Estimation of relative sampling efficiency for various sampling programs targeting outmigrating Chinook 0+ smolt from the Nooksack River

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Abstract

The Lummi tribe has operated a smolt trap in the lower reaches of the Nooksack River for several years in order to develop an annual estimate of smolt production from the Nooksack River. In the past the sampling protocol has been to sample one randomly chosen 6-hour set, approximately every other day during the main outmigration period. This year, however, the sampling protocol was modified to also include a number of days where sampling was conducted over much longer periods of time (up to 24 hours), during which numerous sequential 'subsets' were taken (ranging from ~1 hour to 10 hours each). An analysis of the resulting data was performed using a 3-level, nested analysis of variance with various temporal sampling scales (monthly, weekly, daily) as the three levels of the ANOVA, and within-day subsets as the error term. Only the weeks-within-months temporal scale was considered statistically significant. Assuming that all would be sampled, a table of relative efficiencies was calculated for a range of hypothetical sampling protocols that could be used within each week. This table is presented, along with a discussion of the potential flaws in the methodology used to derive it.

Introduction

Sampling programs often require a significant investment of time, effort, and money to undertake and usually these are limiting factors when planning surveys. Ideally, the costs and benefits of each potential program could be ascertained during the planning phase so that the most efficient allocation of resources can be made. Unfortunately, pilot studies that allow for optimization of survey effort are seldom undertaken in advance.

Sampling effort for outmigrating Chinook smolts in the mainstem of the Nooksack River has historically been modeled on operating a smolt trap situated above the thalweg for a 6 hour period of time, chosen randomly, every second day. In practice, the sampling intensity is slightly lower than this due to the desire by crew to have the weekend off work. Although this sampling protocol has been in place for multiple years there has not been any attempt to determine whether this particular protocol provides optimum data quality given the limitations of staff time and effort. This paper represents an attempt to objectively quantify the relative efficiency of a range of sampling programs so that future sampling can be most effectively targeted at the most appropriate temporal scale to provide the best data (lowest estimated variance) given the limits of staff time and availability.

Methods

In the summer of 2002 a series of '24-hour sets' were undertaken between May and July, on an ad-hoc basis, during the smolt outmigration season. Each of these 'sets' was subdivided into a number of 'subsets' so that within-set changes in smolt catchability could be determined. The primary rationale behind this increase in sampling effort was to obtain additional data during the main part of the outmigration season. Consequently, there was no attempt to ensure equal replication occurred at each of the temporal scales considered in this analysis, or even within each of the days that were sampled using multiple sets. As a result, the 3-level nested ANOVA also used unequal replicates. The temporal scales considered were arbitrarily chosen. These level were days nested within weeks, weeks within months, and months within the outmigration season. Within-day variation between subsets was the residual, or error term.

Because no appropriate statistical software was available, the 3-level nested ANOVA was performed on a specially written Excel spreadsheet. All steps in the calculation were taken from Sokal & Rohlf, 1981 (Biometry, 2nd edition) and modeled on the example provided in Box 10.5. Prior to performing the ANOVA, data was transformed using the natural logarithm of the raw data + 0.1, because subset data tended, overall, to be strongly skewed to the right and also tended to be platykurtic. The conditions for using the Satterthwaite approximation for MS_{days} were met with the raw data but not with the transformed data. Despite this, the Satterthwaite approximation was still used to estimate MS_{days} for the transformed data. Both raw and transformed data met the conditions for using the Satterthwaite approximation for MS_{weeks}.

Optimization of the potential range of sampling programs was performed using the variance associated with the within day and between days within a week levels of the ANOVA, and used the procedure given in Chapter 10.4 of Sokal & Rohlf (1981) where:

$$\text{Relative Efficiency (RE)} = S^2_Y(1) * 100 / S^2_Y(2)$$

$S^2_Y = s^2/ncb + s^2_{c\subset b}/cb + s^2_{b\subset a}/b$ for each sampling program with n subsets per day, c days per week, and b weeks per month. Assuming that all weeks will be sampled each month, S^2_Y becomes:

$$S^2_Y = s^2/nc + s^2_{c\subset b}/c$$

$S^2_Y(1)$ is the estimated total variance associated with a sampling protocol '1' and $S^2_Y(2)$ is the estimated total variance associated with sampling protocol '2'. The result is the relative efficiency of protocol 2 versus 1.

No attempt was made to model costs associated with each combination because of difficulty in quantifying numerous factors that may be more amenable to subjective analysis.

Results

Summary CPUE data from the smolt traps are provided in Table I.

Table I. *CPUE data from each subset during within-day sampling*

Date	Week	Set#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9-May	19	**40**	0.00	1.00	0.00	1.28	0.00	0.44	1.34	4.50	6.38	0.49	0.00	0.00	0.00	0.50	0.00
5/14-15/2002	20	**43**	20.38	48.78	61.09	81.77	97.00	92.37	33.44	72.00	86.60	36.32	6.94	5.55			
5/22-23/2002	21	**47**	37.74	10.75	17.45	38.42	19.02	5.13	10.09	5.71	7.14	5.00	15.00				
30-May	22	**50**	23.08	34.03	4.71												
30-May	22	**51**	50.00	81.25	44.68												
5-Jun	23	**54**	92.38	111.03	125.13	53.08	55.86	135.68	130.59								
11-Jun	24	**57**	39.02	44.43	26.05	44.53	32.95	38.69	93.78	74.05							
13-Jun	24	**58**	29.00	70.50	68.00	13.50	79.65	134.02	236.15	56.22	24.86						
6/17-18/2002	25	**60**	15.67	26.42	20.16	36.39	39.17	29.71	23.11	12.71	8.12	26.63					
6/19-20/2002	25	**61**	3.23	4.46	9.58	5.00	8.76	32.16	25.41								
6/21-22/2002	25	**62**	3.86	14.59	7.60	6.00	13.09	19.13	54.81	59.43							
6/24-25/2002	26	**63**	5.41	2.77	23.85	24.64	16.23	18.91									
6/26-27/2002	26	**64**	6.34	7.50	8.50	4.00	8.28	14.73	22.86	10.59	23.28	16.95	29.27				
7/1-2/2002	27	**66**	3.87	2.44	2.86	6.29	9.36	5.00	16.15	28.99	23.52						
7/3-4/2002	27	**67**	2.49	10.43	1.61	7.11	5.68	9.00	8.39								
8-Jul	28	**69**	14.09	7.50	24.00												
8-Jul	28	**70**	4.80	6.41	12.52	22.62											
7/12-13/2002	28	**72**	4.50	7.57	8.00	9.00											
17-Jul	29	**75**	2.53	1.62	1.00	1.63											
7/24-25/2002	30	**79**	7.64	7.12	14.12	7.18	7.38	6.30									

After transformation the data tended to be only slightly skewed to the left, but remained both heteroscedastic and platykurtic. ANOVA assumed data are homoscedastic and normally distributed. However, Sokal & Rohlf (1981) consider the effect of heteroscedaticity to be minor unless single degree of freedom comparisons are being made. Since there are several degrees of freedom at each level below months this violation is assumed to have negligible impact on the anaylsis. It is also assumed that the transformation of the data will have reduced the potential for error associated with a non-normal distribution of the subset data. Several other transformations were trailed but none were better able to satisfy the assumption of normality or homoscedasticity.

The ANOVA table for the analysis is shown in Table II. The only significant sampling scale proved to be between weeks within months ($p<0.05$).

Table II. *ANOVA table for 3-level, nested analysis of Variance.*

Source of Variation	*df*	SS	MS	Fs	F's	*df* '	Critical Value
Between Months	2	21,897.05	10,948.53	1.26	1.08		3.22
Between Weeks	9	78,010.96	8,667.88	10.31	9.60	8.78	3.58
Between Days	8	6,724.04	840.51	1.50		6.16	2.01
Within Days	127	71,123.98	560.03				
Total	146	177,756.04					

The variances calculated for each temporal scale are provided in Table III.

Table III. *Calculated Variance associated with each temporal scale.*

	Variance	Temporal Scale	Percent of Total Variance
s^2=	0.7	sets within days	25.46%
$s^2_{C\subset B}$=	0.0	days within weeks	0.85%
$s^2_{B\subset A}$=	2.0	weeks within months	70.90%
s^2_{A}=	0.1	months	2.79%
total=	2.8		

Table IV shows the calculated relative efficiencies of all potential sampling programs using 2-hour sampling units for each subset relative to the 6-hour set taken every second day. (Assumes that a 6 hour set is equivalent to 3 sequential 2 hour subsets)

Table IV. *Relative sampling efficiencies of various sampling protocols for the Ferndale smolt trap*.

	N° of 2-3 hour Samples taken per day											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
7 days per week	71%	138%	200%	259%	314%	367%	416%	463%	507%	550%	590%	628%
6 days per week	61%	118%	171%	222%	269%	314%	357%	397%	435%	471%	505%	538%
5 days per week	51%	98%	143%	185%	224%	262%	297%	331%	362%	393%	421%	449%
4 days per week	41%	79%	114%	148%	180%	209%	238%	265%	290%	314%	337%	359%
Every other day	35%	69%	100%	129%	157%	183%	208%	231%	254%	275%	295%	314%
3 days per week	30%	59%	86%	111%	135%	157%	178%	198%	217%	236%	253%	269%
2 days per week	20%	39%	57%	74%	90%	105%	119%	132%	145%	157%	168%	179%
One day per week	10%	20%	29%	37%	45%	52%	59%	66%	72%	79%	84%	90%

Discussion

ANOVA assumptions are primarily made in order to test the significance of the MS calculated for each level in the ANOVA table. Although two of the underlying ANOVA assumptions, namely normality and homoscedasticity were violated in the data used, the underlying variance for each level should not depend on these assumptions as they are a direct measure of the spread of the data values in each group. Consequently, even if the statistical significance results in the ANOVA table were affected, the relative efficiency table given in Table IV should not be. However, I doubt that the between-days-within-a-week level of the analysis would be statistically significant even if the assumptions were met since it explains such a tiny portion of the total variance. The other problem with the ANOVA occurred when the Satterthwaite approximation was used to calculate the modified $MS'_{days,}$ $df'_{days,}$ and F'_{days} based on the transformed data. Once again, however, this step comes after the calculation of the individual variances and would therefore only potentially impact upon the test of significance and not the table of relative efficiencies.

Given the preceding discussion, the only statistically significant timescale for sampling is at the weeks-within-month level (Table II). Week-to-week variability accounts for c.71% of the total variance, while within-day and between-day day variability together only explains c. 26%. This suggests that the primary focus of sampling should be ‘subsets’ within a week, and that the variability within-days is equivalent to the variability between-days in the same week. In other words, one sample on each of two days is of much the same value as 2 samples on one of two days.

This perception is reinforced by the relative efficiencies calculated in Table IV for the spectrum of possible sampling protocols within any given week. Protocols in green indicate a better relative efficiency compared to the historical 6-hour every-other-day protocol (yellow). Values in red are worse compared to the historical protocol. The values in Table IV provide a useful tool for evaluating sampling protocols during the planning stages for a field season. However, I remain cognizant that there is potential for missing significant runs of fish if long periods of time are left unsampled when unrecognized factors stimulate fish outmigration timing.

One possible use of the table is to temporarily increase the relative efficiency of the sampling protocol during periods of high outmigration rates (say from the last 2 weeks of May through to the end of June) and reduce the relative efficiency during quieter times.

References

Sokal, R.R. & Rohlf, F.J. (1981) *Biometry*. 2nd Edition. W.H Freeman & Company, New York. 859pp.