2020 BIOAg Project Report

Report Type:
Progress Report (no-cost extension requested through June 2021)

Title:
Evaluating Commercial Specialty Mushroom Production Feasibility for Diversified Farms and Small Woodland Owners in Western WA

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Abstract:
Forest-grown specialty mushroom production may be an economical, low-impact, ecologically-appropriate enterprise for diversified farms and small woodland owners in western WA and the greater western Pacific Northwest (PNW). Nonetheless, to date, there has been little Extension research, publications, or formalized programs in the PNW on this subject as a commercial enterprise. In contrast, several northeastern and midwestern agroforestry Extension initiatives have developed commercial-scale, forest-grown specialty mushroom production systems and enterprise budgets. These systems use harvested hardwood as a substrate and mushrooms are cultivated under existing forest canopy. In contrast to the environments that these systems were developed in though, the western PNW environment has 1) markedly milder winter temperatures, 2) more limited choices of native hardwoods, and 3) patterns of markedly drier, lower-humidity summers. Nonetheless, our densely-forested, high-precipitation environment should be naturally-conducive to producing mushrooms. This project evaluates the adaptability of production systems developed by Extension in the eastern US for several species of specialty mushrooms to the western PNW. Using three research sites in two distinct regions of western WA, we aim to evaluate 1) multiple species of locally available hardwoods for their potential to sustain mushroom production 2) production systems that mitigate potential negative effects of sustained low-humidity in summers, and 3) estimate commercial forest-grown mushroom production potential for the western PNW context. Project results will be disseminated to farm and forest owners and educators on Extension websites and educational events in year two, to agroforestry researchers via a journal publication, and provide a foundation to substantiate needs for future research and development.

Project Description:
Over the past several decades, Extension researchers in the eastern US (including the eastern-midwest) have refined several systems for diversified farmers and forest owners to produce forest-grown specialty mushrooms on hardwood log substrates. To date though, there is a marked absence of institutional, research-based knowledge about the viability of commercial, forest-grown specialty mushroom production in the western Pacific Northwest (PNW), despite a potentially favorable production climate, proximity to premium markets, and interest from PNW farm and forest owners. Potentially foreseeable aspects affecting these systems' viability in the PNW are 1) differing and relatively limited species of locally-sourceable hardwood substrates, 2) common dry spells during PNW summers that could compromise critical thresholds of log moisture needed for sustaining mushroom vitality, and 3) potential effects resulting from mild winters (commonly wet, and with limited periods of freezing weather) and potentially competitive native fungal species.

In light of this, the aim of this project is to:
1) Establish baseline, research-informed estimations of the viability of adapting current forest-grown commercial mushroom production systems to western PNW environments;
2) Investigate economically feasible, regionally-appropriate management practices for commercial mushroom operation development in the region;
3) Increase awareness of forest-grown mushrooms as a commercial enterprise for forest owners and diversified farms, potential pitfalls, and current knowledge gaps;
4) Develop foundational, research-based information for stakeholders and researchers to use in future decisions about the potential for commercial forest-grown mushroom enterprise development in the western PNW.

To begin to address these objectives, the project includes research trials designed to produce foundational information regarding the viability of current eastern-US-developed commercial mushroom production systems in PNW environments. The trials aim to clarify 1) best practices for maximizing production regarding substrate choice, 2) substrate moisture management, and the 3) suitability of the most commonly cultivated forest-grown mushroom species for production in the western PNW. Three distinct trial sites in two western PNW regions were targeted with one location serving as the main trial site and the two others serving as satellite sites with truncated trials. The trials chiefly focus on "bolt" production systems for producing shiitake (*Lentinula*) mushrooms at all locations (see Figure 1). At the main site location, additional evaluations of 1) "Totem" systems for producing lion's mane (*Hericium*) and oyster (*Pleurotus*) mushrooms (see Fig 1, Appendix 5), and 2) wood-chip bed production systems for producing wine cap (*Stropharia*) mushrooms are being conducted. Red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) are the primary mushroom log substrates being evaluated at all sites, with additional evaluations of wild sweet cherry (*Prunus avium*) and paper birch (*Betula papyrifera*) substrates are being conducted at the main trial location (see Appendix 2). Moisture management treatments focused on three methods of modifying humidity and evaporative potential to mitigate potential log moisture loss throughout the summer (see Appendix 6) with a combination of using breathable, spun polyester fabric covers with passive water diffusion and active sprinkler irrigation under these covers, or immersive soaking of freshly inoculated logs before covering the stack.

Figure 1. *Trial site illustrating bolt systems for shiitake mushroom production (horizontally stacked in a "crib stack" in the foreground) and totem systems for lion's mane and oyster mushroom production (stacked vertically in background left). The figure shows a control treatment equipped with a weather data logger and two moisture-managed treatments under breathable, spun polyester fabric covers (background right) within a treatment block at the project's main trial site in Vancouver, WA.*

Because this is a nascent research area, a peer-reviewed journal publication is targeted as a core project output. Extension outreach products will primarily be web-based for purposes of conducting ongoing edits/updates as research progress is made. The project team will produce two major workshops featuring a guest speaker on commercial mushroom production from a different region, our trial results, and potential growth of future specialty mushroom markets. Trial sites will also dually serve as demonstration sites. Depending on project results and external circumstances, an Extension manual, presentations at conferences, invited talks to stakeholder groups, and press releases will also be targeted as a project output.

Outputs:

Overview of Work Completed and in Progress:

Two replicated research trials established in 2019 in Vancouver and the south Puget Sound continued throughout 2020 (See Figure 1, Table 1, and Appendix 1 & 2). Circumstances and emerging perspectives on the commercial production potential these systems prompted a greater focus on shiitake production systems as the trial evolved into its second season.

An additional replicated sub-trial was added to the Vancouver site in 2020 to augment knowledge gaps that arose in 2019. These sub-trials included 1) an evaluation of Oregon oak as a PNW native substrate for shiitake production, and 2) the effect of substrate harvest timing (cutting logs during vs. after winter dormancy) on production (see Table 2 and Appendix 3). Oregon oak chosen for evaluation because of its availability as a native PNW species, and anecdotal perceptions that oak species are most the most suitable substrates for shiitake production. This additional sub-trials will allow for an evaluation of Oregon oak against select species we included in 2019's trials. Substrate harvest timing was chosen for evaluation because it can affect bark retention, which in-turn, can affect the log's ability to support mushroom production in the long-term. Our 2019 trials were also cut later than planned due to logistical circumstances (as winter dormancy was breaking); this additional sub-trial will allow us evaluate whether log substrates cut during winter dormancy have a longer productive lifespan than the 2019, or whether there are differential effects between species. The sub-trials were completely established by midsummer 2020.

Shiitake "bolts" inoculated in 2019 largely began producing mushrooms in 2020 (see Figure 2), and allowed for the first year of yield data to be taken throughout. Three there were major shiitake harvests of throughout spring, summer and fall 2020 that were dominated by a single "wide range" strain of shiitake (oriented to producing within a wide range of ambient temperatures) that was common to all trial sites. Yield data from a second wide-range strain and a warm-weather oriented strain were collected simultaneously from the south Puget Sound trials. Yield data collection on a cool-weather oriented strain also began as intermittent production commenced in late fall and into the winter season at both trial locations.

Oyster mushrooms began intermittently producing a limited amount of mushrooms in the totem systems in 2020, which allowed for collection of yield data from late fall into winter (see Appendix 3). Logs inoculated with lion's mane spawn did not produce any mushrooms in 2020, and precluded the ability to evaluate yield for this species.

Wine cap mushroom (aka. *Stropharia*) wood-chip bed trials at the main trial site that were not established in 2019 due to capacity constraints, were instead established by late spring of 2020 (see Table 3 and Appendix 4). The wood chip bed systems included all four substrate species included in the 2019 shiitake and oyster/lion's mane trials, and drip-irrigated vs. non-irrigated sub-treatments.

Second measurements of log moisture content originally planned for Fall 2019 were precluded by capacity constraints, and were instead completed in spring of 2020 for the shiitake bolt system. The second moisture measurement on logs in totem systems was abandoned primarily due to risk of damage to the totem structures. In the 2020 Vancouver sub trials, initial moisture log measurements were taken after bolt cutting in spring 2020, and second measurements were taken in late fall 2020.

This year's educational and outreach outputs included six educational events (see Figure 3), and three newsletter articles. Instructional videos are in the editing process, and data analysis has begun for preparing publications for submittal in 2021.

A funding proposal to expand the current project is being prepared for submittal in February 2021.

Methods, Results, and Discussion:

Two replicated research trials were established in 2019 in two differing western PNW ecosystem regions- 1) the greater Willamette Valley (at the main trial location in Vancouver) and 2) the South Puget Sound (the satellite location, in using two sites in Lacey and McCleary). The experimental design used at each trial site is a spatially-balanced complete block design with split-plots and four replications (see Table 1). At the main trial site, each replication contains a shiitake bolt production system and lion's mane & oyster totem production system, with 1) four moisture management treatments, 2) split-plots with four substrate species, and 3) split-split-plots with two different shiitake strains in the shiitake bolt system (see Table 1). The satellite sites each contain two of four total replications of an abbreviated trial containing only shiitake bolt systems, two moisture management treatments, split-plots of two species of substrates and split-split-plots with three different strains of shiitake (two wide range, one cold weather, and one warm weather strain). All replications were placed in shaded, protected locations (prioritizing dominant evergreen canopy, and/or north facing aspects) but were also individually sited to capture a stratified range of microclimates that may be encountered in the western PNW.

Trial location *(Site)*	Replications *per site*	Mushroom species *(System)*	Sample units *per replication*	Main treatment plot *Moisture management*	Sample units *per treatment*	Split-plot *Substrate*	Sample units *per substrate*	Split-split plot *Strain*	Sample units *per strain*
Main (Vancouver)	4	Shiitake (Bolt)	64	Control (unmanaged moisture)	16	Red alder	4	Wide-range shiitake strain	2
				Covered + passive irrigation		Bigleaf maple			
				Covered + active irrigation		Wild cherry		Cool-weather shiitake strain	2
				24-hr immersive soak > covered*		Paper birch			
		Lion's mane (Totem)**	16	Control (unmanaged moisture)	4	Red alder	1	NA	NA
				Covered + passive irrigation		Bigleaf maple			
				Covered + active irrigation		Wild cherry			
				24-hr immersive soak > covered*		Paper birch			
		Oyster (Totem)**	16	Control (unmanaged moisture)	4	Red alder	1	NA	NA
				Covered + passive irrigation		Bigleaf maple			
				Covered + active irrigation		Wild cherry			
				24-hr immersive soak > covered*		Paper birch			
Satellite (Lacey & McCleary)	4 (2 per site)	Shiitake (Bolt)	48	Control (unmanaged moisture)	24	Red alder	12	Wide-range shiitake strain 1	3
								Wide-range shiitake strain 2	
				Tarped + passive irrigation*		Bigleaf maple		Warm-weather shiitake strain	
								Cool-weather shiitake strain	

**Triple-layer of 85% light transmission breathable white spun polyester cover (aka "floating row cover"), "Remay®")*
***Production systems for lion's mane and oyster mushrooms are identical, but are not intended to be compared to one another in statistical analyses.*

Table 1. *Trial treatment layout established at each research site in 2019.*

Moisture management treatments at all sites include 1) un-managed controls (i.e. no moisture management) vs. 2) covered + "passive irrigation" treatments that use static water containers under breathable, spun-polyester fabric covers to modify relative humidity. Two additional moisture management treatments are being trialed at the main trial site, including 1) a covered + "active irrigation" treatment using mist emitters on irrigation timers, and 2) a treatment where substrates were soaked for 24 hrs. post-inoculation, and then placed under covers (see Appendix 1 & 2). A weather station was installed on each control treatment to capture baseline temperature, relative humidity, windspeed, and light intensity conditions within a given trial block. Temperature and humidity loggers were installed under each tarp in the moisture-managed treatments. Core response variables being evaluated are 1) temperature and relative humidity in controls and within each moisture management treatment, 2) log substrate moisture changes over time, and 3) total mushroom yield over time. Observations of factors potentially affecting the system's prospects to support a viable commercial mushroom production enterprise are additionally being documented to inform project results. Response variables will primarily be used to estimate effects of substrate species and moisture management treatments on mushroom yield, and to produce estimates of yield dynamics that can be used to inform enterprise budgets.

Trees used for substrates at the main Vancouver Site in 2019 were cut by the end of March. Shiitake bolts were inoculated beginning in late April, and finished by June, and placed in the final trial site and under the influence of moisture management treatments by July. Totem systems were inoculated and placed under the influence of treatments by the beginning of September. Trees used for the Lacey and McLeary satellite trial sites were cut by mid-April, inoculated by mid-May, and placed in each trial site and under the influence of moisture management treatments by June. Log moisture content measurements were taken when bolts were initially cut, one year later in Spring 2020, and again in Fall 2020 following the summer season. Moisture measurements were determined from a 3" deep log round cut 3" in from the end of the log; cut rounds were then weighed immediately and then again after ~1 week of forced air drying at 220° F. Harvests of wide-range and warm-weather shiitake strains began at both sites began in June 2020 following a 24-hr immersive soaking of the bolts to initiate a flush of fruiting (termed "shocking" or "forced fruiting"). This harvest process was repeated two more times at an interval of ~7 weeks, with the last harvest occurring in October. Bolts inoculated with cool-weather shiitake strains were soaked in October after the third log moisture content measurements had been taken in an effort to try and initiate fruiting and assure that sufficient log moisture was maintained; small harvests of sporadic production began the same month and have continued steadily into winter 2020-2021 every two weeks. Fresh mushroom yield weight and mushroom quantity of was recorded for each bolt at each harvest timing. All mushrooms were harvested when the majority of mushrooms were at a mature stage; all mushrooms with open gills were harvested at a given harvest timing and included in yield measurements. Immature mushrooms (closed gills) were occasionally harvested ~1-2 days later, as needed.

Establishment of the 2020 sub-trials in Vancouver followed the same general protocols and experimental design as those used in the 2019 trials but with modifications to accommodate a substrate harvest timing comparison (see Table 2). Trees used for early-cut bolts treatments were downed in February into the first week of March, and trees for late-cut treatments were downed approximately month later (See appendix 3). Shiitake inoculation began approximately one month after cutting and were completed by May. Bolts were stored in shaded location until they were set into crib stacks in July 2020 adjacent to the crib stacks within each replication of the 2019 trials. Only one moisture management treatment was applied to the 2020 trials, with one of two crib stacks per replication being immersed for 24-hrs before being placed under a triple-layer of the spun polyester fabric covers along with water buckets (passive irrigation). This moisture management treatment was chosen based on promising preliminary observations from the 2019 trials, and because of it's technical simplicity. Initial log moisture content measurements were taken at bolt cutting, and the second measurements taken in late October 2020.

Trial location *(Site)*	Replications *per site*	Mushroom species *(System)*	Sample units *per replication*	Main treatment plot *Moisture management*	Sample units *per treatment*	Split-plot *Substrate*	Sample units *per substrate*	Split-split plot *Strain*	Sample units *per strain*
Vancouver	4	Shiitake* (Bolt)	16	Control (unmanaged moisture)	8	Red alder	2	Early-cut (during winter dormancy)	1
						Bigleaf maple			
				24-hr immersive soak > covered + passive irrigation**		Oregon oak***		Late-cut (after spring bud break)	1
						Paper birch			
		Wine cap (Wood-chip bed)	8	Control (unmanaged moisture)	4	Red alder	2	NA	NA
						Bigleaf maple			
				Drip-irrigated		Wild cherry		NA	NA
						Paper birch			

**All shiitake bolts were inoculated with a single wide-range strain ('West Wind') for consistency with the 2019 trials.*
***Shiitake bolts were placed in crib stacks in July 2020 within several hours after the 24-hr soaking period and covered with a triple-layer of 85% light transmission spun polyester cover (aka "floating row cover", "Reemay®") until late October 2020. Water filled buckets were placed underneath the spun polyester covers adjacent to crib stacks as a static source of humidity.*
****Wild cherry (Prunus avinus) substrates (previously included in the 2019 trials) were eliminated from the 2020 sub-trials due to supply and labor capacity constraints. Oregon oak used in the sub-trial was sourced from a privately-owned oak restoration planting in western OR due to it's protected status in WA.*

Table 2. *Additional shiitake sub-trial treatment layout established in Vancouver in 2020.*

Leftover log substrates of red alder, bigleaf maple, wild sweet cherry and paper birch from the 2019 trials were chipped and used for the wine cap mushroom bed trials. The trial uses a spatially-balanced complete block design with split-plots and four replications that includes a 1) two beds of each of the aforementioned substrate species and 2) drip-irrigation treatment in one of each of the two beds (see Table 3). All replications were sited under deciduous forest canopy, with each replication having distinct combinations of microclimate, degrees of shade, and dominant overstory species. Individual beds were 16 ft^2 with a 4"-deep layer of wood chips and ~2 lbs of sawdust spawn added to each bed. Individual beds were separated by 1' wide strips of landscape fabric. All trial beds were established by July 2020. Due to dry conditions immediately following establishment, all beds were soaked with 25 gallons of water per bed in early August to assure that the wine cap spawn did not become non-viable. The drip-irrigated beds were initially watered for 4 hours every 4 days, but the frequency was increased to 4 hours every other day in August in accordance with observations of moisture retention in the bed as summer weather became drier. All bed irrigation was turned off in mid-October.

Trial location *(Site)*	Replications *per site*	Mushroom species *(System)*	Sample units *per replication*	Main treatment plot *Substrate*	Sample units *per substrate*	Split-plot *Moisture management*	Sample units *per moisture management type*
Vancouver	4	Wine cap (Wood-chip bed)	8	Red alder	2	Control (non-irrigated)	4
				Bigleaf maple			
				Wild cherry		Drip-irrigated	
				Paper birch			

Table 3. *Wine cap mushroom trial treatment layout established in Vancouver in 2020.*

Preliminary findings to-date from the Vancouver site are indicating substantially greater evidence that substrate species is affecting shiitake yield more than moisture management treatments. Evidence from the first and second shiitake harvests is illustrating that birch substrates are showing standout shiitake yield potential, followed by moderately strong yields from red alder. Wild sweet cherry has been a moderate producer, while big leaf maple has been an overtly poor shiitake producer to date at all sites; red alder also overtly out-yielded big leaf maple in the satellite trials. Birch bolts overall showed early indications of a strong spawn run (likewise observed again in the 2020 sub-trials, see Appendix) and early fruiting. By the second harvest of our wide-range shiitake strain there were no birch bolts left in the trial that had not yet produced a mushroom yield. This was not the case for any other substrate species. Birch bolts have also accounted for the vast majority of cool-weather strain shiitakes produced to-date in Vancouver. Evidence of a correlation between log moisture content and shiitake yield data is lacking, but birch logs are nonetheless showing the most substantial evidence of an ability retain moisture between our initial measurement and measurements taken one year later. Alder logs showed the poorest ability to retain moisture content between the two first measurements, although they also contained the highest average initial moisture content of all substrate species, and the relatively sharp moisture decline between the first two measurements did not apparently preclude alder bolts from producing commendable yields of shiitake. Moisture content data to-date is also indicating that all non-producing bolts as a whole tend to have lower average moisture contents (< 25%). Humidity mitigation data has not been analyzed yet, but overall, moisture measurements from the Vancouver site between the initial and second measurements did not provide anticipated evidence of a positive effect from moisture mitigation treatments; in fact, there may have been a negative effect from keeping covers on logs throughout winter as a barrier to soaking rains. Covers were subsequently removed for winter in the 2020 sub trials.

Figure 2. *Shiitake production in trials throughout 2020. Birch substrates have dominated yields to date, followed by red alder yields (top left and center). Yields appeared to be cyclic, where heavy yields were followed by modest yields (bottom left) and vice versa. Wide-range shiitake strains produced throughout summer 2020 would commonly last up to a month in refrigerated storage (top right). Cool-weather shiitake strains have thus far produced low, variable, sporadic yields but were again dominated by birch substrates (bottom right).*

Despite lower evidence of an overall effect of moisture-managed treatments on shiitake yield, moisture management may have positively affected spawn run time; proximal evidence indicates a trend that bolts soaked in 2019 overall produced the earliest yields in 2020, while yields from control treatments initially lagged in contrast. Data trends are also indicating that average shiitake production of all bolts in trial sites with drier microclimates appeared to have a yield lag, and higher incidence of non-producing logs compared the average yields of bolts sited in locations that were inherently more protected and consistently humid.

Yield data has not been completely refined or analyzed to include the third harvest of our wide-range strain, or of the other strains. Overall, 2020's yields from harvest one and two of the wide-range shiitake strain that was used at all sites ('West Wind') produced commendably. Based on calculations from the first two harvests in Vancouver, 100 average-sized (4' x 5") alder bolts producing at our measured average yield and failure rates (% of non-producing logs) would produce ~40 lbs of shiitake per harvest, or 120 lbs. per year. This yield level is nearly 2x greater than average yields reported for from these systems in the northeastern US, and in our trials, birch bolts produced nearly double the yields of alder. Pest control had been a major concern regarding quality control and marketability, but we used a modified version of a "fruiting blanket" (spun polyester covers normally used as a moisture barrier during fruiting) approach to simultaneously control pests. After soaking for a forced fruiting, we used a large piece of spun polyester to completely enclose the all of the bolts during fruiting to exclude pests (see Appendix 5). The vast majority of mushrooms produced in this manner had marketable quality, and the approach would be easily adapted into a commercial production system. Cool-weather strains were not easily adapted to this method though. Unwrapping and re-wrapping the logs is very labor-inefficient for the sporadic low yields that this strain has produced and the method was consequently abandoned in December 2020. Pest pressure fortunately declined with the onset of winter, but overall quality control has been difficult with cool-weather strains because of non-uniform fruiting patterns, reduced ability to control pests, and frequent winter rain. These aspects would be foreseeably challenging within a commercial production enterprise.

Totem systems at the Vancouver site began producing oyster mushrooms in fall of 2020 and have continued into winter 2021. Oyster mushroom yield data has not been analyzed yet, but production patterns have been overtly variable and sporadic with no observed standout effect from any one treatment (See Appendix 6). A notable observation from the totem system in 2020 was pervasive colonization of birch logs by a feral polypore fungus (yet to be identified to species, see Appendix 7). A limited yield of oyster mushrooms nonetheless fruited on birch totems in 2020, and although competition from this fungus seems inevitable, the extent is likely to be undeterminable. Another notable observation is from the totem systems in 2020 is a pattern of oyster mushroom fruiting that occurred on totems closest to misters in the active irrigation treatments. Totems inoculated with lion's mane mushrooms did not produce at all in 2020; this species is known to have a longer spawn run than other mushrooms, but this is nonetheless not an encouraging result for it's potential in a commercial production context. Overall, observations of totem systems to-date indicate several potential issues for use in commercial operations due to variable, sporadic (and possibly low) yields and questionable ability to maintain quality control of the mushrooms produced on totems.

Wine cap mushrooms began producing very sporadically in late summer of 2020 (See Appendix 4) and with the last mushroom fruiting occurring in late fall. Big leaf maple and wild sweet cherry plots have not produced any wine cap mushrooms to-date. Yields have not been analyzed yet, but the quality of mushrooms produced have also not been marketable. Wine cap fruitings occur very quickly (< 2 d), and appear to decline likewise while also simultaneously succumbing to a myriad of pests. Although spawn run for wine cap mushrooms is the quickest of all the specialty mushroom species tested in our trials, the lack of foreseeable market quality control options for these systems is a major concern for applications in a commercial production context.

Publications, Handouts, Other Text & Web Products:
The project was disseminated through articles included in the Association for Temperate Agroforestry's *Temperate Agroforestry* summer newsletter, WSU Extension's *Forest Stewardship Notes* June newsletter, and the Society of American Foresters *The Forestry Source* December newsletter. Formalized Extension

guides on these production systems is still somewhat premature at this point in time, but findings to-date will allow for preliminary, basic guides to be produced. Additional photo and video footage was taken 2020, anticipating the need for material in distanced outreach and education during the COVID-19 pandemic, and is currently being edited for posting as an instructional video on YouTube. Datasets produced by this project will be used to produce a manuscript to be submitted for publication to a peer reviewed journal in 2021.

Outreach & Education Activities:
Project information was shared with a minimum of ~315 stakeholders from at least 19 states, Canada, and Portugal in 2020 through three in-person workshops and two online educational events (see Figure 3), and at the regional PNW Agroforestry Working Group's annual regional Workshop. Hands-on workshop plans were stymied in 2020 due to COVID-19; instructional video footage was instead created as an alternative approach and used during the two online workshops produced in 2020. Annotated project photo and video footage was also posted to the WSU Extension SW WA Ag Program Instagram feed which has garnered 95 image likes and 133 video views related to the project. A project-culminating workshop is being planned for Winter 2021.

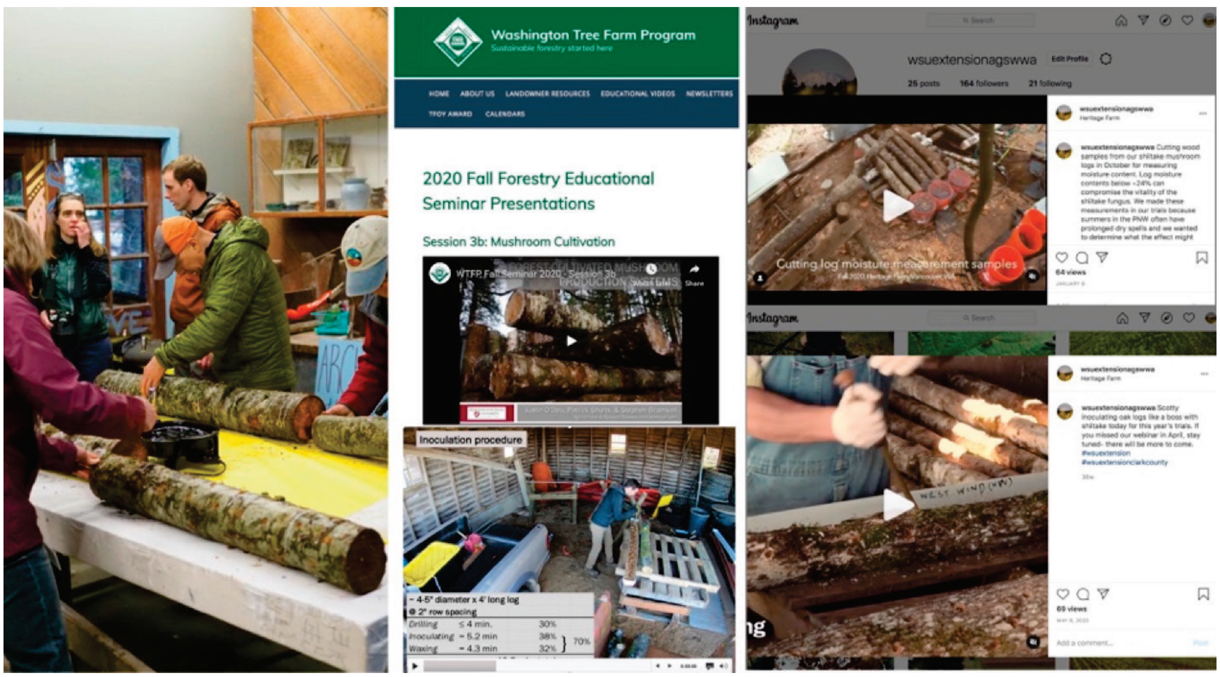

Figure 3. *Various outreach and education outputs from 2020, including a hands-on workshop online workshops featuring enhanced use of video, along with social media posts utilizing video for socially-distanced outreach and education.*

Impacts:

Short-Term: A post-program survey from one of our 2020 online events with 120 participants indicated that 62% of respondents reported an intent to implement new management practices based on knowledge gained, 20% of respondents were considering starting a commercial operation after the workshop, 90% indicated more demand for future Extension programming on this subject.
Intermediate-Term: The project is still fairly nascent to gauge intermediate-term impacts.
Long-Term: Long-term impacts have yet to be noted.

Additional funding applied for/secured:

Project-related funding advancements made in 2020 included 1) inclusion as Co-PD in a USDA-SCRI Planning Grant-funded project focused on developing a commercial specialty mushroom growers network in the western US, and 2) submission of an approved pre-proposal for an additional $25K to continue and expand the project. Additional funding will continue to be sought out in 2021.

Graduate students funded:

No graduate students were funded by this project, but it alternatively provided an internship opportunity throughout Summer 2020 for a visiting scholar from Kazakhstan studying agroforestry.

Recommendations for future research:

1) Trialing additional native PNW hardwood substrates – especially vine maple, hazelnut, and Oregon ash.
2) Trials examining existing mushroom strains best suited to the PNW climate, and whether well-suited strains can lengthen the mushroom growing season.
3) Development of novel strains of shiitake adapted to the PNW.
4) Further study of the effects substrate harvest timing on mushroom production longevity.
5) Further exploration of moisture management approaches.
6) Identifying feral fungal species commonly found on a given substrate species, their degree of competition with the species of mushroom being cultivated, and control methods for any species shown to significantly compromise production.
7) Identifying insect and animal pests of these production systems, and control methods for any species shown to significantly compromise production.
8) Exploration of other specialty mushroom species with potential for commercial forest-cultivated production.
9) Exploration of value-added products and economic assessments of forest cultivated mushroom enterprises within diversified farm operations.
10) Networking with Japanese researchers and producers to connect with contemporary advancements in forest-cultivated mushroom production systems.
11) On-farm trialing to facilitate adoption and grower feedback.

Appendix:

1. *Two different treatment replications established at the main trial site in Vancouver, WA. Photos: Justin O'Dea, WSU.*

***2.** Figures illustrating moisture management treatments used in trials. From L to R: 1) "Active irrigation" treatment using mist emitters on timers; 2) post-inoculation immersive log soaking before tarping; and 3) "passive irrigation" with static water buckets placed under tarps (foreground, before tarp was placed). The active irrigation treatment used in the totem system can also be seen in the background of the picture on the right. Photos: Justin O'Dea, WSU.*

3. *Aspects of additional sub-trials established at the Vancouver site in spring 2020. An evaluation of substrates including Oregon oak (top left and center), and an evaluation of late-cut vs. early-cut substrates (bottom left) were included in the sub-trials. The sub-trials were successfully established with one moisture management treatment in addition to controls (24-hour soaking before stacking and then covering stacks with spun polyester fabric until late fall). Soaked treatments and birch logs were showing strong indications of shiitake colonization by late summer 2020 (bottom and top right). Photos: Justin O'Dea, WSU.*

***4**. Wine cap mushroom production trials established at the Vancouver site in 2020. The trials included wood chips of four different substrates (red alder, big leaf maple, wild sweet cherry and paper birch), with half of the plots fitted with drip irrigation and the other half without (top left). The trials produced low, variable, sporadic yields in 2020 that were always unmarketable due to rapid quality decline and pests (right). Coyote damage also plagued the drip irrigation integrity throughout the summer (bottom left). Photos: Olga Romanova (right) and Justin O'Dea (left), WSU.*

***5**. Modified "fruiting blanket" setup to simultaneously keep conditions humid during fruiting while also excluding pests from reaching the fruiting mushrooms. Photos: Justin O'Dea, WSU.*

***6**. Highly variable, sporadic yields of oyster mushrooms in the totem systems began in fall of 2020. Totems with lion's mane mushrooms did not produce in 2020. Photos: Justin O'Dea, WSU.*

7. Select production issues encountered throughout 2020 with feral fungal growth (bottom left), insect pests (top center right and right, bottom center and right), shiitake desiccation from windy conditions during fruiting (top left), and non-uniform fruiting patterns in cool-weather shiitake strains (top center right). Photos: Justin O'Dea, WSU.