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Reprinted from the Alaska Fishery Research Bulletin
Vol. 11 No. 2, Winter 2005
The Alaska Fisheries Research Bulletin can be found on the World Wide Web at URL:
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Alaska Fishery Research Bulletin 11(2):135–145. 2005.

Estimating Capture Probability of a Survey Bottom Trawl for Bering Sea Skates (*Bathyraja* spp.) and Other Fish

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ABSTRACT: Capture probabilities for skates (*Bathyraja* spp.), 3 species of flatfish, and 7 other fish species were estimated for the standard survey trawl (83-112 Eastern bottom trawl) used to conduct the National Marine Fisheries Service annual eastern Bering Sea bottom trawl survey. Capture probability data were collected by an experimental trawl consisting of a standard survey trawl with an auxiliary net attached beneath the footrope. Capture probability was estimated for each 1-cm length interval by calculating the ratio of fish caught in the standard survey trawl to the sum of fish caught in both standard survey trawl and auxiliary net. Four competing models describing different capture processes were fitted to the data using a maximum likelihood method, and the best model was chosen by likelihood ratio test. Capture probability for skates increased monotonically with length from approximately 0.65 for 30 cm skates to approximately 0.8 for skates >100 cm. Capture probability for flatfish (arrowtooth flounder, *Atheresthes stomias*; rex sole, *Glyptocephalus zachirus*; and Pacific halibut, *Hippoglossus stenolepis*); sturgeon poacher, *Podothecus accipenserinus*; wattled eelpout, *Lycodes palearis*; and great sculpin, *Myoxocephalus polyacanthocephalus,* was constant across lengths and close to unity (> 0.97). Capture probability was constant, but significantly lower than 1.0 for sawback poacher *Leptagonus frenatus* (0.89), searcher *Bathymaster signatus* (0.94), and spinyhead sculpin *Dasycottus setiger* (0.69). For spectacled sculpin *Triglops scepticus* capture probability was 1.0 for fish smaller than 15 cm but decreased for larger fish.

INTRODUCTION

Stock assessments have been typically limited to the most economically important species. However, demands placed on resource managers to initiate more precautionary measures and to incorporate eco-dynamic themes into stock assessments have generated a need to expand assessments. Stock assessments now include species and species groups of potential commercial importance, such as the recently exploited skate group (family Rajidae) and many non-commercial species such as sculpins (families: Ramphocottidae, Cottidae, Hemitripteridae, Psychrolutidae), eelpouts (family Zoarcidae) and poachers (family Agonidae) that interact ecologically with commercial species found throughout Alaskan waters (Mace et al. 2001). Presently, management of these “other” species is restricted to simple time-series monitoring of area-swept abundance estimates generated from multispecies groundfish resource surveys. This is because the data (i.e., commercial catch, size and age composition, and maturity) typically integrated into the complex population dynamics models used with commercial species are unknown. For most of the non-commercial species, stock assessment estimates for the Bering Sea management area use area-swept biomass estimates provided by the annual eastern Bering Sea (EBS) shelf bottom trawl survey and the biennial eastern Bering Sea upper continental slope survey conducted by the Alaska Fisheries Science Center (AFSC). Stock assessments that incorporate survey-estimated biomasses could be further improved by measuring the catch efficiency or capture probability of the survey trawls to apply corrections to the area-swept abundance estimates (Somerton et al. 1999).

Past experiments by the AFSC have demonstrated that escapement of some benthic fauna (crab and flatfish) occurs beneath the footrope of the 83-112 Eastern trawl—the standardized trawl used in the annual EBS shelf groundfish and crab surveys—and that its capture efficiency at the footrope varies with species and size (Somerton and Otto 1999; Munro and Somerton 2001; Munro and Somerton 2002; Weinberg et al. 2004). To assess the potential impact of escaping skates and several other species on abundance calculations, we conducted an experiment to estimate the capture efficiency of the survey trawl. In our experiment, fish escaping beneath the survey trawl footrope were

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Authors: STAN KOTWICKI and KENNETH L. WEINBERG are with the National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Email: stan.kotwicki@noaa.gov

Acknowledgments: The success of this project is due to the efforts of many.We extend our gratitude to captain Jeff Boddington, the crew of the F/V *Arcturus*, and scientists Dan Nichol, Duane Stevenson, Beth Matta and Dan Cooper for their help with data collection. We are also grateful to our reviewers including Dave Somerton, Jay Orr, Gary Stauffer, Gary Walters, and Jerry Hoff.

subsequently captured with an auxiliary net that was attached beneath and behind the footrope of the survey trawl (Engås and Godø 1989).

MATERIAL AND METHODS

Gear Design

Our experimental net consisted of the standard 83-112 Eastern survey bottom trawl modified with an auxiliary net having a separate footrope and codend. The 83-112 Eastern is a low-rise 2-seam flatfish trawl fished with a pair of 1.8 × 2.7-m steel V-doors weighing approximately 816 kg each. During standard survey practice the doors are attached to the net by a pair of 3-m long, 1.6 cm long-link chain door legs, a 12.2 m-long, 1.9-cm diameter stranded wire door leg extension, and a pair of 55-m long, 1.6-cm diameter, bare stranded wire bridles on each side. The 34.1-m long (112 feet), 5.4-cm diameter footrope is designed for use on soft bottom and is constructed of 1.6-cm diameter stranded wire rope protected with a single wrap of 1.3-cm diameter polypropylene line and split rubber hose. The footrope is evenly weighted along its length by 41.3 kg of 7.9-mm diameter proof coil chain from which the webbing is hung. An additional 0.6-m long, 1.3-cm long-link chain extension connects each lower bridle to the trawl wingtips to help keep the footrope close to the bottom. The 25.5-m long (83 feet) headrope is constructed of 1.3-cm diameter stranded wire rope wrapped with 1-cm diameter polypropylene line and utilizes 41 evenly spaced 20.3-cm diameter floats that provide approximately 116.4 kg of buoyancy. The wings and body of the survey net are constructed of 10.2-cm stretch-mesh 3-strand braided nylon (#60). The intermediate and codend (double walled) are constructed of 8.9-cm stretch-mesh, 3-strand nylon (#96). Inside the codend is a 3.2-cm stretch-mesh nylon (#18) liner used to retain small fauna. Detailed construction plans for the 83-112 Eastern are reported in Stauffer (2004).

The footrope of the survey trawl served as a headrope for the auxiliary net with the belly of the trawl also serving as the top panel of the auxiliary net (Munro and Somerton 2002, Figure 1). The wings of the auxiliary net followed those of the survey trawl. The 2 nets separated where the body joins to the intermediate. The construction of the auxiliary net intermediate and codend was identical to that of the survey trawl, however the belly of the body utilized the smaller 8.9-cm stretch mesh nylon. The 38.2-m long footrope of the auxiliary net, constructed with 16-mm long-link chain, was designed to drag through soft bottom approximately 2.8 m behind the trawl footrope at its center and presumably captures all escaping fish. Detailed construction plans for the auxiliary net are reported in Munro and Somerton (2002).

Experimental Design

The experiment was conducted from 24 July to 2 August 2003 aboard the F/V *Arcturus,* one of 2 commercial stern trawlers chartered since 1993 to carry out the National Marine Fisheries Service (NMFS), annual EBS groundfish surveys. Sampling effort was directed at depths ranging from 84 to 161 m (Figure 1) based on historic skate catch data from the most recent (1994–2003) EBS surveys. Tows were made in pairs, one in a northerly direction and one in a southerly direction, and were offset to the east or west by about 0.1 nmi. The direction of the first tow was determined randomly in order to mitigate any bias that the current flow might have on footrope contact with the bottom (Weinberg 2003). With one exception, trawling followed standardized survey protocol, which included towing at a vessel speed of 3.0 knots for 30 min during daylight hours and using locked winches and standardized lengths of trawl warp at each towing depth. The single departure from standard survey protocols was our use of 27.5-m long bridles instead of the standard 55-m long bridles to help offset the loss of wing spread caused by the additional drag of the auxiliary net (Munro and Somerton 2002). Bottom contact sensors (Somerton and Weinberg 2001) were placed at the center of both the survey trawl and the auxiliary net footropes to measure the distance (in centimeters) between the footropes and the bottom. Acoustic net mensuration equipment (Netmind©) measured wing spread and headrope height of the survey trawl during each tow. By design, the wing spread of the auxiliary net was equal to the spread of the survey trawl. For all tows the total catches of all species from each net were first weighed. Skates and several other species for which capture probability estimates were lacking were removed from the catch, weighed, sexed, and measured to the nearest centimeter total length (TL). In a few cases, catches of rex sole *Glyptocephalus zachirus* and arrowtooth flounder *Atheresthes stomias* were too large to process in a timely fashion so a random subsample of lengths was taken.

Trawl Geometry Analyses

Trawl dimensions were compared between the experimental net and the standard survey net (survey years 1994–2003) to confirm that the 2 gear types fished similarly. Mean wing spreads and mean headrope heights from our 46 experimental gear tows were compared to 61 standard survey gear tows made within the same 20 nmi square survey blocks (Figure 1). Means from the 2 gear types were compared with a *t*-test (2-tailed, assuming unequal variances).

Mean distance off-bottom from 46 experimental tows were compared to 23 standard survey tows made in the same general area during 2004, the only year the same bottom contact sensor footrope assembly was used. Means were compared in the same manner as wing spread and net height.

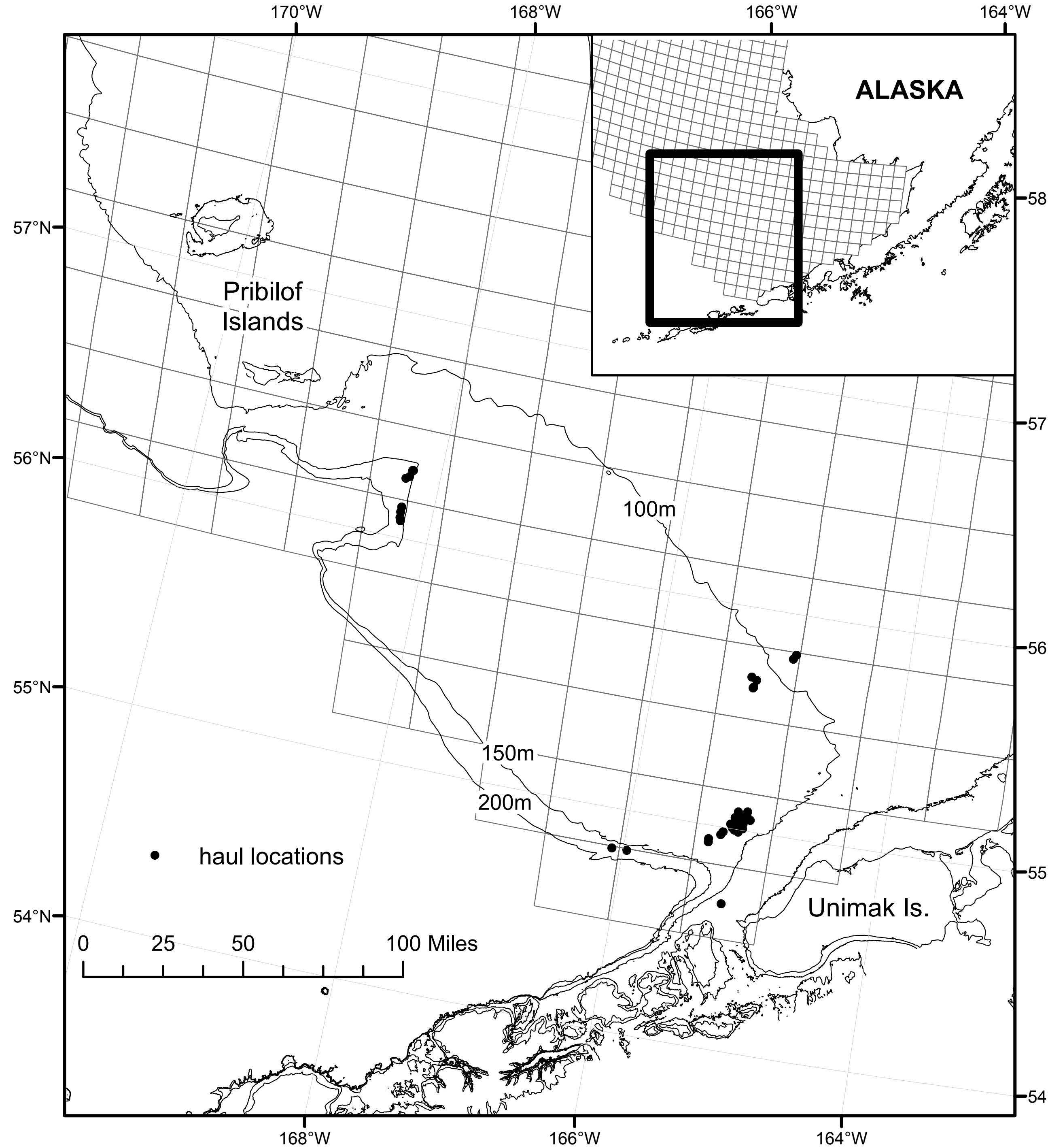

Figure 1. Locations of experimental tows (black dots). Grid of squares represents standard eastern Bering Sea survey blocks.

Estimation of Capture Probability

Capture probability of each species for the experimental gear was estimated from catch data from the trawl and the auxiliary net as a function of fish length (L) using 4 competing models, each representing a different capture process (Munro and Somerton 2002):

$$P_1(L) = \frac{1}{1+e^{-a}} \qquad (1)$$

$$P_2(L) = \frac{1}{1+e^{-(a+bL)}} \qquad (2)$$

$$P_3(L) = \frac{c}{1+e^{-(a+bL)}} \qquad (3)$$

$$P_4(L) = c\left(\frac{1}{1-d}\right)\left(\frac{1-d}{d}\right)^{d}\left(\frac{e^{-d(a+bL)}}{1+e^{-(a+bL)}}\right) \qquad (4)$$

where *a*, *b*, *c*, and *d* are parameters. The models are variants of the logistic function parameterized so that they comprise a nested hierarchy of curves. The more complex models can be converted into a simpler model by assigning certain values to the parameters

$$\lim_{d\to 1} P_4 = P_3 \qquad \lim_{c\to 1} P_3 = P_2 \qquad \lim_{b\to 0} P_2 = P_1 \qquad (5)$$

The simplest model (P_1) represents a capture process in which capture probability is constant within an observed length range. Models P_2 and P_3 represent capture processes in which the probability of capture changes monotonically with increasing fish length. Model P_2 has an asymptote of unity and model P_3 has an asymptote less than unity that is determined by parameter *c*. Model P_4 represents a capture process in which the capture probability first increases with the fish length, and then, after achieving a maximum, decreases with length.

Model parameters were estimated by maximizing the likelihood function using capture and escape data at length from all experimental tows. Because each outcome of the experiment (capture or escape) can be treated as an independent Bernoulli event, we used a likelihood function for binomial distribution (6) (Millar 1992; Munro and Somerton 2002):

$$L = \prod_l \binom{N_1}{n_1} P_l^{n_l}(1-P_l)^{N_l-n_l} \qquad (6)$$

where l = fish length in centimeters, P_1 = probability of capture at length l, N_1 = number of all fish at length l, and n_1 = number of escapes at length l.

Each model was fit to the data by minimizing the negative log likelihood function. The best model was selected using a likelihood ratio test (P<0.05, Hilborn and Mangel 1997). It is assumed in this test that the distribution of the $-2\log(L_1/L_2)$ is approximately equal to χ^2 (where the L_1 and L_2 are likelihoods of competing models). We used a χ^2=3.84146 as our critical value since we compared models with only one observed degree of freedom (e.g., P_1 vs. P_2). Therefore, if the double difference between negative log likelihoods of compared models was larger than χ^2=3.84146, then the model with more parameters was considered better than the model with fewer parameters on a 95% level.

Bootstrapped 95% confidence intervals around the probability curve of the best model were estimated (Efron and Tibshirani 1993), with entire tows being resampled (with replication) 1000 times; the parameters and predicted values for each 1-cm length category were estimated for each replication. Empirical 95% confidence intervals were then determined as the range between the 25th lowest and 25th highest of the bootstrapped capture probability estimates.

RESULTS

Trawl Dimensions

Mean net spread during experimental tows was narrower ($\bar{x}$=16.68 m, n=46) than that observed during standard survey tows ($\bar{x}$=17.67 m, n=61) and this difference was statistically significant (P<0.001, t=7.16146). Mean net height during experimental tows was significantly lower ($\bar{x}$=2.22 m, n=46) than during standard surveys ($\bar{x}$=2.43 m, n=60, P<0.001, t=5.04958). However wing spreads and headrope heights during experimental tows fell well within the range observed during standard surveys (Figure 2). Mean footrope distance off-bottom was significantly (P<0.001, t=10.7772) lower during our experiment ($\bar{x}$=1.2 cm) than during the survey ($\bar{x}$=4.7 cm).

Capture Probability

Capture probability curves were modeled for skates as a group and for the 10 most prevalent species (aside from skates) in our catches (Tables 1 and 2). Capture probability for skates and spectacled sculpin *Triglops scepticus* was estimated with model P_2, indicating that size mattered in the capture process. Capture probability for all other species was estimated with model P_1, indicating that the capture efficiency was constant across all observed lengths.

Capture probability was size-dependent for skates. A total of 1011 skates comprising 5 species having

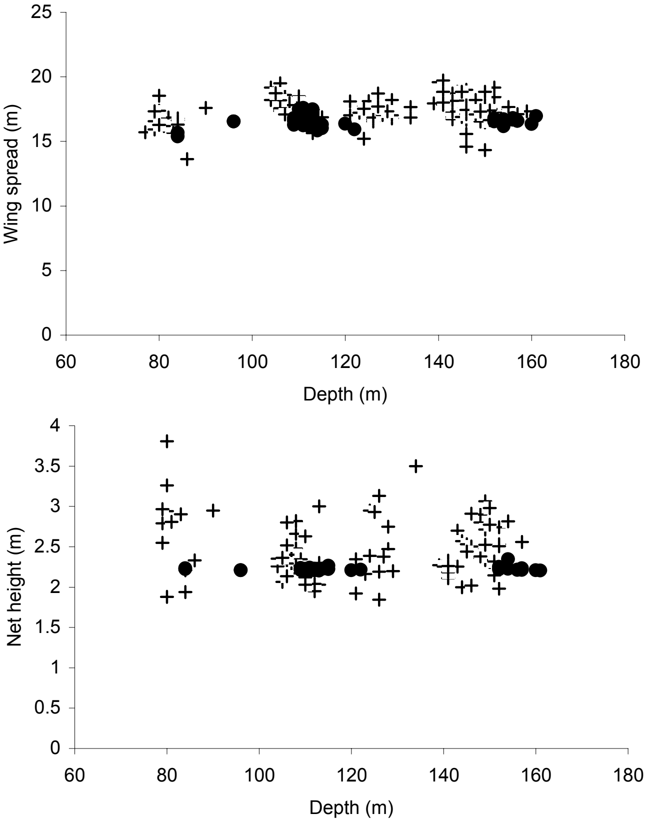

Figure 2. Graphical comparison of the wing spread and net height during experiment (•) to the values observed during standard eastern Bering Sea trawl survey (+) since 1994.

similar body morphology (*B. parmifera*, *n*=849; *B. interrupta*, *n*=142; *B. aleutica*, *n*=14; *B. taranetzi*, *n*=4; and *B. maculata*, *n*=2) were caught and grouped together to compute skate capture probability using model P_2. Capture probabilities were also calculated separately for *B. parmifera* and *B. interrupta*. We performed a model selection procedure based on the Akaike Information Criterion (AIC). The model with these 2 species of skates grouped together had lower AIC (134.34) than 2 separate models (159.84) indicating that one grouped model is more statistically appropriate for skates. Skate length–frequency distributions from captures in both the survey trawl and the auxiliary net were generally trimodal. Considerably higher numbers of skates were taken in the 20–40-cm and 90–110-cm size modes (Figure 3), which consisted almost entirely of *B. parmifera*; whereas the central length mode consisted almost entirely of *B. interrupta*. By combining skate species having similar body morphology, and thus presumably similar swimming and escapement behaviors, we were able to estimate one probability curve for skates that covered all lengths observed. Our results indicated that skate capture efficiency increases with increasing lengths (Figure 4) from about 0.65 at 20–40-cm TL to 0.8 at 90–110-cm TL.

Capture probability for spectacled sculpin neared 1.0 for most of its observed size range but dropped for the largest individuals. However, this decrease in capture probability for larger individuals was associated with very wide confidence intervals indicating considerable uncertainty in this observation. Capture probabilities were estimated using model P_1 for 3 species of flatfish (arrowtooth flounder, rex sole, and Pacific halibut *Hippoglossus stenolepis*), in addition to several non-commercial roundfish (sturgeon poacher *Podothecus accipenserinus,* sawback poacher *Leptagonus frenatus*, wattled eelpout *Lycodes palearis*, searcher *Bathymaster signatus*, spinyhead sculpin *Dasycottus setiger*, great sculpin *Myoxocephalus polyacanthocephalus*, and spectacled sculpin). Estimated capture probabilities were very high (> 0.97) for arrowtooth

Table 1. Catch and length summary data used to compute capture probability of the 83-112 Eastern survey bottom trawl for skates and other species. The model selected to estimate capture probability for each species is presented along with the maximum estimated catch efficiency.

Species	Tows with catch	Fish captured	Fish escaped	Min. length (cm)	Max. length (cm)	Best model	Max. capture rate	Scientific Name
Skates	46	735	287	15	133	P2	0.8459	*Bathyraja* sp.
Arrowtooth flounder	40	8,996	216	5	99	P1	0.9766	*Atheresthes stomias*
Rex sole	33	3,059	65	8	95	P1	0.9792	*Glyptocephalus zachirus*
Sturgeon poacher	15	378	2	18	30	P1	0.9947	*Podothecus accipenserinus*
Spectacled sculpin	9	346	14	9	22	P2	0.9980	*Triglops scepticus*
Sawback poacher	31	201	24	17	26	P1	0.8933	*Leptagonus frenatus*
Pacific halibut	35	146	2	37	106	P1	0.9865	*Hippoglosus stenolepis*
Searcher	19	134	9	8	37	P1	0.9371	*Bathymaster signatus*
Spinyhead sculpin	32	89	40	6	28	P1	0.6899	*Dasycottus setiger*
Great sculpin	23	113	1	36	75	P1	0.9912	*Myoxocephalus polyacanthocephalus*
Wattled eelpout	22	100	1	27	56	P1	0.9901	*Lycodes palearis*

Table 2. Model selection criteria (negative log likelihood and χ^2) and parameters for the best model (bold) with variance and covariance for these parameters.

Species	Model	Negative log likelihood	χ^2	Parameters	Variance	Covariance
Skates	P1	73.8185				
	P2	**68.8248**	**9.9874**	**a = 0.3398**	**0.0440**	**-0.0005**
				b = 0.0103	**0.0000**	
	P3	68.0937	1.4622			
	P4	68.0937	0			
Arrowtooth flounder	**P1**	**444.7576**		**a = 3.7293**	**0.0217**	
	P2	444.7557	0.0038			
	P3	444.7557	0			
	P4	443.9840	1.5434			
Rex sole	**P1**	**137.2411**		**a = 3.8511**	**0.0225**	
	P2	136.8288	0.8246			
	P3	136.7629	0.1318			
	P4	136.6359	0.2540			
Sturgeon poacher	**P1**	**5.4238**		**a = 5.2418**	**81.5287**	
	P2	5.0526	0.7424			
	P3	5.0526	0			
	P4	5.0522	0.0008			
Spectacled sculpin	P1	25.7028				
	P2	**21.3058**	**8.7940**	**a = 15.1396**	**9.0506**	**-0.5022**
				b = -0.0687	**0.0286**	
	P3	21.3050	0.0016			
	P4	21.3050	0			
Sawback poacher	**P1**	**33.1736**		**a = 2.1253**	**0.0800**	
	P2	33.1433	0.0606			
	P3	33.1433	0			
	P4	33.0898	0.1070			
Pacific halibut	**P1**	**4.6012**		**a = 4.2905**	**126.2476**	
	P2	3.8248	1.5528			
	P3	3.8248	0			
	P4	3.5139	0.6218			
Searcher	**P1**	**14.5928**		**a = 2.7006**	**11.3210**	
	P2	14.5657	0.0542			
	P3	14.5657	0			
	P4	14.5403	0.0508			
Spinyhead sculpin	**P1**	**34.6880**		**a = 0.7998**	**0.0882**	
	P2	34.2699	0.8362			
	P3	34.2699	0			
	P4	34.1296	0.2806			
Great sculpin	**P1**	**2.4893**		**a = 4.7274**	**228.7983**	
	P2	2.4867	0.0052			
	P3	2.4867	0			
	P4	2.4728	0.0278			
Wattled eelpout	**P1**	**2.4365**		**a = 4.6057**	**225.1059**	
	P2	2.3813	0.1104			
	P3	2.3813	0			
	P4	2.3605	0.0416			

flounder, rex sole, sturgeon poacher, Pacific halibut, great sculpin and wattled eelpout. Data on juveniles was lacking for all species except arrowtooth flounder and rex sole. Capture probability was also high for sawback poacher (0.89) and searcher (0.94) but wider confidence bounds about these estimates were evident. The lowest capture probability was observed for spinyhead sculpin (0.67).

DISCUSSION

Experimental Trawl Performance

The precision of our estimates depends on the experimental trawl performance. The main assumption we made in our study is that all fish escaping beneath the trawl footrope spill over the auxiliary footrope and are captured by the auxiliary net. Experimental gear

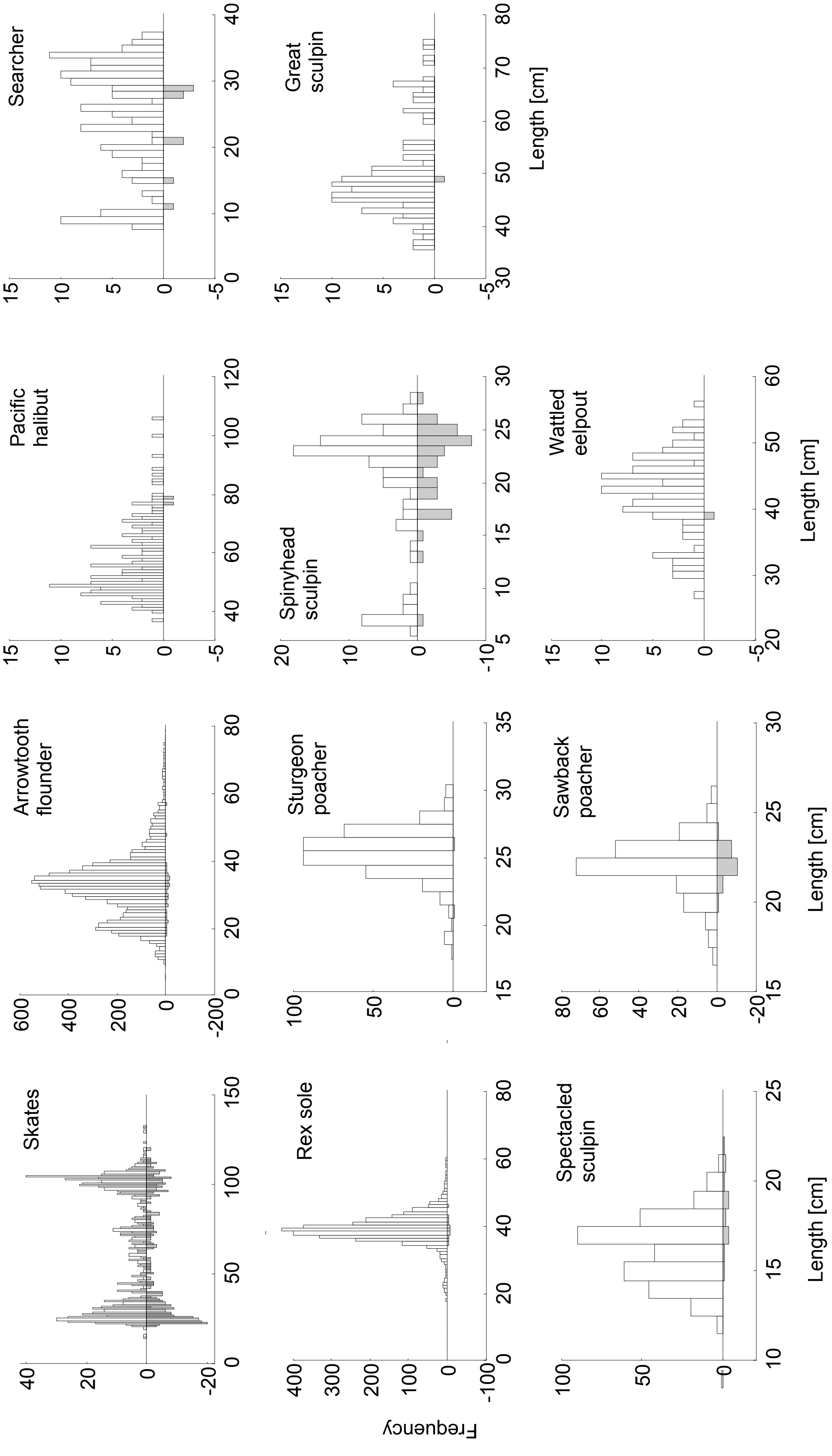

Figure 3. Observed length–frequencies for captured (positive values) and escaped fish (negative values) pooled across experimental tows.

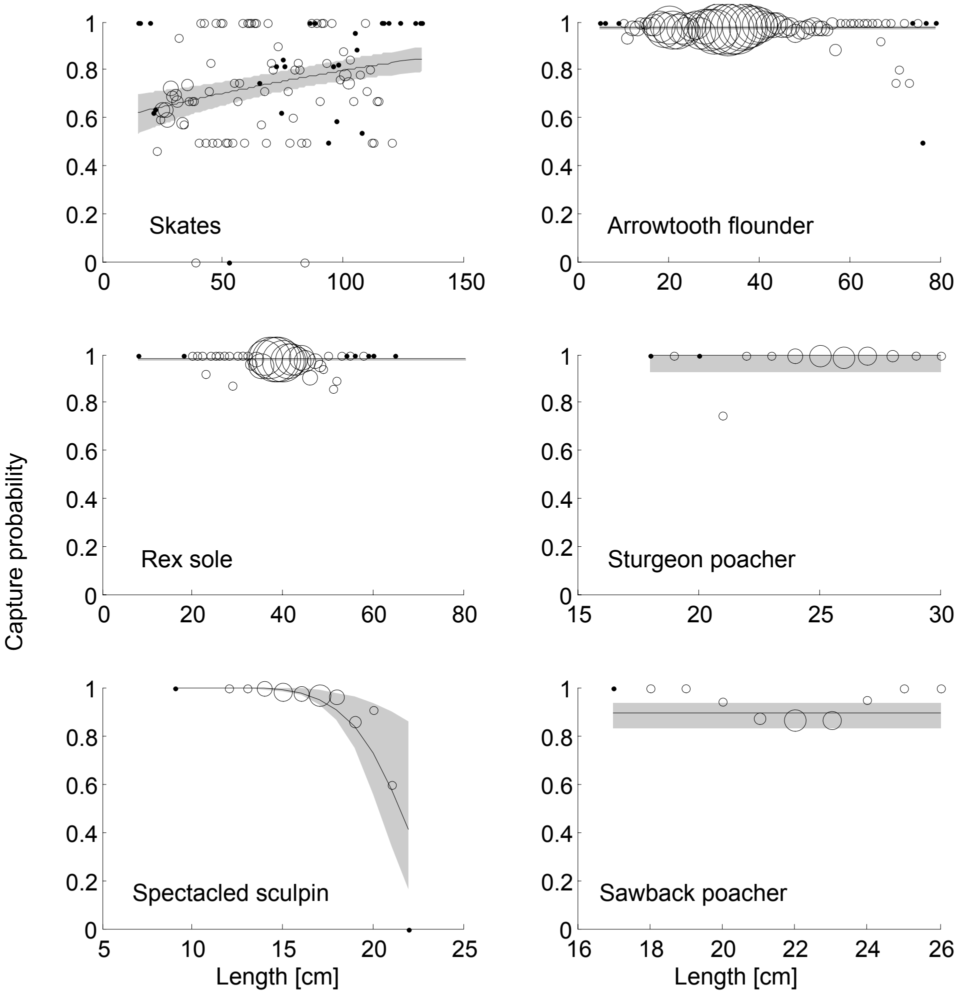

Figure 4. Probabilities of capture estimated by the parametric model is shown along with 95% bootstrapped confidence regions. Circles represent observed capture probabilities. Size of the circle is proportional to number of fish observed in each centimeter length bin.

consisted of the standard trawl with an auxiliary net having a separate footrope and codend attached. The auxiliary footrope consisted of heavy chain link designed to keep contact with a soft, level seafloor and sweep underneath epi-benthic organisms. The presence of large amounts of benthic debris (shells and stationary invertebrates) in the auxiliary codend supports our assumption, as did the bottom contact sensor placed in the center of the auxiliary footrope, which indicated consistent footrope contact with the seafloor.

The accuracy of our estimates is also dependent upon several other trawl performance characteristics and how well the experimental net duplicated survey trawl dimensions during standard surveys. To address this issue we measured 3 aspects of trawl geometry: wing spread, headrope height, and trawl footrope contact.

Because the added drag of the auxiliary net has been shown to reduce the wing spread of the 83-112 Eastern trawl (Munro and Somerton 2002, Weinberg et al. 2004), we shortened the bridle lengths to half the length of the survey standard bridles. Even with this change the path width of the experimental trawl was reduced (by about 1-m on average), as was the variance of wing spread (Figure 2). We attribute greater variance in survey wing spreads to 2 factors. First, the added drag of the auxiliary net likely served as a stabilizing force against the natural tendency of the doors to spread the net to its maximum. Second, because we used 10 years of survey wing spread measurements to compare to the 8 d of experimental net towing, the survey trawl was exposed to more naturally variable environmental conditions (e.g., current velocities, sea state) that affect net spread than was experienced over the

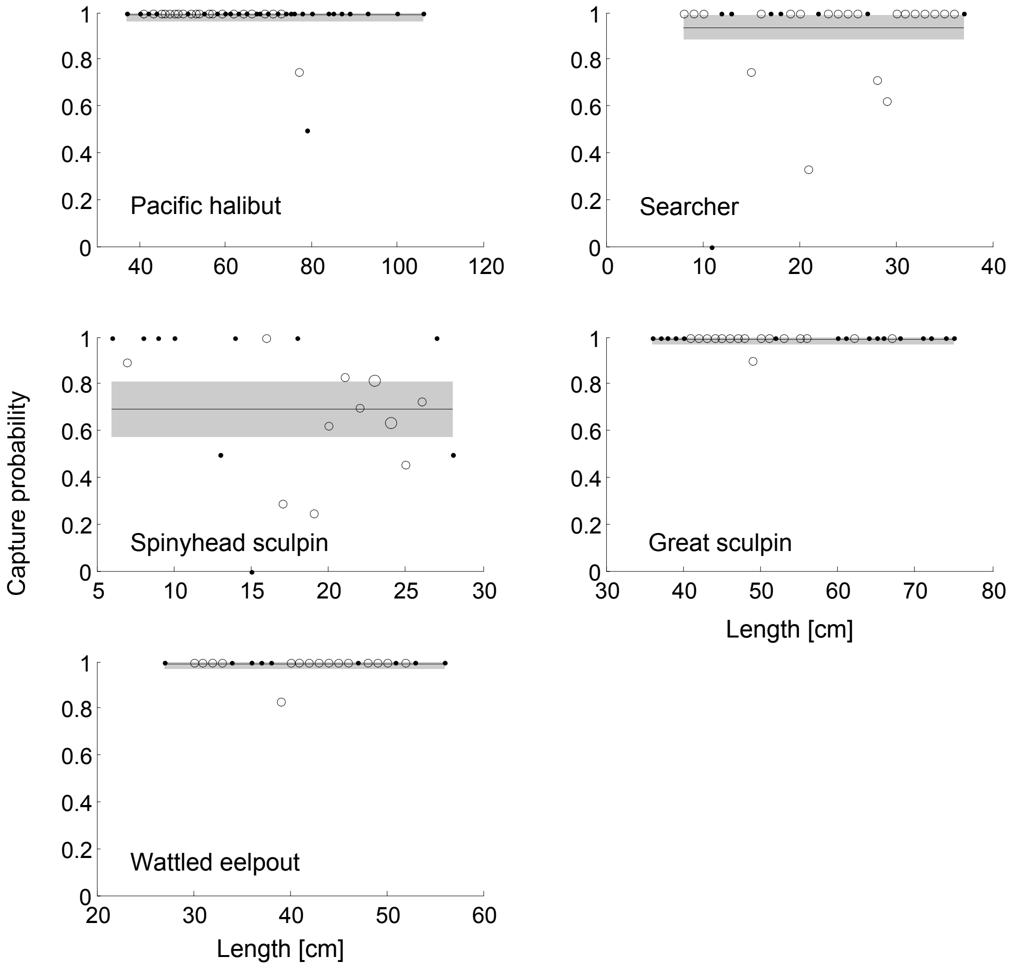

Figure 4. Continued.

experiment. Shortened bridles could also influence the herding capability of the trawl, thus introducing bias to our capture estimates. However, because we perceived skates to be slow swimming (based on video images in front of the trawl footrope) and sculpins, poachers, and eelpouts to be low-endurance burst swimmers, the herding effect of bridles is likely nominal.

As with net spread, mean headrope height and the variance of net height for the experimental gear differed from that of the standard survey trawl. However, unlike wing spread, we reason that our capture probability estimates were not affected because escapement over the headrope of the trawl for these benthic species appears unlikely. The greater variability in the survey spread and height data may also be from the use of several different nets over several survey years (as opposed to just one used in our experiment). While considerable effort is expended to standardize nets between surveys, differences in performance may still occur, particularly as meshes stretch and knots tighten. Aside from these differences, we showed (Figure 2) that the observed experimental gear net spread and headrope height fell within the range of means observed for the standard survey trawl.

Trawl geometry can also introduce bias to efficiency estimates through trawl footrope contact with the bottom. To study this effect, we compared the means and variances of the observed footrope distances off-bottom, measured at the center, from the experimental tows to the same for 2004 EBS survey tows made within the same area and depth using the same bottom contact sensor mounting apparatus. Our results showed that the experimental trawl footrope distance off-bottom was on average about 3.5 cm lower than the footrope of the survey trawls. Weinberg et al. (2004) also reported differences in measured off-bottom footrope distances between these 2 gear types and reported that footrope distances off-bottom increased with increasing amounts of trawl wire (i.e., depth). They found the survey footrope lifted 2.4 cm off-bottom when using 320 m of trawl wire, but the difference between gear types was less than 1 cm and this difference remained constant throughout the depth range of the study. We found that when using even more trawl wire (up to 457 m), not only were measured footrope distances greater but the differences between gears were also greater (3.5 cm). It is not clear what effect these greater footrope heights have on escapement; however, one might expect escapement to increase, as observed by Weinberg et al. (2003) for skates when a different trawl was used. If this holds true, then the actual capture probability of the 83-112 Eastern bottom trawl would be lower than our estimate, but this higher estimate of capture probability would still improve stock assessment models, which currently assume a capture probability of 1.0 (Gaichas et al. 2003).

Another factor that could affect capture probability estimates for small fish when using this type of experimental gear is escapement through mesh. If escapement occurred through the belly of the auxiliary net and into the open sea, then our estimates of capture probability would be higher than the real trawl efficiency. For this case our models would err to the conservative side, thus minimizing the chance of overestimating population size or recruitment numbers.

Capture Probability

Of the fish studied here, only skates displayed a significant length-dependent capture probability, with net efficiency increasing with increasing fish size. Estimated capture probability for skates was also the lowest among those species studied. Skates are slow-swimming fish that prefer soft bottoms composed of mud or sand, often burying themselves (Mecklenburg et al. 2002). Videos taken of the trawl footrope center show skates typically laying still on the bottom, reacting to the trawl only after they are touched (Weinberg, personal communication). Often the fast approaching footrope had already passed over most of the body before they reacted, thus trapping them beneath the footrope and ensuring their escape. Skates observed actively swimming in front of the footrope were near to the bottom and generally were captured, although some were seen gliding to the bottom just as the footrope passed over them. Swimming skates seen at the trawl mouth were quite possibly alerted to the trawl by an earlier encounter with the trawl sides.

Capture probability for Pacific halibut in our experiment (0.9865) was very similar to that reported in 2002 by Munro and Somerton (0.9833). Other flatfish investigated in this experiment (arrowtooth flounder, rex sole) also had capture probabilities close to 1.0, regardless of size. They probably reacted differently than the skates to the trawl. Reaction behavior of these flatfish was probably also different than that of yellowfin sole *Limanda aspera,* which has a higher rate of escapement under the footrope of the survey trawl (Munro and Somerton, 2002). Two types of flatfish behavior at the footrope of trawl gear were described by Bublitz (1996) who suggested that different reactions to the footrope may be species specific. It is likely that the 3 species investigated here are actively responding to the trawl by fleeing and then are being eventually overcome by the trawl.

We lack behavioral information on the other species investigated here, and we can only speculate that differences in behavior determine the capture probability for these species. Great sculpin, wattled eelpout, and sturgeon poacher were nearly always captured by the survey trawl, while spectacled sculpin, spinyhead sculpin, and sawback poacher had lower capture probabilities. Differences in capture probabilities for these species may result from differences in near-bottom behaviors or different reactions to the approaching footrope.

Management Considerations

Although capture probabilities were computed for 3 flatfish species: Pacific halibut, arrowtooth flounder, and rex sole, we restrict our discussion to groundfish that management does not have fishery catch data (for computing fishing mortality) or any species-specific life history data (required for input into catch-at-age models). As such, scientific knowledge of these species, pertinent to their management, is limited to records of their distribution and abundance from groundfish resource surveys. This leaves us with species belonging to either the “Other species” (which includes skates and sculpins) or the “Non-specified species” (which includes poachers, searchers, and eelpouts) categories of the 2004 North Pacific Fishery Management Council Bering Sea/Aleutian Island Fishery Management Plans. For these species it has been assumed that the survey trawl is 100% efficient at catching individuals swimming between its wingtips. However, catch efficiency experiments such as those by Munro and Somerton (2002) and our study have shown that fish do escape beneath the footrope of the Bering Sea survey trawl and that corrections to the survey area-swept estimates may lead to improved estimates of biomass.

The "Other species" category contains fish or invertebrates that have the potential for future commercial exploitation, such as skates (a directed fishery for skates in the Gulf of Alaska management region began in 2003) and sculpins (particularly large species). While no directed U.S. fisheries for these species have occurred in the Bering Sea to date, they have been reported as bycatch in fisheries targeting other species; hence they are of concern to stock assessment scientists interested in adopting precautionary management measures. According to EBS shelf survey results, 97% of the aggregate Bering Sea skate biomass is composed of 2 species, *B. parmifera* (91%) and *B. interrupta* (6%). These same species comprised 98% of the total number of skates encountered in our experiment used for predicting skate capture probability. Skates are long-lived, slow-to-mature species having relatively low fecundity (Moyle and Cech 1996). Excessive removal of large individuals could precipitate a serious population decline such as has been reported by Brander (1981) for *Raja batis* and Casey and Myers (1998) for *R. laevis* in the North Atlantic. About 44 species of sculpins are found in the Bering Sea, yet very little is known about their life histories. Again, our capture probability estimates will help in the improvement of survey abundance estimates for a few species, but further work on identifying important life history traits is recommended. The AFSC recognizes these shortcomings and has initiated efforts to collect and analyze samples for some species.

The "Non-specified species" category contains species that are currently viewed as having no potential commercial importance; such as poachers and eelpouts, but may be incidentally affected by fisheries (e.g., bycatch). These fish are of primary importance from an ecological perspective (e.g., as predators or indicator species of the general health of the ecosystem [Crosby and Reese 1996]). Monitoring of these fish populations might prove useful to ecosystem level management. Collection of additional data to help determine other biological reference points for "Non-specified" species is recommended and should be initiated when the financial resources become available.

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