Designing and evaluating length–frequency surveys for trap fisheries with application to the southern rock lobster

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Abstract: A survey design for estimating the length distribution of harvested southern rock lobsters (*Jasus edwardsii*) was developed for the South Australian fishery. Experimental sampling was carried out by volunteer fishers in spring 1996 and autumn 1997 to test three proposed survey designs. A variance components analysis indicated that it would be more efficient to sample one pot per trip from all trips rather than the previous design of sampling multiple pots from a few trips. The variation among licenses (fishers) accounts for most of the remaining sample variance. Onboard research sampling by scientists, who in the past measured from all pots on selected trips, was shown to be the least efficient design option in comparison with volunteer sampling by fishers. A sampling protocol where fishers measure one to three pots per trip has been adopted by the South Australian rock lobster fishers. Estimators, based on a three-level sampling hierarchy of pot, day, and license, are presented for estimating the mean and sample variance of the numbers harvested overall and within each length category.

Résumé : Nous avons élaboré un plan d'échantillonnage pour estimer la distribution des longueurs des Langoustes (*Jasus edwardsii*) récoltées dans la zone de pêche du sud de l'Australie. Un échantillonnage expérimental a été mené par des pêcheurs volontaires au printemps 1996 et à l'automne 1997 pour évaluer trois plans d'échantillonnage. Une analyse des composantes de la variance a révélé qu'il était plus efficace d'échantillonner un casier par sortie dans toutes les sorties que d'échantillonner plusieurs casiers de quelques sorties, comme on le faisait antérieurement. Les variations observées entre les détenteurs de permis (pêcheurs) explique presque entièrement le reste de la variance. Un échantillonnage scientifique à bord des bateaux par des chercheurs, qui dans le passé mesuraient les langoustes de tous les casiers lors de sorties choisies, s'est avéré moins efficace que l'échantillonnage volontaire par les pêcheurs. Les pêcheurs de langoustes du sud de l'Australie ont adopté un protocole d'échantillonnage dans lequel ils font des mesures dans un à trois casiers à chaque sortie. Nous présentons des estimateurs basés sur un échantillonnage hiérarchique à trois niveaux, casier, jour et détenteur de permis, pour déterminer la moyenne et la variance de l'échantillon des nombres de langoustes récoltées en totalité et dans chacune des catégories de longueur.

[Traduit par la Rédaction]

Introduction

For exploited populations of species, often invertebrates, that cannot be aged, length samples serve as the principal data source for measuring changes in population structure. Among the range of dynamic stock assessment approaches employing length–frequency samples (Fournier and Doonan 1987; Schnute 1987; Sullivan 1992) are models for continuously growing fish (Deriso and Parma 1988; Fournier et al. 1990) or molluscs (Sainsbury 1982) and for discretely growing crustaceans (Zheng et al. 1998). Several of these models apply specifically to trap fisheries (Bergh and Johnston 1992; Punt and Kennedy 1997). However, to our knowledge, formal estimators for calculating the precisions of trap survey estimates of numbers harvested, or of numbers by length group, have not been published. Length–frequency sampling is usually characterized by high variance because of varying density and the tendency for animals caught together to be more similar than those in the entire population (Pennington and Vølstad 1994). Sample strategies that reduce this variance can, therefore, substantially improve the quality of length-based stock assessments.

In the South Australian southern rock lobster (*Jasus edwardsii*) fishery, a formal survey design was needed for the ongoing monitoring of length structure for yearly stock assessment. As with most trap fisheries, it is not feasible to survey the lobster population directly (e.g., with divers or submersibles); the survey is of the commercial catch.

The aim in this paper is twofold: (*i*) to assess a range of trap survey designs for an optimal choice of survey protocol and (*ii*) to develop estimators of means and their precision (i.e., sample variance), which can be applied to estimate the overall catch and the catch by numbers within each length category. A survey protocol was sought that was optimal in two ways. First, the design should minimize the work and inconvenience required to carry out length measurements in the course of daily fishing operations. To conform as closely

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Table 1. Sampling protocol options for the South Australian rock lobster catch length monitoring survey, 1996–1997.

Option	Sampling region		
	Northern Zone	Northern Southern Zone	Southern Southern Zone
A	5 days, all pots	4 days, all pots	3 days, all pots
B	10 days, 1/5th pots	10 days, 1/7th pots	10 days, 1/10th pots
C	30 days, 1/15th pots	30 days, 1/21th pots	30 days, 1/30th pots

as possible to a sampling protocol that fishers favored, fishers were direct participants in the choice of measurement protocol. Second, for a given number of pots sampled, the estimates of population (i.e., the catch) characteristics should be more precise (yield a lower predicted sample variance) among the range of practical survey designs compared.

The principal outcome is that optimal design is achieved by allocating greater coverage among the highest sampling unit, namely licenses. Thus, in comparing surveys where researchers board vessels (and generally measure all the pots lifted on a given trip-day) with surveys that achieve cooperation from fishers who sample only one to three pots on a subsample of fishing days, the latter strategy achieves far higher precision for equal total numbers of pots sampled.

Materials and methods

The South Australian lobster fishery is divided into two zones, Northern and Southern, managed under effort controls and individual quotas, respectively. A license entitles a single vessel to fish for lobsters using a designated number of traps (pots) varying from about 40 to 80 per vessel. Pots are baited, set individually overnight, and hauled the next morning when captured lobsters are removed and stored live onboard. The season is 7 months in both zones, October–April in the Southern Zone and November–May in the Northern Zone. Effort in both zones is higher at the start of the season, stays high through summer (December–February), and tapers off, more gradually in the Northern Zone than in the Southern where, as quotas are reached, fishing more rapidly ceases. Molting of lobsters occurs in midsummer and peaks in January, which alters the length composition of the population and thus of the catch. Lobsters below the legal size limits of 102 mm carapace length in the Northern Zone and 98.5 mm carapace length in the Southern Zone (“sublegals”) must be returned to the sea. Female lobsters carrying eggs, which occur in October–November, are also returned. Most pots do not have escape vents. While some movement occurs, the large majority (88%) of tagged lobsters were recaptured within 5 km of the release site (Prescott et al. 1998)

Catch sampling has been undertaken yearly at sea in both zones since 1991 (Prescott 1992). Fishers are asked to randomly choose specific pots for sampling at the start of each sampling season and mark them by adding a colored tag. On fishing days when sampling is carried out, all the lobsters in any designated sample pot are measured for length and sex, and if female, sexual maturity status is recorded. Empty pots are also recorded. In most years, volunteer fishers did about half of the sampling during the course of commercial fishing operations, with the remainder done by onboard researchers who measured all the pots lifted on a given trip-day. In 1996–1997, the year of data collection for the survey methodology assessment presented here, all samples were carried out by volunteer fishers.

The state lobster fishery waters were divided into three sampling subregions (strata) based on average catch rates (Fig. 1). In the southern Southern Zone, lobsters are densely populated and catch rates in numbers per pot lift are relatively high. In the northern Southern Zone, and to a greater extent in the Northern Zone, mean catches per pot lift are lower. There are two surveys during the 7 months of fishing. The first spans 2 months in southern spring (November–December) and the second is over 3 months in autumn (February–April). January, which is the peak month of molting and hence growth, is not surveyed. To reduce survey cost (measured as volunteer sampling effort by fishers), the first and last months, October and May, during which only one or the other zone is open to fishing, were omitted because these are months with high variation in catches and effort.

Three sampling options were endorsed at a license-holder workshop (Table 1), each giving approximately equal numbers of pots per fisher to sample. Option A was to sample all pots set and lifted on a sample trip (i.e., day) for 3, 4, or 5 sample days. Option C was to sample approximately two, three, or four pots each sample day over 30 boat-days of sampling. Option B was an intermediate strategy of sampling approximately 10 pots per boat-day. To equalize the numbers of lobsters measured by each participating vessel, the sampling protocol took into account the variations in catch rates among the three subregions (Table 1) and differing numbers of pots being set per vessel. Using their preferred sampling option, volunteer fishers sampled 11 665 pots and measured 24 270 lobsters during the 1996–1997 fishing season.

Because traps are subsampled from all those lifted, the days sampled by a fisher are a subsample of days fished, and not all fishers (i.e., licenses or vessels) participate, this survey represents a case of three-stage sampling (Cochran 1977). We denote the primary sampling units as “licenses” (which are equivalent to vessels or boats or individual fishers, skipper, and crew who carry out the sampling work), the second sampling unit as “days” (the days sampled by each fisher out of the full season of fishing days), and the third (lowest) sampling unit as “pots” (i.e., traps). This hierarchy describes surveys of many fisheries using baited traps, notably for crab and lobster.

Selecting a survey design

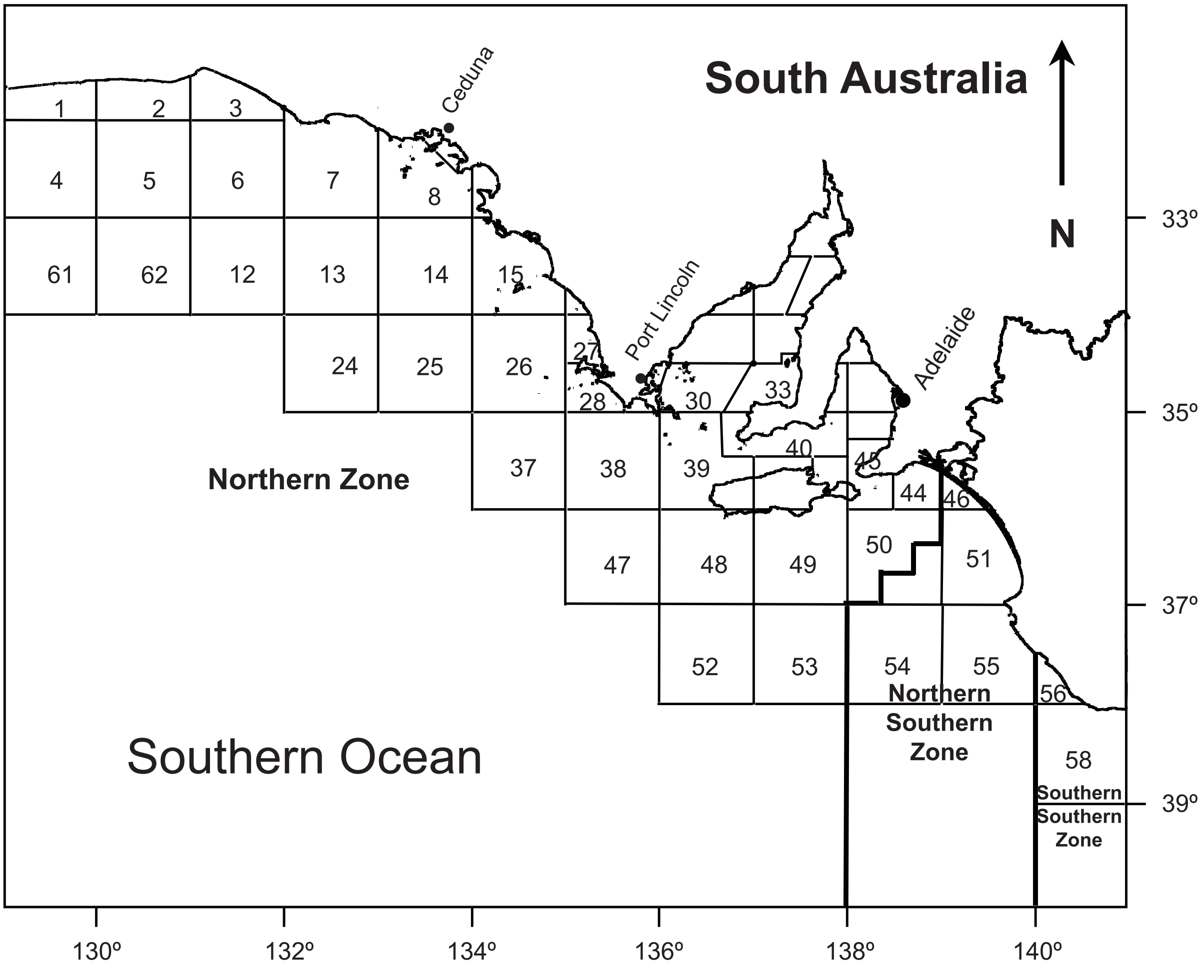
The number of lobsters, y, in a pot can be written as a function of its deviations from the mean number of lobsters per pot at each sampling stage (Box et al. 1978):

$$(1) \qquad y = \mu + e_l + e_d + e_p$$

where μ is mean number of lobsters per pot lifted in the entire fishery, the e_l component represents the difference between the mean catch by license l and the grand mean μ; e_d represents the difference between the mean catch by license l and its mean catch on day d, and e_p represents the pot-to-pot deviation (given license and day). For the purpose of assessing survey designs, it is assumed that each license fishes the same number of days and sets the same number of pots each trip. If n licenses are chosen at random, m trip-days are chosen randomly for each license, and within each trip, k pots are sampled at random, then the variance of the average number of lobsters per pot ($\bar{\bar{\bar{y}}}$, which denotes the average number per third-stage unit, i.e., pot) is given by (Cochran 1977)

$$(2) \qquad \mathrm{Var}(\bar{\bar{\bar{y}}}) = (1 - f_1)\frac{\sigma_L^2}{n} + (1 - f_2)\frac{\sigma_D^2}{nm} + (1 - f_3)\frac{\sigma_P^2}{nmk}$$

Fig. 1. Map of South Australia showing the three rock lobster survey subregions. The South Australian statistical reporting blocks for catch and effort log data are enumerated.



where σ_L^2, σ_D^2, and σ_P^2 are the variance components for license, day, and pot and f_1, f_2, and f_3 are the proportion of licenses, days, and pots sampled, respectively, at each stage. In most practical situations, the number of days fished and the number of pots set by each license will vary. If a fixed proportion of trips and pots (f_2 and f_3) are sampled for each license, then eq. 2 with m and k replaced by their average values will apply approximately (Cochran 1977).

Equation 2 permits assessment of sampling designs, in particular to determine which gives the lowest sample variance. If all three variance components are nonzero, then sampling more pots per trip (i.e., increasing k) only reduces the last term in eq. 2, leaving the contribution due to variance among days and licenses unaffected. Sampling on more days (increasing m) for each license reduces the variance contributed by the last two components, pots and days. Finally, if the number of licenses sampled were increased (n), then all three sources of variability would be reduced proportionally. Thus, the most efficient design for sampling a fixed total number of pots (= nmk and ignoring the relative costs of using the different sampling schemes) would be to collect pots from as many licenses as possible and then from as many different days fished by each license as possible.

If the lengths of lobsters caught in the same pot or during the same trip or by the same license tend to be more similar than those in the entire catch, then this also implies that sampling should be distributed as widely as possible to more precisely estimate the length distribution of the catch (Pennington and Vølstad 1994).

The length of an individual sampled at random will have an additional fourth variance component due to within-pot variability in length. Lobster length, x, can be expressed as

$$(3) \qquad x = \mu + e_l + e_d + e_p + e_w$$

where e_w is the within-pot component. Because every lobster in a sampled pot is measured, the within-pot variance does not contribute directly to the sample variance.

The survey (catch-monitoring) data from 1996 and 1997 are from six strata: spring and autumn surveys in each of the three subregions. The variance component models for these data (eqs. 1 and 3) are completely nested models, and therefore, analysis of variance techniques were used to estimate the variance components for each stratum (Searle et al. 1992). The analysis of variance estimators used are presented in Searle et al. (1992).

To evaluate the efficiency of various sampling schemes for estimating the number of harvested lobsters, the estimates of the variance components for the number of legal lobsters per pot were substituted into eq. 2. The efficiency of a sampling strategy was assessed based on (i) the variance of the sample mean, eq. 2, for a given number of pots sampled and (ii) the estimated effective sample size, which is the number of pots in a true random sample of the overall catch needed to yield the same precision as that produced by a particular sampling scheme (see Pennington and Vølstad 1994; Folmer and Pennington 2000).

Table 2. Estimates of the variance components for the number of harvested rock lobsters caught per pot during the 1996–1997 season.

Survey	$\hat{\sigma}^2_T$	$\hat{\sigma}^2_L$	$\hat{\sigma}^2_D$	$\hat{\sigma}^2_P$	n
Northern Zone					
Spring	3.97	0.18	0.52	3.29	3954
Autumn	3.36	0.14	0.42	2.81	1995
Northern Southern Zone					
Spring	5.10	0.41	0.00	4.93	2109
Autumn	3.07	0.53	0.00	2.72	1359
Southern Southern Zone					
Spring	7.01	0.97	0.00	6.25	1463
Autumn	3.04	0.13	0.08	2.89	787

Note: The variance component $\hat{\sigma}^2_T$ is the estimated total variance, $\hat{\sigma}^2_L$ is the license component, $\hat{\sigma}^2_D$ is the trip component, $\hat{\sigma}^2_P$ is the pot component, and n is the total number of pots sampled.

Estimating total catch

The variance components analysis above was used to indicate the sources of variability and to develop a sampling scheme. In this section, estimators for mean and variance are presented. Survey data provide information on the catch per pot and the proportion of the catch in each length bin. The specific quantities to be estimated are the total number of lobsters caught in 4-mm length bins. South Australian rock lobster logbook data provide the total number of days fished and the number of pots set each day by a fisher. Since the number of days fished by each license varies, as does the number of pots set, a ratio-type estimator was used (Cochran 1977).

For license l, an estimate of the number of lobsters caught per pot lift (total, or by length bin) on sample day d (the estimated daily catch per unit effort) is

$$(4.1)\qquad \bar{y}_{l,d} = \frac{\sum_{p=1}^{k_{l,d}} y_{l,d,p}}{k_{l,d}}$$

where $k_{l,d}$ is the number of survey pot lifts by license l on sample trip-day d and $y_{l,d,p}$ is the number of lobsters in a particular length category in sample pot p. The estimated average catch per pot lift by license l during the season is given by

$$(4.2)\qquad \bar{\bar{y}}_{l} = \frac{\sum_{d=1}^{m_l} K_{l,d}\bar{y}_{l,d}}{\sum_{d=1}^{m_l} K_{l,d}}$$

where m_l is the number of days that license l collected samples and $K_{l,d}$ is the total number of pots lifted (from logbook records) by license l on sample day d. The estimate of the average catch per pot lift for the fishery is

$$(4.3)\qquad \bar{\bar{\bar{y}}} = \frac{\sum_{l=1}^{n} K_l\bar{\bar{y}}_l}{\sum_{l=1}^{n} K_l}$$

where n is the number of licenses that collected samples and K_l is the total number of pots set (from logbook data) during the season by license l. Finally, the estimate of the total number of harvested lobsters, $\hat{y}_{tot}$, is

$$(4.4)\qquad \hat{y}_{tot} = K_{tot}\bar{\bar{\bar{y}}}$$

where K_{tot} is the total number of pots lifted in the fishery during the season. An approximate estimate of the variance of $\hat{y}_{tot}$ (adapted from Sukhatme and Sukhatme 1970) is given by

$$(5)\qquad \mathrm{Var}(\hat{y}_{tot}) = \frac{N^2}{n}(1-f_1)\sum_{l=1}^{n}\frac{K_l^2(\bar{\bar{y}}_l-\bar{\bar{\bar{y}}})^2}{n-1} + \frac{N}{n}\sum_{l=1}^{n}\frac{K_l^2(1-f_{2,l})s^2_{2,l}}{m_l} + \frac{N}{n}\sum_{l=1}^{n}\frac{K_l^2 f_{2,l}}{m_l^2}\sum_{d=1}^{k_{l,d}}\frac{(K_{l,d}/\bar{K}_l)^2(1-f_{3,l,d})s^2_{3,l,d}}{k_{l,d}}$$

where

$$s^2_{2,l} = \sum_{d=1}^{m_l}\frac{(K_{l,d}\ /\ \bar{K}_l)^2(\bar{y}_{l,d}-\bar{\bar{y}}_l)^2}{m_l-1}$$

$$s^2_{3,l,d} = \sum_{p=1}^{k_{l,d}}\frac{(y_{l,d,p}-\bar{y}_{l,d})^2}{k_{l,d}-1}$$

and N is the total number of licenses in the fishery, n is the number of licenses collecting samples, m_l is the number of days that license l sampled, $k_{l,d}$ is the number of pots that license l sampled on day d, f_1 is the proportion of licenses collecting samples, $f_{2,l}$ is the proportion of days fished that license l collected samples, $f_{3,l,d}$ is the proportion of pots sampled by license l on day d, and $\bar{K}_l$ is the average number of pots set by all the licenses in the fishery. An alternative and more flexible technique for estimating the variance is the jackknife method, which in some situations is more accurate than eq. 5 (Cochran 1977; Pennington and Vølstad 1994).

For fisheries where detailed information is available only from the licenses that collect samples, the estimator of the total catch (eq. 4.4) can be modified. For example, if the total number of licenses, N, in the fishery is known but the total number of pots set, K_{tot}, is unknown, then an estimate of the total number caught is given by

$$(6)\qquad \hat{y}_{tot} = (N\bar{K}_{l'})\bar{\bar{\bar{y}}}$$

where $\bar{K}_{l'}$ is the average number of pots set by the sampled licenses. An approximate estimator of the variance of eq. 6 is obtained by substituting $\bar{K}_{l'}$ for $\bar{K}_l$ in eq. 5.

Equations 4.1–4.4 were applied to the six data sets to estimate the total number of lobsters caught by sex and subregion in each 4-mm length-class. Estimates of the standard errors were generated using eq. 5.

Results

Choosing a survey design

Estimates of the three variance components for the number of legal lobsters per pot lift are given in Table 2. Since these data are not balanced, the sums of the variance components are slightly different from the estimated total variances (see Searle et al. 1992). The largest variance component for all the six survey data sets is the pot-to-pot within-day component, σ^2_P. The day-to-day (within-license) component, σ^2_D, is relatively large in the Northern Zone compared with its value in the two Southern Zone subregions. The survey

Table 3. Assessment of various sampling designs for estimating the number of rock lobsters per pot lift in the spring Northern Zone survey.

Sampling strategy	No. of licenses participated	Days sampled per license	Pots sampled			SE (% of mean)	Effective sample size
			Per day	Per license	Total		
Option A	38	5	60	300	11 400	4.62	827
Option B	38	10	12	120	4 560	4.22	990
Option C	38	30	4	120	4 560	3.77	1243
Plan implemented	38	50	1	50	1 900	4.24	983
Increase no. of	50	50	1	50	2 500	3.33	1594
licenses sampled	60	50	1	50	3 000	2.73	2365
	70	50	1	50	3 500	2.22	3623
	75	50	1	50	3 750	1.96	4602

Note: A total of 75 licenses are registered in the Northern Zone.

license-to-license component, σ_L^2, contributes relatively more to the variance in the Southern Zone.

The estimates of the variance components were substituted into eq. 2 and the resulting formula was used to assess the effect of various sampling schemes on the precision of the estimators of catch. The comparison of sampling designs (Table 3) was based on the variance component estimates for the spring survey in the Northern Zone.

The first three rows of Table 3 summarize the assessment of survey designs based on the three proposed sampling options (Table 1) giving estimated standard errors and effective sample sizes for each. The effective sample size quantifies how well the sampling design performed compared with (not physically realizable) simple random sampling. For example, a simple random sample of 827 pots would yield the same precision obtained by sampling 11 400 pots using option A (Tables 1 and 3). The reason the effective sample size is much smaller than the number of pots sampled is that the numbers of lobsters in pots from the same trip, or from trips made by the same fisher, tend to be more similar than those in the entire population of pots that were set during the season. Of the three sampling options, C was the most efficient, and as expected, it is better to sample from as many days as possible.

For the present level of sampling participation (38 of 75 licenses in the Northern Zone), 50% of the remaining variance (given the sample sizes for pots, days, and licenses as allocated) is due to license-to-license variability, even though the license component only makes up 4.45% of the total variance (Table 2). This source of variance can only be reduced significantly if the number of fishers sampled is increased. One way to encourage more fishers to collect samples is to minimize the number of pots that each needs to sample. If each license sampled one pot per trip for a total of 50 pots during a season (fourth row in Table 3), then the standard error would be 4.24% of the mean compared with 3.77% for option C and each fisher would sample 58% fewer (50 versus 120) pots per season. The last four rows in Table 3 indicate the gain in precision if more licenses sampled one pot per trip. Not only does the precision increase significantly, but the effective sample size becomes greater than the number of pots sampled when the number of fishers collecting samples approaches 100%; if all fishers participate, the survey design is two-stage sampling stratified by license.

The estimated variance components for length (Table 4) yielded similar choice of optimum survey design. As with numbers per pot lift, the license component accounted for a large part of the remaining variance of the estimates. Since all lobsters in a pot are measured, the license component contributed considerably more than it did for numbers to the variance of the estimates, as indicated by the relative size of the remaining components (columns 3–5 in Table 4). Thus, the same conclusion holds for length as for numbers, i.e., for estimating catch at length, it is better to sample as many fishers and then trips as possible.

Table 4. Estimates of the variance components for length of legal-size rock lobsters caught.

Survey	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	*n*
Northern Zone						
Spring	239.3	20.4	16.9	16.6	186.1	5689
Autumn	381.3	29.4	36.1	19.6	298.8	2551
Northern Southern Zone						
Spring	211.7	44.0	11.3	12.5	146.8	3228
Autumn	475.0	63.2	24.3	66.5	325.6	1510
Southern Southern Zone						
Spring	100.7	8.7	0.0	10.9	82.8	3226
Autumn	237.2	18.1	0.0	54.5	187.0	1003

Note: The variance component $\hat{\sigma}_T^2$ is the estimated total variance, $\hat{\sigma}_L^2$ is the license component, $\hat{\sigma}_D^2$ is the trip component, $\hat{\sigma}_P^2$ is the pot component, $\hat{\sigma}_W^2$ is the within-pot component, and *n* is the total number of lobsters measured.

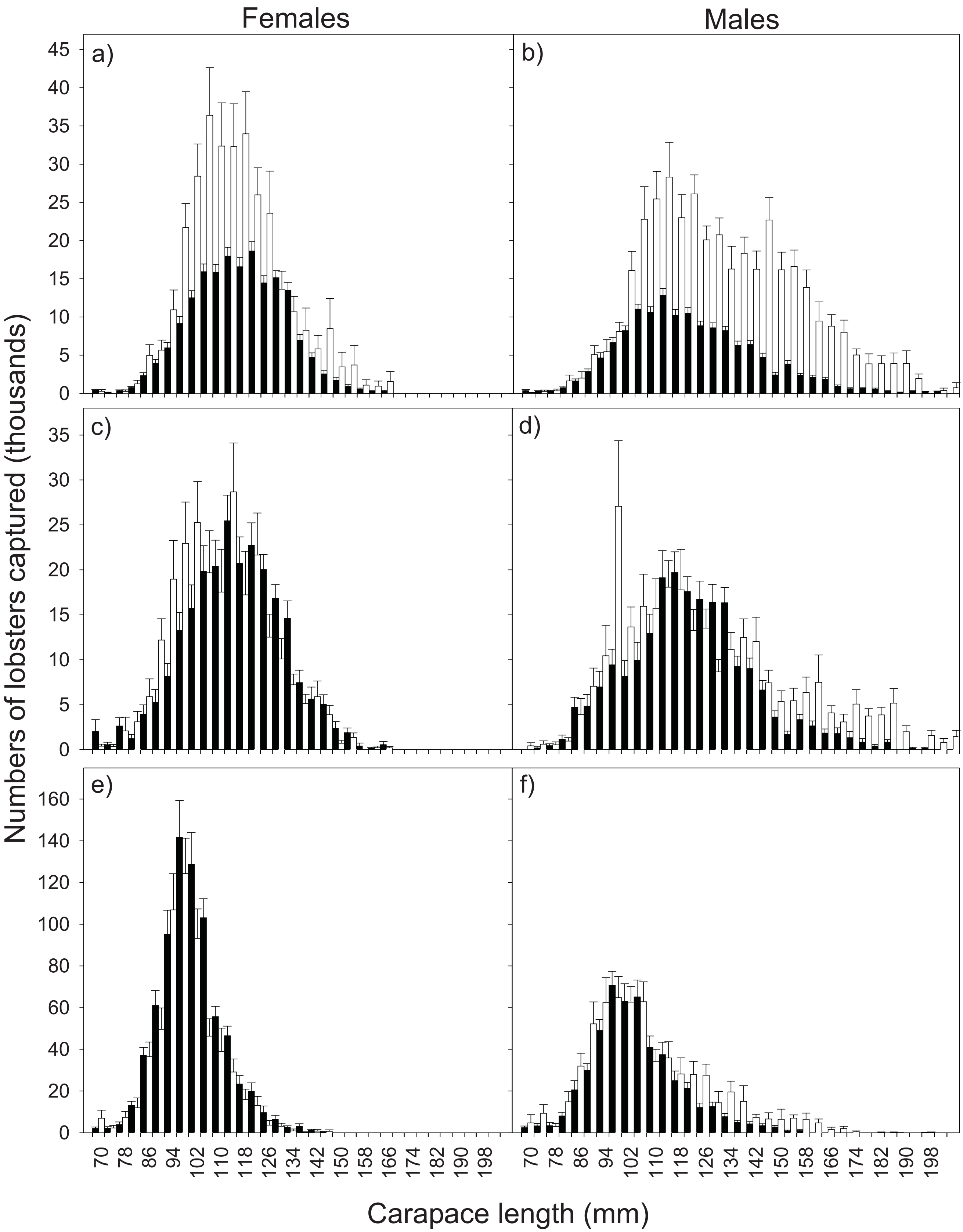
Estimation of total numbers harvested by length-class

Equations 4.1–4.4 were used to estimate the number of lobsters caught in each 4-mm length bin by sex for spring and autumn in the three subregions, generating frequency distributions for the 12 data sets (Fig. 2). The error bounds of the estimated numbers (Fig. 2) were calculated as the square root of the variance from eq. 5. It should be noted that the estimates for legal-size lobsters are harvest estimates, while those for sublegals and egg-bearing females are estimates of the numbers caught and subsequently returned to the sea. The different nature of the estimates, legals sampled without and sublegals with replacement, needs to be considered when assessing or modeling the stock.

Discussion

Conveniently, the strategy yielding lowest variance was the one that fishers preferred. Survey polls by mail, a series

Fig. 2. Estimated length–frequencies of the total numbers of rock lobsters caught, by sex, survey region, and season (spring = black; autumn = white), in 4-mm bins. Error bars indicate 1 SE (from eq. 5) of estimated number caught in each length bin. (*a* and *b*) Northern Zone; (*c* and *d*) northern Southern Zone; (*e* and *f*) southern Southern Zone.



of port meetings with fishers, and a final large 1-day workshop with all scientists and most participating volunteer survey fishers indicated clear preference for the sampling protocol of fewer pots on correspondingly more days.

For a fixed number of pots, sampling fewer pots per trip and increasing the number of trips sampled will increase the effective sample size for the number of pots sampled and for the number of individual lobsters measured (Pennington and Vølstad 1994). The problem of obtaining a small effective sample size compared with the number of animals actually measured appears to be much less severe with trap surveys than with trawl surveys that have been examined (Pennington and Vølstad 1994; Folmer and Pennington 2000). This is because a pot lift is a relatively small sample unit compared with the haul of a net, and small sampling units are generally more efficient than large units for surveying marine populations (Pennington and Vølstad 1991, 1994; Gunderson 1993).

Vessels (i.e., licenses) that did not participate in the volunteer survey are surveyed by onboard researchers who measure all lobsters brought up in pots during a sample trip-day (in general, chosen opportunistically). The results above, indicating that sampling all pots for a small number of days is the least efficient sampling regime, imply that researcher effort is being employed inefficiently, and thus, sampling entire trips by researchers has now been significantly curtailed.

The most efficient way to increase the precision of the southern rock lobster catch surveys is to encourage more fishers to participate as volunteers. This reduces sample variance (and possible biases) by gathering a more representative sample. Additional fishers may participate if the amount of work involved in sampling is reduced. Towards this end, the new sampling protocol is for a fisher to sample one pot from each trip. Among the survey designs analyzed, this design will generate the most precise estimates for a given number of sampled pots, is the one that the fishers prefer, and greatly reduces the number of pots sampled by each volunteer fisher during a survey. Some fishers nevertheless chose to continue sampling two or three pots as they had done previously.

The choice of order for the three-level sampling hierarchy follows the actual procedure by which sample units were selected in practice. Thus, while in theory there is no reason a sample protocol could not be constructed where days were the highest level of sampling and licenses were chosen from each randomly chosen sample day, in the South Australian rock lobster fishery, this protocol was not followed. In general, there will always be some licenses that do not participate, so the first level of selection, for that reason, is of those licenses that do participate in sampling. If, however, a sampling protocol were adopted in another fishery where days were selected first, then the same equations presented above for the sample means and variances would continue to apply, although inputs and outputs to each level would be reassigned accordingly.

The difference in the classification of sampling, without and with replacement, for the two cases of (*i*) legal lobsters that are kept after being measured and (*ii*) sublegals and egg-bearing females that are returned to the sea, poses no problem in practice, since the percentage of the population actually returned to the sea in either the spring or the autumn surveys is small, being less than 1%, so very few are actually resampled a second time. Moreover, the use of this survey information for legals and sublegals differs. Legals are used to characterize the catch in stock assessment estimation modeling. Sublegals are taken as a time series of “prerecruits,” assuming that in the following year, most will enter the legal stock. If exploitation rates are higher than in South Australia so that a significant number of sublegals are resampled, this should be taken into account when estimating an abundance index or a length distribution for the sublegals.

In qualitative analysis of a length survey for the same species of lobster in New Zealand (Starr and Vignaux 1997), no strong differences were observed between researcher- and volunteer-fisher-gathered survey numbers per pot lift and in the corresponding length–frequency distributions. However, assessment was subjective scoring by eye of the graphed length distributions, and for a considerable number of samples (by month and statistical area, summed over 3 years of comparisons), the two surveys failed the subjective equivalence test, underlying a need for more formal methods to quantify survey performance and to calculate the sample variances.

Improved length-based stock assessments would be achieved by explicit recognition of calculated confidence intervals of survey catches by length. In stock assessment models, a weighting on each fitted length bin frequency could be assigned inversely proportional to the calculated sample variance using eq. 5 or its equivalent (Seber 1973). And it appears that more efficient designs are achieved by use of volunteer-fisher sampling, which permits more widely representative samples and thus lower sample variances.

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