Trawl Survey Designs for Reducing Uncertainty in Biomass Estimates for Patchily-Distributed Species

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Introduction

Survey biomass estimates of Gulf of Alaska (GOA) Pacific ocean perch (POP), and other rockfish species, exhibit large interannual variations that are generally inconsistent with their longevity. These variations can be attributed to sampling variability that reflects the "patchiness" of the population's spatial distribution, which results in estimation error when high density patches are either over-represented or under-represented in survey trawls. Because resource management is based heavily upon the survey abundance estimates, errors in these estimates directly affect the level of conservation applied.

Several two-stage sampling designs can potentially improve biomass estimates of patchily-distributed species, including adaptive cluster sampling (ACS) and double sampling. The Trawl-Acoustic Presence-Absence Sampling (TAPAS) proposed by Everson et al. (1996) is a form of double-sampling which can be conducted in a single survey phase. Under TAPAS, a series of trawl stations is pre-defined prior to the survey (as in traditional sampling) and hydroacoustic data is used to identify locations of high-density patches during the course of the survey. When high density patches are encountered, the lengths of the patches along the survey trackline are determined and a randomly located sample is collected from each patch.

The purpose of this research is to use simulation modeling to evaluate the performance of the TAPAS design with respect to the following three aspects: 1) the spatial pattern of the high-density areas; 2) the strength of the relationship between hydroacoustic data and trawl survey catches; and 3) the level of sampling of the high-density areas observed from hydroacoustic data.

Methods

Simulation of hydroacoustic strength

Simulation of hydroacoustic data were scaled to have a median S_v (the mean volume backscattering strength) that matched the median of data collected from the Yakutat area during the 2005 Gulf of Alaska trawl survey. High density areas were defined as those exceeding the 80% quantile from the 2005 field data. Two general spatial patterns of hydroacoustic data were simulated over a 30 × 30 grid (**Figure 1**).

1) *Spatially correlated S_v pattern*. A variogram fit to S_v values estimated for the Yakutat area during the 2005 Gulf of Alaska trawl survey resulted in the range parameter (the spatial scale of correlated variance) of 3.62 km. This variogram was used as the basis for simulation of the spatially correlated S_v pattern.

2) *Random S_v pattern*. Randomly distributed S_v values were simulated by setting the variogram range parameter to 0.1, essentially eliminating any spatial autocorrelation.

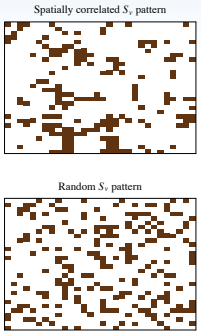

Figure 1. Example spatial maps of the simulated spatially correlated S_v pattern (top) and the random S_v pattern (bottom); brown cells indicate regions where the simulated S_v exceeded a threshold value.

Simulation of population density

Simulation of fish population density was based on the simulated S_v spatial pattern and relationships between fish density (kg/km^2) and S_v (**Figure 2**).

1) *"Strong" relationship between S_v and fish density*. Based upon a significant relationship between log catch per unit effort (CPUE, kg/km^2) and S_v for tows in Alaskan trawl surveys in 2001 and 2002 (Hanselman and Quinn 2004).

2) *"Weak" relationship between S_v and fish density*. A "weak" relationship was obtained by reducing the slope estimated by Hanselman and Quinn 2004 (0.1438) by approximately two-thirds to 0.048.

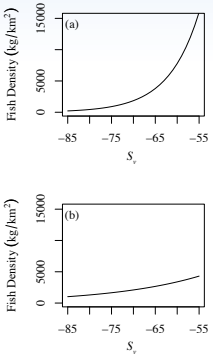

Figure 2. Example simulations of the "strong" (a) and "weak" (b) relationships between fish density and S_v.

Simulation of survey sampling

For each combination of S_v spatial pattern and strength between S_v and fish density, the four sampling fractions of 1%, 3%, 5%, and 7% were evaluated (corresponding to sample sizes of 9, 27, 45, and 63). Five hundred surveys were conducted for each of the 16 combinations of S_v spatial pattern, strength between S_v and fish density, and sampling fraction. For each simulated survey, random grid cells were selected and a vessel trackline between stations was computed. Biomass estimates were made with three sampling designs; simple random sampling (SRS), TAPAS, and a modified version of the TAPAS design.

1) *SRS*. The biomass estimate is obtained as the product of the total survey area and mean density from the sampled tows

2) *TAPAS*. Under TAPAS, an estimate of the proportion of the sampling area in the high-density S_v patches is made from the proportion of the trackline observed in the patches. If a planned tow is found to occur in a high-density patch, the tow is replaced by one randomly located in the patch. Also, additional tows are made in patches that are observed on the trackline but do not have planned tow. The sampling area is thus divided into "patch" and "background" areas, with corresponding estimates of area size (from the trackline) and density (from the tows).

3) *Modified TAPAS*. Under the TAPAS design, encountering and sampling many patches may not allow time to complete the background stations within the time and budget allocated for the survey. For this reason, a modified version of the TAPAS design was also examined in which every third patch is sampled.

A schematic of stations sampled under each design is shown in **Figure 3**.

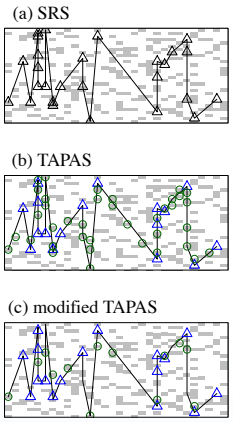

Figure 3. Example tracklines and stations sampled with three sampling designs. In SRS (a), the stations (triangles) are randomly chosen without respect to the patches of high S_v (grey cells). In the TAPAS design (b), additional samples (green circles) are collected in the high S_v patches observed along the trackline to augment to background samples (blue triangles). In the modified TAPAS design (c), only a portion of the patches encountered are sampled.

Performance indicators

The performance measures for comparing the survey designs focused upon bias and relative efficiency (RE). Bias is measured by the relative percent error in biomass estimate, 100*($\hat{B}$ - B)/B. Efficiency compares the variance of an estimator to the theoretical variance from a simple random sample of equal sample size. A relative efficiency greater than one indicates greater precision than an SRS design with equal sample size.

Results

1) Biomass estimates from the three estimators were unbiased, as the average percent error did not exceed 1.5% for any of the cases examined (**Table 1**).

2) The average sample sizes for the TAPAS design were approximately twice the sample sizes for the SRS design, whereas the samples sizes for the modified TAPAS design were more comparable to those for the SRS design (**Table 1**).

3) The relative efficiencies of the TAPAS and modified TAPAS designs were larger with a strong S_v- density relationship than with a weak S_v - density relationship. In Figure 4, the efficiencies of the TAPAS and modified TAPAS designs were divided by the relative efficiency of the SRS design; thus, efficiencies greater than 1 indicate a larger relative efficiency than the SRS design. With a strong S_v - density relationship, efficiencies for the random S_v pattern were larger than those for the spatially correlated S_v pattern (**Figure 4**).

4) Other factors being equal, the modified TAPAS design gave higher efficiencies than the TAPAS design, as the substantial increase in sample size for the TAPAS design was not accompanied by a correspondingly large decrease in variance (**Figure 4**).

5) The largest efficiencies occurred with the modified TAPAS design with spatially random S_v and a strong S_v - density relationship, ranging from 1.71 to 2.13 times the efficiency for the SRS design. With a weak S_v - density relationship, the TAPAS design was less efficient than the SRS design, whereas the modified TAPAS design was approximately as efficient as the SRS design with a spatially correlated S_v. With a weak S_v - density relationship, efficiencies were consistently larger than those for SRS (ranging from 9% to 25% increase) only with the random S_v pattern and the modified TAPAS design.

Table 1. Mean sample size and average bias for the simulated cases.

Mean Sample Sizes			Average Bias (percent)		
TAPAS	Modified TAPAS	SRS	TAPAS	Modified TAPAS	SRS
Random S_v, strong S_v - density relationship					
23.4	12.7	9	-0.33	-0.11	-0.76
59.8	33.9	27	0.29	0.18	0.09
91.3	53.6	45	-0.43	-0.21	-0.18
120.8	72.5	63	0.20	0.10	0.83
Random S_v, weak S_v - density relationship					
24.7	13.1	9	0.24	0.60	0.89
63.4	35.0	27	0.64	0.71	0.79
96.8	55.0	45	0.51	0.64	1.07
128.5	74.8	63	0.39	0.24	0.34
Spatially correlated S_v, strong S_v - density relationship					
18.9	11.5	9	0.19	-0.80	-0.05
49.3	31.2	27	-0.66	-0.47	0.20
76.6	50.1	45	-0.65	-1.22	-0.07
102.7	68.4	63	-0.18	-0.40	0.01
Spatially correlated S_v, weak S_v - density relationship					
18.5	11.3	9	0.47	0.41	0.63
47.9	30.6	27	0.33	0.63	0.47
74.5	49.1	45	0.45	0.35	0.48
99.3	66.8	63	0.22	0.38	0.15

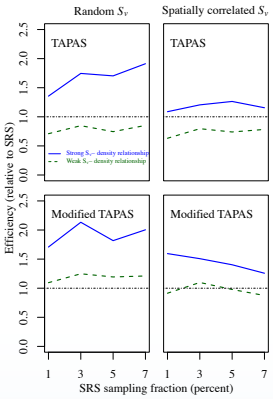

Figure 4. The relative efficiency of the TAPAS and modified TAPAS design (scaled to the relative efficiency of the SRS design) as a function of SRS sampling fraction, spatial S_v pattern, and strength between S_v and density.

Discussion

The effectiveness of either the TAPAS or modified TAPAS design is dependent upon the strength of the relationship between S_v and density, as the efficiencies of these designs are not substantially higher than those for SRS when this relationship is weak. For Alaska rockfish, however, a number of factors contribute to uncertainty in this relationship. First, rockfish reside in habitats with several other species, and the hydroacoustic signal may reflect something other than the species of interest. Second, it is difficult to detect fish in the acoustic "dead zone" near the substrate, or to distinguish between the fish and substrate in areas with rough substrate. Finally, the observed rockfish aggregations may reside in a particular location for short time periods, complicating sampling even within a single-phase survey. The improvement in efficiency when a strong relationship exists between S_v and density offers motivation to continue to refine our understanding of rockfish spatial patterns and the methods used to classify hydroacoustic data.

References

Everson, I., M. Bravington and C. Goss. 1996. A combined acoustic and trawl survey for efficiently estimating fish abundance. Fisheries Research 26:75-91.

Hanselman, D.H. and T.J. Quinn, II. 2004. Sampling rockfish populations: adaptive sampling and hydroacoustics. In: Thompson, W.L. (Ed.), Sampling rare or elusive species. Island Press, Washington, pp. 271-296.

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