amphibian populations across nested sub-catchments.
O2. Quantify streamflow to enable quantification of wildfire effects on nutrient yields (fluxes), water supply, and habitat quality and availability for fish and amphibians across nested sub-catchments.
O3. Relate water quantity and water quality responses across the nested sub-catchments to spatial data on catchment and wildfire characteristics to identify drivers of variability in post-fire responses.
O4. Leverage data from the original Hinkle Creek Watershed Study to compare effects of wildfires on streamflow, chemical water quality, and fish and amphibians to effects from forest harvesting.

Summary of Accomplishments toward Objectives:

Toward O1, we collected water samples every month during the summer low flow period and three times each month during the winter high flow period from ten sites through the stream network for a total of ~330 samples during this past year. Those samples were filtered and sent to the Cooperative Chemical Analytical Laboratory (CCAL) at OSU for analysis of nitrate (NO_3^-), total nitrogen (TN), orthophosphate (PO_4^{3-}), total phosphorus (TP), and dissolved organic carbon (DOC), as planned. Last year, we also re-established automated water samplers (ISCOs) at the six sites from the original Hinkle Creek study to collect water samples during fall and winter storm flows. These samplers captured daily composite water samples for instream turbidity and suspended sediment analysis from October 2022–June 2023. ISCO's will be redeployed in October 2023 to collect samples during the upcoming winter.

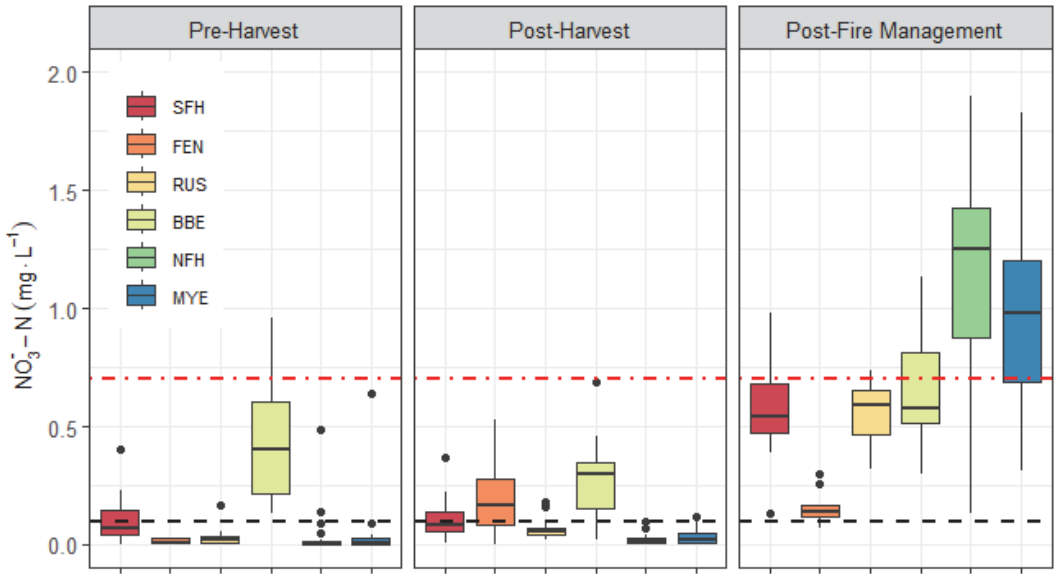

Figure 1. Preliminary box plots of stream nitrate (NO_3^--N) concentrations during pre-harvest, post-harvest, and post-fire periods from the Hinkle Creek sub-watersheds. This is an example of data that will support both O1 and O4.

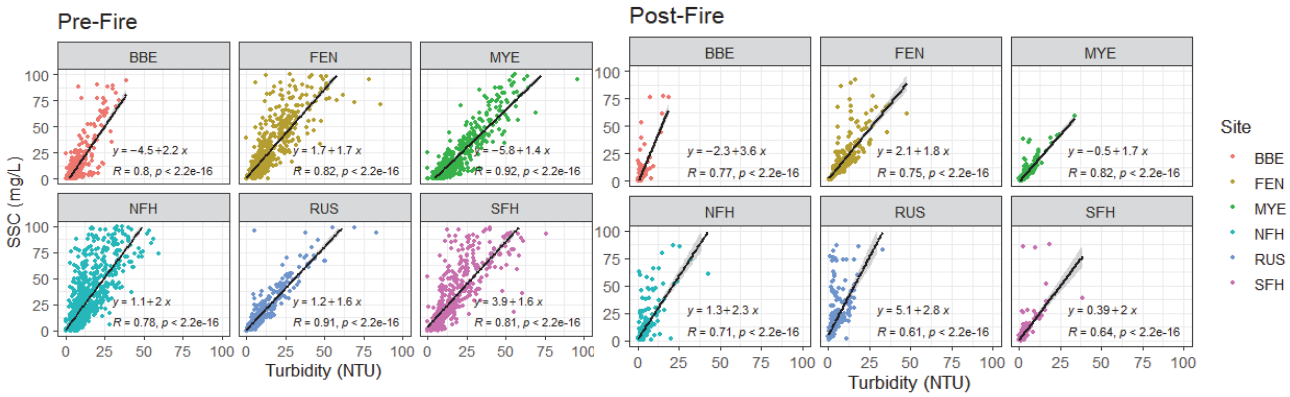

Figure 2. Preliminary results on the relationship between turbidity and suspended sediment concentrations during pre-fire and post-fire periods from the Hinkle Creek sub-watersheds. These data are derived from water samples collected with automated water samplers (ISCO's) to address O1.

Toward O2, we have been quantifying stage in five Montana flumes in the headwater sub-catchments at locations from the original study. We have also been quantifying continuous stream stage at 7 downstream locations in the stream network. This data will be converted to volumetric discharge using the rating curves we have been developing at each of these locations (Figure 3) to quantify the spatial variation in post-fire streamflow. This infrastructure will be critical to providing reliable and accurate measurements of streamflow, which will enable us to compare the post-fire hydrological response to the original Hinkle Creek Watershed Study data. This work is still in progress.

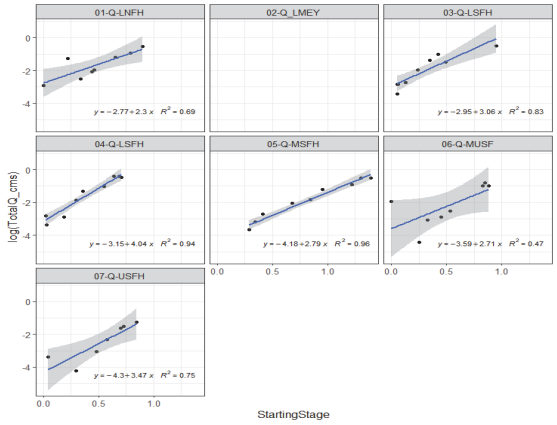

Figure 3. Preliminary rating curves to quantify volumetric discharge rates throughout the Hinkle Creek sub-watersheds to address O2.

Toward 03, we have downloaded spatial datasets of local sub-catchment information, land-use history, underlying geology, and estimated fire burn severity from the MTBS database. We are exploring other spatial datasets that we may use in this analysis. This analysis is still in progress.

Toward O4, we have compiled and begun preliminary analysis on much of the original Hinkle Creek Watershed Study data. This data was poorly organized across network drives; however, we now have most of the data organized to facilitate completion of this objective once we quantify the post-fire effects. Initial datasets that have been compiled from the original study include canopy cover, stream temperature, instream turbidity and suspended sediment concentrations, nutrient concentrations (both nitrate and orthophosphate), streamflow, and fish populations.

Problems and Barriers:

- As active data collection is still ongoing, we have not yet made substantial progress toward completion of O3 and O4. In regard to O3, we have identified potential spatial datasets we plan to apply. Analyses comparing data from the original Hinkle Creek study to our post-fire measurements to address O4 are also ongoing. This will require us to continue our sample and data collection over this upcoming year. We have a strategic plan developed to fulfill these objectives, as planned.

Planned Work:

- Over the next year, we will complete another round of sampling for all parameters envisioned in the original proposal including streamflow and water quality data, which will enable relationships to be developed with primary productivity and fish, which are being quantified through other project support. Continued monitoring will provide critical insights into the post-fire recovery trajectory.

List of names and brief overview of graduate and/or undergraduate engagement in project

- Kate McCredie (MS student): Primarily responsible for collection of water samples to measure post-fire nutrient concentrations and deployment of the ISCO water samplers across the study catchments. She has started processing samples to quantify post-fire turbidity and suspended sediment. Kate has also led the effort to capture the depth integrated water samples of water to provide some preliminary quantification of nitrogen, phosphorus, and carbon in the streams. She has coordinated with CCAL to submit and analyze post-fire nutrient samples. She has also collected soil samples, which will also be analyzed for nitrogen, phosphorus, and carbon to link the terrestrial processes to the in-stream response. Her thesis work is nearing completion and will defend in fall 2023.
- Jansen Ivie (MS student): Completed his second summer evaluating post-fire fish responses in the watershed. Jansen's MS research is focused explicitly on expanding the preliminary research on fish populations that inhabit the study watersheds and trying to relate those observations to physical water quality parameters and the original Hinkle Watershed Study. In summer 2023, Jansen and field assistants completed a second successful field season that included measuring instream habitat conditions and watershed-scale longitudinal pool sampling to quantify fish density and biomass via single-pass electrofishing in pool habitats along SF Hinkle and major fish-bearing tributaries during August, with an emphasis on locations sampled during the Original Hinkle Watershed Study. Jansen also assisted with other measurements that will be relevant for his analysis including collection of stream temperature, canopy cover, and benthic algal abundance, and macroinvertebrate data. His analysis is ongoing and is anticipated to complete his thesis spring of 2024..
- Our undergraduate field technicians (Kelly Andrus, Alessandra Berttucci, Hailey Bond, Gillian Campbell, Brenna Cody, Weylin Crouch, Bradley Gerdes, Indy Gerhardt, Jo Nelson, and Emily Nussdorfer) have been instrumental to our ability to successfully complete our work and have gained broad field, laboratory, and data analysis skills associated with quantifying fish biomass, fish populations, primary productivity, aquatic habitat, canopy closure, stream temperature, suspended sediment, nutrients, precipitation, and streamflow. These students worked full-time through the summer and/or have worked for us through the current academic year.

List of Presentations, Posters etc.:

- Roon, D.A., McCredie, K.E., Ivie, J.C., Warren, D.R., and Bladon, K.D. 2023. Quantifying the effects of wildfire on water quantity, water quality, aquatic ecology, and fish: The Hinkle Creek Watershed Study revisited. Partnership for the Umpqua Rivers monthly watershed council meeting. Oct. 17, 2023, Roseburg, OR.
- *McCredie, K.E., DeLuca, T.H., Bladon, K.D., 2023. Wildfire Effects on Soil Health and Stream Water Quality in a Western Oregon Watershed. 8th Interagency Conference on Research in the Watersheds. Jun. 5–8, 2023, Corvallis, OR.
- *Roon, D.A., Bladon, K.D., Flitcroft, R., Ebersole, J., and Compton, J. 2023. Synthesizing the effects of wildfire and shifting fire regimes on aquatic ecosystems in the Pacific Northwest. 8th Interagency Conference on Research in the Watersheds. Jun. 5–8, 2023, Corvallis, OR.

- *McCredie, K.E., DeLuca, T.H., Bladon, K.D., 2023. What is the impact of forest harvesting and wildfire on soil properties and water quality? Observations from a western Oregon watershed after compound disturbance. Pacific Northwest Water Research Symposium. April 17, 2023.
- *McCredie, K.E., DeLuca, T.H., Bladon, K.D., 2023. Water Quality and Soil Properties After Compound Disturbance: A History of Forest Harvesting, Severe Wildfire, and Post-Fire Management in a Western Oregon Watershed. Colorado University Hydrosciences Symposium. April 13, 2023. Awarded Best Student Presentation.
- Bladon, K.D., Borisenko, A., Compton, J., Donahue, D., Grieger, S., *Ivie, J., *Kang, H., *McCredie, K., *Miralha, L., Myers-Pigg, A., Roebuck, J.A., *Roon, D.A., *Wampler, K.A., and Warren, D.R. 2022. Wildfire and water security: Quantifying the effects of fires on water quantity, water quality, aquatic ecosystems, and community drinking water treatment. Chemical, Biological & Environmental Engineering Seminar Series. Mar. 13, 2023, Corvallis, OR.
- *McCredie, K.E., Bladon, K.D., DeLuca, T.H., 2023. The Influence of Harvest History, Fire Severity, and Post-Fire Soils on Water Quality in the Hinkle Creek Watershed, Western Oregon. USFS Post-Fire Research and Monitoring Symposium. February 10, 2023.
- *Ivie, J.C., Warren, D.A., Bladon, K.D., and Roon, D.A. 2023. Quantifying the response of coastal cutthroat trout to wildfire in the Oregon Cascades. Oregon Chapter of the American Fisheries Society, 59th Annual Meeting, Feb. 28–Mar. 3, 2023, Eugene, OR. Awarded Best Student Poster.
- Roon, D.A., Bladon, K.D., Flitcroft, R., Ebersole, J., and Compton, J. 2023. Identifying the drivers of aquatic ecosystem vulnerability to wildfires in the Pacific Northwest. Oregon Chapter of the American Fisheries Society, 59th Annual Meeting, Feb. 28–Mar. 3, 2023, Eugene, OR.
- *Ivie, J.C., Warren, D.A., Bladon, K.D., and Roon, D.A. 2023. Quantifying the response of coastal cutthroat trout to wildfire in the Oregon Cascades Oregon Post-fire Research and Monitoring Symposium, Feb. 7–9, 2023, Corvallis, OR.
- *McCredie, K., Bladon, K.D., and DeLuca, T.H. 2022. Disentangling pre- and post-fire forest management effects on water quality and soil health in the Hinkle Creek Watershed, Western Oregon. Oregon Post-fire Research and Monitoring Symposium, Feb. 7–9, 2023, Corvallis, OR.
- Roon, D.A., Bladon, K.D., Warren, D.A., *Ivie, J., and *McCredie, K. 2023. Quantifying the effects of wildfire on water quantity, water quality, aquatic ecology, and fish: The Hinkle Creek Watershed Study revisited. OR Post-fire Research and Monitoring Symposium, Feb. 7–9, 2023, Corvallis, OR.
- Bladon, K.D., Cole, R.P., Donahue, D., Graham, E., Grieger, S., *McCredie, K., Myers-Pigg, A., Roebuck, J.A., Roon, D.A., Scheibe, T., *Wampler, K.A., and Warren, D. 2022. Wildfire effects on catchment hydrology and biogeochemical processes. American Geophysical Union Fall Meeting. Dec. 12–16, 2022, Chicago, IL. (Invited)
- *McCredie, K., Bladon, K.D., and DeLuca, T.H. 2022. Disentangling pre- and post-fire forest management effects on water quality and soil health in the Hinkle Creek Watershed, Western Oregon. American Geophysical Union Fall Meeting. Dec. 12–16, 2022, Chicago, IL.
- Roon, D.A., Bladon, K.D., Warren, D.R., Swartz, A., *McCredie, K., and Ivie, J. 2022. Wildfire and post-fire management effects on water quantity, water quality, and aquatic ecology: The Hinkle Creek Watershed Study revisited. Sep. 28, 2022. National Council for Air and Stream Improvement Fall Meeting, Vancouver, WA.
- Warren, D.R., Roon, D.A., Swartz, A., Bladon, K.D. 2022. Cold-water fish persist in a stream system with elevated summer temperatures after a severe wildfire. Sustainable Forestry Initiative, Oregon State Implementation Committee Meeting. Sep. 21, 2022. Virtual.
- Roon, D.A., Bladon, K.D., Flitcroft, R.L., and Ebersole, J.L. 2022. Modeling the effects of fire on aquatic ecosystems in the Pacific Northwest. Joint Aquatic Sciences Meeting. May 14–20, 2022. Grand Rapids, MI.

- McCredie, K., Bladon, K.D., and DeLuca, T.H. 2022. Disentangling the biochemical effects of overlapping forest disturbances in western Oregon. Western Forestry Graduate Research Symposium. Apr. 15, 2022. Corvallis, OR.
- McCredie, K., Bladon, K.D., and DeLuca, T.H. 2022. Disentangling the biochemical effects of overlapping forest disturbances in western Oregon. Pacific Northwest Research Symposium. Apr. 13–14, 2022. Corvallis, OR.
- Bladon, K.D., Robinne, F.-N., Hallema, D.W., Wagenbrenner, J.W., *Cole, R.P., *Wampler, K.A., *McCredie, K., Roon, D.A., and Warren, D.R. 2022. Wildfire and post-fire management effects on water quantity, water quality, and aquatic ecology. Oregon Chapter – American Fisheries Society 58th Annual Meeting. Mar. 2–4, 2022, Virtual.
- Roon, D., Bladon, K.D., Flitcroft, B., and Ebersole, J. 2022. Modeling the effects of wildfire on aquatic ecosystems in the Pacific Northwest. Oregon Chapter – American Fisheries Society 58th Annual Meeting. Mar. 2–4, 2022, Virtual.
- Warren, D.R., Roon, D.A., Swartz, A., and Bladon, K.D. 2022. Cold-water fish persist in a stream system with elevated summer temperatures after a severe wildfire. Oregon Chapter – American Fisheries Society 58th Annual Meeting. Mar. 2–4, 2022, Virtual.
- Bladon, K.D., Warren, D.R., *Roon, D.A., Swartz, A., and *McCredie, K. 2021. Wildfire and post-fire management effects on water quantity, water quality, and aquatic ecology: The Hinkle Creek Watershed Study revisited. Nov. 9, 2021. National Council for Air and Stream Improvement Fall Meeting.
- Extension:
    - Field tour: Hinkle Creek Watershed Study Revisited: Wildfire effects on water quantity, water quality, and aquatic ecology. September 15, 2022, Hinkle Creek Watershed, OR. OFIC and NCASI members. (17 attendees)
    - Field tour: Hinkle Creek Watershed Study Revisited: Wildfire effects on water quantity, water quality, and aquatic ecology. May 6, 2022, Hinkle Creek Watershed, OR. (2 attendees)

List of Publications, Thesis Citations:

- Warren, DR., Roon, D., Swartz, A., and Bladon, K.D. 2022. Cold-water fish persist in a stream system with elevated summer temperatures after a severe wildfire. Ecosphere. 13(9): e4233. doi: 10.1002/ecs2.4233.

Fish and Wildlife Habitat in Managed Forests

Progress Report

Title: Post-wildfire resurvey of terrestrial salamanders on managed forests

Investigators: Tiffany Garcia, Jessica Homyack, Claudine Reynolds, Meg Krawchuk, Andrew Kroll

Objectives: Compare pre- and post-fire changes in salamander occupancy and abundance on managed timberlands.

Summary of Accomplishments toward Objectives:

This progress report will focus on the tasks and findings associated with our first field season and look ahead to prep for our final field season and publication preparation in spring/summer 2024. As such, we will focus on A) personnel, B) study design and data collection, C) preliminary results, and D) science communication.

A Personnel: Jasmine Williamson, a MS student in OSU's Department of Fisheries, Wildlife, and Conservation Sciences, is the project crew lead and has managed all data collection, storage, and analysis. She is currently funded off a NSF Graduate Research Fellowship and is in Tiffany Garcia's lab.

We hired two seasonal technicians, Joseph Barnett and Ben Zeitler, who started 1 March 2023 and assisted in the Year 1 data collection. Their employment spanned 12 weeks.

B- Study Design and Data Collection: We identified 75 potential survey sites, all of which were fit the original criteria of being forested stands >50 years old, >10 acres in size, located below 2500ft in elevation, and being in or near the 2020 Beachie Creek and Riverside wildfire perimeters, with all burned sites located in high burn severity areas.

Our 4 original stand treatments included:

1. Mature stands that did not burn (**Unharvested/Unburned**; # Resurvey plots = 15)

2. Stands that were harvested post-2015 and did not burn (**Harvested/Unburned**; # Resurvey plots = 15)

3. Stands that were harvested post-2015 and subsequently burned in the 2020 fires (**Harvested/Burned**; # Resurvey plots = 15)

4. Mature stands that burned in the 2020 fires and were subsequently salvage-logged (**Unharvested/Burned/Salvaged**; # Resurvey plots = 7, # new plots = 8)

We added a treatment to the original design due to availability of intensively managed stands that had not been harvested before the 2020 fires and had not been salvage logged post-burn. As such, the study expanded to include 5 treatments:

5. Mature stands that were burned in the 2020 fires (**Unharvested/Burned;** # Resurvey plots = 2, New plots = 13)

2023 surveys were conducted on 67 of the 75 stands, all of which were located on Weyerhaeuser, Port Blakely, BLM, and Oregon Department of Forestry timberlands. Seven 9mx9m sub-plots were established within each stand and surveyed using 3 subsequent 10 minute, time constrained sampling sessions. Data was collected on stand- and sub-plot- level habitat characteristics, including abiotic (humidity, temperature, weather) and biotic (salamanders detected, downed wood size and density) factors. Additional measurements were taken on downed wood condition, including char class and decay class. A light-touch survey methodology was employed to minimize habitat disturbance. When salamanders were detected, individuals were identified to species and substrate type at the point of

detection was noted.

C- Preliminary Results: Preliminary analysis has been performed on species diversity and species counts by date; future analysis is focusing on species detection probability, abundance and occupancy rates, and downed wood associations.

Over the 12 week field season, a total of 180 individual salamanders were identified (Figure 1). These included 110 Oregon Slender salamanders (*Batrachosepts wrighti*), 67 Ensatina salamanders (Ensatina eschscholtzii), 1 Northwestern salamander (*Ambystoma gracile*), 1 Clouded salamander (*Aneides ferreus*), and 1 Dunn's salamander (*Plethodontid dunni*). Unharvested stands had the highest counts of individual salamanders relative to other treatments. The treatment with the fewest number of salamanders detected was the salvage logged treatment. Across all treatments except for the burned/unharvested treatment, we found more Oregon Slender salamanders than the other most numerous amphibian, the Ensatina salamander.

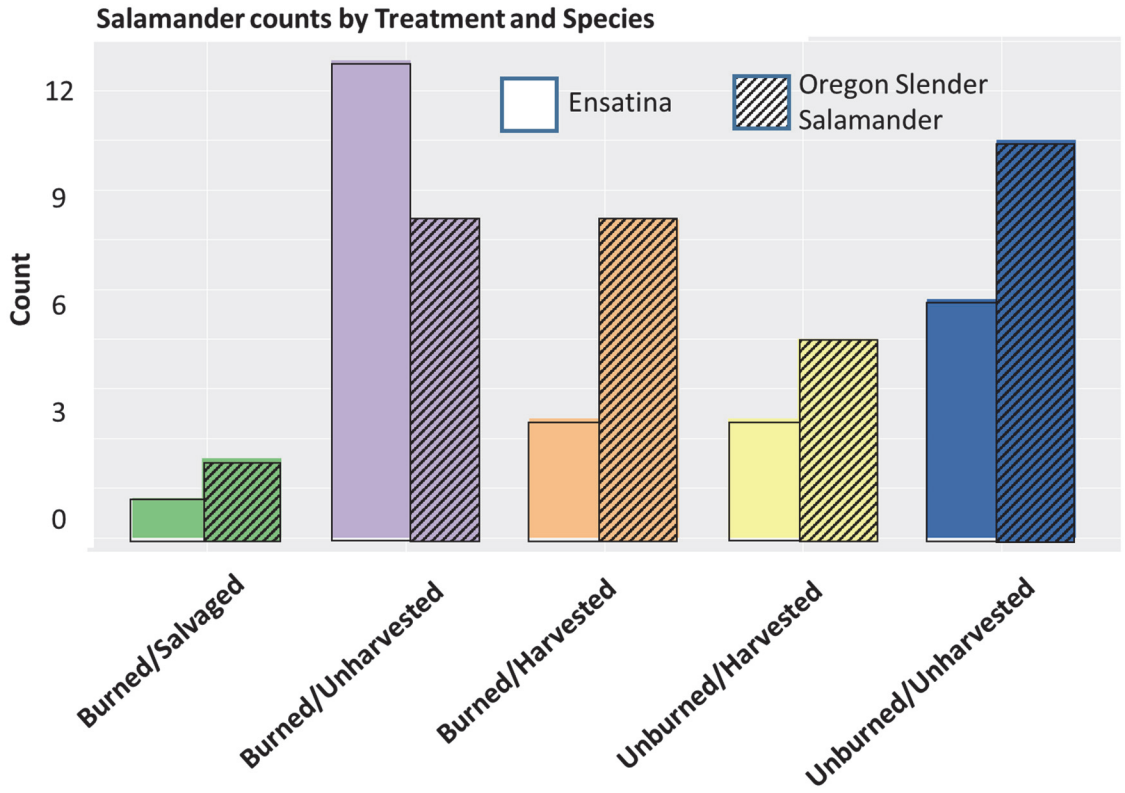

Figure 1- total counts of salamanders found during the 2023 12-week survey across the 5 treatment types and the two salamander species that accounted for the majority of detections: Ensatina salamanders (open bars), and Oregon Slender salamanders (cross hatched bars).

Of the 67 stands surveyed, 32 stands were determined to be occupied by Oregon Slender salamanders, equating to a naïve occupancy estimate of 48%, while Ensatina salamanders were detected in 28 of the sampled stands, resulting in a naïve occupancy estimate of 41%.

The efficiency of survey efforts was not consistent across the 12-week survey season. Instead, we found a strong temperature relationship with the number of salamanders detected, with reduced search success during the colder, early season and the warmer, late season (Figure 2).

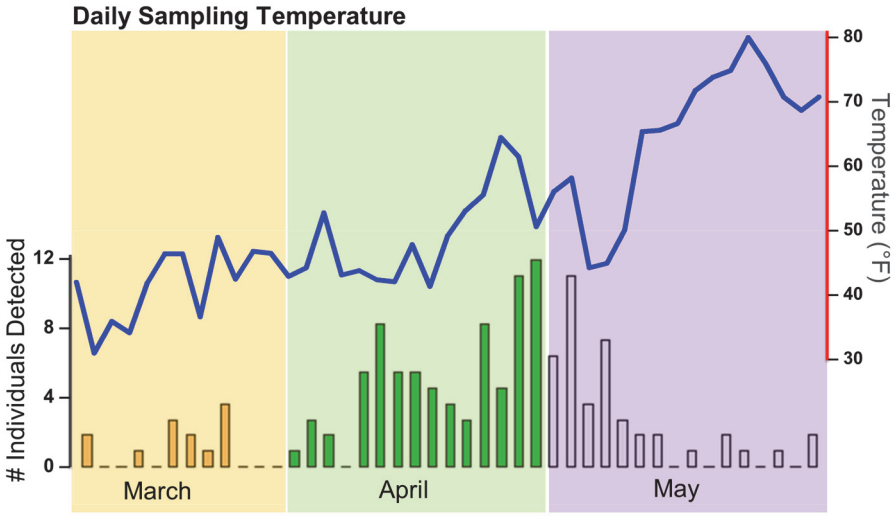

Figure 2- Counts of individuals detected across the 12-week survey, with daily average temperatures (˚F) overlaid across all three months of the 2023 survey season.

Problems and Barriers:

Weather and housing were the two primary challenges with the 2023 survey season.

Winter weather extended well into March, making it difficult to find salamanders until early April when ambient temperatures began to warm (i.e. exceeded 50˚F). Amphibians, particularly terrestrial salamanders, emerge from underground hibernacula when temperatures are warm enough to facilitate dispersal. As such, unseasonably cold temperatures can delay the onset of spring salamander activity. Similarly, amphibians are sensitive to hot temperatures as they are dependent on humid habitats to keep their skin moist. Salamanders will often return to underground hibernacula when summer temperatures exceed 65˚F to avoid drying out. Unfortunately, the 2023 survey season suffered from a long winter and an early summer, allowing for only ~6-weeks of productive sampling.

Housing in the Molalla area is difficult to find due to many structures burning in the 2020 Labor Day wildfires. No state or federal- run field houses were available, nor any company housing. As such, we rented two privately owned cottages through Air BnB, each for 6-week stints. Oregon State University is neither efficient nor adept at handling this kind of housing agreement, resulting in late payments, angry homeowners, and a frustrated crew.

Planned Work: [if progress report]

- Reapply for IACUC and ODFW scientific take permits
- Hire 2024 seasonal technicians (2)
- Conduct a second 12-week survey (March-June 2024)
- Finalize data analysis using a Bayesian occupancy approach
- Publish summary paper in scientific journal
- Present paper at the 2024 Ecology Society of America annual meeting

List of names and brief overview of graduate and/or undergraduate engagement in project: [e.g., thesis, research experience for UG, etc.]

Jasmine Williamson, MS student, Department of Fisheries, Wildlife, and Conservation Sciences, College of Agricultural Sciences, Oregon State University. Jasmine is the crew lead and research organizer on this

project. She is taking a lead role in the management of the project, data, analysis, and communication of results.

Joseph Barnett, Undergraduate Student, Biology Department, Texas State University, San Marcos. Joseph was a research technician on the 2023 field crew and gained valuable research experience. He was brought to a scientific meeting (2023 Plethodontid Conference) during his employment on the project and he participated in several other lab projects as a volunteer.

Ben Zeitler, Undergraduate Student, Department of Biology, University of Central Michigan. Ben was a research technician on the 2023 field crew and a valuable member of the Garcia Lab during his time in Oregon. He spent several weeks assisting with other projects after this field season was finished, and accompanied the lab to Louisiana for the 2023 Plethodontid Conference.

List of Presentations, Posters etc.:

Williamson, J, TS Garcia. 2022. Post-wildfire resurvey of salamanders on managed timberlands in the Western Oregon Cascades. The Wildlife Society, Oregon Chapter. Bend, Oregon. Oral Presentation.

Williamson, J, TS Garcia. 2023. Slender Surprise: A preliminary look at Batrachoseps response to timber harvest and extreme weather events. Plethodontid Conference, Hammond, Louisiana. Oral Presentation.

Williamson, J, J Homyack, TS Garcia. 2023. Wildfire and Timber Harvest: Examining their Influence on Terrestrial Salamanders. The Wildlife Society, Annual Meeting. Louisville, Kentucky. Oral Presentation.

List of Publications, Thesis Citations: [published or anticipated]

N/A

Fish and Wildlife Habitat in Managed Forests

Progress Report

Title: Responses of Fish to Forest Management: Evaluating How Different Riparian Reserve Configurations Affect Fish and Food Webs in Headwater Streams

Investigators: Dana Warren, Ashley Coble

Objectives:

The core objectives of this proposed project were to:

(1) Continue data collection across all sites for a large-scale before-after control-impact study quantifying the response of habitat, ecosystem processes and biota to 4 different riparian reserve configurations (and relating those to an unmanaged control) in 6 replicated blocks.

(2) Synthesize, analyze, and contextualize results from the first two blocks in regard to changes in (1) temperature, (2) light, (3) benthic biofilms, and (4) fish density, biomass and growth in a master's thesis that will ultimately be developed into one or two peer-reviewed publications.

Summary of Accomplishments toward Objectives:

In the last year we have made substantial progress toward accomplishing the goals of this project. Key accomplishments are listed below.

- Treatments were applied to the final 4 blocks (one-sided treatments) in the study.
- In Spring 2023, we cleaned, refurbished, and calibrated all field equipment and field instruments to maintain consistent data collection for the duration of the study (this included sending all dissolved oxygen meters to MiniDOT for recalibration).
- We hired and trained five new undergraduate student technicians in 2023.
    - Two of the summer 2023 students are developing data from this project for use in their undergraduate honors theses.
- The first summer of post-harvest data collection was completed at the four one-sided sites.
- The second (final) summer of post-harvest data collection was completed at the Walton Block.
- Overall, in summer 2023, we collected data on stream habitats, benthic biofilms, and aquatic biota (vertebrates and invertebrates) at 25 stream sites across the Oregon Coast Range.
- Data entry, with associated quality assurance-quality control (QAQC) from summer 2023 fieldwork has been completed for habitat data and for fish data.
- Water samples and aquatic macroinvertebrate samples have been sent to external labs for analysis and identification.
- The MS student on the project completed her thesis and is preparing a manuscript from that work with anticipated submission in December, 2023.
- The undergraduate student using data from this project (and who was a technician in 2022) completed her honors thesis in spring 2023. The thesis is being revised for publication with anticipated submission in February 2024.
- Results from work by both the MS student and the undergraduate student were presented at regional meetings (Salmon Restoration Federation conference in Fortuna, CA, and the Oregon Chapter of the American Fisheries Society meeting, in Eugene, OR).
- A manuscript using data from this study and led by an undergraduate student who was a field technician in 2021 was submitted in June 2023 and was recently accepted (pending minor revisions) in *Northwest Science*.

Field work (June - September 2023)

Summer 2023 fieldwork was successful in accomplishing all of our planned data collection across site. This summer's fieldwork was particularly interesting as it provides our first opportunity to assess responses at the four one-sided buffer sites and to complete data collection for the two-sided buffer sites.

Preliminary Results

Trout

Two-Sided Treatments: The MS student, Ashley Sanders, focused her thesis work on the 2-sided sites. Adult trout responses were variable. While some sites showed positive responses in year one, (e.g. variable retention site at the Valsetz block and canopy gap site in the Walton block), others showed no response (fixed-width in the Valsetz sites) or a net decline relative to the reference sites (e.g. fixed-width in the Walton Block). In year 2 all but the Walton fixed-width site had relative increases in adult trout. We attributed this year 2 response in adult fish to recruitment of a strong YOY year class from year 1. Ashley found positive responses of YOY fish to all of the treatments relative to the reference sites with some locations showing substantial changes. While these responses in YOY were striking, the magnitude of the responses did not scale with the amount of change in stream light, as we had hypothesized (Figure 1).

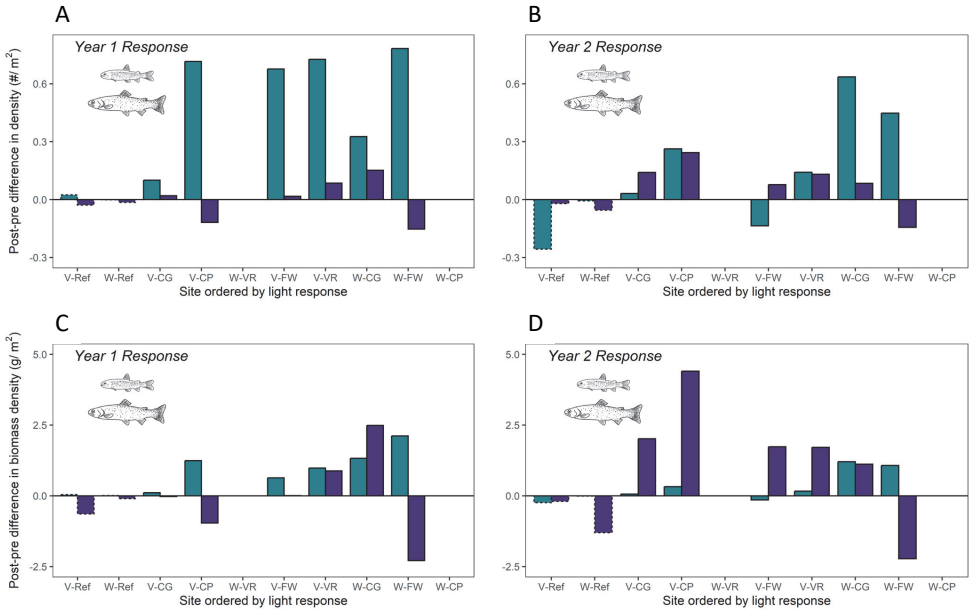

Figure 1. Changes in the abundance (A, B) and biomass (C, D) of adult (dark blue) and juvenile (green) cutthroat trout before versus after riparian buffer treatments across the Valsetz and Walton blocks. The two reference (unmanaged) sites on the left and the treatment sites are listed from left to right in rank order of their light response. (from A. Sanders thesis).

One-Sided Treatments: The responses of adult trout at the four one-sided treatment sites were mixed (Figure 2). In the Scappoose block, the biomass of adult trout increased or was largely unchanged relative to the treatment sites. In the Astoria block, two streams were removed from the study (Covid-constraints). All three sites had a decline in trout biomass in 2023 relative to the mean of the two pre-treatment years, and although the declines were smaller in the two treatment sites, the overall responses were quite muted. In Newport and Veronia blocks, responses were mixed with some sites showing a positive response in adult trout and others showing no response or a relative decline. The potential mechanisms for these responses will be explored more explicitly once we have stream

temperature and food web (biofilm and macroinvertebrate) data.

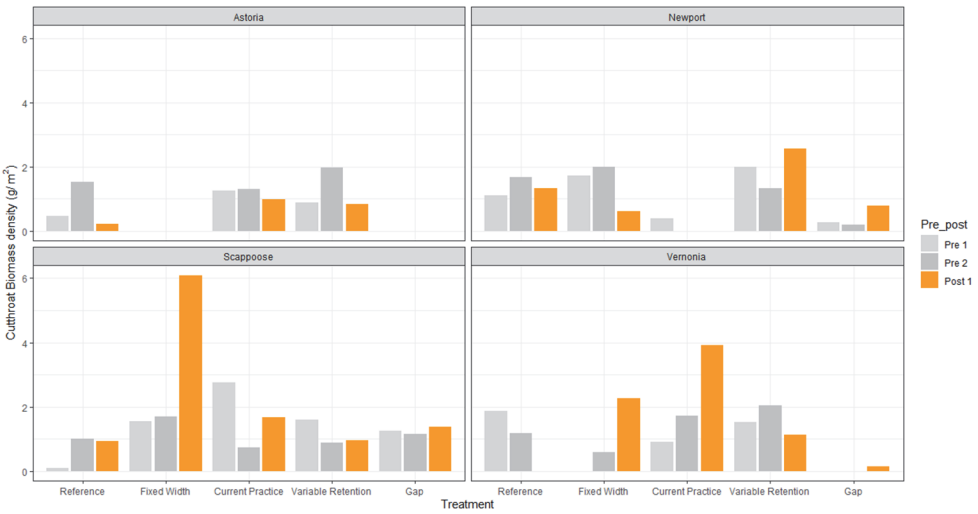

Figure 2. Biomass density (g m^{-1}) of adult (age 1+ and older) cutthroat trout across the four one-sided treatment blocks. The two grey bars are pre-treatment years (2021, 2022) and the orange bar is the first year post-treatment (2023).

While we saw some of our most consistent responses in the two sided buffer sites among the age 0+ (young of year; YOY) fish, results were less consistent for the one-sided buffer sites. We did see some strong positive responses in the treatment sites relative to the reference reaches, but we also saw some relative declines (Figure 3). We attribute this in part to potential interactions with adult fish in some of these sites, for example, in the Scappoose fixed-width site, there were no YOY in the reach in the first year after treatment but this site saw some of the largest relative increases in adult trout. And, in the Vernonia reference site there were no adult trout but a large number of YOY's.

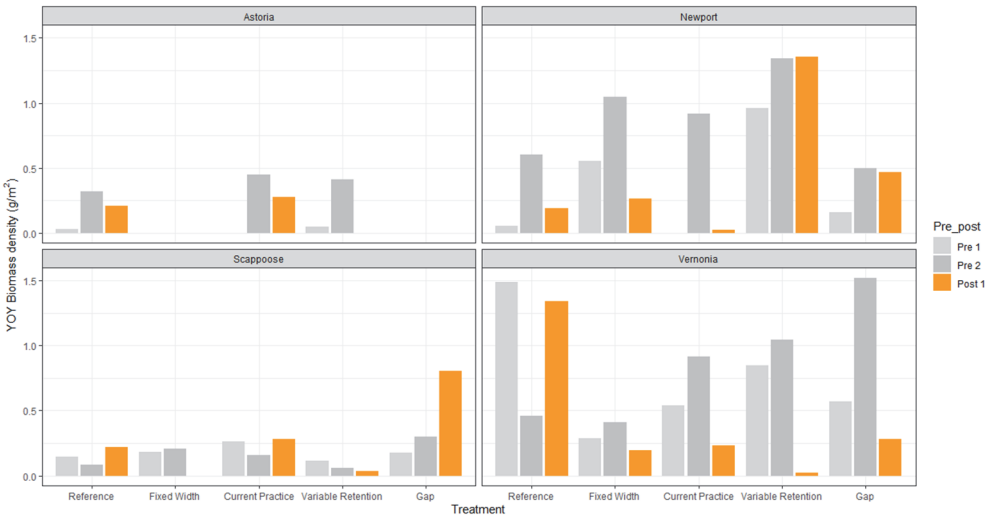

Figure 3. Biomass density (g m^{-1}) of YOY (age 0+) cutthroat trout across the four one-sided treatment blocks. The two grey bars are pre-treatment years (2021, 2022) and the orange bar is the first year post-treatment (2023).

Problems and Barriers:

As in 2022, there were reaches in the Walton Bock that could not be surveyed for stream vertebrates due to slash across the stream (we did collect data on light, stream temperature, dissolved oxygen, canopy cover, periphyton, macroinvertebrates). In some of the one-sided sites, we also ran into issues with slash from the 2022-2023 harvests affecting our ability to survey for vertebrates. There were no cases in which slash loads were so high that we cut out sites, but the access/visibility issues associated with added slash could have compromised the integrity of the BACI study design by decreasing capture probabilities at treatment sites relative to reference sites thereby potentially affecting our assumptions about comparable assessment effectiveness before and after treatment. We will be reviewing the capture probability outputs from the population estimate program to evaluate this issue.

Planned Work:

Over the next year, we plan to complete the following:

- We will continue to organize and manage data in an accessible, cloud-based database.
- Ashley Sanders, will submit her manuscript assessing responses in the two-sided treatment sites in December, 2023.
- We will make suggested revisions to Nathaniel Neal's manuscript and resubmit by Dec 13 (deadline provided by the journal for revisions).
- We will process summer 2023 periphyton samples in the lab and for chlorophyll a and ash-free dry mass
- We will receive 2023 results of macroinvertebrate taxonomy and water chemistry (N, P, C), which have been sent to an external taxonomist and NCASI's Newberry, FL analytical lab.
- We will analyze all six replicate blocks together to evaluate the core questions and foci of this research.
- We will present results from this study at state, national, and international meetings.
- We will have two undergraduate students analyze aspects of the data for their honors theses.
- We will hire four additional undergraduate students to help with the final summer of data collection at the four one-sided sites.

List of names and brief overview of graduate and/or undergraduate engagement in project: [e.g., thesis, research experience for UG, etc.]

- OSU undergraduate field technicians for the 2023 season were **Andrew Copsey, Emma Legault, Lauren Ringrose, Ava Glowacki, and Jay Lollman**. Field technicians assisted with data collection from June to September, learning a wide variety of stream ecology protocols and traveling to sites across the Coast Range. Toward the end of the season, they contributed to a significant volume of data entry which allowed for a quick transition to data analysis in the fall. They were also involved in many conversations with crew leads about forest management, DEI in ecology, and professional development.
- **Ashley Sanders** (MS student) led assessments of the two-sided treatments and completed her MS thesis in 2023 (see below).
- Undergraduate **Nathaniel Neal**, who was a summer field technician in 2021, finished converting his 2022 honors thesis to a manuscript, which was submitted to Northwest Science in June 2023 and was recently accepted pending minor revisions (which are due Dec. 13, 2023) (see below)
- Undergraduate **Nicole Miller**, who was a summer field technician in 2022, finished her honors thesis in 2023 (see below)
- **Lauren Ringrose**, who was a summer field technician in 2023, will conduct her honors thesis study evaluating results from 2023 data collection (with previous years work) at the one-sited sites with input from project.

- **Emma Legault**, who was a summer field technician in 2023, will conduct her honors thesis study evaluating results from 2023 data collection (with previous years work) at the one-sited sites with input from project.

List of Presentations, Posters etc.:

Sanders, A. M., A. A. Coble, and D. W. Warren. How does light change cutthroat trout populations in low-order streams in the Oregon Coast Range? (Paper) *Salmonid Restoration Federation* in Fortuna, CA, in person, April 2023.

Sanders, A, A.A. Coble, and D.R. Warren. 2023. How does light change cutthroat trout populations in low-order streams in the Oregon Coast Range? (Paper) Annual Oregon American Fisheries Society Meeting. Eugene, OR March 1-3.

Miller, N., A. Sanders, A.A. Coble, and D.R. Warren. 2023. Assessing the consistency of stream ecosystem characteristics in accounting for Variation in trout Abundance between summers with low versus high flow conditions? (Poster) Oregon American Fisheries Society Annual Meeting. Eugene, OR March 1-3.

Warren, D.R. 2023. *Assessing the response of stream ecosystems and stream biota to different riparian buffer configurations* NCASI Technical Program Meeting - Forestry (virtual). Jan. 17, 2023

List of Publications, Thesis Citations: [published or anticipated]

Peer-reviewed Journal Articles

Neal, N.G., A.M. Sanders, A.A. Coble, and D.R. Warren. ***In Revision***. Evaluating abiotic and biotic predictors of coastal giant salamander (*Dicamptodon tenebrosus*) populations in fish-bearing headwaters of the Oregon Coast Range. : *Northwest Science.*

Sanders, A.M., A.A. Coble, and D.R. Warren. **In Preparation**. Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) responses to increased stream light in headwater ecosystems via alternative riparian buffers in managed forest landscapes. In preparation for: *Ecosphere*

Theses

Sanders, A. June 2023 MS Thesis. *Coastal Cutthroat Trout (Oncorhynchus clarkii clarkii) Responses to Increased Stream Light via Alternative Riparian Buffers in Low-Order Headwater Streams in the Oregon Coast Range.*

Miller, N. June 2023 Honors Thesis. *Assessing the consistency of stream ecosystem characteristics in accounting for variation in trout abundance between summers with low versus high flow conditions*

Fish and Wildlife Habitat in Managed Forests

Progress Report

Title: Synthesis and Application of Research on the Biodiversity of Early Seral Forests in Fire-generated and Intensively Managed Forests

Investigators: Meg Krawchuk, Matt Betts, Jim Rivers, Mark Swanson, Jake Verschuyl

Objectives: Our work focuses on *Science Synthesis* and *Land Owner and Land Manager Engagement & Outreach* for research outcomes of the Early Seral Biodiversity Project. The Project was the focus of Graham Frank's PhD dissertation and studied early seral biodiversity among stand-scale disturbance contrasts within Douglas-fir dominated forests of SW Oregon: i) intensively managed tree plantations on private lands (partnering with Roseburg Forest Products and Manulife Investment Management – formerly Hancock), ii) high severity burned stands on federal lands (USFS and BLM), and iii) high severity burned stands on federal lands that were subsequently salvage logged (BLM). This retrospective, field-based project covered three temporal periods (ages) of early seral in the disturbance treatments: young early seral (1-5 years old), intermediate early seral (6-10 years), and advanced early seral (17-20 years old); burned and salvage logged sites were only available in the adolescent early seral temporal period due to recent re-burns. Within the disturbance-age study design we measured bird, bee, carabid beetle, and plant communities, as well as forest structure and composition. Graham Frank defends his PhD dissertation on November 30, 2023 and in January 2024 he will begin his postdoc focused on *Science Synthesis* and *Engagement & Outreach* from those data and findings.

Summary of Accomplishments toward Objectives: Our project begins January 2024.

Problems and Barriers: None at this time.

Planned Work: *Objective 1 – Land Owner and Land Manager Engagement & Outreach.* Given the growing need for science support for early seral management decisions, we have an opportunity to broaden the outreach scope beyond what was originally proposed for the Early Seral Forest Biodiversity project. In this project we will invest in *Engagement & Outreach* to support the development and delivery of fact sheets, presentations, workshops or field tours, and other products identified through direct consultation with forest owners and managers. We will collaborate with FNR Extension to engage directly with land owners and managers to develop outreach products that disseminate the overall findings of the Early Seral Forest Biodiversity work. These collaborations, and the continued efforts of FNR Extension to conduct local needs assessments throughout the state, will enable us to understand how best to share results with end users and design communication materials most useful for management decisions. It will also allow us to build upon existing, ongoing efforts by FNR Extension to communicate core principles of early seral forest ecology and management.

Objective 2 – Science Synthesis. From a new science perspective, we will complete a quantitative analysis synthesizing the bird, bee, beetle, plant community, and forest structure data collected from the Early Seral Forest Biodiversity field project as a capstone to the project. Graham Frank focused his three PhD data chapters on treatment contrasts and relationships to biophysical correlates for each of the wildlife groups individually (birds, bees, beetles). A necessary capstone that we will focus on here is a quantitative synthesis of all biodiversity metrics holistically. Graham Frank will also complete a review paper highlighting temporal dynamics within these young forests and variability among ecological and management contexts, as an important resource and conceptual model for scientists and managers.

Together, these two objectives maximize use of collected data through scientific analyses and synthesis on the holistic suite of species and forest conditions, and support engagement with land managers and Extension professionals to impact management decisions.

List of names and brief overview of graduate and/or undergraduate engagement in project: This project supports Graham Frank in a Research Associate/Postdoctoral position.

List of Presentations, Posters etc.: None yet.

List of Publications, Thesis Citations: None yet. Graham Frank will defend his PhD dissertation November 30th 2023. Three peer reviewed publications are expected soon after defense. Additional publications expected in the next year, as described above.

Fish and Wildlife Habitat in Managed Forests

Progress Report

Title: Evaluating insect pollinator response to dry forest fuels treatments

Investigators: James Rivers (FERM, OSU), James Johnston (FES, OSU)

Objectives:

The objectives of our study are to (1) quantify how wild bee communities respond to three commonly implemented fuel-reduction treatments: mechanical thinning, prescribed fire, and a combination of mechanical thinning + prescribed fire, relative to unmanipulated control sites, and (2) assess how fuel-reduction treatments vary in their influence on the floral resources and nesting substrates needed to support wild bee communities. By addressing these objectives in concert, our project will provide new information about the degree to which contemporary fuels treatments provide habitat to support wild bees, a critically important group that is fundamental for maintaining biodiversity in managed forests. Such information is necessary for crafting management strategies to enhance forest resilience while also protecting biodiversity and providing timber supplies from federal lands to rural economics in eastern Oregon, where efforts to generate wood products to support rural economies often faces opposition because of concerns about the effects of timber harvest on biodiversity.

Summary of Accomplishments toward Objectives:

Given the timing of funding availability (July 1, 2023) we designed our study to be conducted during the 2024-2025 summer field seasons. As such, field data collection has not commenced, and our current focus is on finalizing study site selection, ordering gear, and interviewing candidates for the M.S. position that will lead field data collection work in summer 2024 and then matriculate into the graduate program in the OSU Department of Engineering, Resources, and Management in fall 2024.

Problems and Barriers:

No problems or barriers have arisen to date that has slowed expected progress. Although we initially sought to bring on a M.S. student in fall 2023, there was a limited pool of applicants to the M.S. position when it was advertised in spring 2023. Therefore, we decided to forgo filling the position in spring 20023 and instead pivoted to re-advertising the position in fall 2023, when there typically is a larger and stronger applicant pool for graduate school. Therefore, we have shifted the timing of when the graduate student will join the CoF graduate program, but that has not impacted data collection or changed our proposed timeline.

Planned Work:

All of our planned work remains the same from our original proposal. Briefly, our goal is to quantify native bee communities in areas of the Malheur National Forest that have been mechanically thinned, subjected to prescribed fire, and have undergone thinning + prescribed fire relative to untreated sites during the 2024-2025 bee flight seasons (June-August). This work includes undertaking passive and active sampling of pollinators, in addition to measuring floral resources and habitat measurements (e.g., coverage of bare ground) that are expected to be linked to the composition of bee communities.

List of names and brief overview of graduate and/or undergraduate engagement in project:

We will hire a M.S. student for this work, in addition to at least 1 undergraduate research assistant in each for the two years during field data collection. We also expect to have additional undergraduates involved with this program via programs such as the URSA Engage Program and the Mentored Employment Program at OSU.

List of Presentations, Posters etc.:

There have been no presentations on this work to date. However, we anticipate giving several research presentations at scientific conferences such as the Western Forestry Graduate Research Symposium, the Oregon Chapter of The Wildlife Society and/or the Entomological Society of America.

List of Publications, Thesis Citations:

We anticipate a M.S. thesis produced by a student (TBD) in Rivers' lab group by fall 2026, with 1-2 publications that emerge from core project objectives.