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Effect of population structure, sampling strategy and sample size on the estimates of selection parameters for shrimp (*Crangon crangon*) trawls

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Abstract

In selectivity experiments with shrimp trawls, very high numbers of animals in the catches of single hauls are a common feature and therefore, sub-sampling is inevitable. In order to find an acceptable balance between work-load and accuracy in the estimation of the selection parameters, it is important to have a sensible idea on the minimum numbers of shrimps to be measured in each catch fraction (cover, discards and landings). The present theoretical study tries to answer this question by means of computer simulations of different sampling strategies and sample sizes applied to catches with known size compositions.

The results of the simulations are discussed in relation to population structure, shape of the cod-end selection curve, sampling strategy (as the relative amounts measured from the different catch fractions) and sample size, and the method used to calculate the selection parameters.

Samples of 750 animals provide an acceptable compromise between work-load and reliability of the estimated selection parameters, provided that sufficient numbers of length classes are available. Population structure, selection curve and sample size (in that order) largely determine the reliability of the estimates, whereas the sampling strategy, on the other hand, only has a minor effect. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Cod-end selectivity; Beam trawl; *Crangon crangon*; Sampling; Simulation

1. Introduction

In Belgium, most of the commercial trawling for brown shrimp (*Crangon crangon*) is done in the coastal zone, by double rig beam trawlers operating two trawls with a beam length of 7–9 m each. The netting material is polyamide, and the cod-end mesh size is 22 mm. Although the shrimp trawlers primarily target brown shrimp, their catches often comprise large quantities of both commercial and non-commercial fish, together with a wide variety of benthic species (mostly crustaceans, echinoderms and molluscs).

As a rule, the sieving and grading of the catches onboard the Belgian shrimp trawlers is done with a rotating riddle. Once on deck, the catch is put through

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the riddle, to separate the commercial shrimps (usually >45 mm total length (TL)) from the "trash" (non-commercial by-catch) and the small shrimps, which are then discarded. This procedure needs to be taken into account when setting up selectivity experiments, since as a result of the shrimp sieving process, the cod-end catches are sub-divided into two fractions (viz. discards and landings) which have to be sampled separately.

In 1995, a comprehensive research programme was started, aiming at a reduction of the by-catches in the Belgian shrimp fishery. The first phase of this program, viz. an inventory of the fleet, with particular emphasis on vessel characteristics, gear types used and onboard catch handling procedures, was concluded in early 1996. In the second phase of the programme, the "whole trawl" selectivity of commercial shrimp trawls has been studied. For the cod-end, this is done with the covered cod-end technique, while for the body of the net, it is done by means of small meshed pockets attached to the different net sections. Further phases of the program focus on the species- and size-composition of the discards in the shrimp fishery, and on the effects of by-catch reducing devices such as sieve nets and grids.

In selectivity experiments, the catch (i.e. cod-end and cover combined) from a haul of standard duration (usually between 60 and 90 min) may contain anything from 10 000 to 100 000 shrimps, with sizes ranging from 20 to 90 mm TL. Since measuring large quantities of shrimp (say, 1000 or more animals per catch fraction) is extremely labour intensive, particularly when the animals have to be measured at a high level of precision (e.g. 1 or 2 mm size classes), it is common practice to sub-sample the catches, and to raise the length frequency data for each catch fraction to total catch before calculating the selection parameters.

When sub-sampling catches or catch fractions, however, it is important to have a sensible idea on the minimum numbers of shrimps to be measured (under different conditions with respect to, e.g. the size composition of the catches and the likely shape of the selection curves), in order to reduce the effect of sampling error on the estimates of the retention rates and to obtain sufficiently accurate estimates of the selection parameters. To answer this question, several sets of theoretical simulations were carried out, in an attempt to identify the effect of catch composition, sampling strategy and sample size on the estimates of the selection parameters.

2. Methods

2.1. General background

The basic idea for the simulations was to start from a theoretical "population", with a known size distribution, which was then sub-divided into three catch fractions (cover, discards and landings) by means of equally known selection curves for the cod-end and the shrimp riddle. Next, random samples were taken from each fraction, under specific, user-defined conditions with respect to sampling strategy and sample size. The numbers-at-length thus obtained were then used to calculate the retention rates for each size class in the population and subsequently to "re-calculate" the selection parameters for the cod-end. For each combination of population structure, cod-end selection curve, sampling strategy and sample size, this procedure was repeated 1000 times. Finally, the re-calculated selection parameters were compared with the "true" values for the original selection curve, using standard statistical techniques.

By altering each of the elements in the system (population structure, shape of the cod-end selection curve, sampling procedure and sample size), it was possible to identify their impact on the reliability of the re-calculated selection parameters, and to draw conclusions on the optimum sampling strategies and sample sizes.

In order to achieve maximum similarity between the theoretical simulations and the situation in the "real", the simulations were based on true size compositions of the shrimps entering the cod-end (the "population") and on true estimates of the selection curves for the cod-end and the shrimp riddle. All these data were derived from preliminary surveys carried out in May 1995.

2.2. The "population"

The choice of the length frequency distributions (LFDs) of the shrimps entering the cod-end was based on data collected during several selectivity experiments. From these, a representative LFD was chosen, which was then used as a basis to calculate a theoretical population (see Redant, 1996, for further details on the methods used). The observed LFD was first smoothed to reduce the levels of background noise in the original numbers-at-length. Then, the smoothened LFD was "re-constructed" by means of a series of superposed normal distributions. Whether these have a biological meaning, in the sense of age or brood classes, is of little relevance. What matters is that the technique produced a realistic population with precisely known numbers-at-length (Fig. 1), which could then be sub-divided into cod-end and cover catches, and as far as the cod-end catches are concerned, into discards and landings, also with precisely known LFDs.

After some preliminary simulations with the original theoretical population (from now on called "Type 1" population), it was decided to also run the simulations using a population with a slightly modified size composition. This so-called "Type 2" population had a much weaker first "cohort", at 1/5 of its original strength (Fig. 1). The reason why this new population was introduced in the study was because LFDs similar to the Type 2 theoretical population are frequently observed in certain areas and at certain times of the year, when the smallest size classes of shrimp are almost absent from the catches. Previous selectivity experiments have shown that particularly with this LFD selectivity parameters are obtained with very high standard errors.

2.3. Cod-end selection

The cod-end selection curves used to sub-divide the populations into cod-end and cover catches were equally based on preliminary selectivity experiments, carried out with the covered cod-end technique. The logistic function was used to describe the cod-end selectivity. This function is the cumulative distribution function of a logistic random variable and is specified by the following equation:

$$\mathrm{RR} = \frac{\exp(a + b \cdot \mathrm{TL})}{1 + \exp(a + b \cdot \mathrm{TL})},$$

where RR is the probability that a fish of length TL is retained in the cod-end. a and b, which are the two parameters to be estimated, represent the intercept and the slope, respectively, after a logit transformation. L_{25}, L_{50} and L_{75} are the body lengths at which 25%,

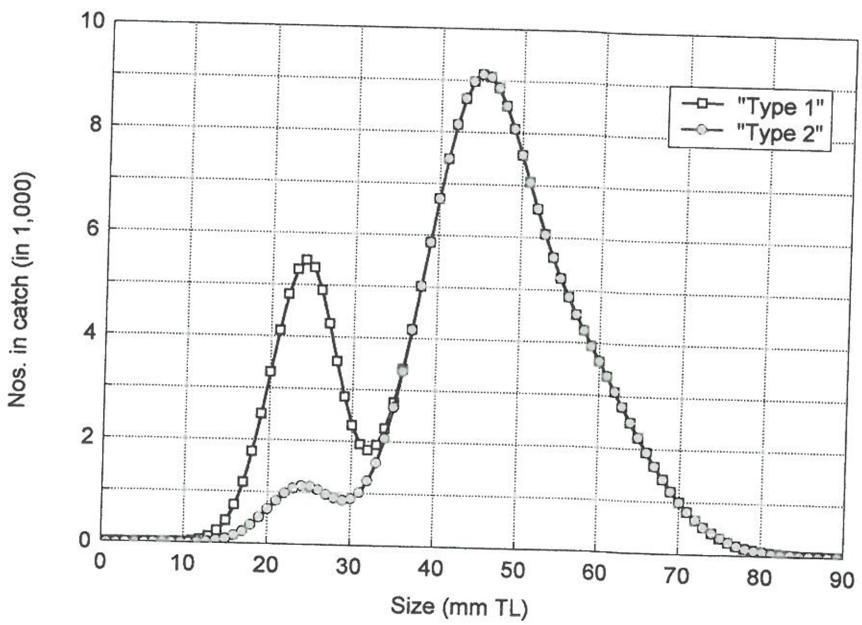

Fig. 1. The two theoretical populations (referred to as Types 1 and 2) used as an input for the simulations.

Table 1
General features of the inputs of the simulations

Code[a]	Theoretical population	Cod-end selection curve[b]	Riddle selection curve[b]
1-A	Type 1: standard See Fig. 1	A: steep a=−10.75; b=0.25 See Fig. 2	Standard a=−22.70; b=0.45 See Fig. 2
1-B	Type 1: standard As in simulation 1-A	B: intermediate a=−5.18; b=0.14 See Fig. 2	Standard As in simulation 1-A
1-C	Type 1: standard As in simulation 1-A	C: smooth a=−3.00; b=0.14 See Fig. 2	Standard As in simulation 1-A
2-A	Type 2: first cohort reduced to 1/5th of its original strength See Fig. 1	A: steep As in simulation 1-A	Standard As in simulation 1-A
2-B	Type 2: first cohort reduced to 1/5th of its original strength As in simulation 2-A	B: intermediate As in simulation 1-B	Standard As in simulation 1-A
2-C	Type 2: first cohort reduced to 1/5th of its original strength As in simulation 2-A	C: smooth As in simulation 1-C	Standard As in simulation 1-A

[a]Code: the number in the code refers to the type of theoretical population and the letter in the code refers to the cod-end selection curve used for the simulations.
[b]a and b refer to parameters a and b in the logit curve: RR=1/(1+exp(−(a+b×TL))), where RR=retention rate, and TL=total length.

50% and 75% of the shrimps are retained in the cod-end.

Three typical selection curves were used (Table 1 and Fig. 2):

- *Ogive A*. A relatively steep logit curve, with an L_{50} of 43.0 mm TL, and a selection range (SR) of 9.0 mm TL;
- *Ogive B*. A fairly smooth logit curve, with an L_{50} of 36.5 mm TL, and an SR of 15.5 mm TL; and
- *Ogive C*. An even smoother logit curve, with an L_{50} of 30.0 mm TL, and an SR of 22.0 mm TL.

The sharpest selection ogive is typical for "clean" catches, while the others (ogives B and C) were found to be associated with increasing amounts of seaweed and hydroids, which may cause considerable clogging of the meshes.

2.4. Selection by the shrimp riddle

The selection of the shrimps by the rotating riddle can perfectly be described by means of a logistic curve. A typical riddle has an L_{50} of 50.0 mm TL and an SR of 5.0 mm TL. A similar curve (Table 1 and Fig. 2) was used throughout the simulations to subdivide the shrimps in the cod-end fraction into discards and landings.

The different combinations of theoretical population, cod-end selection curve and riddle selection curve are summarised in Table 1. From now on each of these combinations will be referred to by the two digit code number given in the first column of this table. The total numbers of shrimps in each catch fraction, for each combination of theoretical population and selection ogive, are summarised in Table 2, together with their respective size ranges. The subdivision of the catches into cover, discards and landings is shown in Fig. 3 for Type 1 and in Fig. 4 for Type 2 population.

2.5. Sampling strategies and sample sizes

Overall sample sizes (i.e. the total number of shrimps measured for all fractions combined) were arbitrarily set at 150, 270, 375, 750, 1500 and 3000.

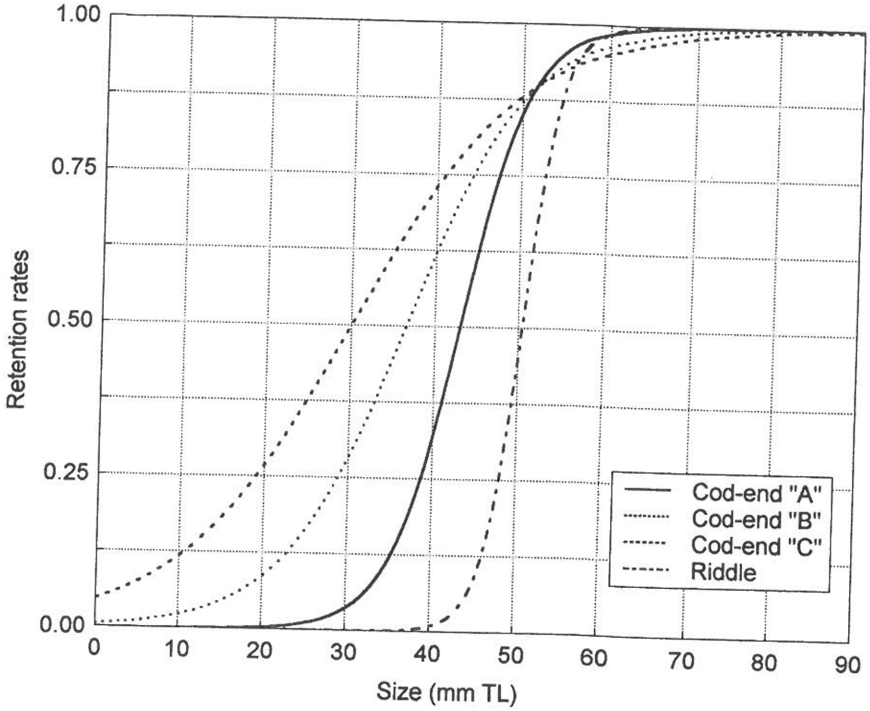

Fig. 2. Cod-end and shrimp riddle selection curves used in the simulations.

In addition to varying sample sizes, five different sampling strategies were tested (Table 3):

- *Sampling strategy* 1 (S1). Equal numbers of shrimps are taken from each catch fraction (for an overall sample size of, e.g. 750 shrimps, this would come to 250 from the cover, 250 from the discards, and 250 from the landings).
- *Sampling strategy* 2 (S2). Equal numbers of shrimps are taken from the cod-end and the cover, actually meaning that twice as many shrimps are taken from the cover than from the discards and the

Table 2
Numbers (N, in 1000) and size ranges (mm TL) of *Crangon* in each catch fraction, as generated from the theoretical populations, for each combination of theoretical population (Type 1 or 2) and selection curve (A, B and C)

Code[a]	Cover		Discards		Landings		Total Sum of N's
	N	Size range	N	Size range[b]	N	Size range[b]	
1-A	115.4	12–59	60.0	23–61	74.6	41–82	250.0
1-B	86.0	12–64	89.4	17–60	74.6	40–82	250.0
1-C	66.5	12–68	109.2	15–59	74.3	40–82	250.0
2-A	72.3	14–61	59.4	30–61	74.6	41–82	206.4
2-B	49.3	13–66	82.5	19–60	74.6	40–82	206.4
2-C	38.6	13–70	93.5	17–60	74.3	40–82	206.4

[a]Code: the number in the code refers to the type of theoretical population and the letter in the code refers to the cod-end selection curve used for the simulations.

[b]Size ranges refer to those size classes for which the expected nos. at length in a sample of 1000 individuals are >0.5.

landings (for an overall sample size of 750, this would come to 375 from the cover, and assuming that equal numbers are taken from the discards and landings fraction, 188 from both the discards and the landings).

- *Sampling strategy* 3 (S3). The catch fractions containing the size classes within the selection range of the cod-end (viz. cover and discards) are given a higher weight. In this particular exercise the weights were arbitrarily set at 3 for the cover and the discards, and at 1 for the landings (for an overall sample size of 750, this would come to 321 from both the cover and the discards, and 108 from the landings).

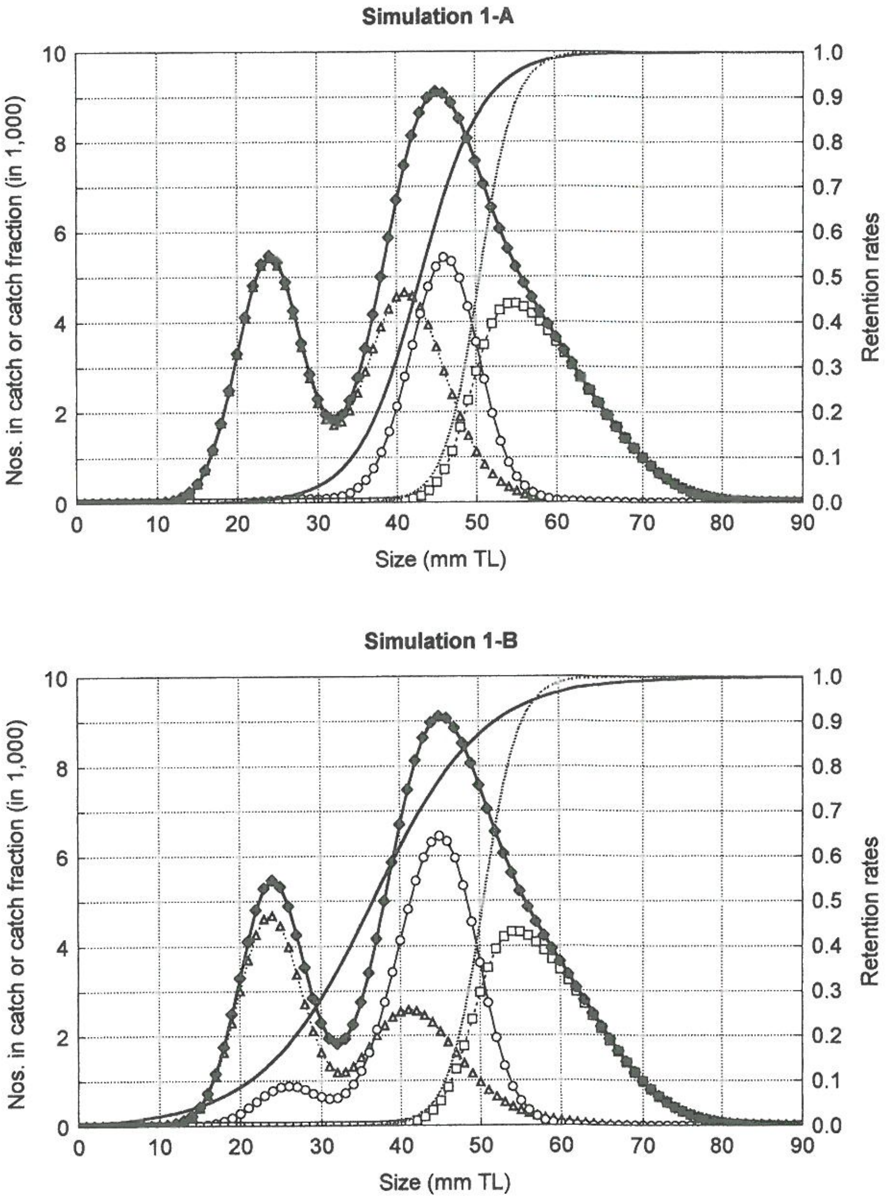

Fig. 3. Size compositions of the catch fractions used in simulations 1-A, 1-B and 1-C.

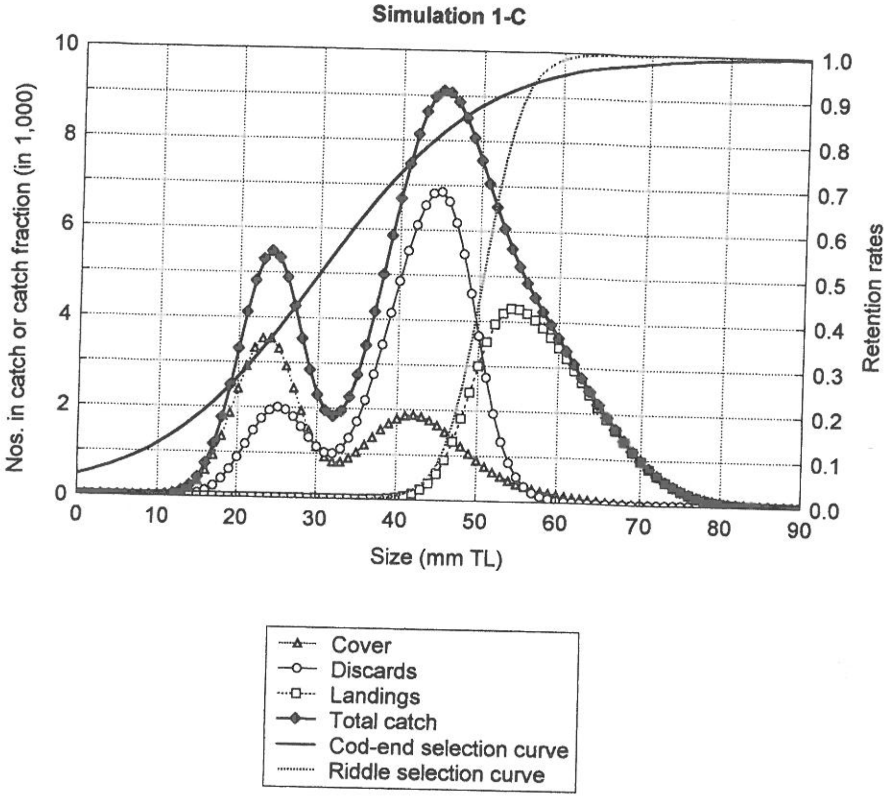

Fig. 3 (*continued*).

- *Sampling strategy* 4 (S4). The numbers of shrimps taken are proportional to the size range of each fraction (for population Type 1, cod-end selection ogive A and an overall sample size of 750, this would come to 315 from the cover, 198 from the discards, and 237 from the landings).
- *Sampling strategy* 5 (S5). The numbers of shrimps taken are proportional to the total numbers in each fraction (for population Type 1, cod-end selection ogive A and an overall sample size of 750, this would come to 351 from the cover, 185 from the discards, and 214 from the landings).

Methods S1, S2 and S3 are straightforward and easy to use in the field, whereas S4 and S5 require some preliminary information on the length distribution and the numerical strength of each catch fraction. In practice, this information can be collected either prior to or during the actual processing of the samples. In the latter case, however, the numbers of shrimp to be measured may have to be adjusted as the measurements proceed and more details on, e.g. the size range of each catch fraction become available.

2.6. Calculation of the selection ogives

The selection ogives were calculated by fitting a maximum likelihood logit curve to the "observed"

Table 3
Sampling strategies tested for each combination of population and cod-end selection curve

Code	Sampling strategy				
	S1	S2	S3	S4	S5
1-A	×	×	×	×	×
1-B	×				
1-C	×				
2-A	×				
2-B	×				
2-C	×	×	×	×	×

Within each strategy the total nos. of shrimp measured (N) were set at 150, 270, 375, 750, 1500 and 3000.

retention rates. The retention rates in question were obtained from the "scaled" LFDs of the cod-end and the cover samples, i.e. from the numbers-at-length in the samples raised by their corresponding raising factors. In this approach, however, the error calculation of the selection curves is not statistically rigorous (Millar, 1994).

Millar (1994) proposed an alternative technique to calculate selection ogives directly from the numbers-at-length in the samples, instead of from the raised numbers. This "direct" method gives much more reliable error estimates. Millar also showed that the differences in point estimates between the scaled and the direct method are negligible, provided that the

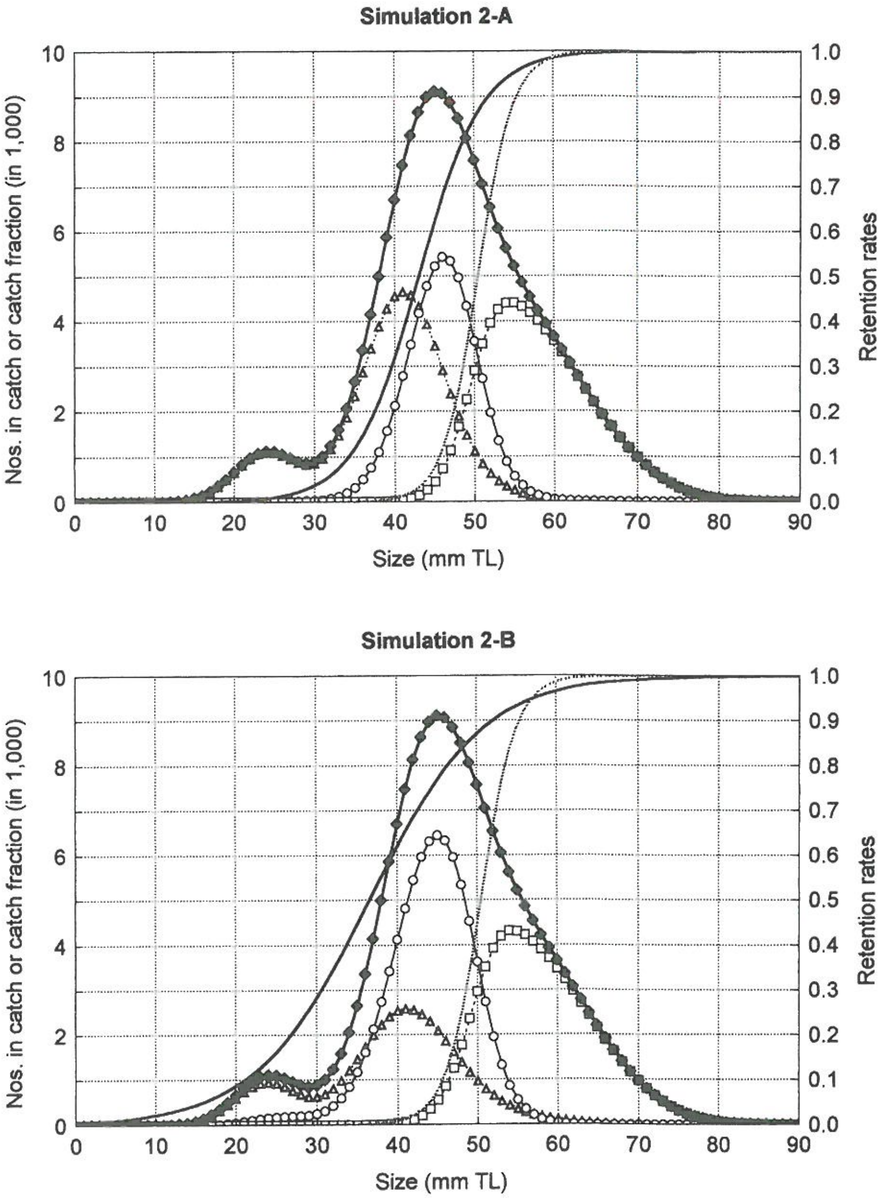

Fig. 4. Size compositions of the catch fractions used in simulations 2-A, 2-B and 2-C.

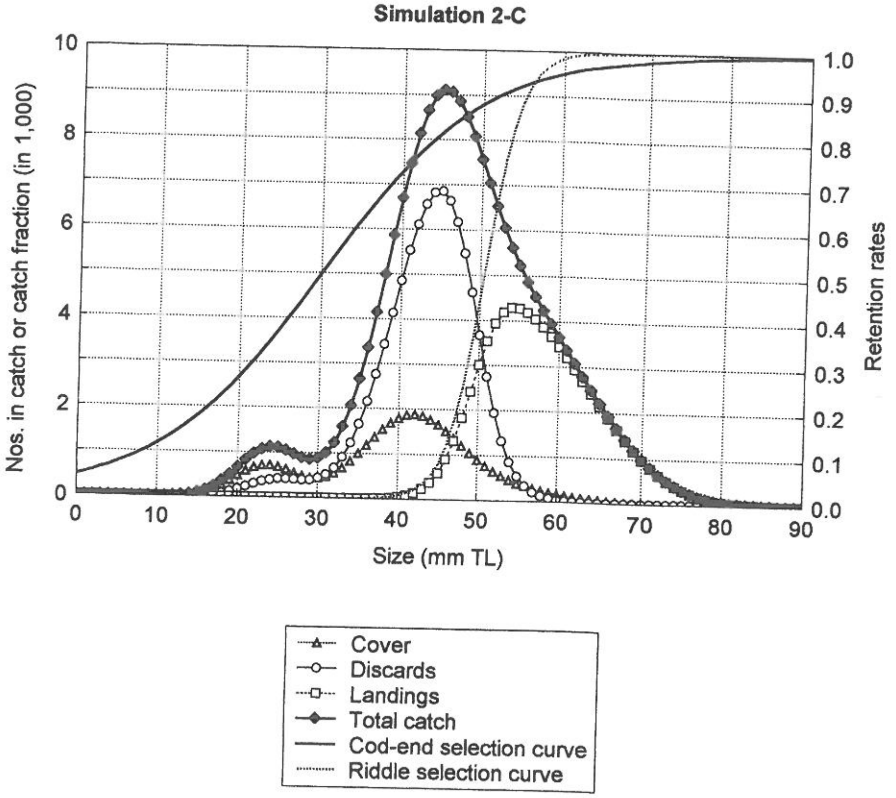

Fig. 4 (*continued*).

ratio between the scaling factors for cover and cod-end is close to 1. This was the case for most of the simulations in this study. Since the scaled method is easier to use with three catch fractions, and since the main focus of the simulations was on the reliability of the re-calculated selection parameters (and not on their standard errors), it was decided to use this technique as a standard routine to compute the selection ogives and the L_{25}'s, L_{50}'s and L_{75}'s.

3. Results

The effect of sampling strategy and sample size on the estimation of the selection parameters was examined for two combinations of population structure and selection ogive, viz. 1-A and 2-C (Table 3). The 2.5 and 97.5 percentiles of the differences between the re-calculated L_{25}'s, L_{50}'s and L_{75}'s, and the "true" L_{25}'s, L_{50}'s and L_{75}'s of the original selection curves are shown in Fig. 5 for all sampling strategies and sample sizes tested. Note that the scale of the y-axis is the same for the three graphs.

The differences in accuracy between sampling strategies, for a given number in the sample, are almost negligible (Fig. 5). In general, however, S3 seems to perform slightly better, and S2 slightly worse than the other strategies (particularly for the estimation of the L_{25}'s), but the differences are too small to conclude that any of the investigated sampling strategies should definitely be preferred over the others. As could be expected, the correspondence between the re-calculated and the true selection parameters improves more or less asymptotically with increasing sample sizes.

The effect of population structure and selection range on the reliability of the re-calculated selection parameters was investigated by comparing the results for different combinations of population structure (viz. Types 1 and 2) and selection curve (viz. A, B and C). These results are also shown in Fig. 5. Since the choice of the sampling strategy hardly affects the estimates of the re-calculated parameters (see previous paragraph), only the results for sampling strategy S1 are discussed.

The best results, in terms of reliability of the re-calculated selection parameters, were obtained in simulations 1-A and 2-A, i.e. the ones with the sharpest selection curve. For an overall sample size of 750, 95% of the L_{25}'s, L_{50}'s and L_{75}'s fall within a range 2.0, 1.5 and 2.0 mm TL, respectively, for 1-A, and within a range 1.6, 0.8 and 1.2 mm TL for 2-A (Fig. 5).

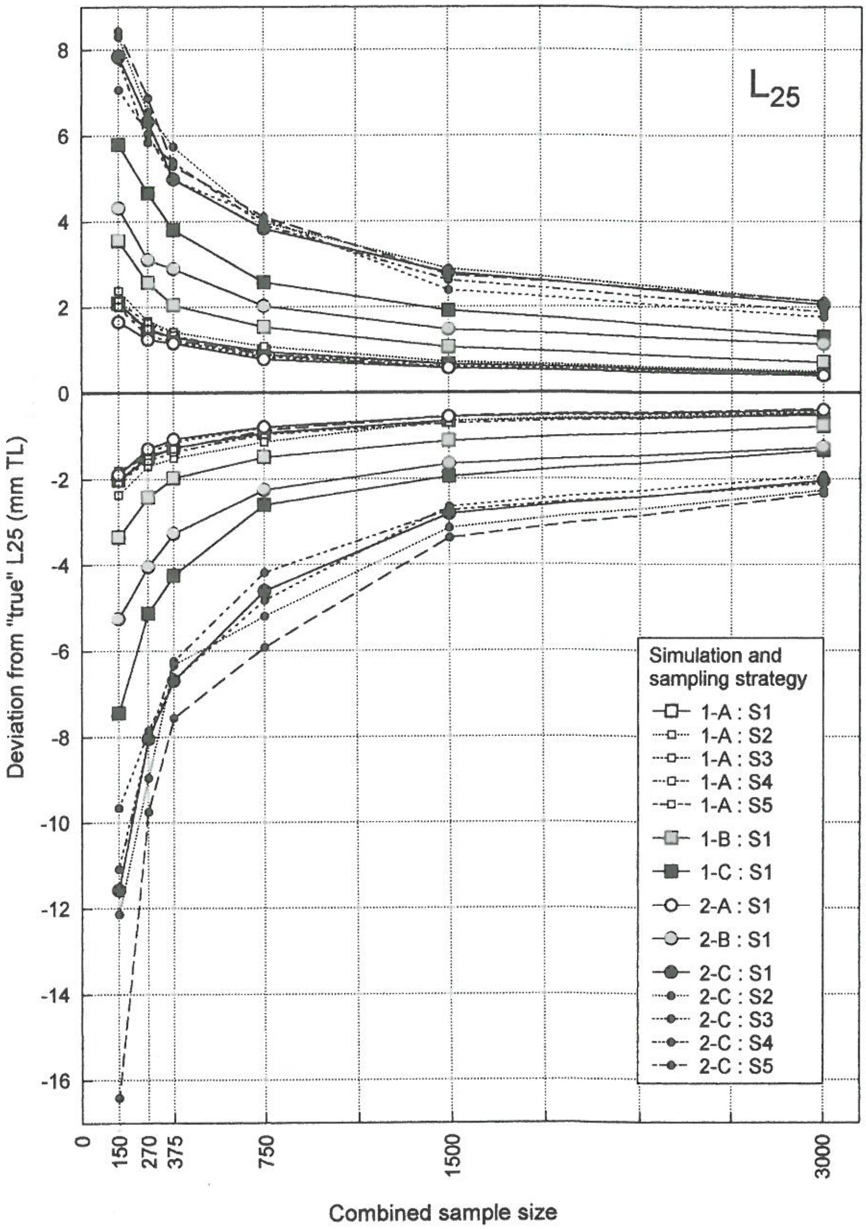

Fig. 5. 2.5 and 97.5 percentiles of the deviations of the "re-calculated" L_{25}'s, L_{50}'s and L_{75}'s from their "true" values for different sampling strategies and sample sizes. The numbers 1 and 2 in the legend code refer to the type of theoretical population, the letters A, B and C refer to the type of selection curve and S1 to S5 refer to the sampling strategy.

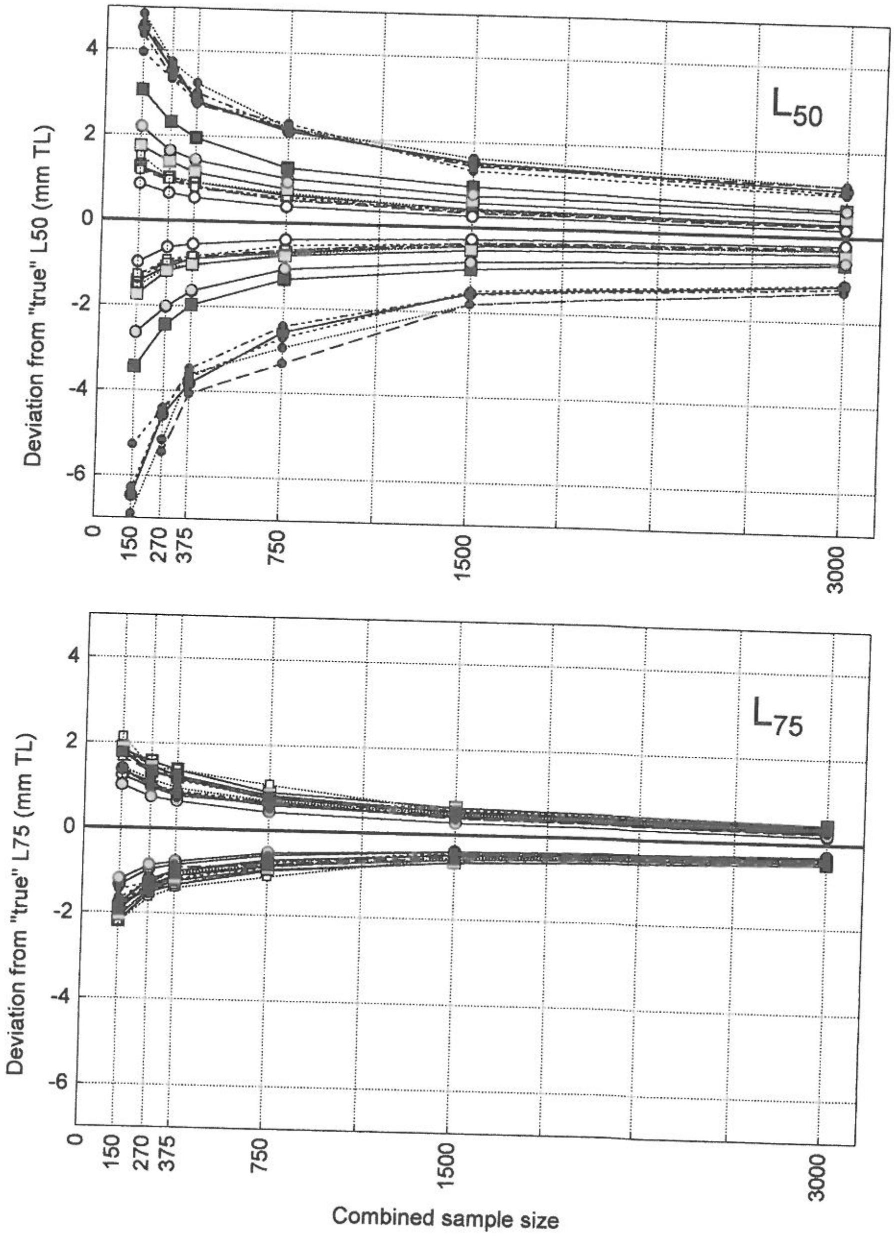

Fig. 5 (*continued*).

As the selection curve gets smoother (from A to B and, further on, from B to C), the accuracy of the estimates of particularly the L_{25}'s and the L_{50}'s gets worse (Fig. 5). This effect is much more pronounced for the population with the weak left cohort (Type 2 population) than for the one with the strong left cohort (Type 1 population).

4. Discussion

4.1. *Effect of sampling strategy and sample size*

For the combination of population Type 1 and selection ogive A, and with only 150 shrimps measured, 95% of the re-calculated L_{25}'s, L_{50}'s and L_{75}'s fall within a range 4.0 (i.e. from 2.0 above to 2.0 mm below the true value), 3.0 and 4.0 mm TL, respectively (Fig. 5). For comparative studies on the selectivity of individual hauls, such levels of accuracy might be too low. When the number of shrimps measured is increased to 750, the noise levels decrease to an acceptable 2.0, 1.5 and 2.0 mm TL, respectively, whichever sampling strategy is used. Measuring more than 750 animals reduces the background noise even further, but the gain in accuracy is too small to justify the increase in work-load.

For the combination of population Type 2 and selection ogive C, however, the overall reliability of the re-calculated L_{25}'s and L_{50}'s is very low (Fig. 5). Under the most performant sampling regime (S3), and with 150 shrimps measured, 95% of the re-calculated L_{25}'s and L_{50}'s fall within a range 17.0 and 9.0 mm TL, respectively. A sample size of 750 individuals reduces the background noise to 9.0 and 5.0 mm, respectively, which is still very high. Even if the number of shrimps measured is increased to 3000, an overall level of accuracy similar to the one obtained for 1-A with only 750 measurements, is not reached. The reasons for these differences in accuracy between different combinations of population structure and selection ogive are discussed in Section 4.2.

Even though the absolute improvement in reliability of the re-calculated selection parameters differs strongly between the simulations for a given increase in sample size, the overall relative reduction in background noise is very similar, viz. between 75% and 80%, when sample sizes are increased from 150 to 3000.

4.2. *Effect of population structure and selection range*

Smoother selection curves (from A to B, and further on, from B to C), together with a weak left cohort (Type 2 population) lead to a low accuracy of the estimates. The reasons for these differences in accuracy are closely connected to the size composition of the population, and more precisely, to the availability of sufficient numbers of length classes, critical to the calculation of the selection ogives.

In the case of simulations 1-A and 2-A, the selection range is right in the middle of that part of the population which contains most of the shrimps (viz. the strong right cohort). As a result, all length classes within the slope of the selection ogive are well represented in the samples, and this allows the calculation of reliable retention rates, and hence of reliable selection curves.

When the selection curve gets smoother, an increasing number of length classes, particularly for the sizes below the L_{25} or even below the L_{50}, will be poorly represented in the samples (if not completely absent). The lower the relative abundance of a length class in a population, the more difficult it becomes to obtain accurate estimates of its numbers-at-length. The levels of background noise in the estimated numbers-at-length for individual length classes almost exponentially increase when their relative abundance decreases (Redant, 1996), and this adversely affects the reliability of the retention rates derived from these data. The impact of this on the reliability of the re-calculated selection parameters progressively increases from simulation 1-B to 2-B, and again to 1-C, and reaches a peak in simulation 2-C, where most of the length classes between the L_{50} and the L_{25} are very poorly represented in the catches, and where no size classes are available below the point of 20% retention (Fig. 4). As a consequence, the quality of the estimated selection parameters is also extremely poor (Fig. 5).

In an attempt to resolve this problem, and to improve the quality of the retention rates for the size classes in the lower end of the selection curve, one could consider the possibility of "over-sampling" that particular part of the population. In the maximum likelihood method, however, the retention rates for each individual length class are weighed by its relative abundance in the scaled size distribution, and therefore, no matter how many animals are measured, the extra effort of over-sampling the poorest length classes is not rewarded in terms of better estimates of the L_{50}'s and the L_{25}'s. This also explains why the sampling strategy that actually did give more weight to the size classes in the lower part of the selection curve (strategy S3) hardly scored any better than the others. There is reasonable hope, however, that this problem might be overcome by using the method proposed by Millar (1994). The exploration of the potential of Millar's approach was beyond the scope of the present study, but investigations along this line are planned for the near future.

5. Conclusions

With regards to the numbers of shrimps to be measured, the simulations clearly showed that samples of 750 animals (all catch fractions combined) provide an acceptable compromise between workload on the one hand, and reliability of the estimated selection parameters on the other, provided that sufficient numbers of length classes are available over the whole range between the lowest and the highest retention rates. The poorer the length classes below the L_{25} or even below the L_{50} are represented in the catches, the more the reliability of the selection parameters decreases. Taking larger samples only partly resolves the problem, particularly if the selection curve is very smooth and the numbers of shrimps below the L_{25} very small.

The simulations also demonstrated that the choice of the sampling strategy hardly affects the reliability of the estimates, as long as the selection parameters are calculated by the scaled method. Population structure, selection curve and sample size (in that order) largely determine the reliability of the estimates of the selection parameters, and especially of the L_{50}'s and the L_{25}'s. Nevertheless, it is worth mentioning that the method which puts more weight on the length classes within the selection range (sampling strategy S3), usually gave slightly better results, and that it is likely to give even better results with the direct, sample-based method of Millar (1994) to calculate selection ogives. This, and the fact that the method is rather straightforward and easy to use, make this sampling strategy the better choice for this type of selectivity experiment.

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