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Video scallop survey in the eastern Gulf of Alaska, USA

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Abstract

Alaska Department of Fish and Game research personnel conducted the state's first video stock assessment survey for weathervane scallops *Patinopecten caurinus* in the eastern Gulf of Alaska during May and June 2002. Six discrete beds were identified for sampling using logbook data collected through an observer program. Primary sampling equipment was a towed sled equipped with a miniature digital video camcorder that captured images of scallops on the substrate. The sled was successfully deployed at 135 randomly selected stations and over 12,000 scallops were counted from about 124,000 m^2 of the bottom surveyed. Tows were also made with a mesh-lined 2.44 m survey dredge to obtain specimens for use in establishing a statistical relationship between scallop shell height and meat weight. Approximate measurements of scallop shell height were also obtained directly from video. The survey produced an overall density estimate of 1.0 scallops per 10 m^2, or 131.6 million scallops accounting for 1566×10^3 kg of meats. To reduce that amount of time required for video review, tapes were reviewed at regular playback speed without stopping or rewinding, and measurements were made on a subsample of the scallops captured on video. The work showed that video surveys are a viable method for fishery-independent assessment of Alaska's scallop stocks.

Keywords: Weathervane scallops; Stock assessment survey; Underwater video; Scallop dredge

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1. Introduction

Alaska is home to a relatively small commercial fishery for weathervane scallops *Patinopecten caurinus* that has produced average harvests of about 400×10^3 kg shucked scallop meats valued at US$ 5.6 million per year over the past decade. The fishery is jointly managed by the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS). Regulations governing the fishery include an onboard observer requirement that has been in effect since 1993. The observer program provides fishery managers and researchers with biological information on the stocks and detailed logbook data. Guideline harvest ranges (GHRs) for each fishing area are set annually by ADF&G following review of observer-collected data including catch per unit effort (CPUE), fishing locations, and size structure of the catch. GHRs specify harvest ceilings that are not to be exceeded, and areas may also close to fishing before the upper end of the GHR is reached if managers are concerned about localized depletion of scallops, declining trends in CPUE, or high bycatch of other commercially important species, particularly *Chionoecetes* crabs (Rosenkranz, 2002).

Although the observer-collected data are valuable, they do not provide a sound basis for estimating stock

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abundance or fishing mortality. Utilizing fishery CPUE as an index of abundance requires the assumption that effort is proportional to fishing mortality, but in practice, the relationship between effort and fishing mortality is likely to vary both spatially and temporally (Hilborn and Walters, 1992; Quinn and Deriso, 1999). Our own work with logbook data from the scallop observer program has shown that spatial distribution of effort in the fishery is highly aggregated, while variance of CPUE from proximate tows is often large, suggesting a need for collection of fishery-independent data.

ADF&G began reviewing scallop survey methodology in 1999 (Alaska Department of Fish and Game and University of Alaska Fairbanks, 2000). Although dredges have been used to survey scallop populations in Alaska (Bechtol, 2003) and in many other parts of the world (e.g. Mohn et al., 1987; Fifas and Berthou, 1999), efficiency and size selectivity problems of scallop dredges are well-documented. McLoughlin et al. (1991) showed that the efficiency of Australian mud dredges declined with *Pecten fumatus* size regardless of dredge mesh size, and Beukers-Stewart et al. (2001) found that efficiency of Newhaven spring-toothed dredges was significantly lower for *Pecten maximus* <90 mm shell height (SH) than for larger animals. Caddy (1968) concluded that efficiency and size selectivity of New Bedford offshore dredges (the same type used in the Alaska scallop fishery) varied substantially with bottom type, and in a later work (Caddy, 1989; p. 565) referred to the scallop dredge as a “semiquantitative tool”. These problems led ADF&G to focus on video survey techniques such as those employed by Giguère and Brulotte (1994) and Stokesbury (2002).

Our initial week-long pilot survey occurred in spring 2000. We used a video drop camera to film 400 m^2 of the bottom in a traditional fishing area in the northern Gulf of Alaska (GOA) and counted a total of 19 scallops. This research indicated that a sampling device that could cover more area than the drop camera would be necessary to obtain meaningful density estimates. We constructed and began testing a towable aluminum sled the following spring and were able to cover 40,000 m^2 of the same bed during 2 weeks pilot survey. Developmental work with the sled continued, with deployments in different fishing areas from different vessels and several rounds of equipment modifications. By spring 2002, we had developed enough confidence in our equipment and methodology to attempt a complete survey.

This paper details Alaska’s first video scallop survey, which took place during May and June 2002 in the eastern GOA. Besides survey methods and data analysis, we describe the techniques used during video review, which is an important component of any video research project. Our objective is the development of methods that will provide reliable fishery-independent estimates of scallop abundance for Alaska’s major commercial beds, including estimates of the abundance of pre-recruit scallops, which we define as those scallops <100 mm SH. An additional goal is to stimulate interest in and discussion of underwater video survey methodology.

2. Methods

2.1. Sampling

The survey took place from 17 May to 4 June 2002 in the eastern GOA between Cape Suckling (59°59′N, 143°51′W) and Icy Point (58°23′N, 137°05′W; Fig. 1). Beds were delineated by plotting the starting location of all scallop tows in the region as recorded in pilothouse logbooks since inception of the observer program in 1993. Geographical information system software was then used to construct polygons that enclosed areas that were repeatedly fished during 1993–2001. This led to the six discrete beds depicted in Fig. 1. A numbered grid of points on 1 km × 1 km spacing was then laid over each bed, and stations were selected by sampling without replacement using computer-generated pseudo-random numbers. In each bed, we attempted samples at about 10% of the grid points.

Sampling was conducted from the 20 m ADF&G R/V Pandalus. We deployed the sled near the point location of each station and towed in the most practical direction given sea and current conditions for 15 min at a target speed of 2.8 km/h. The sled was equipped with a miniature digital video (mini-DV) camcorder inside a watertight housing, two 100 W flood lights, and a battery that provided power to the lights. Video was recorded through a domed glass port on the end of the camcorder housing. The housing was mounted on

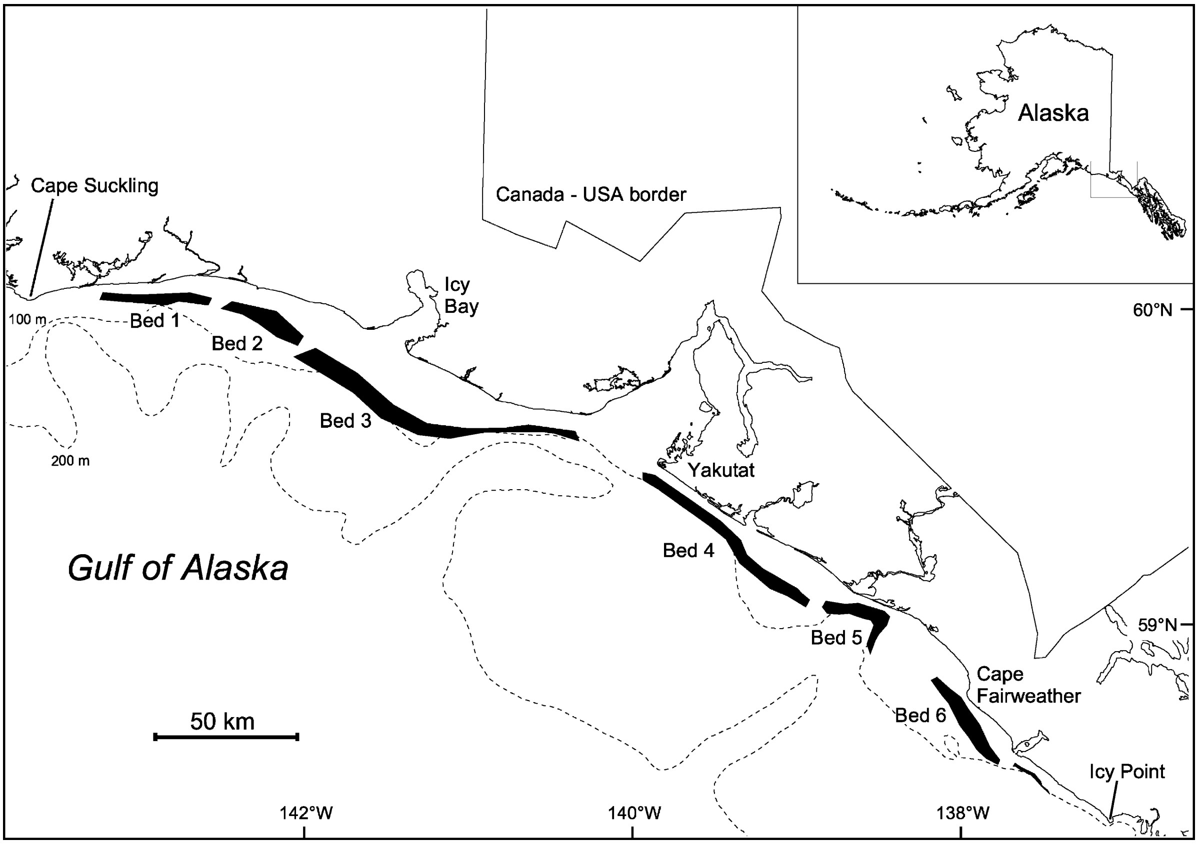

Fig. 1. Map showing scallop beds surveyed in the eastern Gulf of Alaska. The small bed north of Icy Point was included as part of Bed 6.

the sled such that the camcorder was aimed downward towards the substrate with a slight forward tilt (∼3°) from a height of 1.15 m. Video was recorded onboard the sled by the camcorder only with no live feed to the surface. Time and position were recorded each second during all tows by a global positioning system (GPS) aboard the R/V Pandalus that was accurate to ∼5 m, and time was recorded on mini-DV tape by the camcorder as well. Camcorder time was synchronized with shipboard GPS time daily.

Sampling to establish a relationship between SH and meat weight was conducted with a 2.44 m New Bedford offshore scallop dredge. The dredge weighed approximately 725 kg and was equipped with a 3.8 cm mesh liner. Tow duration was approximately 5 min at a target speed of 7.4 km/h. Selection of tow locations was haphazard; we attempted to sample with the dredge in multiple locations in each bed, but because the dredge was more difficult to deploy in rough weather than the sled, dredge tows occurred when weather conditions were favorable. After each dredge tow, the scallop catch was counted and weighed, then a subsample of about 75 scallops was individually weighed, SHs were measured, the animals were shucked, and meat weights were obtained to the nearest gram using a motion-compensated balance.

2.2. Video review and data analysis

Video review and enumeration of scallops took place in our office after the survey was completed. Primary equipment was a mini-DV tape deck connected to a 432 mm video monitor. The authors independently reviewed video from each tow at normal playback speed with no pauses and recorded each scallop observed by clicking a computer mouse. A subset of tows was reviewed a second time to check for bias in the original counts. Video from these tows was transferred digitally to the hard drive of a computer and reviewed using video editing software that allowed precision control of playback; pause, reverse, and slow motion were used to obtain the most accurate counts possible. We assumed that densities from the secondary review were the true densities and calculated bias by subtracting the true densities from the original density estimates.

Area surveyed on each sled tow was calculated as the product of video width and distance towed. Analysis of underwater video images of objects of known size indicated that the field of view on the review monitor was 1.25 m wide. To compensate for scallops that were partially visible at the edge of the field of view, we added 120 mm, the approximate diameter of an average-sized scallop, which brought the total width surveyed by the camera sled to 1.37 m. We added 120 mm because our earlier research indicated that when less than half a scallop was visible at the edge of the field of view, positive identification was difficult or impossible. Start and end times of all usable segments of video were obtained from the mini-DV tape and matched with shipboard GPS track data. We assumed that the sled traveled the same distance as the vessel during the time the segments were recorded.

A bootstrapping procedure was employed to estimate the number of scallops in each bed. At each iteration, stations were selected by sampling with replacement until the number of stations in the bootstrap replicate matched the number of stations in the original sample. For each selected station, a scallop count was chosen with equal probability from the two author's original review counts. Scallop counts and area surveyed were summed over the replicate to produce a density estimate which was then multiplied by the total area of the bed to obtain an estimate of the number of scallops. After 1000 replicates, we took the 0.5, 0.025 and 0.975 quantiles of the bootstrap distribution as point and 95% confidence bound estimates for the number of scallops in the bed.

To convert estimated numbers of scallops to meat weight, we first fit an allometric model of the SH–meat weight relationship using the dredge tow data and assuming a multiplicative error structure (Quinn and Deriso, 1999; p. 130). With this error assumption, the allometric model:

$$W = \alpha \mathrm{SH}^{\beta} \mathrm{e}^{\varepsilon}$$

is linearized as:

$$\ln W = \ln \alpha + \beta \ln \mathrm{SH} + \varepsilon$$

where W is the scallop meat weight (g), SH the scallop shell height (mm), and ε the normally distributed error. Preliminary analysis indicated that between-tow differences in regression parameter estimates were due to between-tow differences in SH distributions; in addition, we found no signs of systematic variation in the relationship along environmental gradients such as latitude or depth. For these reasons, we pooled data from all dredge tows and used the regression model to estimate an area–wide relationship of average meat weight given SH. Due to concerns about size selectivity of the lined dredge (i.e. small scallops were likely captured with lower efficiency than larger animals), we then used the model to calculate weight estimates for scallop size measurements obtained from video. This was accomplished by capturing digital still images (tagged image file format, TIFF files) of scallops from randomly selected video tows in each bed, using image analysis software to measure scallop diameter in pixels, then converting each measurement from pixels to millimeters based on the position of the scallop within the field of view.

Preliminary work revealed two sources of error intrinsic to the video measurements: (1) orientation of scallops on the substrate could not always be determined, so measurements could be of shell diameter rather than SH (perpendicular distance from the umbo to ventral margin of the top valve); (2) accurate detection of scallop shell edges was limited by the digital nature of the images. To evaluate the first source of error, we made six measurements of shell diameter on each of 18 scallop shells collected in the eastern GOA that ranged from 57 to 143 mm SH. Mean magnitude of the error of these measurements (shell diameter − SH) was 3.7 mm, and mean error was 1.1 mm. In practice, SH measurements were obtained when possible, so we assumed that mean error from this source would be small (∼1 mm or less). Precise edge detection of shapes within digital images is problematic. Enlarging a black and white digital image on a computer monitor shows that edges that appear sharp to the human eye at normal resolution are composed of regions of black and white pixels separated by a few pixels that are varying shades of gray. This is due to computer algorithms that deal with the fact that edges within the image never exactly match the borders between pixels. With our camcorder lens set 1.15 m above the substrate and a capture card that produced 720 × 480 pixel images, each pixel of the TIFF images represented 1.81–2.21 mm on the substrate depending on position within the field of view. Because the image-processing software measures pixel to pixel, and contrast between scallop shells and the surrounding substrate is low, errors on the order of 5–10 mm per measurement were possible, but we found no reason to suspect bias and consequently assumed that the mean of the errors was close to zero.

Our sampling goal was to obtain a minimum of 300 such measurements from five or more tows in each bed. Bed-by-bed meat weight estimates were calculated as the product of scallop counts and the mean of the model-predicted meat weights for all scallop measurements taken from within each bed. We also used video measurements and model predictions to estimate scallop meat biomass of pre-recruits. This was accomplished by finding the proportion of model-predicted meat weight due to scallops <100 mm SH and applying it to the total meat weight estimate for each bed. We note that regulations require commercial scallop dredges in Alaska to be fitted with 102 mm rings, and observer data indicate that almost all scallops <100 mm SH that are landed are subsequently discarded.

3. Results

The sled was deployed at 150 stations with depths ranging from 48 to 130 m; usable video was obtained at 135 stations. A total of 124,223 m^2 of the bottom was viewed and over 12,000 scallops were counted by each reviewer, producing an overall average density estimate of 1.0 scallops per 10 m^2 (Table 1). Our point estimate for the total number of scallops in the area was 131.6 million with a 95% confidence interval from 92.0 to 174.4 million scallops.

Between-station variability within beds was substantial and greatly exceeded between-reviewer variability. Density estimates for Bed 6 (Fig. 2), which were typical of data from other beds, ranged from 0.1 to 2.5 scallops per 10 m^2, while the largest between-reviewer difference for the bed occurred at station 122, with counts of 146 scallops (1.70 scallops per 10 m^2) and 135 scallops (1.58 scallops per 10 m^2). Overall, zero counts were recorded by both reviewers at four stations, and estimated densities exceeded 2.0 scallops per 10 m^2 for at least one station in each bed.

Regression fit of the allometric model (Fig. 3) was good, with $r^2 = 0.80$ ($P < 0.001$), and parameter estimates $\alpha = 1.02 \times 10^{-5}$ ($P < 0.001$) and $\beta = 2.94$ ($P < 0.001$). Median SH varied considerably between beds and was lower for video measurements than for dredge tow measurements in each bed (Table 2). The mean model-predicted meat weights from video measurements that were used to convert scallop counts to biomass ranged from 9.6 g in Bed 4 to 14.8 g in Bed

Table 1
Summary statistics from eastern Gulf of Alaska video scallop survey

Bed	Area (million m^2)	Surveyed area (m^2)	Number of stations	Review counts[a]		Estimated density (scal/10 m^2)	Estimated number scallops (millions)		
				GR	SB		Point estimate	95% Confidence interval	
								Lower	Upper
1	121.79	10861	12	1728	1632	1.5	18.83	13.66	24.67
2	154.77	16495	18	1679	1543	1.0	14.96	11.09	19.36
3	457.94	43071	46	3981	3916	0.9	41.86	30.50	53.48
4	287.15	27618	30	3138	3215	1.1	32.93	23.13	42.90
5	130.95	8833	11	397	412	0.5	5.96	2.66	10.05
6	183.94	17345	18	1619	1609	0.9	17.09	10.92	23.98
Total	1336.55	124223	135	12542	12327	1.0	131.63	91.96	174.44

[a] Initials designate the two authors.

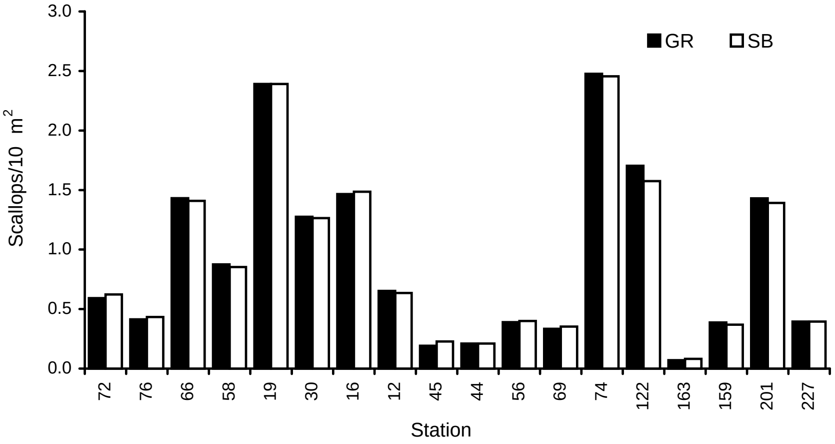

Fig. 2. Density estimates from review of Bed 6 video. Initials denote the two authors.

3 (Table 2). Total estimated biomass of scallop meats was 1566×10^3 kg, with the largest contribution coming from Bed 3 with 619×10^3 kg (Table 3). Overall, 11% of the scallop meat biomass was attributed to the pre-recruit portion of the population, ranging from 1% in Bed 3 to 20% in Bed 4.

A secondary video review to check for bias was completed for 14 tows. On average, densities were

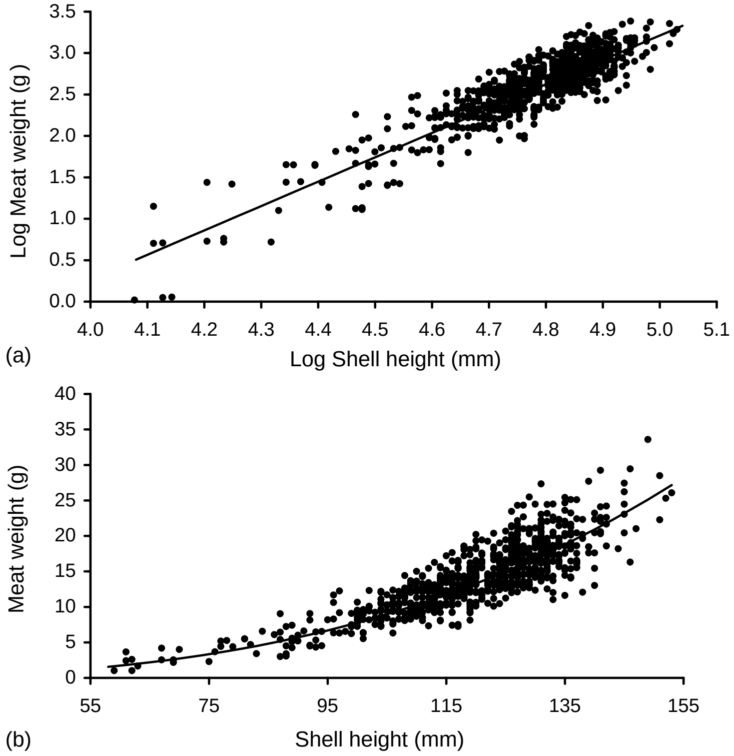

Fig. 3. Log–log regression (a) and raw data (b) for the allometric relationship between scallop shell height and meat weight from dredge tow data, $n = 773$, $r^2 = 0.80$.

Table 2
Summary of scallop shell height–meat weight data

Bed	Dredge tow measurements			Video measurements			
	Number of tows	Number of scallops	Median SH (mm)	Number of tows	Number of scallops	Median SH (mm)	Mean model meat weight (g)[a]
1	2	202	125	5	370	114	12.0
2	2	170	120	5	301	112	10.8
3	4	303	127	6	454	123	14.8
4	1	75	111	6	462	107	9.6
5	0			5	281	108	9.7
6	2	157	112	5	363	110	10.8

[a] Mean of predicted values from allometric model.

Table 3
Scallop meat weight estimates by bed

Bed	Biomass ($\times 10^3$ kg)	95% confidence interval		Pre-recruits	
		Lower ($\times 10^3$ kg)	Upper ($\times 10^3$ kg)	Percentage[a]	Biomass ($\times 10^3$ kg)
1	226	164	296	9	21
2	162	120	209	13	22
3	619	451	792	1	6
4	316	222	412	20	63
5	58	26	99	17	10
6	185	118	259	12	22
Total	1566	1101	2066	11	144

[a] Percentage of model-predicted meat weight totals attributed to scallops <100 mm SH.

underestimated by about 0.01 scallops per 10 m^2, or 6%, during normal speed playback review (Fig. 4). Expressed another way, the original scallop counts by the two reviewers were 96 and 92% of the slow review counts. The bias analysis also showed that as the review progressed, counts from both reviewers became closer together and more accurate. Misidentification of scallop shells as scallops did not appear to be a problem; when scallop shells were observed, orientation on the bottom was different than for live scallops, probably due to movement of the shells by scavengers.

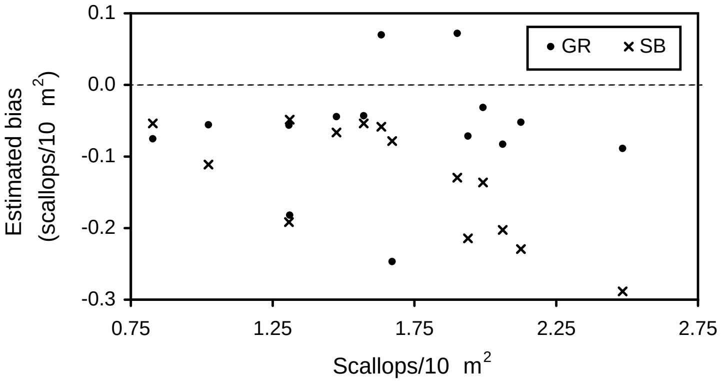

Fig. 4. Bias estimates from secondary video review, $n = 14$. Initials denote the two authors.

4. Discussion

Video review is arguably the most challenging aspect of underwater video surveys. Franklin et al. (1980) used underwater television to survey scallops *P. maximus* and queens *Chlamys opercularis* off the southern coast of England and reported that tape review was difficult and fatiguing. Giguère and Brulotte (1994) compared video and dredge techniques for sampling sea scallops *Placopecten magellenicus* in the Gulf of St. Lawrence and concluded that video sampling produced better estimates of scallop density than dredge sampling, but they noted that time demands for video review were unreasonably high. Our approach was to set towing speed so that video could be reviewed at normal playback speed with a high probability of correctly identifying scallops as they passed through the field of view. Video from each tow was reviewed at normal speed without pauses because stopping, rewinding, and restarting the tape can lead to large increases in review time. We set tow length at 15 min because our earlier work showed that counting scallops from video fatigued the eyes, and 15 min was about the maximum time reviewers could fully concentrate on the task without a break. Giguère and Brulotte (1994) made tows that were 650 m long and took approximately 4 h to review, which included time spent measuring as many scallops as possible. In contrast, our 15 min tows averaged 674 m in length and took about 15 min to review to obtain scallop counts, with video measurements made separately on a subsample of tows.

Our analysis of bias (Fig. 4) indicated that a small percentage of scallops were not counted during the normal speed review. We essentially traded a small amount of negative bias in the abundance estimates for substantial savings in review time. As the review progressed, we realized that capture of TIFF images for measurement of scallop SH could be combined with the secondary review, providing additional time savings. We chose not to incorporate bias into the abundance estimates, as our stock assessment program is still in the developmental stages, and the results of this survey will not be used as a basis for fishery management decisions. Our experience agrees with that of Franklin et al. (1980), who noted the importance of practice when counting scallops filmed on the bottom; our counts became more accurate as the review progressed, and in future surveys we would expect to achieve bias $<5\%$ using trained reviewers.

Conversion of scallop counts from video to meat weight estimates is another problematic area of the methodology. Median SH values from our video measurements were consistently lower than those from dredge tows (Table 2), suggesting that scallop meat biomass would be overestimated by using dredge tow SH distributions for conversion. Yet the video SH measurements included an unknown error component that precluded us from making direct statistical comparisons of the dredge and video SH distributions. Another area of concern is the sampling method used to select scallops for measurement. We used simple random sampling within beds to select video tows for analysis, but selection of scallops within tows was not random. We attempted to measure up to 100 scallops from each selected tow, but some of the TIFF images were not usable due to poor quality or because the scallops were positioned near the edge of the field of view. Given the number of scallops counted during review (Table 1), it does not appear to be practical to measure every scallop observed or to use true random sampling, with the probability of selection for measurement equal for each scallop observed. As a comparison, Giguère and Brulotte (1994) measured 3745 scallops of 4362 counted over the course of 3 years, Stokesbury (2002) measured 2005 scallops of 3439 counted, and 2231 scallops of about 12,500 counted from our survey were measured. Despite these concerns, we feel that the video measurements combined with the allometric model provide more accurate meat weight estimates than could be obtained utilizing size structure observed in dredge catches, where SH measurements are highly accurate but their distribution is affected by size selectivity.

Because our equipment did not include live video feed to the R/V Pandalus, we were unaware of problems with the sled or video equipment when they occurred, and survey time was lost due to poor underwater visibility and various technical problems. Poor visibility caused by towing wire contacting the substrate ahead of the sled led to partial loss of data from eight tows, while naturally suspended bottom sediments made review of video from five tows difficult or impossible. Sinking phytoplankton that caused visibility problems during our earlier work was not a factor during this survey, although it occurred in May and June when photosynthetic activity is generally high. Installation of an additional 80 kg of lead ballast on the sled after the survey eliminated the related problems of dragging towing wire and the sled's tendency to lift off the bottom in rough sea conditions. The camcorder aboard the sled performed reliably for the most part but stopped functioning in mid-tow on three occasions, and the equipment was not set up and adjusted properly prior to deployment for four other tows. Although live video feed to the surface would theoretically lead to more efficient use of vessel time, the cost is prohibitive given the current level of funding for our scallop stock assessment program.

Our methods contrast with those presented by Stokesbury (2002), who used a video drop camera to survey *P. magellenicus* in closed areas on the US side of Georges Bank. His systematic survey design samples more stations but less area of the bottom than our methods given a similar-sized study region. Densities of *P. magellenicus* in the Georges Bank study areas are considerably higher than densities of weathervane scallops in areas of Alaska where video equipment has been deployed. As noted in the introduction, we initially experimented with a drop camera but constructed and began using the sled because over 90% of our video drops produced zero scallop counts.

This survey marked the first attempt by ADF&G to assess a scallop population using underwater video rather than a dredge, and the results indicate that video surveys are a viable method for assessing Alaska's scallop stocks. Video sleds are less intrusive to bottom habitat than other sampling gear such as dredges or trawls, which can be important for researchers working in sensitive regions or areas closed to fishing. For assessing scallops, direct counts from video circumvent problems of efficiency and size selectivity commonly encountered in dredge surveys. Our work offers guidance to researchers who may be interested in underwater video survey methods but are concerned about the amount of time required for video review. In the future, we hope to conduct video surveys of Alaska's three most productive scallop fishing areas on an annual rotating basis and eventually combine survey and fishery data in size- or age-based stock assessment modeling.

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