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EVALUATION OF THE TWELVEMILE CREEK RESTORATION MONITORING PROJECT

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Sitka Conservation Society
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INTRODUCTION

Twelvemile Creek is 20 mi^2 watershed located on Prince of Wales Island, approximately nine air miles southwest of Hollis and eight air miles northeast of Hydaburg, Alaska. Historic timber harvest (47 percent of the total basin area and 97 percent of the total riparian area) left a high percentage of the mainstem channel devoid of large wood and riparian areas fragmented, resulting in large homogenous stream reaches and low large wood recruitment potential. In addition, the high road density (2.9 mi/mi^2) has diverted streams, restricted fish passage at some culverts, and created chronic fine sediment sources (Jacobson 2013). Efforts to restore habitat in Twelvemile Creek began in 2011 with instream log placement and off-channel reconnection projects implemented in two tributaries (Azalea and Yellowlegs creeks). Mainstem large wood placement projects were implemented in Twelvemile Creek in 2012 and 2013. The Twelvemile Creek project area includes the mainstem of Twelvemile Creek, several tributaries and the inter-tidal basins that drain into Twelvemile Arm (Figure 1).

A biotic restoration effectiveness monitoring project was implemented in 2011 which included monitoring of Coho salmon (*Oncorhynchus kisutch*), Steelhead (*O. mykiss*), and Dolly Varden (*Salvelinus malma*) smolts. Adult Steelhead (1995-2015 with missing years) and Coho salmon (2004-2015 with missing years) have been estimated with snorkel surveys. Emigrating smolts have been counted and coded-wire-tagged with a screw trap and Estuary and Culvert traps (2012-2015), although 2012 was only a partial count due to late installation. Adult Coho salmon have been sampled for coded wire tags (CWT) (2014-2015), and CWTs have been recovered from marine fisheries (2013-2015). Additional adult CWT sampling both instream and through fisheries is expected to be completed through 2016. While the monitoring program has been comprehensive, concerns have been raised over whether the monitoring design is adequate to detect a response to restoration. The following report provides a critical review of the smolt and adult monitoring program and the ability of the Twelve Mile Creek Restoration Monitoring Project to effectively evaluate restoration actions.

Goals and Objectives

The goals of this contract report are twofold:

1. Analyze and summarize existing smolt and adult data from Twelvemile Creek and determine whether it can be used to detect a response to restoration, and
2. Provide a third-party review of the Twelvemile Creek Restoration (biotic) Monitoring Project to help project partners do the following:
    a. Better address stream restoration monitoring needs, and
    b. Understand how this particular project fits within the context of salmonid stream restoration monitoring efforts in the Pacific Northwest.

Specific objectives include:

1. Estimate smolt (Coho, steelhead, Dolly Varden) production from the whole watershed and compare estimates based on smolt trap and adult CWT returns.
2. Estimate Twelvemile Coho salmon marine harvest and contribution to different fisheries.

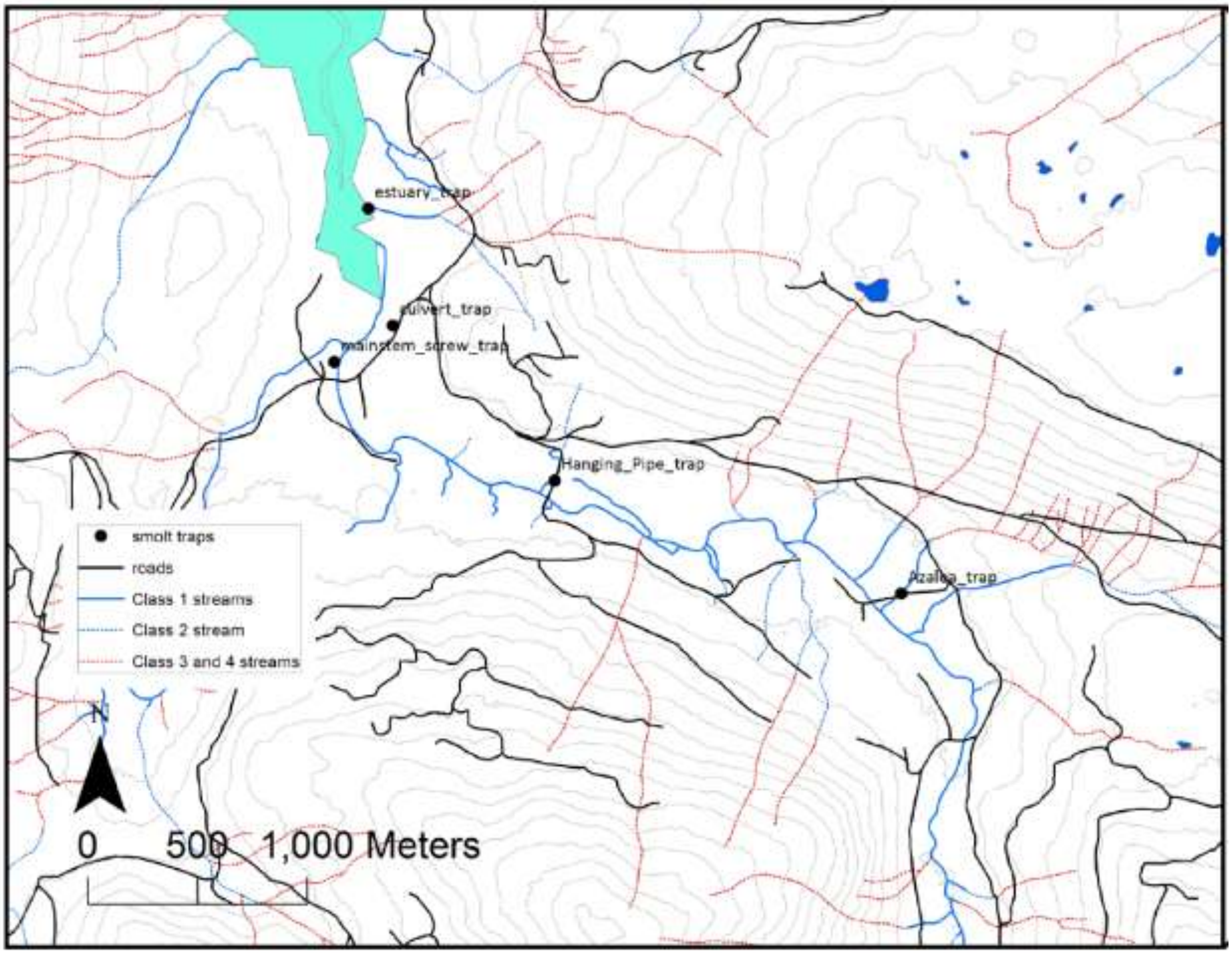

Figure 1. Map of Twelvemile Creek and location of mainstem and other smolt trapping locations.

3. Estimate adult salmon (Coho, steelhead) escapement to the Twelvemile watershed for all years of existing data.
4. Analyze and discuss temporal trends in smolts and adults.
5. Provide a template for refining the above statistics with 2016 adult data and target sample size.
6. Determine progress on objective of evaluating a salmonid response to restoration actions in the watershed?
7. Assess adequacy of current data and monitoring to evaluate restoration actions? Why or why not?
8. Determine additional actions needed to monitor salmon response to restoration in the watershed.
9. Describe an ideal monitoring project (minimum time, resources, funding) that would evaluate a salmonid response to the type of restoration actions in this watershed.
10. Describe the contribution of this monitoring project to the knowledge gained from similar monitoring efforts in the Pacific Northwest.

METHODS AND RESULTS

Objective 1: Estimate smolt (Coho, steelhead, Dolly Varden) production from the whole watershed and compare estimates based on smolt trap and adult CWT returns.

Methods

Smolt production based on CWT marking of smolts and recapture of marked adults

Details for smolt trapping and recapture of marked adults are described in Jacobson (2013) and McCurdy (2014). Total Twelvemile Watershed smolt production based on coded wire tagged (CWT) smolts in 2013 and 2014 and recapture of marked adult returns during 2014 and 2015, respectively was estimated using a Lincoln-Peterson (Peterson) estimate with Chapman modification as outline in Jacobson et al. (2013) and Volkhardt et al. (2007).

Equation 1.

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

Equation 2.

$$V[\hat{N}] = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}$$

$\hat{N}$ = Estimated smolt production for period

V = Variance

n_1 = Number of marked smolts

m_1 = Number of unmarked adults

m_2 = Number of marked adults

n_2 = Total adults examined

Smolt production based on mainstem Twelvemile Creek smolt trap

To estimate total smolt production from the Twelvemile mainstem trap, we used the method of Carlson et al. (1998) (See also Volkhardt et al. 2007; Toping and Anderson 2014; Zimmerman et al. 2015) for a single trap with efficiency estimates using the following formulas:

Equation 3.

$$\hat{U}_i = \frac{u_i(M_i + 1)}{m_i + 1}$$

Equation 4.

$$V(\hat{U}_i) = \frac{(M_i + 1)(u_i + m_i + 1)(M_i - m_i)u_i}{(m_i + 1)^2(m_i + 2)}$$

Where:
$\hat{U}_i$ = Number of unmarked fish migrating during discreet period i
u_i = Number of unmarked fish captured during discreet period i
M = Number of marked fish released during discreet period i.
m = Number of marked fish captured during discreet period i.

This modified Peterson approach estimates migration for discreet time periods, typically a day or a week, using a single test to estimate trap efficiency or by pooling several efficiency trials to develop a mark-recapture based estimate of the emigrant population for the time period.

The total smolt production for a year was estimated by summing $\hat{U}_i$ for each time period. Variance was estimated by the summing the variance for each time period and then using the following equation to estimate 95% confidence interval (C.I.).

Equation 5.

$$\hat{U} \pm 1.96\sqrt{V(\hat{U})}$$

Trap efficiency was estimated daily. However, we stratified by week as it was not possible to stratify by day, due to insufficient daily sample sizes and marked fish were often not recaptured for a few days. As suggested by Carlson et al (1998), we combined strata (weeks) when less than 5 fish were recaptured during a recapture period. In addition to estimating by week, we estimated total smolt production for the entire season by pooling all mark-recapture estimates. While the later method is likely less accurate, it provides an indication of the improvements in the estimates by adding stratification.

Results

Smolt production based on CWT smolts and adults

Total Coho smolt production based on CWT smolts and marked returning adults was estimated to be 206,064 smolts (95% C.I. = 133,291 – 278,836) in 2013 and 183,811 smolts (95% C.I. = 146,370 – 221,252) in 2014 (Appendix 1). The 2014 smolt production based on adult returns had lower variance and tighter confidence interval than the 2013 estimate using the same methods. This is due to the increased numbers and higher proportion of the population marked with CWTs.

Basic assumptions of Peterson mark-recapture estimates include: (1) all fish had an equal probability of being marked in event 1 (smolt tagging), *or* all adults had an equal probability of being inspected for marks in event 2 (adult recapture) (requiring that marked and unmarked fish survive at the same rate), *or* marked fish mixed completely with unmarked fish in the population between events (also requiring equal survival rates between marked and unmarked fish); (2) there was no recruitment to the population between events (closed population); (3) marking did not affect catchability of fish; (4) fish did not lose their marks between events; and (5) all marks were reported on recovery in event 2 (adult recapture). As noted by McCurdy (2014) assumptions 3 through 5 were unlikely to have been violated, but assumption 1 was likely violated in 2013 (marking did not occur over entire period). Upon review of the tagging data for 2013 and 2014, it does appear that fish were tagged throughout the migration period. However, it is not clear whether fish trapped in the culvert or estuary traps had an equal probability of being marked. Given that these traps do not appear to capture the total smolt output from this portion of the watershed, it is likely that not all smolts had an equal likelihood of being marked.

What is overlooked is that a Peterson mark-recapture estimates assume a "closed" population (Assumption 2); for this assumption to be satisfied, there must be a relatively short time between marking and recapture events. There is increasing literature about Coho parr movement among watersheds and migration into the estuary to rear and potential stray rates (Koski et al. 2009; Roni et al. 2012). Therefore, using a closed population estimator such as the Peterson estimate seems inappropriate for estimating smolt production based on marked smolts and adults. More importantly, the long period between marking of smolts and recapture of adults violates Assumption 2 (short time between mark and recapture) and seems unlikely that, given all the variable mortality that may occur over an 18 month period, one can reasonably back calculate smolt production using this method. This is further emphasized by the high variability in the estimates and by the observation that the estimates of total smolt production for a given year using this method exceed that generated using traditional smolt trapping methods by almost an order of magnitude (See following section). Therefore, a different model (estimator) such as Cormack-Jolly-Seber (CJS) that allows for an "open" population, would be more appropriate. The open CJS approach would require keeping track of individualized recapture histories over a series of field sampling events (smolt trap, CWT recoveries in fishery, adult returns) and thus allow calculation of the level of population change (immigration and emigration), survival, and probability of capture via multinomial distributions (Cormack 1964; Jolly 1965; Seber 1965). By estimating these parameters, the CJS approach relaxes the assumption that a population is closed.. To apply this to Twelvemile Creek would likely require some modification of the current field methods for smolt tagging and adult recapture which would need to be built around the specific CJS model selected.

Smolt production based on mainstem Twelvemile Creek smolt trap

The total smolt production from Twelvemile Creek based on the weekly stratification correcting for trap efficiency ranged from 16,944 – 68,342, 1,835 – 3,500, and 288 –– 26,604 for Coho, Steelhead and Dolly Varden, respectively, from 2012 to 2015 (Table1). These numbers are slightly higher than those with no stratification (i.e., simply pooling data for entire season) (Table 1), but the weekly stratification accounts for variability in trap efficiency due to changes in flow, temperature and other factors and are considered more robust estimates. The un-stratified estimates provided in Table 1 are provided simply to show the benefits of stratification. It should be noted that 2012 was a pilot year, the trap was not operational the entire season, and there were some other irregularities. Thus it should not be considered a complete estimate of smolt migration for 2012. Other than the 2012 season, the other years appear to meet the basic assumptions of Peterson estimates outlined above.

The stratification by week is thought to provide better estimates in most years as it accounts for differences in efficiency from week to week, which can be substantial. All calculations including trap efficiencies are provided in Appendix 2. Carlson et al. (1998), Toping and Anderson (2014),

Table 1. Peterson estimates and 95% C.I. of total smolt production for Coho, Steelhead, and Dolly Varden from 2012 to 2015 for Twelvemile Creek mainstem screw trap. "Stratified by week" indicates that population estimates were done for each week separately and then all weeks pooled to get total smolt production estimate. "Seasonal" indicates estimates were based on pooling all trap efficiency data for entire season (i.e., no stratification). These estimates are for the mainstem trap only and thus do not include any smolt production from areas below the mainstem Twelvemile trap. 2012* = Pilot year, trap was not run entire smolt migration season.

	Number of smolts					
	Stratified by week			Total # Seasonal		
Year	Estimate	95% CI		Estimate	95% CI	
			Coho			
2012*	16,944	11,070	22,819	8,352	7,090	9,614
2013	59,583	53,895	65,270	58,796	53,813	63,778
2014	68,342	63,026	73,659	77,633	71,757	83,508
2015	36,354	34,035	38,673	35,794	34,020	37,568
			Steelhead			
2012*	1,835	1,024	2,647	1,396	997	1,795
2013	1,030	342	1,719	644	341	946
2014	1,851	996	2,705	1,792	1,080	2,503
2015	3,500	2,466	4,533	3,010	2,438	3,582
			Dolly Varden			
2012*	288	(36)	611	288	(36)	611
2013	26,604	12,694	40,513	32,997	14,334	51,660
2014	15,949	9,540	22,358	14,120	9,694	22,358
2015	20,745	16,318	25,172	20,041	15,936	24,146

and Zimmerman et al. (2015) determined strata by using a G-test of proportions to determine whether strata should be combined. That could be applied to this dataset, but we thought it was unnecessary as sample sizes on a weekly basis were fairly large and combining strata further appeared to provide little additional benefit in terms of precision of estimate.

The Peterson method used to estimate smolt production from the mainstem Twelvemile Creek (Carlson et al. 1998) has the same assumptions as estimates based on CWT smolts and adult returns. The variable capture efficiency, and the fact that some marked fish took multiple days to reach the trap, suggest that the assumption that fish had equal probability of being captured or recaptured may have been violated. This assumption largely depends upon trap efficiency which can vary by flow and species. We accounted for this in part by stratifying by week.

For estimating total smolt abundance from a rotary screw trap, a potential improvement to the current modified Peterson estimator would be to use a CJS estimator or a “robust design” framework (Pollock 1982; Nichols et al. 1984; Kendall and Pollock 1992). Both methods incorporate capture-mark-recapture methods for open populations and can provide estimates of abundance, survival, and population change over time (immigration and emigration). Either model would be more robust to trap avoidance, individual behavioral effects, or differing capture efficiencies than a standard Lincoln-Petersen estimate (Clavel et al. 2008; Hines et al. 2003). Moreover, these methods allow determination of the influence of trap avoidance, individual behavioral effects or capture efficiency on population estimates.

The CJS and other more complex estimators have become more common in recent years particularly with increasing use of software such as MARK or rMARK (http://www.phidot.org/software/mark/index.html). However, the Peterson method used in this report is still widely used for smolt-trap data on the West Coast, particularly for small and large streams with a single smolt trap (e.g., Carlson et al. 1998; Volkhardt et al. 2007; Topping and Anderson 2014; Zimmerman et al. 2015). Moreover, stratification of estimates by time period and combination of time periods with similar capture efficiencies are considered robust approaches for estimating smolt abundance from smolt trapping data and are used in recent published studies on smolt production (Toping and Anderson 2014; Zimmerman et al. 2015). Therefore, we think that the Peterson estimate with stratification is still the most appropriate approach for Twelvemile Creek smolt trapping data. Because some marked fish appear to take multiple days to be recaptured, batch-marking fish or individual marking fish would improve resolution of trap efficiency and determine if a more complex CJS might be warranted in the future.

Comparison of two methods for estimating total smolt production

To compare total smolt production from the Twelvemile Watershed based on smolt traps and total smolt production based on CWT smolts and recapture of marked adults, we included smolt counts from Culvert and Estuary traps with those from stratified Peterson estimates from mainstem trap (Table 2). It should be noted that the Culvert and Estuary traps are weir type traps and no efficiency estimates were conducted. Adding smolts from these two traps provided small additional numbers of fish to initial Peterson estimates from the mainstem trap. However, the mismatch between the estimates based on adult returns and the smolt traps suggest that one or both the methods are inaccurate. For example, if one compares the total Coho smolt production based on CWT fish and adult returns to the total adult returns for 2015, the data suggest a smolt-to-adult return rate of less than 1% (1477 adults/183,811 smolts = 0.008) which would be extremely low. However, if one uses the numbers from the smolt traps, more reasonable estimate of smolt-to-adult return rate of 2.0% is obtained (1477 adults /72,349 smolts), which is within range reported for other Coho salmon populations, but still low for Southeast Alaska (Shaul et al. 2007; 2010; 2011). Smolt-to-adult survival rates reported for Coho salmon populations in Alaska and Pacific Northwest average 10% but range from 1% to as high as 20% (Sandercock 1991; Bradford 1995; Quinn 2005). However, our estimates do not include potential harvest: If harvest rates approach 60%, smolt-to-adult return rates prior to harvest would be nearly double the above reported value. Given the number of problems with using a Peterson estimate to back-calculate smolt production from CWT smolts and returning adults, we conclude that the smolt trap numbers are a better estimate or index of smolt production from Twelvemile Creek.

Table 2. Total smolt production from Twelvemile Creek 2013 to 2015 based 1) on combining the mainstem trap estimate (stratified Peterson) and the catch in Culvert and Estuary traps and 2) that provided by back-calculating smolt production based on CWT smolts and adult returns.

	Smolt traps				CWT &
Smolt Year	Mainstem	Culvert	Estuary	Total	Adult Returns
2013	59,583	3,078	NA	62,661	206,064
2014	68,342	1,203	2,804	72,349	183,811
2015	36,354	2,688	2,082	41,124	NA

Objective 2. Marine harvest of Twelvemile Coho salmon and contribution to different fisheries

Methods

To estimate marine harvest rates of Twelvemile Coho, we used 1) the CWT tag recovery data from Alaska Department of Fish and Game (including gear type, location, date etc.), 2) the proportion of marked (CWT) and unmarked fish captured on the spawning grounds, and 3) the snorkel survey estimates of total adult returns.

The harvest rates were calculated as follows:

Step A. Calculate proportion of marked fish on spawning grounds using the following equation:

CWT fish on spawning grounds = Total number of fish observed during snorkel surveys *(CWT fish captured in river/unmarked fish captured)

Step B. Calculate exploitation (harvest) rate with following equation:

Exploitation rate = CWT contribution to fishery/ (Total marked fish observed on spawning grounds + CWT contribution to Fishery)

CWT contribution to fishery = expanded estimate of coded wire tagged Twelvemile Coho in fishery as provided by Alaska Department of Fish and Game.

We made the following assumptions:
1) Contribution to the fishery as estimated by ADFG from recovered marked (CWT) represents an accurate estimate of exploitation rate
2) Marked and unmarked adult Coho were captured at equal rates in the fishery
3) Marked and unmarked adults had equal probability of being captured on the spawning grounds during sampling
4) The snorkel surveys provide a reasonable estimate of total returning adults
5) The proportion of marked and unmarked fish captured on spawning grounds can be applied to all fish observed during snorkel surveys.

Results

Overall adult harvest rates were estimated at 63 and 58% in 2014 and 2015, respectively (Table 3) with highest harvest rates being in the troll fishery (Table 3; Figure 2).

Table 3. Estimated marine harvest rates of Twelvemile Creek Coho in 2014 and 2015 based on CWT recoveries (expanded contribution) and marked and unmarked fish captured on spawning grounds.

	Number of CWT Coho Taken in Fishery					
Return Year	All Gear Types	Drift	Purse	Troll	Other	Harvest Rate
2014	177	17	39	97	22	63%
2015	178	26	59	89	3	58%

Our method for estimating harvest rates is a simple calculation based on contribution to fishery reported by ADFG (expanded numbers based on CWT recovered), number of marked and unmarked Coho adults sampled in Twelvemile Creek, and adult snorkel surveys. It is not clear if the assumptions that underlie our estimate are valid. However, U.S. Forest Service and Sitka Conservation Society project staff accept the uncertainty in the assumptions. The proportion of fish in each fishery provided by ADFG is assumed to be reasonable, but these exploitation rates should be viewed with caution. Marine harvest estimates are based on a sample of the fishery, with CWT recoveries expanded according to sample rates, which vary by fishery (goal is 20%; http://mtalab.adfg.alaska.gov/CWT/reports/). These expansions are used to calculate overall contribution to each fishery. In 2014 and 2015, 114 tags from Twelve Mile Creek were recovered in the sampled portion of the commercial catch and, based on expansion, the total contribution was estimated to be 355 marked fish. This is the number of marked fish expected to be detected if the entire catch had been sampled. The accuracy of these expansions depends in part on the number of tagged fish sampled/recovered in the fishery. If this number is relatively small, there can be considerable error in the estimates. Of the 114 Twelvemile CWT fish recovered in fisheries by ADFG, three had insufficient data for ADFG to expand recoveries to estimate harvest for that location and date. For these three fish, we used an expansion factor of 1.0 for each, which is the most conservative (i.e. an underestimate) method to include these fish for the calculation of marine harvest. In the equations above, the total number of Coho observed during snorkel surveys (an index count - see below section) was 1,895 in 2014 and 1,477 in 2015.

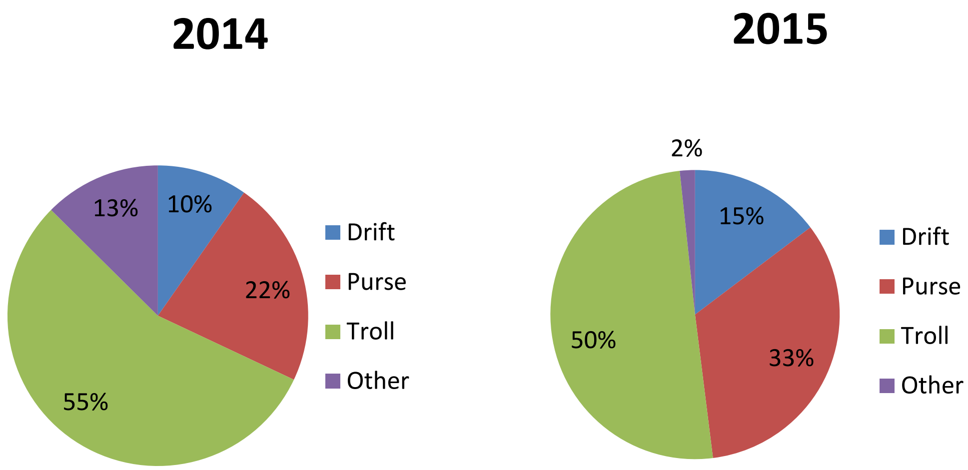

Figure 2. Proportion of harvest of Twelvemile Creek Coho by different harvest methods based on CWT recoveries.

Objective 3: Adult Coho and Steelhead escapement trends in the Twelvemile Watershed

Methods

We next examined adult Coho (2004 to 2015) and Steelhead (1995 to 2015) to determine if there were increasing trends in abundance that could be attributed to restoration. Both Coho and Steelhead adult abundance estimates were based on the highest count observed during snorkel surveys and thus represent an index of abundance rather than total spawner escapement. We did a simple trend analysis to see if abundances were increasing through time. Because restoration was completed in 2013, there were only two years of post-treatment data, which were not enough to compare means or trends before and after restoration.

To determine the amount of additional years of adult monitoring needed to detect an increase in fish abundance following restoration (Roni et al. 2005; 2013), we did a power and sample size analysis (Roni et al. 2005; Zar 2010). We assumed a β of 0.80 (probability of Type II error) and an α of 0.10 (probability of Type I error) and effect size (minimum detectable increase) of 350 adult Coho and 11 adult Steelhead (~25% of mean annual snorkel counts). Previous work has suggested that detecting changes in salmon abundance less than about 25% of the mean is not feasible due to interannual variation in fish abundance (Roni et al. 2010). Moreover, most restoration programs that have a specific fish response target are looking to increase fish numbers by 50% or more and an increase of less than 25% would not be seen as achieving that target.

Results

A simple graphical analysis of trends suggests an increasing trend through the entire monitoring period for Coho (Figure 3), but not necessarily Steelhead. The regression was significant for Coho ($p = 0.03$) but not for Steelhead ($p = 0.10$). However, given that restoration began in 2011 and was completed in 2013, it is unlikely that the slight increase can be attributed to the restoration actions. Moreover adult returns for Coho have actually decreased in the last three years, while steelhead numbers have gone up. Given that these represent the progeny of fish produced 1 to 2 years previous to adult Coho returns and potentially 2 to 4 years prior to adult Steelhead returns, it is even less likely that this slight increase (Steelhead) or decrease (Coho) in adults is related to restoration actions that occurred in 2012 or 2013. Examining overwinter survival or smolt-to-adult survival would be another approach to see if productivity of freshwater habitat or fitness of smolts has increased with restoration. However, adequate data were not available to perform these types of analyses. It should also be noted that even if there were more years of post-treatment data, without a control or reference stream or some knowledge of trends in adult returns in other nearby streams, it would be difficult to attribute the increase in adult abundance to restoration measures.

The power analysis indicated that a total of 18 years of monitoring would be needed to detect an increase in mean Coho adults of 350 or more fish, and 28 years to detect an increase of at least 11 more Steelhead per year. As there are currently 11 years of data for Coho and 18 for Steelhead, an additional 7 years and 10 years would be needed for Coho and Steelhead, respectively. A larger minimum detectable difference results in a shorter time frame of monitoring needed to detect a change. For example, if the minimum detectable difference for Coho was 400 fish, the total years of monitoring needed would decrease from 18 to 14, or 3 more years of adult monitoring. Regardless, this analysis suggests that adult monitoring should be continued for at least another 7 to 10 years.

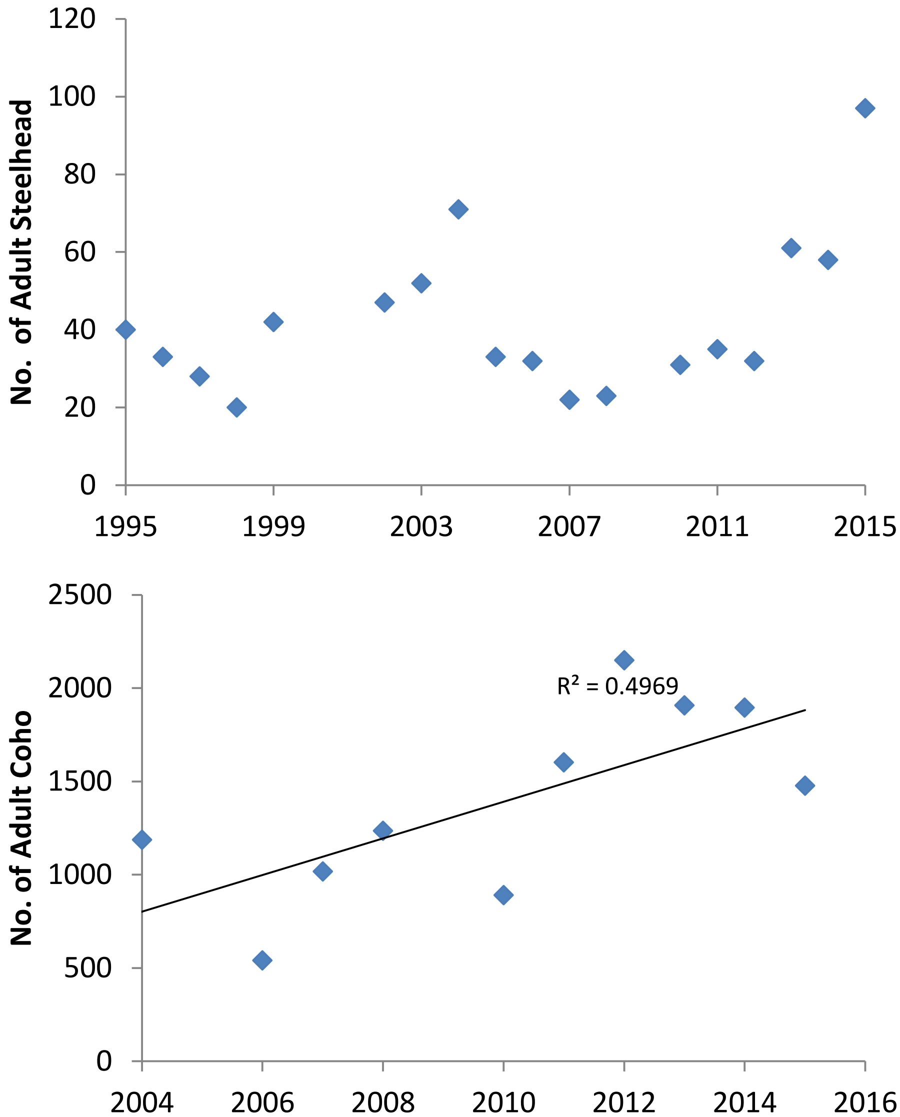

Figure 3. Trends in adult Coho and Steelhead abundance through time. Simple linear regression suggests Coho trend is significant through time, while that for steelhead was not (at 0.05 level).

Objective 4: Analyze and discuss temporal trends in smolts and adults

See analysis above for adults. There were not enough years of smolt data to examine temporal trends (2012 was incomplete, leaving only three years of data).

Objective 5: Provide a template for refining the above statistics with 2016 adult data and target sample size

An Excel sheet is provided with formulas and placeholders for marked, unmarked and total escapement numbers to be input in 2016 (Appendix 1). This will automatically calculate estimated 2015 watershed wide smolt abundance and a 95% C.I..

Objective 6: Progress on objective of evaluating a salmonid response to restoration actions in the watershed.

Because of the lack of pretreatment smolt counts and a control or reference stream, it is not possible to use smolt counts, smolt condition, or survival (overwinter or marine) to evaluate the biological effectiveness of restoration measures in Twelvemile Creek. The adult returns remain a promising avenue for determining long-term restoration effectiveness, though it is too early to determine if abundances have changed due to restoration for three reasons, including: 1) limited post-project monitoring to date, 2) most adult returns to date are from brood years prior to or during the time when restoration occurred, 3) lack of information about adult returns in other streams in the region and whether they show similar trends.

Objective 7: Is current data and monitoring adequate to evaluate restoration actions?

As noted in the analysis of smolt and adult data above, while the smolt trapping data is informative of production for the watershed, and may be useful for other reasons (e.g. planning future restoration, productivity of watershed), it is of little utility for evaluating restoration implemented from 2011 to 2013. This is because the smolt monitoring was initiated after restoration had begun and thus there is little pre-project data. If there was a long enough time series of adult and smolt data as well as data on the harvest rate on adults, it might have been possible to reconstruct smolt production in years prior to restoration. This could be an argument for continuing to monitor smolt production in the future, but this is not recommended as back-calculating smolt production from adult returns would be problematic and as these analyses carry their own assumptions and uncertainties.

The adult data remain the most promising biological data for evaluating fish response to restoration in the Twelvemile Creek watershed. This is because there is a long time series before restoration occurred, it is also relatively easy to collect compared to some other biological data types. However, adult data are highly variable, and ocean conditions and harvest rates can greatly affect return rates. Estimates of adult Coho harvest during the years of monitoring would be helpful, as these are likely not constant through time and could affect escapement and thus ability to detect restoration response.

Objective 8: What additional actions are needed to monitor salmon response to restoration in the watershed?

As noted previously, adult monitoring should be continued. Continuing to mark fish with CWTs could be useful, as that would enable continued estimation of total run size before harvest. This would only be useful if it is possible to obtain estimates of harvest from ADFG for adult Coho returns prior to 2014. However, if accurate harvest rates can be obtained from ADFG without tagging smolts, total run size could be calculated without CWT fish specifically in Twelvemile Creek. Comparing estimated harvest rates of adults in 2014 and 2015 (63 and 58%) with ADFG estimates for other streams in the area/or region should allow determination of whether tagging smolts with CWTs is still needed or regional harvest rates applied by ADFG can be used to estimate total run size.

Objective 9: Describe an ideal monitoring project that would evaluate a salmonid response to the type of restoration actions in this watershed.

There are three major ways that one can monitor watershed (or reach)-scale fish response to restoration actions including: 1) before-after control-impact (BACI) design, 2) before and after (BA) design and 3) intensive post-treatment design (IPT) which monitors treatment and control watershed only after restoration (post-treatment). The most powerful is the before-after control-impact design, commonly called BACI, which includes not only monitoring a watershed before and after restoration, but monitoring a similar watershed that has not been restored (control) before and after restoration. Typically a minimum of three years of pre- and post-project data are needed, but more would be beneficial. This is obviously logistically difficult as it often requires monitoring 3 to 5 years before restoration and 3 to 5 years after restoration. This does not include the time it might take to complete restoration, which can be done quickly in a small watershed, but may take several years in a large watershed. The only design more powerful than a BACI design would be a multiple BACI design which examines multiple treatment and control watersheds. This was the design used by Solazzi et al. (2000) in arguably the most successful watershed scale evaluation published to date.

A less powerful approach would be a simple before and after monitoring restoration in a single watershed, which is what you have for adult data in Twelvemile Creek. The obvious short-coming of simple BA monitoring is that it is hard to be certain that trends occurring in key metrics are due to restoration, as similar trends may be occurring in other watersheds. The weakest design would be an IPT which simply monitors both treatment and control watersheds after restoration and does not include collection of pre-project data. The shortcoming here is obviously that one has to assume that the trend one sees post restoration was not already occurring prior to restoration. Typically this kind of design is replicated in space (i.e., multiple paired treatment and control watersheds) to address the concern that observed trends are unlikely unique to one pair of watersheds or that the observed trends had started before restoration.

An example of an ideal BACI monitoring program using a watershed and restoration program similar to Twelvemile Creek is provided in Table 4. We have assumed that the watershed is small enough that much of the anadromous area could be surveyed using census techniques rather than some type of subsampling. Monitoring larger watersheds would require stratified random sampling or generalized random tessellated sampling (a form of stratified random sampling that assures adequate spatial coverage), or some other type of subsampling to cover the entire area. This would be particularly important for juvenile parr and instream habitat surveys.

The staff time and funding needed to conduct a thorough BACI design is considerable. If one assumes that at least 8 to10 years of monitoring are needed, then staff to conduct habitat surveys, fish surveys (juvenile and adult) would be needed for that period. Moreover, consistent training and a database would be needed to assure data is collected similarly each year and stored in a consistent database. The costs for this could vary widely, but could easily approach $100,000 more per year on even a small watershed unless some of the monitoring is already being conducted by other agencies or entities. It should be noted that cost, consistent training, and data base management have proven to be the Achilles heel of many of the Intensively Monitored Watersheds implemented in the Pacific Northwest in the last 10 years (Roni et al. 2015; Bennett et al. 2014).

To distill this ideal design down to the minimum needed to answer the above goals and monitoring questions, we recommend the following:

- Eliminate summer parr sampling and simply count smolts and adults every year, and conduct habitat surveys immediately before restoration and 1, 3 and 5 years after restoration.
- If the main goal of habitat restoration is to improve overwinter habitat, conduct only winter habitat surveys.
- A Hankin and Reeves (1988) or similar approach to sampling habitat could be employed rather than a complete census of whole watershed or anadromous reaches.
- Habitat surveys could be stripped down to most basic habitat types (pool, riffle, and glide) and measurements limited to habitat area and depth (residual).[1]

If money were available to do only one thing, we recommend monitoring smolt production before and after restoration as this incorporates all freshwater life stages influenced by watershed restoration activities (i.e., egg, fry, parr and smolt lifestages). While adult spawners would seem to incorporate all freshwater and marine lifestages, their survival in the marine environment is highly variable, affected by smolt fitness, ocean conditions, harvest, predation and other factors; thus changes in adult abundance are more variable than smolts and could be influenced by other factors than freshwater restoration actions and require a longer period of monitoring.

Objective 10: Describe the contribution of this monitoring project to the knowledge gained from similar monitoring efforts in the Pacific Northwest.

[1] We've gone to using a modification of Mossop and Bradford (2006) approach to surveying habitat, which is efficient and highly repeatable.

Table 4. Example of an ideal monitoring program to evaluate physical and biological response to whole watershed restoration. I've assumed here that this is a relatively small watershed (50 km^2) with less than 10 kms of anadromous habitat and census techniques could be used rather than some type of sampling approach. Steps are based on Roni et al. (2005. 2013).

Monitoring Design Step	Description
Restoration Goal	Restore habitat and increase adult Coho and Steelhead abundance
Specific Goals and Objectives	Increase pool frequency, LWD levels, habitat complexity and off-channel and overwinter habitat Increase smolt production and adult returns by more than 50%
Monitoring Questions (hypotheses)	Did restoration lead to watershed scale increased pool frequency, depth, habitat complexity during summer and winter? Did habitat restoration lead to increased overwinter habitat and off-channel habitat? Did smolt and adult production significantly increase following restoration?
Study Design & Scale	Before-after control-impact design at a watershed scale Paired watersheds including two similar nearby watersheds one of which will serve as treatment and the other as control
No. of sites & years	Two watersheds (sites) 10 years of monitoring including 4 before and 6 after restoration in both treatment and control watershed
Parameters to monitor	Habitat – pool area, residual pool depth, LWD abundance, habitat complexity (number and type of habitats), pond/off-channel habitat in both summer and winter. Fish – salmonids parr abundance (summer electrofishing or snorkeling), smolt production (smolt traps), and spawner surveys (watershed wide)
Sampling scheme	Habitat – complete census of entire anadromous reach Juvenile fish – stratified random sample based on channel and habitat types Smolts – smolt trap at downstream most of end of study watersheds Adults - complete survey of all anadromous reaches.

The monitoring and evaluation of whole watershed restoration, commonly referred to as an Intensively Monitored Watershed (IMW), has become increasingly common. There are nearly 20 different IMW efforts underway in Washington, Oregon, Idaho, and California to evaluate fish response to restoration (Bennett et al. In press). Unfortunately, most of them have suffered from a variety of problems both technical (e.g. design, replication) and procedural (e.g. funding, crew training, reporting, doing actual restoration). Thus some of the same issues such as lack of pre-project data or lack of suitable control or reference have come up in many of these IMWs. This is due in part to the opportunistic nature of many of these monitoring programs.

There have been relatively few published IMW efforts compared to reach scale evaluation of restoration. Out of more than 400 papers found in a 2014 review of literature on restoration effectiveness, only four published studies report on watershed or population level physical and biological response to habitat restoration (Roni et al 2014). These include Reeves et al. (1997), Solazzi et al. (2002), Slaney et al. (2003) and Johnson et al. (2005). Reeves et al. (1997) and Johnson et al. (2005) produced inconclusive results though large flood events and some design issues appear to have limited ability to detect results. Reeves et al. (1997) used a BA design, which was limited by lack of controls and while Johnson et al. (2005) was a BACI study, the control stream did not track the treatment well and thus did not help explain background variability (i.e. it wasn't a very good control). Slaney et al. (2003), which focused on nutrient additions, initially showed increased juvenile steelhead growth but no improvement in survival or adult returns. Unfortunately, the final results of this study were never published or the study was never completed. In contrast, the Solazzi et al. (2000) study, perhaps the most robust and ambitious of the existing studies, demonstrated that creation of winter rearing habitat increased overwinter survival for Coho salmon, as well as the number of smolts. Solazzi et al. (2000) included two treatment and control pairs (BACI design with 2 replicates) and found that restoration measures increased winter rearing habitat for Coho by roughly 700% which resulted in overwinter survival and number of smolts increased by about 200%. The Solazzi et al. (2000) study demonstrates the importance of focusing on the limiting life stage and habitat. They conducted extensive analysis prior to restoration to determine that winter habitat was limiting and then designed restoration specifically to increase that habitat type.

A few other recent studies have reviewed watershed-scale evaluations to restoration and provided recommendations for monitoring and design. Roni et al. (2014, 20154) summarized the results of three different IMWs and review of other unpublished IMWs to provide monitoring guidance. They reported two major conclusions. First, because costs can balloon quickly and many IMW programs have measured factors that are unlikely to respond to restoration, monitoring programs need to be judicious about which parameters to monitor, and to focus on selecting parameters that respond to restoration in order to address goals and questions of the project. Second, failure to properly coordinate timing, location, and implementation of restoration, monitoring and other management activities can prevent the most well designed program from detecting a watershed or population level response to restoration. For example, in one IMW, restoration actions occurred before adequate pre-treatment data had been collected, making it impossible to compared fish abundance before and after restoration. In another watershed, a large number of hatchery fish were outplanted into the control watershed mid-way through a ten-year monitoring program, masking the response of naturally produced fish to restoration. Bennett et al. (In press) reviewed several of the IMWs along the West Coast and provided similar guidance to Roni et al. (2015) They suggest an IMW is the best way to evaluate restoration, although the problems they outline with IMWs do not support that assertion. We argue that an IMW is only appropriate in very specific situations, where funding, restoration planning, monitoring and other management activities are certain and can be controlled through the life of project.

In context of published work and ongoing IMWs focused on fish response to restoration, Twelvemile Creek has some similar shortcomings to some other programs that have been completed and some others underway. The strength of the Twelvemile Creek project is the long-term monitoring of adult fish and the focus on a modest number of key variables (adults, smolts) specifically related to the goals of restoration. Twelvemile and many of the other ongoing IMWs emphasize the importance of planning the monitoring well in advance, the need to build the monitoring correctly from the outset, and the challenges of opportunistic selection of a study watershed. This is not meant to be overly critical as many biologists, restoration practitioners, and researchers in the region have implemented and invested far more time and money in similar projects.

A final factor to consider when designing a monitoring program to determine watershed or population level response to restoration is the total amount of restoration required to produce a detectable response. This was highlighted in a study in the Puget Sound basin that showed that more than 20% of most watersheds would need to be restored to see a 25% increase in Steelhead or Coho smolt abundance (Roni et al. 2010). Estimating the expected fish response to restoration can be difficult for many techniques that don't directly improve habitat (e.g., road removal, riparian planting), but relatively good estimates exist for wood placement, culvert removal, and creation or reconnection of floodplain habitat. To assist with this, in Table 5, we provide increases in Coho and Steelhead parr and smolts m^{-1} or fish m^{-2} for some common habitat improvement techniques. By taking the length or area treated and multiplying the area by the appropriate number, an estimate of the potential increase in fish number can be calculated. The standard deviation of these estimates is provided to provide an idea of what the variability is around the predicted increase in fish abundance. It is relatively large due to small sample sizes for some projects and the variability in success or treatment intensity of different projects. Regardless, it will help determine how much fish abundance will increase and whether the increase in fish abundance will be large enough to lead to a watershed increase in fish abundance (see Roni et al. 2010 for additional details).

SUMMARY

Estimated Coho smolt production from Twelvemile Creek from 2013 to 2015 based on mainstem smolt trap ranged from 36,354 to 68,342. Coho smolt production based on CWT smolts and returning adults was considerably higher (206,064 and 183,811 for 2013 and 2014), but the smolt production from mainstem trap are believed to be more accurate than back calculating from adult returns. This is in part because the Peterson mark-recapture methodology is appropriate for the mainstem smolt trap but not the CWT smolts and adults return data. Marine harvest based on CWT recoveries in the sport and commercial fisheries was 63% and 58% in 2014 and 2015, respectively. Long-term trends in adult returns suggest little change since restoration for either Coho or Steelhead, though there was a slight positive trend for Coho adults largely driven by increasing returns since 2011. Because there is a long time series prior to restoration, the adult data represent the best opportunity for detecting a response to restoration in Twelvemile Creek. Unfortunately, because the smolt trapping did not start until restoration was already underway, it is not possible to use the smolt trapping data to determine if there has been or will be an increase or decrease in Coho or steelhead smolts following restoration. Other IMWs around the Pacific Northwest have struggled with similar problems of collecting adequate pre-project data. Based on these findings and on our evaluation of Twelvemile Creek, we provide recommendations for an ideal before-after control-impact design to evaluate whole watershed response to restoration in other watersheds similar to Twelvemile.

Table 5. Mean and standard error of Coho and Steelhead parr and smolt to different habitat restoration and improvement techniques. For in-channel techniques the values shown are fish/m and for floodplain techniques they are fish/m^2. Study designs are as follows: PT = posttreatment, BA = before–after, BACI = before–after control–impact. From Roni et al. (2010).

				Summer (parr)				Winter (smolts)			
				Coho		Steelhead		Coho		Steelhead	
Restoration type (reference)	Study design	Applicable sites or habitats	No. of sites	Mean	SE	Mean	SE	Mean	SE	Mean	SE
In-channel techniques											
Culvert replacement (barrier removal); Pess et al. 1998)	BACI	Small streams	6	0.36	0.17	0.05	0.01	--	--	--	--
LWD in small streams (Roni and Quinn 2001)	PT	Small streams	28/22*	0.59	0.18	-0.06	0.10	0.21	0.07	0.04	0.02
Boulder weirs (Roni et al. 2006a)	PT	Medium streams	13	0.66	0.18	0.02	0.01	--	--	--	--
Constructed logjams (Pess et al. In review)	BA	Large streams	16/6**	2.32	0.55	0.71	0.47	0.19	0.10	0.09	0.06
Floodplain techniques											
Restored floodplain habitats (Roni et al. 2006b)	BA	Floodplain reconnection	30	--	--	--	--	0.37	0.07	--	--
Constructed groundwater channels (Morley et al. 2005)	PT	Floodplain habitats	22	1.70	0.31	0.06	0.03	0.34	0.09	0.03	0.01

* 28 sites contained coho, 22 steelhead

**Paired treatment and control sites in Elwha River - 16 during summer, 6 during winter

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APPENDIXES

Appendix 1. Calculations for estimating smolts from adult returns

See 2012_2015 Peterson Estimates.xlsx excel workbook.

Appendix 2. Calculations for estimating smolt production based on rotary screw trap.

See 12mile_CWT Harvest Estimates 2013to2015.xlsx excel workbook.