

Abstract.—We used hydroacoustic techniques to obtain biomass estimates of yellowtail rockfish, *Sebastes flavidus*, in a 100-km² area off the west coast of British Columbia, Canada. The purpose of our study was to estimate sampling variance and explore the effect of diel aggregation behavior on the precision of biomass estimates. A set of eight transects was sampled eight times: four at night, four during daylight. Although we observed a pronounced diel behavioral pattern of diurnal aggregation and nocturnal dispersion, we found no significant differences between nocturnal and diurnal estimates of mean biomass. Diurnal estimates showed a tendency towards higher variance, but the differences were not significant in most comparisons and were too small to influence survey design. The coefficient of variation of the eight observations for any individual transect ranged from 13 to 128%. The coefficient of variation in biomass for the whole survey area, based on repeating the set of eight transects eight times, was 13.9% and the estimate of mean biomass for the survey area was 1152 t. The observed diel behavioral patterns did not, in this study, produce different estimates of yellowtail rockfish biomass. Survey time might therefore be optimized without concern for this source of variance for this species.

Diel vertical migration by yellowtail rockfish, *Sebastes flavidus*, and its impact on acoustic biomass estimation

Richard D. Stanley

Robert Kieser

Bruce M. Leaman

Ken G. Cooke

Biological Sciences Branch

Fisheries and Oceans

Pacific Biological Station

Nanaimo, British Columbia, V9R 5K6 Canada

E-mail address (for R. D. Stanley) : stanleyr@dfo-mpo.gc.ca

Yellowtail rockfish, *Sebastes flavidus*, are an important component of the British Columbia (B.C.) trawl fishery. Annual catches of 4000–5000 t represent about 20% of the total rockfish (*Sebastes* spp.) landings and over 5% of the total domestic trawl landings from the B.C. coast (Rutherford, 1996). The stock assessments for these species have typically relied upon population dynamics models tuned with catch-per-unit-of-effort indices (Stanley, 1993) or swept-area surveys (Leaman and Stanley, 1993). However, problems with both these methods have led us to investigate more direct methods.

Previous hydroacoustic work indicated that some of the trawl-caught rockfishes are aggregating species and that they are usually found associated with specific bathymetric features (Wilkins, 1986; Leaman et al., 1990; Kieser et al., 1992; Richards et al., 1991). Submersible observations and acoustic tagging of a small number of fish confirmed this association for yellowtail rockfish (Percy et al., 1989), although the acoustic tagging did not indicate consistent diel patterns (Percy, 1992). This aggregating behavior off the bottom in predictable locations suggests that this species may be a suitable candidate

for hydroacoustic biomass estimation. However, because individual yellowtail rockfish stocks are thought to occupy large areas (Stanley, 1993; Stanley et al., 1994), such comprehensive hydroacoustic surveys would be costly and time-consuming. This accentuated the need for a prior study of fish behavior and sampling variance to assess the feasibility of such an approach and to optimize survey effort. We were also concerned about the impact of diel aggregating behavior on the precision and bias of biomass estimates (Olsen, 1990; Appenzeller and Leggett, 1992; Simmonds et al., 1992). Within the same genus, Richards et al. (1991) reported strong diurnal aggregation by Pacific ocean perch (*S. alutus*), and Wilkins (1986) has reported strong nocturnal aggregation by widow rockfish (*S. entomelas*).

We investigated these issues with an experimental survey in November 1991 in waters 10 km west of Vancouver Island, British Columbia, Canada (Fig. 1). The objective was to estimate yellowtail rockfish abundance within a small area and, in doing so, to examine the variance within and among transects. In addition, we wished to characterize diel patterns of behavior and document the effects of such behavior on the precision of the biomass esti-

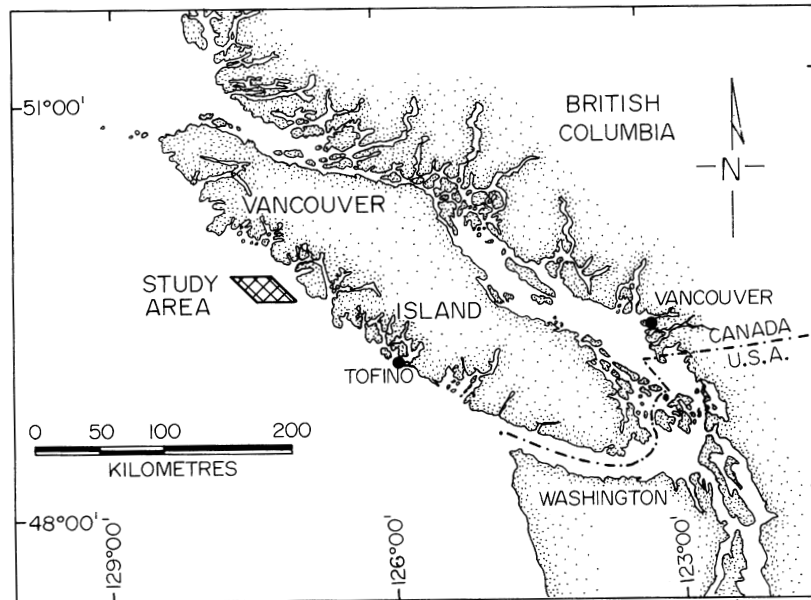


Figure 1

Location of study area off the southwest coast of Vancouver Island, British Columbia, Canada.

mates. In this report, we summarize our observations from this study and discuss the implications of the results to hydroacoustic survey design for yellowtail rockfish.

Methods

Study area

We first surveyed a 250-km² area along the shelf edge off Nootka Island to locate concentrations of rockfish (Fig. 1). This area produces 1000–3000 t of yellowtail rockfish per year (Rutherford, 1996). An initial grid included nine parallel transects 9–13 km in length and 2.8 km apart. They were oriented southwest to northeast, perpendicular to the isobaths. The southwestern end of the track lines extended well beyond the shelf break, whereas the shallower northeastern end extended onto the shelf to the 130-m isobath. This A series was covered during one 24-h period. The northern half of the A series showed the greatest concentrations of rockfish. From this northern area, we selected a B series of transects to conduct the study (Fig. 2). No further use was made of A-series measurements because the respective transects were not comparable with the B-series transects. The distance between transects was halved to 1.4 km, and the length of each was reduced to span depths from the 140-m isobath to just beyond the shelf break (180 m). The A series had shown that

essentially all fish concentrations were between these limits. The B series was repeated in the same sequence (B9–B2) through four 24-h cycles to produce a balanced design of four diurnal and four nocturnal observations per transect. In addition to the acoustic estimates for the eight replicates of B2–B9, we selected B5 and B6 for continuous soundings, resulting in ten additional observations for these two transects.

The bottom topography of transects B2–B9, with the exception of B8, was characterized by one or two underwater cliffs. They appeared to be 10–15 m high and followed a north–south axis through the study area, landward of the shelf break (Figs. 2–4). The transects were oriented perpendicular to the axes of the cliffs. At the southernmost transect (B9), the cliffs were approximately 1.5 km inshore of the shelf break. This distance increased to about 7.0 km by transect B2. The cliffs were found at a progressively shallower depth. This topographic feature is well known to fishermen as the “clay bumps” on the Nootka fishing grounds. Fishermen report that catches of yellowtail rockfish can be made year-round by towing bottom trawl nets in an east to west (shallow to deep) direction over the cliffs. Transect B5 corresponds to a commonly used commercial fishery tow (Figs. 2–4).

We excluded the results of transect B1 from our analyses. It passed over an extended underwater ridge such that the modal depth was less than 130 m rather than the targeted depth of 150 m. These depths are shallower than the November habitat

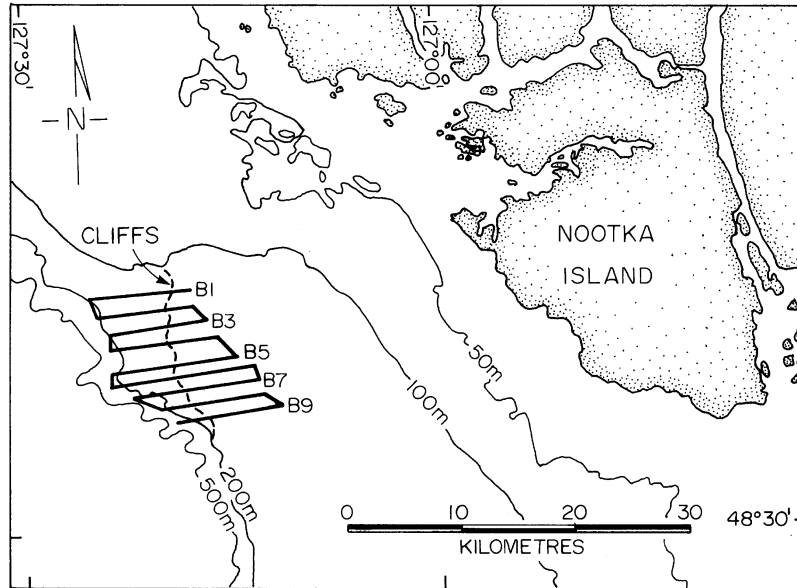


Figure 2

Area covered by the B-series transects and location of the shelf edge (200 m) and the cliffs in relation to the study area.

range for yellowtail rockfish (Nagtegaal, 1983). We also had to exclude the third of the four nocturnal replicates of transect B4. The vessel had to slow and change course to avoid traffic, leading to an unusable acoustic estimate. We used an average from the other three nocturnal estimates in our principal analyses to maintain a balanced ANOVA design. We also substituted a range of values in place of the missing value to examine the stability of the results.

Constant transects allowed us to compare behavior over the same location, but in doing so we sacrificed the improved statistical power we would have achieved with a stratified random design (Jolly and Hampton, 1991).

Time of the transect was classified according to the moment the vessel passed over the cliffs, the observed center of fish abundance. These times were then classified as diurnal or nocturnal according to the time of sunrise and sunset for Tofino, approximately 100 km southeast of the study area (Atmospheric Environment Service, Environment Canada).

Transect length

We derived two density estimates, based on a short and a long section from each completed transect, to examine the impacts of the choice of endpoints. For both sections and for each transect, we chose a standard beginning and end in relation to the cliffs (Fig. 3). The ends for the short sections of the transects were defined as the shoreward and seaward limits

of the nocturnal dispersion of the cliff aggregations, judged visually from the echograms for all replicates. An individual transect required about one hour to complete. For these sections, the seaward end was inshore of the shelf break. The long sections used the same shoreward or shallow end, whereas the seaward or deep end was extended to a 180-m bottom depth. This depth incorporated the apparent deep-water limit of the shelf break aggregations (Fig. 3). The echograms for replicate transects (Fig. 3) differ in length because of differences in vessel speed over the ground. We calculated an average surface density (g/m^2) based on the constant length for each replicate of the short and long sections from all transects.

Hydroacoustic equipment and echo processing

Echo integration was used to estimate fish abundance in the survey area (Forbes and Nakken, 1972; Clay and Medwin, 1977; Foote, 1987; MacLennan and Simmonds, 1991). The calibrated echo integration system was operated from the Canadian Coast Guard Ship, *W. E. Ricker*. The acoustic processing equipment consisted of a BioSonics 38 kHz Model 101 echo sounder, BioSonics Model 111 chart recorder, BioSonics Model 121 digital echo integrator, PCM/VCR tape recording system, and auxiliary equipment. The transducer components included a towed body with a Simrad ceramic transducer and armored tow cable.

The echo integrator was programmed to analyze the return echoes for a series of depth strata (range slices) from the transducer to the bottom (Kieser et al., 1987). Bottom tracking was obtained with a 5-m bottom buffer. An echo integration sequence was completed every 60 pings (1 minute), and the measured echo intensities were stored on a personal computer. Echo integrator and chart recorder thresholds were set to 0.2 V; time-varied gain (TVG) was set to 20 log R. Thus all integrated echoes were displayed on the echogram. At this threshold level, noise was negligible at all depths of interest. Vessel speed was approximately nine knots.

The integrator output was processed with custom software to exclude extraneous signals from the ocean bottom, as well as noise and echoes from other unwanted sources in the water column.

A target strength (TS) of -32 dB/kg was used to convert the measured backscatter cross section to fish volume density (g/m^3) and fish surface density (g/m^2) estimates. This value was obtained from a review of the literature (Foote, 1987; Kieser, 1992); no *in situ* rockfish TS were available at that time. Only a relative TS was required because the study focused on the acoustic availability of rockfish and relative rather than absolute biomass and variance estimates.

Biomass estimates were obtained by extrapolating surface densities to cells that were bounded by lines equidistant between adjacent transects and by lines perpendicular to the transect and passing midway between measurements. An estimate of the total fish biomass for the area was obtained by summing the products of surface densities and cell areas.

Fishing and sampling

We conducted three bottom trawl tows (Table 1). Two were conducted along the path of transect B5 and the other along transect B6. All three targeted diurnal aggregations at the cliffs. The tows ran from shallow to deep and were terminated at the seaward side of the cliffs, prior to encountering the aggregations near the shelf break. Planned additional bottom and midwater trawl fishing was curtailed owing to operational difficulties aboard the vessel.

Analysis of variance

Transect series 1, 2, 3, and 4 were conducted 17–18, 20–21, 22, and 24–25 November (Table 2). We initially tested for diel, transect, and series effects with a three-factor ANOVA:

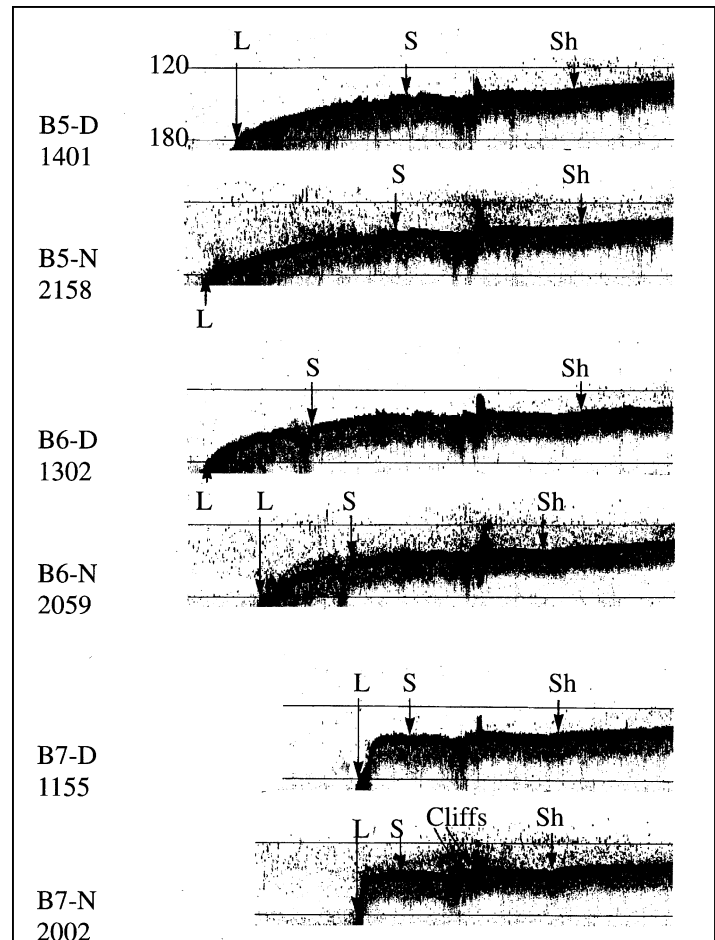


Figure 3

Diurnal (D) and nocturnal (N) echograms from transects B5, B6, and B7 for November 17. "Sh" identifies the shallow end of both long and short transects. "S" and "L" identify the deep ends of the short and long sections of the transects. Time shown represents the approximate time the vessel passed over the cliffs.

$$\bar{D}_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijk},$$

where \bar{D}_{ijk} = surface density for transect i , day or night j , and observation (or series) k ;
 μ = the overall mean;
 α_i = the transect effect;
 β_j = the diel effect;
 γ_k = the influence of the date (series); and
 ε_{ijk} = the error term, normally distributed with a mean of 0 and variance of σ^2 .

To test whether diel variances were heterogeneous, we conducted a one-way randomization ANOVA limiting the factors to the diurnal-nocturnal effect. We conducted this test on a scaled version of the observations. Because it was obvious that the variance

among transects was, in part, proportional to the mean, we removed the transect effects by scaling all the observations. Each observation was multiplied by the overall mean for the data set ($n=64$) divided by the mean for all eight observations (diurnal and nocturnal) of the transect. Thus the variation in the data set was reduced to the scaled "within transect" and diel effects.

Following examination of the balanced treatment of all transects, we examined the observations for transects B5 and B6 (Table 3). These data included observations from the four series as well as additional nonpaired observations. The two transects were ex-

amined separately. Homogeneity of variance between diel periods was examined by using an F -ratio test.

We used nonparametric randomization tests (Manly, 1991) to examine the sources of variance owing to concern about the small sample sizes, non-normality, and heterogeneity of variance. In particular, we hypothesized that variance among repeated transects would be proportional to the biomass estimates and, owing to the extreme densities and localization of the diurnal aggregations, that diurnal variance would be significantly greater than nocturnal variance.

Randomization involves resampling without replacement from one parent population. The observed value of the response statistic (for example, mean diurnal biomass minus mean nocturnal biomass) is compared with a large number of responses generated by treating all observations (diurnal and nocturnal) as coming from one parent population. Each of 4999 resamplings randomly allocates the observations into two groups, each time simulating new diurnal and nocturnal sets. The observed difference in mean biomass is then compared with the 4999 simulated differences. If the observed difference in biomass is significant ($\alpha < 0.05$), then the observed difference should be greater than 95% of all the simulated differences.

Results

Fish behavior and species composition

Four aggregation types were observed on the echograms. Each was associated with a different habitat. The first, our targeted group, was located near the cliffs over depths of 150–160 m (Fig. 3). These dense schools were located near the bottom during each day, then the fish dispersed vertically and horizontally at twilight. By early nighttime, the scattered targets were distributed from 80 to 150 m. The diel cycle was completed by downward migration and rapid reformation of schools at dawn.

With the exception of benthic species like flatfish, which produce a negligible contribution to the acoustic measurement, the species composition in the catch from this aggregation type was over 85% yellowtail rockfish in the three tows (Table 1), indicating that this species dominated in the diurnal aggregations targeted near the cliffs. The continuous transition from day to night distributions (Fig. 4) implies that the nocturnal aggregations were also yellowtail rockfish, but it was not possible to confirm this assumption during the cruise. Subsequent discussions with fishermen familiar with nighttime trawling in the area supported the assumption that the nocturnal

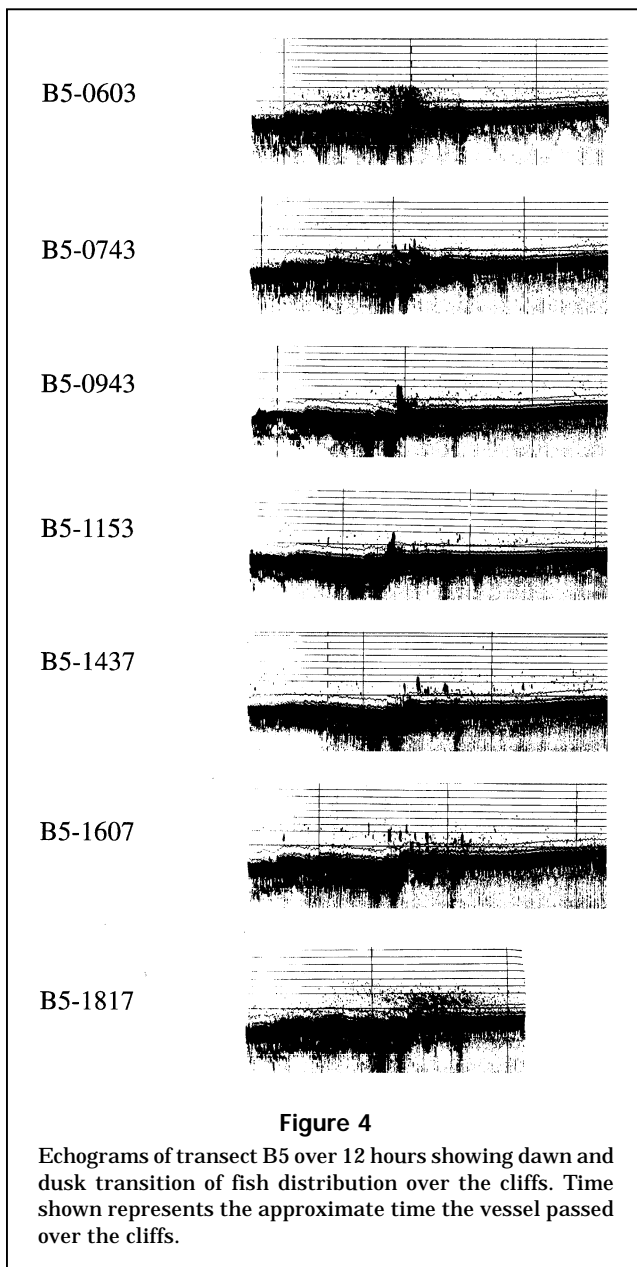


Table 1
Catch composition (%) by weight and by species from diurnal bottom trawl tows ("tr" signifies trace, <0.05%).

	Tow			Total
	1	2	3	
Rockfish				
Silvergray rockfish (<i>Sebastes brevispinis</i>)	3.8	4.6	7.7	4.0
Widow rockfish (<i>S. entomelas</i>)	0.9	0.5	1.3	0.8
Yellowtail rockfish (<i>S. flavidus</i>)	88.2	83.2	38.5	85.9
Bocaccio (<i>S. paucispinis</i>)	7.1	2.8	tr	6.2
Other rockfish (<i>S. spp.</i>)	tr	tr	3.8	0.2
Other species (with swimbladders)	tr	0.3	2.6	0.1
Other species (without swimbladders)	tr	8.4	46.2	2.8
Total catch (kg)	1989	393	78	2460

Table 2
Biomass estimates (t) for the short and long sections of the transects ("na" indicates not available, measurement aborted owing to vessel traffic).

Transect	Series							
	1		2		3		4	
	Short	Long	Short	Long	Short	Long	Short	Long
Day								
2	93	119	65	70	96	104	170	188
3	162	162	228	232	114	118	103	106
4	98	99	37	50	126	134	46	60
5	124	130	84	92	124	136	92	124
6	424	448	520	522	32	32	396	402
7	148	148	39	40	186	194	111	116
8	4	4	58	58	161	208	18	20
9	187	187	209	278	296	345	118	123
Night								
2	181	200	112	124	116	123	59	68
3	92	113	152	166	85	90	124	134
4	56	112	77	103	na	na	74	84
5	128	230	112	162	128	180	92	100
6	156	216	150	180	476	512	128	144
7	198	212	114	138	224	235	229	241
8	185	224	142	169	131	173	146	157
9	76	126	178	202	240	357	168	208

targets would probably have been yellowtail rockfish. Commercial fishery records from these fishing grounds consistently indicate a predominance of yellowtail rockfish in midwater and bottom trawl tows.

The daytime tows support the assumption that the aggregation over the cliff was that of yellowtail rockfish, and the nocturnal dispersion of these aggregations is obvious from the night transects. These aggregations appear almost as dense as the bottom on our daytime echograms. The cliffs can be identified

only in the echogram during the night (Figs. 3 and 4). We are not, however, suggesting that all fish in the transect were yellowtail rockfish, nor are we suggesting that the diurnal aggregations at the cliff represented all the yellowtail rockfish that were present in the transects. The nocturnal "cloud" may have included fish that were close to the bottom but not adjacent to the cliffs.

Figure B6-N indicates that there was some movement from off the edge onto the long and short ver-

Table 3
Biomass estimates (t) for the short and long sections of B5 and B6 (all observations).

	Type	Transect	Series										
			—	1	2	3	4	—	—	—	—	—	
Day	Short	5		124	84	124	92	64	182	116	610	38	
	Long	5		130	92	136	100	172	182	132	632	332	
	Short	6		424	520	32	396	300	500	312	92		
	Long	6		448	552	32	402	308	508	320	124		
Night	Short	5	136	128	112	128	92	28	170	120	102	132	
	Long	5	188	230	162	180	124	28	212	156	140	288	
	Short	6	170	156	150	476	128	238	212	240	176	294	244
	Long	6	192	216	180	512	144	272	256	262	232	244	280

sions of the transect, suggesting some added contamination; however most of the backscatter was still concentrated near the cliffs.

A second aggregation type was represented by the schools observed at the shelf break, 10–20 m deeper than the base of the cliffs (Fig. 3). These schools, although exhibiting diel behavior similar to that of the first group, remained closer to the bottom during daytime. The greater depth of the aggregations (160–180 m), their closer proximity to the shelf edge, and their stronger bottom affinity suggested to us, as well as to various fishermen with whom we consulted, that these aggregations probably consisted of a combination of Pacific ocean perch (*S. alutus*), canary (*S. pinniger*), redstripe (*S. proriger*), sharpchin (*S. zacentrus*), and silvergray (*S. brevispinis*) rockfish (Leaman and Nagtegaal, 1982, 1986; Leaman et al., 1990).

The third and fourth target types included small schools or individual targets within the shallow end of the transects and scattered distributions over much deeper water beyond our transects and the shelf edge. The shallower signals were thought to be plankton or small fishes. Fishermen reported that attempts to fish on these aggregations were unsuccessful and suggested that the source of the signals was too small to be retained by their gear. No *in situ* target strength measurements were conducted. Signals in deeper water, off the edge of the shelf break, have been shown in other studies to be a deep plankton layer or hake (*Merluccius productus*) (Saunders¹). Signals close to the slope off the edge could also be generated by side echoes.

Analysis of variance

The randomization tests provide the percent of the random re-orderings that exceed the value of the

¹ Saunders, M. 1991. Pacific Biological Station, Nanaimo, B. C., Canada V9R 5K6. Personal commun.

Table 4

Results of three-factor randomization ANOVA (df=degrees of freedom; **>1% significance level). Percentages indicate the % of 4999 random combinations of the observed data which resulted in a difference between treatments greater than the observed difference.

Factor	df	% greater than observed	
		Short section	Long section
Diurnal and nocturnal	1	87.94	47.40
Transect	7	**0.08	**0.08
Series	3	80.50	66.89
Error	53		
Total	64		

observed response. Statistical significance is assumed when fewer than 5% of the re-orderings exceed the observed response. The three-factor ANOVA indicated for both short and long transect sections (Table 4) that

- 1 there was no significant difference in mean biomass between night and day;
- 2 there was a highly significant difference in mean biomass among transects; and
- 3 there was no significant difference in mean biomass among different series (over time).

Bartlett's test for homogeneity of variance indicated no significant difference between the variance of diurnal and nocturnal observations, although the trend was towards greater diurnal variance (Table 5).

We repeated the same basic analysis using the larger but nonpaired set of observations for transects B5 and B6 (Table 3). Each transect was analyzed separately to test for significant differences between diurnal and nocturnal mean biomass and for homo-

Table 5

Results of Bartlett's test for significant difference between variance of diurnal and nocturnal observations (χ^2 for $P=0.01$ is 2.706; χ^2 for $P=0.05$ is 3.841).

	Short section	Long section
χ^2	2.45	2.23

generity of variance between the two diel periods (Table 6). These data included the observations from the comparisons above; therefore, the data sets and tests are not independent of the main ANOVA.

Results for the short segments for B5 and B6 also showed no significant differences between mean nocturnal and diurnal biomass. However, unlike the results of the expanded B5 data set and the original all-transect test, diurnal variance for B6 was significantly higher than nocturnal variance for this transect.

Missing observation

The impact of using an average value (69 t) for the missing nocturnal observation was examined by conducting the randomization tests with minimum and maximum values of 56 t and 76 t for the nocturnal observations from B4. The alternate values had a negligible impact on the results.

Nocturnal dispersion beyond the shallow end of the transect

During one night series, the echograms indicated that the cliff aggregations dispersed beyond our empirically chosen shallow endpoint in transects B5–B9. We therefore slightly underestimated the nocturnal abundance of the cliff aggregations this one night. We re-analyzed the biomass for these transects with the new endpoints and then repeated the statistical analyses for the B2–B9 and B5–B6 series only. The changes to the one night's observations did not affect the results significantly.

Variance in transect and total biomass estimates

Independent total biomass estimates for the study area were estimated as the sum of the transect biomass estimates from each series (Table 7). The overall average was 1152 t with a CV of 13.9% among series for the short sections. For the long sections, the average was 1329 t with a CV of 15.4%. The within-transect CVs ranged from 16.6% to 65.8% for the eight transects (short sections).

Table 6

Results of comparison of expanded observation set from transects B5 and B6 (* indicates > 5% level of significance). Percentages indicate the % of 4999 random combinations of the observed data which resulted in a difference between treatment means greater than the observed difference in means.

Transect	Factor	% greater than observed	
		Short section	Long section
5	Diurnal and nocturnal	35.79	22.54
	<i>F</i> -ratio	16.08	15.90
6	Diurnal and nocturnal	5.28	10.08
	<i>F</i> -ratio	16.10	1.60*

Table 7

Coefficients of variation of biomass estimates (\hat{B}) among transects and series (short and long sections).

Area	<i>n</i>	Short section		Long section	
		$\hat{B}(t)$	CV%	$\hat{B}(t)$	CV%
Total area					
Day	4	1167 t	7.7	1256	7.9
Night	4	1137 t	19.8	1402	19.3
Day+	8	1152 t	13.9	1329	15.4
Night					
		CV% range		CV% range	
Within transects					
Day	4	19.8–117.8		19.0–128.5	
Night	3–4	14.9–73.0		14.3–64.1	
Day+	7–8	16.6–65.8		31.4–68.1	
Night					
Among transects					
Day	4	54.3–106.7		58.4–100.6	
Night	4	24.5–67.3		20.6–62.2	

Aglen (1983) derived an empirical formula for predicting the CV based on the ratio of linear distance surveyed (*L*) over the square root of the surveyed area (*A*), which he called the “degree of coverage” or DOC:

$$Predicted\ CV = 0.5 \left(\frac{L}{\sqrt{A}} \right)^{-0.41}$$

The variance among the eight series replicates of the area were significantly less than the predicted value

from Aglen's formula whereas the variance for the combined area of B5 and B6 was higher (Table 8). In both cases, the observed variance among surveys was typical of acoustic surveys.

Discussion

We have assumed that the dominant part of the acoustic signal selected from the short transects represented yellowtail rockfish, a conclusion supported by fishing results and the continuity on the echograms between diurnal and nocturnal distribution. The longer sections of the transects, which indicated about 16% (5–30%) more total biomass, probably included other species of deeper-dwelling rockfishes.

Yellowtail rockfish share with other species a diel pattern of diurnal schooling and nocturnal dispersal (Simmonds et al., 1992). We observed that the schools reform at dawn near a minor but nearly continuous topographic feature that crosses the study area on a north–south axis. The strong and persistent affiliation of yellowtail rockfish with this small cliff is consistent with long-term commercial fishing records at this location. The diurnal schools are near the bottom at dawn then rise slowly during the day, dispersing at dusk. This is congruent with fishermen's observations that early morning is the most productive time for bottom trawling for this species. The fidelity to topographic features is consistent with reports of Percy (1992) and Carlson and Haight (1972). Percy's reports on acoustically tagged specimens includes an example of "homing" near to the original capture sites, even as far as 2 nmi overnight.

Because we conducted the study at only one time of year, we could not examine how diel behavior would vary with season. Fishermen report that yellowtail rockfish occupy the "cliffs" at all times of year. They also report that the dawn tows are the best fishing on a year-round basis. We would suggest that if diel vertical movement is triggered by or at least associated with light intensity at depth, then the effect would be more obvious during summer months when light

intensity increases and the twilight period shortens. It might also be more dramatic on brighter days.

The diversity of species, especially near the shelf edge, illustrates that a difficult issue facing acoustic assessment of rockfish will be species identification. This process will be complicated by the difficulty of trawling much of the habitat. Our study was based on single-beam and single-frequency acoustic observations. Encouraging results on species identification have been obtained by more advanced acoustic analysis of individual fish schools (Kieser and Langford, 1991; Scalabrin and Masse, 1993), comparison of day and night survey data (Gerlotto, 1993), and multifrequency and wide band observations (Simmonds and Armstrong, 1990; Zakharia, 1990). In this context, innovative transducer design and deployment will be important to obtain more detailed acoustic data from individual fish and schools near the bottom.² Supplemental information on habitat and depth preference by species, perhaps developed from simultaneous use of submersible devices or side-scan bathymetry, may help to estimate species' proportions (Richards et al., 1991).

Diurnal versus nocturnal density and biomass estimates

Although the echograms showed differences in diel distribution for yellowtail rockfish, they did not indicate the extreme densities which lead to acoustic shadowing (Foote, 1990). In contrast to other studies (summarized in Appenzeller and Leggett, 1992), which report higher density estimates from night observations, our day and night estimates were similar. We conclude that, for yellowtail rockfish, diel behavior patterns do not bias hydroacoustic biomass estimates. It remains possible, however, that the similarity between diel periods is purely fortuitous in that the various factors that could affect estimation, such as movement in and out of the study area

² Dalen, J., and H. Bodholt. 1991. Deep towed vehicle for fish abundance estimation, concept and testing. ICES Council Meeting (CM) 1991/B:53, 13 p. [Mimeo.]

Table 8

Observed coefficient of variation (CV) of biomass estimates from short section in comparison with predicted CV from formula by Aglen (1983). Sample size, *n*, is the number of replicate coverages of either the area represented by transects B5 and B6, or the overall area of B2–B9.

Transect	<i>n</i>	Section	Distance (km)	Area (km ²)	DOC	Predicted CV%	Observed CV%	Mean estimated biomass (t)
B5-6	19	Short	11.0	15.2	2.82	32.7	48.0	397
B2-9	8	Short	39.6	55.5	5.33	25.2	13.9	1152

or diel variability in tilt angle, may simply have cancelled each other out.

We assumed that there are no diel changes in fish target strength. Such changes have been observed for other species and have been linked to swimming behavior or mean tilt angle (Miyashita et al., 1995; Buerkle and Sreedharan, 1981; Olsen, 1990; Misund, 1997). Target strength variation between night and day may be smaller for yellowtail rockfish because these fish tend to remain in the same general depths. They are not moving from the bottom to surface waters and therefore not encountering large relative changes in pressure.

The observed diel behavior of increased aggregation during the day led us to hypothesize that variance in biomass should be greater for diurnal observations. We observed that yellowtail rockfish move towards the cliffs at dawn. We assumed that they would concentrate further along that narrow band to produce discrete schools. We viewed the nocturnal distribution as a relatively dispersed band (three-dimensional cloud) of individuals in the general vicinity of the cliffs. We assumed that the diurnal distribution, which lay along the orientation of the cliff, would be a much narrower string of individual schools and hence of highly varying density, perhaps to the extent of approximating a "beaded pattern" of distinct schools following the length of the cliff. We expected that diurnal estimates derived from transects that pass perpendicular to the cliffs would be highly variable because the path of the acoustic beam could range from "missing entirely" to "completely ensonifying" a dense school.

We found that, for the short transect version of the all-transect data, the variance of diurnal biomass estimates was not significantly greater than that of nocturnal biomass estimates. Diurnal variance was significantly higher in the expanded set of the B5–B6 set of observations but only for the long version of transect B6.

The weak or mixed indication of higher diurnal variance implies that the apparent aggregation towards the cliffs, evident in the echograms, is not matched to the same degree by aggregation along the axis of the cliffs. We expected discrete diurnal schools following the axis of the cliffs. This tendency to aggregate into a continuous band of fish along the cliffs, as opposed to discrete schools, may be unique to this area where there is a longitudinal topographic feature along the preferred depth. In areas of the coast lacking in such a linear feature, fish may tend to aggregate over a specific point, such as a pinnacle, producing greater daytime variance among estimates of biomass. Results of this experiment, however, do not support the hypothesis that estimates from the

dispersed condition will show less variance for yellowtail rockfish. The similarity in variance between nocturnal and diurnal periods indicates that no substantial gains in efficiency or precision can be achieved by sampling during one or other of the diel periods.

The among-transect variance overwhelms the other sources of variance even within a small coastal area. From the perspective of two-stage sampling (among-transect or within-transect variance), precision of the overall estimator is reduced by allocating sampling effort in proportion to variance contributed by each stage. Because among-transect variance is much greater, survey design should maximize the number of transects at the expense of replicating transects. The only exception to this principle would arise when the cost of replicate samples is much lower. Because the cost of collecting a replicate transect estimate is almost equal to that for an additional transect over the scale we are considering, it would be more efficient to maximize the number of different transects.

By repeating the survey eight times, we were able to determine the variance of the biomass estimate directly rather than by inferring it indirectly through geospatial analysis of "within" variance (Petitgas, 1993). This calculation of "among" survey variance follows from work by Williamson (1982), who resampled from the individual samples averaged over one minute within a transect, and by Robotham and Castillo (1987), who bootstrapped cumulative transect observations as we did. There is no question that a formal investigation of the spatial impact on variance would require treatment at the granular level of the observations, which the geospatial methods provide. These procedures also facilitate an investigation of the impact of additional explanatory variables and development of model-based inference. However, the requirements of our study were realized by the simpler transect-based analysis.

Total biomass estimate and survey design

The overall biomass estimate of 1152 t for the study area appears consistent with overall coastal biomass estimates of 50,000–60,000 t for a stock that is assumed to extend from the study area to the border of B.C. and Alaska (Stanley, 1993). The fact that the overall coefficient of variation among the eight series for the study area was under 14% is encouraging and better than that predicted from the formula of Aglen (1983). This precision may not, however, apply to all rockfish species. Wilkins (1986) found that the CV for widow rockfish was 2–3 times higher in spite of a more comprehensive estimation procedure that included the use of side-scan sonar in conjunction with echosounding. We can also expect

greater variation if repeated estimates were conducted at greater time intervals.

Over a one-week period and an area of over 100 km², we have demonstrated precision (CV=15%) in acoustic biomass estimates that is acceptable in a stock assessment context for yellowtail rockfish. Variance among replicated transects is low enough that survey effort can be distributed to maximize the number of different transects, either to increase the area of the survey or the density of coverage. We have shown that a survey of yellowtail rockfish can be conducted throughout the diel cycle and thus reduce survey costs.

This study also indicates that yellowtail rockfish can aggregate within a well-defined bathymetric range near topographic features. If these tendencies are consistent over the whole range of this species, they may provide the basis for stratification and possible further gains in efficiency. Our results indicate that a simple systematic transect design with transects oriented perpendicular to the long axis of the fish concentrations (the edge of the continental shelf) is a satisfactory choice for the elementary sampling distance unit (ESDU) (Simmonds et al., 1992; Simmonds and Fryer, 1996). If the preferable depth range is narrow over most of the coastline and the survey must thus cover a long narrow corridor, then a systematic zig-zag would be preferable (Simmonds et al., 1992).

The affiliation of yellowtail rockfish with a minor topographic feature within a depth range indicates that the density distribution of yellowtail rockfish is "nonstationary," in that the densities will not be randomly distributed in a study area or stratum, even after bathymetric stratification (Simmonds et al., 1992). This is an important characteristic of the species and should be noted if more advanced survey design and analysis procedures, such as geostatistical spatial averaging and cokriging, are to be investigated (Foote and Stefansson, 1993; Marcotte, 1991).

Although the results of the experiment support the potential for acoustic estimation of this species, the generality of the conclusions will have to be tested over a larger scale and more varied habitat. The study site was chosen carefully to minimize the unknowns, in particular the presence of other species. The hypotheses will have to be re-examined over different depths and topography. It is also possible that the annual cycle of maturation, mating, and parturition for these live-bearing fish may be associated with different behavior.

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