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Estimation of trap selectivity for male snow crab (*Chionoecetes opilio*) using the SELECT modelling approach with unequal effort data

by

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Abstract

The SELECT modelling approach was used to study trap selectivity for male snow crab (*Chionoecetes opilio*) in St. Mary's Bay, Newfoundland. The symmetric logistic function with estimated split parameter appears to be most appropriate for expressing the selection curve because the asymmetric model does not improve the fit significantly. The carapace widths at the retention probabilities of 25%, 50% and 75%, L_{25}, L_{50} and L_{75}, were estimated to be 85.4, 93.0 and 100.6 mm before the fishing season and 87.8, 96.7, 105.5 mm after the fishing season, respectively, from the symmetric model. The split factor, p, in the symmetric model was estimated to be 0.77 and 0.82, respectively, for the pre-season and post-season surveys, which is larger than the theoretical values of 0.66 and 0.67 (66% and 67% of the traps used were large mesh for the pre-season and post-season surveys, respectively). This implies that the large mesh trap fished more efficiently than the small mesh trap. The small selection factor (estimated to be 0.70 for the pre-season and 0.73 for the post-season surveys, respectively) suggests that the body shape of crabs makes it difficult for them to escape from the trap.

Résumé

Le modèle SELECT a été utilisé pour étudier la sélectivité des pièges pour le crabe des neiges mâles (*Chionoecetes opilio*) dans la baie St. Mary, Terre-Neuve. La fonction logistique symétrique avec paramètre «scindé» (*split parameter*) estimé semble la plus appropriée pour exprimer la courbe de sélection parce que le modèle asymétrique n'améliore pas l'ajustement de manière substantielle. A partir du modèle symétrique, on a estimé que les largeurs de carapace aux probabilitiés de retenue de 25, 50 et 75 %, L_{25}, L_{50} et L_{75}, étaient respectivement de 85,4, 93,0 et 100,6 mm avant la saison de pêche et de 87,8, 96,7 et 105,5 mm après la saison. Dans le modèle symétrique, on a estimé que le facteur de «scindage» (*split factor*), p, était de 0,77 et 0,82 respectivement pour les relevés d'avant et d'après saison, ce qui est plus élevé que les valeurs théoriques de 0,66 et 0,67 (66 et 67 % des pièges utilisés avaient de grandes mailles pour les relevés d'avant et d'après saison, respectivement). Cela implique que les pièges de grandes mailles étaient plus efficaces que les pièges de petites mailles. Le faible facteur de sélection (estimé à respectivement 0,70 et 0,73 pour les relevées d'avant et d'après saison) laisse entendre que la forme du corps des crabes fait qu'il leur est difficile de s'échapper du piège.

Fishing gear selectivity has received increased attention in fisheries studies in recent years, and is better understood now than a decade ago (MacLennan 1992). A proper statistical method called SELECT (Share Each Lengthclass's Catch Total) was recently developed to analyze data from covered codend, alternate haul and trouser trawl experiments (Millar 1991b, 1992). This procedure looks at the proportion of the catch at a given size in each of two types of gear rather than looking at the ratio of the catches. The procedure thus avoids the problem of a ratio with zero in the denominator. The SELECT method has been applied to gear selectivity studies by Cadigan and Millar (1991), Suuronen et al. (1991), Millar and Walsh (1992) and Walsh et al. (1992).

Trap mesh selection for male snow crab (*Chionoecetes opilio*) along the coast of Newfoundland was studied qualitatively by Miller (1976) using three types of traps (91 mm, 119 mm and 129 mm stretched-mesh) and by Hoenig and Dawe (1991) using two type of traps (25 mm and 133 mm stretched-mesh) and trawl gear. These studies only looked at differences in relative frequency of size-classes in the various gears and did not attempt estimation of selection curves. Here, we use the SELECT modelling approach to construct selection curves for male snow crab in St. Mary's Bay, Newfoundland.

Japanese style, conical, baited traps with a stretched-mesh size of 133 mm are used for both the commercial fishery and the research sampling for snow crab in Newfoundland. The data from both the fishery and research sampling are used in estimating the stock abundance (Xu et al. 1992). Therefore, it is important to understand trap gear selectivity for snow crabs in order to get a better estimate of the population size. It is also worthwhile to estimate trap selectivity so optimal mesh size can be used to reduce the waste of the resource and the damage to the population caused by the discard of sublegal-size crabs by fishermen.

Materials and Methods

1. Design of the experiment

Pre-season (Aug 23 to Sept 2, 1991) and post-season (Oct 21 to Oct 31, 1991) research surveys were carried out in St. Mary's Bay, Newfoundland, using conical-shaped Japanese-style top-entry traps baited with squid. The two surveys had 40 and 41 sets, respectively, which were randomly located in the snow crab fishery area in St. Mary's Bay in water greater than 40 m in depth. Two small-mesh traps (control gear) and four large-mesh traps (experimental gear) were used in each set. Unsuccessful trap hauls due to bait loss or overturning were eliminated, resulting in the effective numbers of large-mesh and small-mesh traps being 148 and 76, respectively, in the pre-season analysis and 157 and 79, respectively, in the post-season analysis.

The large-mesh traps are the same type as used in the commercial fishery and have a 122 cm diameter base that tapers to a 71 cm diameter top. The trap frame, made from 6 iron rods welded together, is covered with 133 mm stretched-mesh polyethylene webbing with a plastic cone at the top which allows crabs to enter but is funnel shaped to prevent their escape. The structure of the small mesh trap is the same as the large-mesh one but with stretched-mesh size of 25 mm. The two types of traps were fished together in each set and therefore had the same soak time (duration of immersion) which was approximately 24 hours. Each of the six traps was tied with a support rope of 1.3 cm in diameter and 3.7 m in length, and then was attached to the groundline made of 1.6 cm diameter polypropylene rope. The traps were separated by 37 m from each other. A 14 kg weight was attached to each end of the groundline to prevent shifting and overturning of the end traps. The buoyline, made of the same material as the groundline, was 20-30 fathoms longer than the depth of the water to allow for tide, wind and depth changes. Two bouys were used on each end of the buoyline. Dawe (1989) gave a detailed description of the method of gear deployment.

The size-frequency distribution of the catch by trap type was constructed by measuring the crab carapace widths and grouping by 5 mm intervals (Table 1).

2. The SELECT models and selection curves

The selectivity of passive traps depends on the escape, through the meshes, of the animals which have entered the trap. Therefore, the selection curve for trap gear as a function of the size of the animals should be a sigmoid form as for trawls (Pope 1975; Krouse and Thomas 1975). The symmetric logistic function can be used to model the selection curve for traps

$$r(l) = \frac{e^{a+bl}}{1+e^{a+bl}} \tag{1}$$

where $r(l)$ is the probability that an animal of size l is retained by an experimental trap and a and b are parameters to be estimated. If a is a large negative number and b is positive, then $r(l)$ will approach 1 as size approaches a very large size at which animals cannot escape from the gear, and $r(l)$ will approach 0 as size approaches 0.

The SELECT modelling approach incorporates a split parameter, p, in the model to quantify the possibly different fishing efficiencies of experimental and control gears. The proportion of the total catch of size l animals expected in the experimental gear (large-mesh trap) then is expressed as (Millar 1991b)

$$\begin{aligned}\phi(l) &= \frac{pr(l)}{(1-p)+pr(l)} \\ &= \frac{pe^{a+bl}}{(1-p)+e^{a+bl}}\ .\end{aligned} \tag{2}$$

In the SELECT approach, the parameters a, b and p are estimated by fitting $\phi(l)$ to the observed proportion of total catch for each size interval taken by the experimental gear.

If the split between the experimental and control gears is equal, that is, if the probability of an animal entering a small-mesh trap is equal to the probability of entering a large-mesh trap, p would be expected to be 0.5. Nominally, we have unequal fishing efforts for the two different types of traps because we used two small-mesh traps and four large-mesh traps in each set. Therefore the split would not be expected to be equal. Since there are some unsuccessful trap hauls during the surveys which were eliminated before the analyses, the value of p, in theory, should be equal to the proportion of the traps which were large-mesh, i.e., 147/(147+76) = 0.66 for the pre-season survey and 157/(157+79) = 0.67 for the post-season survey, respectively, if the traps have equal fishing ability (equal numbers expected to enter each trap). Note that we can estimate the value of p and compare it to the theoretical value.

If the selection curve appears asymmetric, we can use a Richards' curve of the form

$$r(l) = \left(\frac{e^{a+bl}}{1+e^{a+bl}} \right)^{1/\delta} \tag{3}$$

for the retention probability (Richards, 1959, Millar 1991a) and

$$\begin{aligned} \phi(l) &= \frac{pr(l)}{(1-p)+pr(l)} \\ &= \frac{p}{p+(1-p)(1+e^{-(a+bl)})^{1/\delta}} \end{aligned} \tag{4}$$

for the proportion of catch in the large mesh trap. Here δ is a parameter to describe asymmetry.

In this study, we use the SELECT modelling approach to fit equations 2 and 4, and then use the estimated parameters to get the selection curves from equations 1 and 3. The parameters can be estimated using the *nlmin* function in *Splus*. Millar and Cadigan (1991) also developed a FORTRAN program to fit the symmetric function.

The selection range, *SR*, is defined as the difference between L_{75} and L_{25} (Pope et al. 1975)

$$SR = L_{75} - L_{25}$$

where L_{75} and L_{25} are the sizes at which 75% and 25% of the animals are retained, respectively. Because different types of animals may have very different body shapes, one might be interested in looking at the relative selection range compared to L_{50}

$$\text{Relative selection range} = (L_{75} - L_{25})/L_{50}$$

where L_{50} is the size at which 50% of the animals are retained.

The selection factor, SF, is

$$SF = l_c/m$$

where m is the mesh size and l_c is the mean selection length and is equal to L_{50} if the selection curve is symmetrical or approximately symmetrical (Gulland 1983, Pauly 1984).

Results

1. Selection curves

The symmetric model (2) and the asymmetric model (4) were fitted using the SELECT approach with the pre-specified split factor and with the split factor estimated for the pre-season data (Figure 1) and the post-season data (Figure 2). It can be seen from the model deviance values (Tables 2 and 3) that the symmetric logistic function with estimated split factor fits the data as well as the asymmetric function with estimated split factor. The estimated split parameter is greater than the theoretical value, and the hypothesis of equal fishing efficiency of the large mesh and small mesh traps is clearly rejected (p_α <0.001). The symmetric logistic function with estimated split factor appears to be most appropriate for expressing the selection curve since it is easier to fit than the asymmetric model, and since the asymmetric model does not improve the fit significantly. The carapace widths at the retention probabilities of 25%, 50% and 75%, L_{25}, L_{50} and L_{75}, were estimated to be 85.4, 93.0 and 100.6 mm before the fishing season and 87.8, 96.7, 105.5 mm after the fishing season, respectively, from the symmetric model with estimated split parameter. The split factor, p, in the symmetric model is estimated to be 0.77 and 0.82, respectively, for the pre-season survey and for the post-season survey, which is larger than the theoretical values of 0.66 and 0.67 (66% and 67% of the traps used are large mesh for the pre-season and post-season surveys, respectively). The symmetric selection curves were constructed using the parameters obtained from the symmetric model with estimated split parameter for the two surveys (Figure 3).

The selection range, relative selection range and selection factor were estimated to be 15.2, 0.16 and 0.70, respectively, for the pre-season survey, and were estimated to be 17.7, 0.18 and 0.73, respectively, for the post-season survey from the symmetric model with estimated split parameter (Tables 2 and 3). The small selection factors suggest that the body shape of crabs makes it difficult for them to escape from the trap.

Using the standard errors given in Tables 2 and 3, one would conclude that the L_{25} values of pre-season and post-season selectivity are not significantly different at the 5% level. The L_{50} and L_{75} values are marginally significantly different between surveys. However, as pointed out by Fryer (1991) and Suuronen et al. (1991), these standard errors are unable to fully take into account between haul variation and hence must be treated solely as lower bounds on the true standard errors. For this reason, and because significance was only marginal, we conclude that there is insufficient evidence to indicate a change in selectivity after the fishery.

2. Adjusting the research samples using the selection curves

The pre-season and post-season research samples obtained with large-mesh traps are considered to be biased due to the gear selectivity and are adjusted using symmetric selection curves with estimated split parameter (Table 4). The adjusted number in each size-class is equal to the actual number caught in the large-mesh trap divided by the retention probability in that size-class. The adjusted samples show great difference from the research samples for the carapace width classes smaller than 105 mm.

Discussion

The large-mesh traps appear to retain less than 50% of the crabs less than 95 mm in carapace width (Table 4). This suggests that surveys conducted with large-mesh traps will seriously underestimate the ratio of abundance of immediate pre-recruits (78 - 95 mm carapace width) to legal sized crabs.

It appears that the use of small-mesh traps gives a more reliable estimate of the size composition of crabs in the sea with carapace width larger than 78 mm. However, the fact that the estimated split parameter is somewhat greater than its theoretical value suggests that the large-mesh traps are more efficient than the small-mesh traps, at least for the largest size crabs. Because we do not know how the relative fishing power (efficiency) may change with crab size (i.e., we do not know if the split parameter changes with size of the animal), we do not have an unambiguous picture of the retention probability of either type of trap.

The fact that the estimated split parameter is greater than its theoretical value also implies that the small-mesh traps may underestimate the relative abundance of the largest crabs if the split parameter varies with the size of the animal.

Thus to use the results of this study to make inferences about the size composition of crabs in the sea, it is necessary to assume the split parameter does not vary with the size of the animals.

Although we believe the small-mesh traps give the best picture of the size composition of the crabs in the sea, we recognize that sampling with large-mesh traps is also important for two reasons. First, the large-mesh traps are the same as those used in the commercial fishery. Consequently, a pre-season survey with large-mesh traps is likely to be the best predictor of conditions in the fishery. Also, there is a large body of information available from previous surveys with which one can compare current survey results.

Second, results from a pre-season survey with large-mesh traps can be used to estimate the magnitude of the discarding. For example, the proportion of legal-size crabs was 54.25% in the pre-season research sampling with the large-mesh traps in 1991. The total number of crabs and the number of legal-size crabs caught by the fishery in 1991 was 687,949 and 628,373, respectively (Xu et al. 1992). The number of sublegal-size crabs discarded by the fishermen at sea is thus estimated to be 628,373/0.5425 - 687949 = 470,342. This is likely to be an overestimate because the research survey was conducted at randomly selected locations whereas the commercial fisherman may have avoided areas with high catches of sublegal sized crabs. However, if information is available on the specific locations of the commercial fishing grounds, it is possible to compute the proportion of legal-sized crab in the research survey traps for that portion of the survey on the commercial fishing grounds.

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Table 1. Catch in number of male snow crabs from the pre-season (Aug. 23 to Sept. 2, 1991) and post-season (Oct. 21 to Oct 31, 1991) research surveys using Japanese-style, conical, baited traps in St. Mary's Bay, Newfoundland.

Carapace width class (mm)	Pre-season survey		Post-season survey	
	Large mesh	Small mesh	Large mesh	Small mesh
26 - 30	-	-	0	1
36 - 40	0	1	-	-
41 - 45	-	-	-	-
46 - 50	0	3	-	-
51 - 55	2	22	0	9
56 - 60	1	78	2	58
61 - 65	12	221	15	214
66 - 70	39	395	65	422
71 - 75	78	518	114	561
76 - 80	164	547	227	699
81 - 85	462	785	670	922
86 - 90	1239	1160	1388	1277
91 - 95	1880	1049	1923	1102
96 -100	1360	649	1256	526
101-105	922	391	812	276
106-110	644	211	587	177
111-115	442	128	424	90
116-120	178	40	172	36
121-125	43	9	38	15
126-130	9	2	9	2
131-135	1	0	1	0

Table 2 Estimates of the parameters from pre-specified split factor (p=0.66) and estimated split factor with symmetric and asymmetric models for the pre-season survey. Values in parentheses are standard errors.

	Symmetric model		Asymmetric model	
	p=0.66	estimated p	p=0.66	estimated p
a	-16.31	-13.45	-52.49	-14.14
	(0.56)	(0.43)	(17.17)	(3.38)
b	0.1904	0.1446	0.5730	0.1515
	(0.0068)	(0.0057)	(0.1850)	(0.0336)
p	--	0.77	--	0.77
		(0.010)		(0.015)
δ	--	--	4.32	1.07
			(1.52)	(0.33)
L_{25}	79.9	85.4	81.2	85.3
	(0.3)	(0.7)	(0.3)	(0.8)
L_{50}	85.7	93.0	86.5	92.7
	(0.3)	(0.9)	(0.3)	(1.3)
L_{75}	91.4	100.6	90.0	100.1
	(0.4)	(1.1)	(0.4)	(2.4)
Selection range, SR	11.5	15.2	8.8	14.8
SR/L_{50}	0.13	0.16	0.10	0.16
Selection Factor	0.64	0.70	0.65	0.70
	(0.002)	(0.007)	(0.002)	(0.010)
Model deviance	190.3	27.3	125.9	27.3
d.f.	17	16	16	15

Table 3 Estimates of the parameters from pre-specified split factor (p=0.67) and estimated split factor with symmetric and asymmetric models for the post-season survey. Values in parentheses are standard errors.

	Symmetric model		Asymmetric model	
	p=0.67	estimated p	p=0.67	estimated p
a	-14.88 (0.49)	-11.97 (0.34)	-51.98 (18.28)	-12.99 (3.77)
b	0.1747 (0.0061)	0.1239 (0.0048)	0.5645 (0.1961)	0.1337 (0.0367)
p	--	0.82 (0.012)	--	0.82 (0.020)
δ	--	--	4.85 (1.82)	1.11 (0.40)
L_{25}	78.9 (0.3)	87.8 (1.0)	80.1 (0.3)	87.5 (1.4)
L_{50}	85.2 (0.3)	96.7 (1.3)	86.2 (0.3)	96.1 (2.3)
L_{75}	91.4 (0.5)	105.5 (1.6)	90.1 (0.4)	104.5 (3.8)
Selection range, SR	12.5	17.7	10.0	17.0
SR/L_{50}	0.15	0.18	0.12	0.18
Selection factor,	0.64 (0.002)	0.73 (0.010)	0.65 (0.002)	0.72 (0.017)
Model deviance	263.6	20.1	196.8	20.0
d.f.	16	15	15	14

Table 4 The estimation of the adjusted research samples for large-mesh traps using the symmetric selection curve with estimated split factor.

Carapace width class (mm)	Pre-season survey		Post-season survey	
	Research sample	Adjusted sample	Research sample	Adjusted sample
51 - 55	2	702	0	0
56 - 60	1	171	2	256
61 - 65	12	1002	15	1042
66 - 70	39	1599	65	2460
71 - 75	78	1593	114	2375
76 - 80	164	1710	227	2650
81 - 85	462	2575	670	4519
86 - 90	1239	3990	1388	5679
91 - 95	1880	3905	1923	5123
96 -100	1360	2071	1256	2381
101-105	922	1155	812	1203
106-110	644	723	587	739
111-115	442	468	424	483
116-120	178	183	172	185
121-125	43	43	38	40
126-130	9	9	9	9
131-135	1	1	1	1

Figure 1 Proportion of catch in large mesh trap in pre-season survey

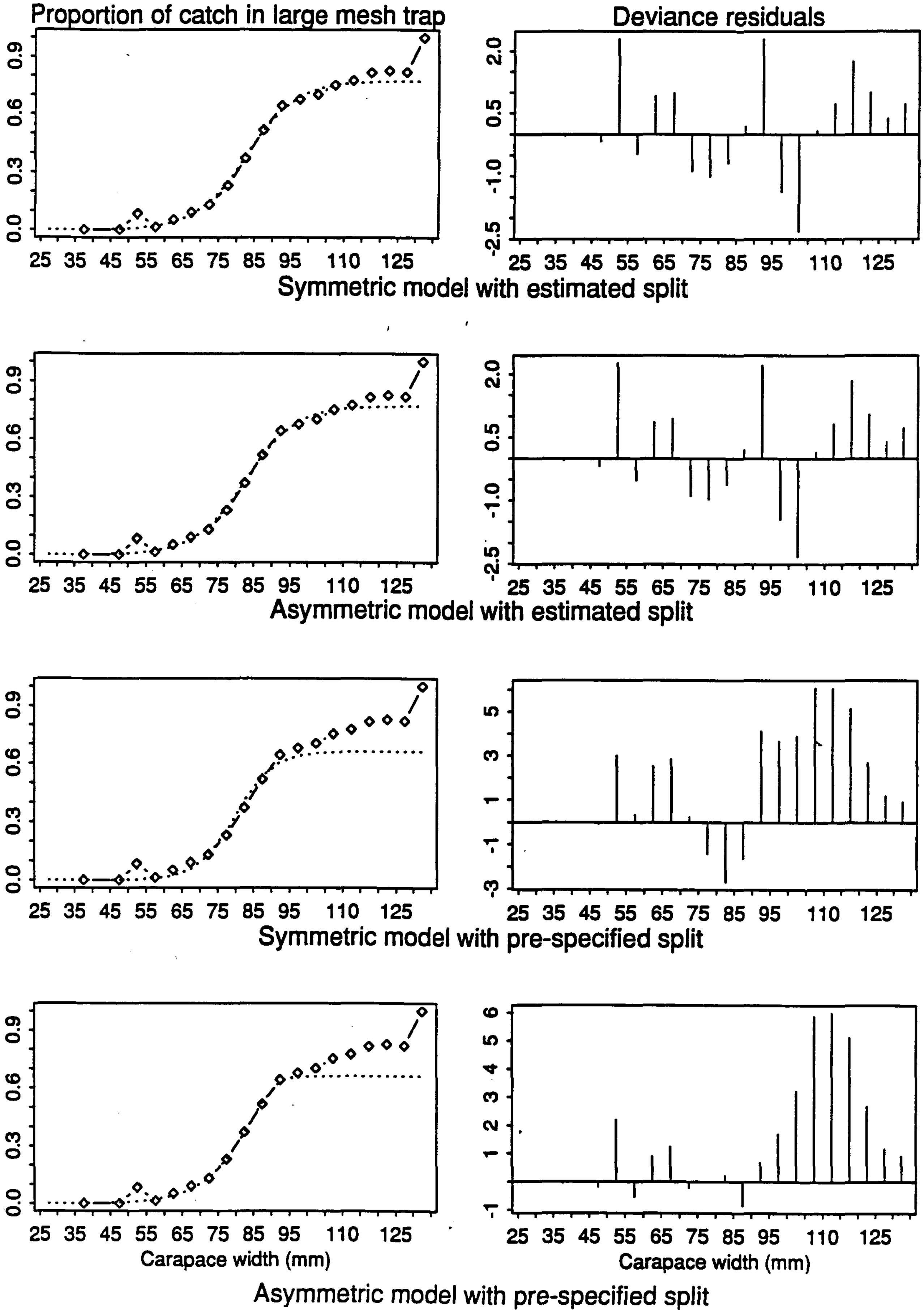


Figure 2 Proportion of catch in large mesh trap in post-season survey

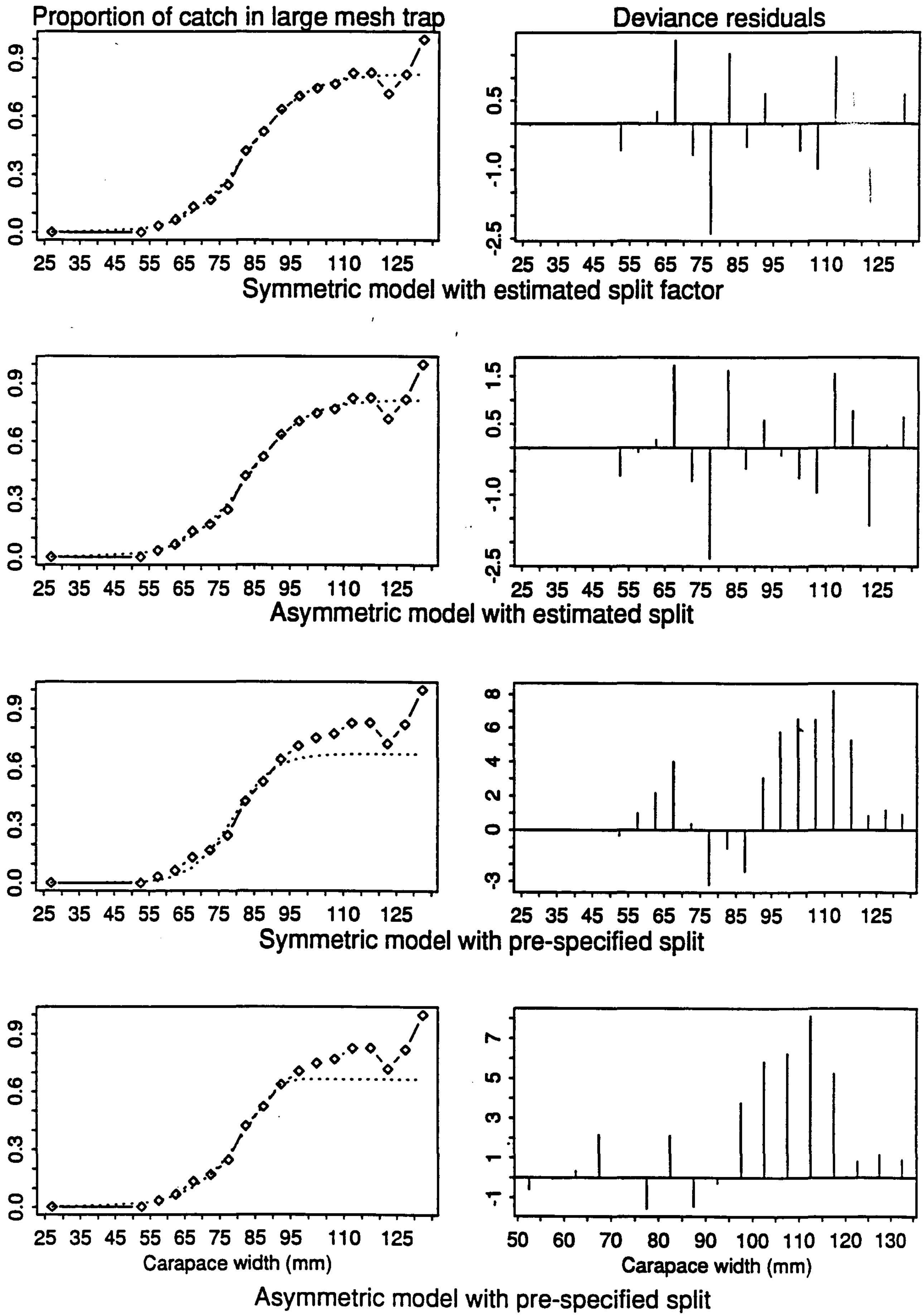
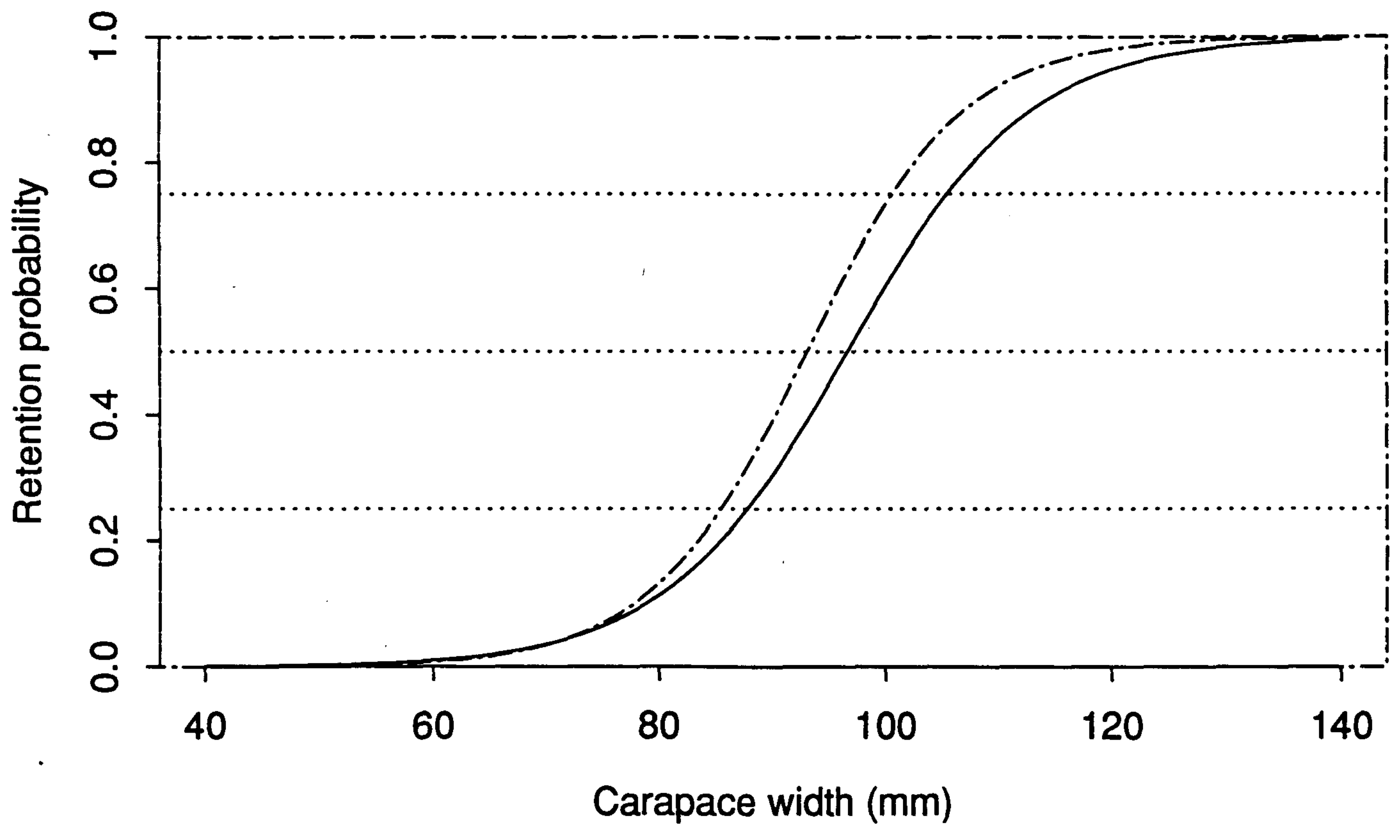


Figure 3. Symmetric selection curves for pre-season and post-season surveys



Broken line with dot -- pre-season   Solid line -- post-season