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# TRAP SELECTIVITY AND THE EFFECTS OF ALTERING GEAR DESIGN IN THE SOUTH AFRICAN ROCK LOBSTER *JASUS LALANDII* COMMERCIAL FISHERY

*D. S. SCHOEMAN*, A. C. COCKCROFT†, D. L. VAN ZYL† and P. C. GOOSEN†*

The current trap fishery for the West Coast rock lobster *Jasus lalandii* in South African waters results in the capture, sorting and release of large numbers of undersized animals. Once removed from the water, they are vulnerable to damage from numerous sources. Even sub-lethal injury may result in a considerable reduction to individual productivity through decreased growth or reproductive potential. Given that the *J. lalandii* resource is heavily depleted, such wastage may have severe repercussions for the sustainability of the fishery. In an attempt to reduce these losses, 20% of the fishing gear used by the rock lobster industry has been modified to include grids designed to allow undersized rock lobsters (mainly females) to escape the traps before they are hauled. The efficiency of this gear (and two alternatives) was assessed by comparison with standard commercial gear over a range of fishing grounds. Results indicated that, in comparison to standard commercial traps, none of the alternative trap designs would be beneficial to the fishery in the long term, provided that overnight sets remain the most common fishing method. SELECT models were used to evaluate the fishing properties of commercial and bottom-grid traps relative to those of control (fine-mesh) traps. The results indicated that, given the choice, a rock lobster would preferentially enter a commercial trap, followed by a control trap, with bottom-grid traps being the least attractive. This suggests some level of saturation of control traps, a possibility that is of particular concern because the control trap design is used in a fishery-independent monitoring survey.

Key words: escape gaps, *Jasus lalandii,* rock lobster, SELECT models, trap selectivity

The indiscriminate nature of most contemporary marine industrial fishing methods results in the incidental capture of both non-target species and undesirable sizes of target species. Rock lobster fisheries provide excellent examples of these phenomena; many of those using baited traps are managed using minimum legal sizes and, as a direct consequence, must resolve the problems associated with catching undersized animals. The major concern is that, during capture, sorting and release, these lobsters run the risk of either being killed or sustaining sub-lethal injuries. Whereas the potential consequences of mortality to population productivity are fairly obvious, the loss of limbs, displacement from home reefs or even exposure to air and light may have more subtle effects on individual somatic or reproductive production, or both (Chittleborough 1975, Davis 1981, Brown and Caputi 1985). Managers of most lobster and rock lobster fisheries have responded by introducing escape vents of various sizes and shapes (Krouse 1989, Miller 1990, Everson *et al.* 1992, Arana and Ziller 1994, Rosa-Pacheco and Ramírez-Rodríguez 1996, Treble *et al.* 1998, Schoeman *et al.* 2001). Although these mechanisms are implemented specifically because they successfully allow undersized specimens to escape (Arana and Ziller 1994, Treble *et al.* 1998), some studies have provided evidence that, in certain circumstances, they simultaneously increase the catch rates of legal-sized animals (Fogarty and Borden 1980, Brown 1982, Everson *et al.* 1992, Rosa-Pacheco and Ramírez-Rodríguez 1996). Where this occurs, it is believed to be a response to a decrease in trap saturation effects, which may have resulted from intraspecific interactions in traps crowded with small animals (Miller 1990, Xu and Millar 1993, Treble *et al.* 1998).

The South African fishery for the West Coast rock lobster *Jasus lalandii* has been regulated by a minimum legal size since 1933 (Cockcroft and Payne 1999). Although this limit was reduced from its historic value of 89 mm carapace length (*CL*) to 75 mm *CL* during the early 1990s (Cockcroft and Payne 1999, Pollock *et al.* 2000), the proportion of the commercial catch <75 mm *CL* remains around 35–40% (Marine & Coastal Management [MCM], unpublished data). At present, the biomass of the *J. lalandii* resource that is larger than the minimum legal size is estimated at about 6% of its pristine value, whereas the spawning biomass (of mature female rock lobsters) is estimated to be 21% (Johnston 1998). Consequently, it can be concluded that the resource is heavily depleted, and that there is little scope for wasted production through

* Department of Zoology, University of Port Elizabeth, P.O. Box 1600, Port Elizabeth, 6000, South Africa; formerly Marine & Coastal Management, Private Bag X2, Rogge Bay 8012, South Africa. E-mail: zliad@upe.ac.za
† Marine & Coastal Management, Cape Town

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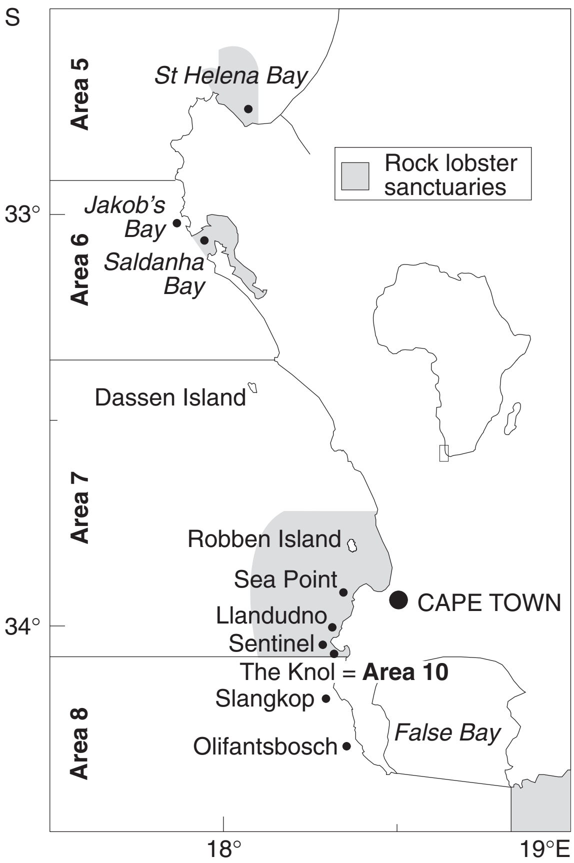


Fig. 1: The west coast of South Africa showing the sampling areas

unnecessary damage to undersized lobsters.

Exacerbating the decrease in estimated population size has been an abnormally low somatic growth rate over the past decade (Cockcroft and Goosen 1995, Pollock *et al.* 1997, 2000). It is this growth rate that regulates the biomass available to the fishery, through its influence on population productivity (Bergh and Johnston 1992). It has been postulated that undersized *J. lalandii* released after sorting aboard fishing vessels preferentially channel energy into repairing handling-related injury at the expense of individual somatic growth (Cockcroft and Goosen 1995). As a result, several of the operational modifications imposed on the fishery over the past 30 years (Schoeman *et al.* 2001) have aimed to reduce the catch of animals smaller than the minimum legal size, which by law have to be discarded. In terms of the traps used in the commercial fishery, the most notable of these adaptations have been the changes made in 1984 to mesh covering of the trap (with the aperture increased from 62 to100 mm, stretched) and the introduction of bottom-grid traps a decade later (Schoeman *et al.* 2001).

The efficiency of both standard and bottom-grid traps covered by 62-mm mesh have been investigated at the historical minimum legal size (Newman and Pollock 1969, Crous 1976, Pollock and Beyers 1979). However, there are no available field data that describe how these traps perform under the current regulations, which require a larger mesh size and smaller minimum legal size. Without this knowledge, the suitability of any gear envisaged for use in the *J. lalandii* fishery as an alternative to the standard trap cannot be properly evaluated. Furthermore, appropriate information regarding gear selectivity curves is indispensable when making inferences about catch rates from population size structures that differ from that of the fished population (Sparre and Venema 1998). The present study provides information that addresses both of these needs.

Several criteria are required for an assessment of the efficiency of any gear contemplated as an alternative to the standard trap. First, the catch rates by the alternative gear of legal-sized and undersized lobsters must be estimated relative to those for the standard gear. Second, it must be ascertained whether or not the catch made by the alternative gear is representative of the population. Third, estimates must be obtained both of the effort that would be required to land a unit mass of rock lobsters, and of the potential reduction in catch of undersized animals using the alternative gear relative to that using standard gear.

For the purposes of this paper, standard commercial gear will be defined as a trap having side panels covered by 100-mm (stretched) mesh. The alternative trap designs are: bottom-grid traps (100 mm-mesh, 44-mm grid spacing); small mesh (62 mm) traps, which are currently used in a fishery-independent monitoring survey (FIMS) to obtain annual estimates of relative abundance and of population size structure (Pollock *et al.* 2000); and a new trap design that has been proposed as an alternative to the bottom-grid trap. Apart from the latter, which resembles standard gear, but has only a single entrance funnel located at the top of the trap (hence the name top-entry traps), all gear types have been described by Schoeman *et al.* (2001). Along with bottom-grid traps, the top-entry traps are intended to reduce the catch rates of undersized rock lobsters in the commercial catch, without negatively affecting catch rates of legal-sized specimens. By contrast, the FIMS traps are designed to obtain representative samples of the population >60 mm *CL*.

Therefore, the aims of this investigation are: (i) to assess the degree to which each of the trap types

Table I: Wilcoxon paired-sample tests of various hypotheses regarding the efficiency of the four gear-types. All response variables were measured per trap

| Hypothesis | Valid *N* | *T* | *Z* | *p*-level |
|---|---|---|---|---|
| $H_0$: $\text{Mass}^{\text{Legal-size}}_{\text{Commercial}} = \text{Mass}^{\text{Legal-size}}_{\text{Bottom-grid}}$ | 93 | 940.0 | 4.56 | <0.001 |
| $H_0$: $\text{Number}^{75-80\text{ mm }CL}_{\text{Commercial}} = \text{Number}^{75-80\text{ mm }CL}_{\text{Bottom-grid}}$ | 93 | 524.5 | 4.65 | <0.001 |
| $H_0$: $\text{Number}^{\text{Undersize}}_{\text{Commercial}} = \text{Number}^{\text{Undersize}}_{\text{Bottom-grid}}$ | 93 | 242.0 | 6.61 | <0.001 |
| $H_0$: $\text{Number}^{\text{Mature female}}_{\text{Commercial}} = \text{Number}^{\text{Mature female}}_{\text{Bottom-grid}}$ | 93 | 627.5 | 5.06 | <0.001 |
| $H_0$: $\text{Mass}^{\text{Legal-size}}_{\text{Commercial}} = \text{Mass}^{\text{Legal-size}}_{\text{Top entry}}$ | 19 | 42.0 | 2.13 | 0.0329 |
| $H_0$: $\text{Number}^{\text{Undersize}}_{\text{Commercial}} = \text{Number}^{\text{Undersize}}_{\text{Top entry}}$ | 19 | 91.5 | 0.14 | 0.888 |
| $H_0$: $\text{Number}^{\text{Legal-size}}_{\text{Commercial}} = \text{Number}^{\text{Legal-size}}_{\text{FIMS}}$ | 93 | 785.5 | 5.08 | <0.001 |
| $H_0$: $\text{Number}^{75-80\text{ mm }CL}_{\text{Commercial}} = \text{Number}^{75-80\text{ mm }CL}_{\text{FIMS}}$ | 93 | 326.5 | 6.50 | <0.001 |
| $H_0$: $\text{Number}^{>80\text{ mm }CL}_{\text{Commercial}} = \text{Number}^{>80\text{ mm }CL}_{\text{FIMS}}$ | 93 | 1 539.0 | 1.59 | 0.112 |
| $H_0$: $\text{Number}^{\text{Undersize}}_{\text{Commercial}} = \text{Number}^{\text{Undersize}}_{\text{FIMS}}$ | 93 | 88.0 | 7.88 | <0.001 |

achieves its stated goal; (ii) to describe the size-specific selectivity properties of selected trap designs; and (iii) to identify the potential advantages and disadvantages of altering the design of the traps used in the commercial fishery for *J. lalandii*.

## MATERIAL AND METHODS

### Field procedures

During research cruises between October 1996 and March 1999, 11 sites were sampled (Fig. 1), including locations both within and outside commercial rock lobster sanctuaries. Only three sites were sampled more than once: Olifantsbosch (five times); Dassen Island (six times); and The Knol (nine times). During each visit, 3–5 longlines of traps were deployed on rocky reefs thought to support rock lobster in reasonable abundance . Each longline consisted of 8–10 traps, strung at regular intervals along a 50 m-long bottom rope. Of these, the three central traps were, in haphazard order: a standard commercial trap, a FIMS trap and a bottom-grid trap. All traps on a line were uniformly baited using either hake heads or yellowtail flesh. This arrangement provided a single data point for each gear type from each set, while avoiding potential bias resulting from the possibility that catches in "end traps" may be lower than those in the rest of the traps on a longline.

From December 1998 to March 1999, a fourth trap-type (the top-entry trap) was added to this experimental array. By eliminating the entrance funnels at the sides of the trap, top-entry traps expose a far greater area of 100-mm mesh to captive rock lobsters than any of the other gear-types, thereby offering greater opportunity for smaller animals to escape.

Although soak time varied between 4 and 36 h, only three longline sets were hauled within 18 h of being deployed, all at Dassen Island. The remaining longlines were soaked overnight, as is assumed to be conventional in the commercial fishery. On hauling, the contents of each trap in the experimental array were sexed and measured to the nearest millimetre using steel vernier calipers. The mass (g) of each captured specimen was estimated from its *CL* (cm), using Heydorn's (1969) length-mass relationship:

$$\text{Mass} = 0.6518\ CL^{2.9081} \quad .$$

### Hypothesis testing

Because of the primary uses of the trap-types tested, five response variables are of particular interest:

(i) The number of undersized rock lobsters (<75 mm *CL*) caught per trap, which relates to the potential magnitude of mortality or somatic damage among individuals released from the deck of the fishing vessel after interaction with the fishing gear.

(ii) The mass of legal-sized (≥75 mm *CL*) rock lobsters caught per trap, which determines the ability of the various gear-types to land the commercial total allowable catch (*TAC*).

(iii) The number of specimens in the 75–80 mm *CL* size range, which determines the commercial desirability of the gear-type, because this is currently one of the most sought-after size categories.
(iv) The number of mature female rock lobsters caught per trap, which determines the potential damage to egg production of each of the gear-types.
(v) The number of legal-sized rock lobsters caught per trap, which provides information regarding the ability of rock lobsters larger than the minimum legal size to escape each of the gear types.

These response variables were used to test the several hypotheses with regard to the efficiency of the various gear-types as alternatives to standard commercial traps (Table I). Each valid longline set provided data for a single trap of each of the designs under investigation. Because the hypotheses involved individual comparisons of specific aspects between standard commercial trap catches and those of one alternative, two-sample analyses were considered appropriate. To account for the variability in conditions among sets, the observations were paired (standard commercial trap v. alternative) from individual longline sets and a paired-sample analytical approach was adopted. Furthermore, because the normality assumption required by the parametric paired-sample *t*-test could generally not be met, the non-parametric, two-tailed Wilcoxon paired-sample test was used. In comparison to the *t*-test, this procedure has only 5% less power to detect differences, but has substantially less stringent assumptions regarding the shape of the response variable distributions (Zar 1984). Because paired observations of zero catch provide no additional information regarding the efficiency of the various gear-types, but may inflate the degrees of freedom, data from all samples that yielded no rock lobster in either commercial traps or bottom-grid experimental traps were excluded from analyses. For top-entry traps, comparisons were made only with standard commercial traps on corresponding longlines.

## Selectivity curves

The size-specific selectivity properties of standard commercial and bottom-grid traps were examined using the SELECT (Share Each LEngth class's Catch Total) method (Millar and Walsh 1992). This procedure assumes that an experimental gear with unknown selectivity characteristics is fished alongside a control gear that retains all animals entering it. For the purposes of these analyses, it was assumed that the FIMS traps acted as an appropriate control for the other gear-types, which were tested against them in a pair-wise fashion.

According to the SELECT method, for any given length of individual, $l$, the proportion of the total catch (sum of catches in the control and the experimental trap) caught in the experimental gear, $\phi(l)$, may be calculated as follows:

$$\phi(l) = \frac{pr(l)}{pr(l) + (1-p)} \quad .$$

The parameter $p$ is the "relative fishing intensity" and may be interpreted as the probability that any individual encountering the two trap-types under consideration will enter the experimental gear in preference to the control gear (Millar and Walsh 1992). The function $r(l)$ describes the probability of any individual of length $l$ having entered the experimental gear being retained by it. For the purposes of these analyses, it is assumed that $r(l)$ takes the symmetrical logistic form frequently used in length-based stock assessments (Sparre and Venema 1998):

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

where the length-at-50% retention ($L_{50}$) and the selection range ($SR = L_{75} - L_{25}$) are defined as:

$$b = \frac{2\ell n(3)}{SR}$$

and

$$a = -bL_{50} \quad .$$

The desired selectivity curves were fitted using the SAS routine provided by Millar (1993) and, wherever necessary, hypothesis tests and corrections were made in accordance with the recommendations of Millar and Walsh (1992).

## Modelling catches

A simple, deterministic model was constructed in order to investigate the likely repercussions of varying the proportion of experimental traps (i.e. traps other than standard commercial design) in the commercial gear. The response variables examined were: the effort required to land a unit mass of legal-sized rock lobsters; and the concomitant changes in catches of undersized and mature female animals. Only two scenarios were investigated, commercial gear being substituted by bottom-grid traps or replaced by FIMS traps.

Given the legislated proportion ($\alpha$) of experimental traps, the relative catch rate (*cpue*) of rock lobsters belonging to size- (or any other) category β was estimated as:

$$Cpue_{\alpha}^{\beta} = Cpue_{\alpha=0}^{\beta}\left((1-\alpha)+\alpha\gamma_{\beta}^{trap-type}\right) \quad ,$$

where $\gamma_{\beta}^{trap\text{-}type}$ is the efficiency of the experimental trap-type in capturing β-category rock lobsters relative to that of commercial traps.

In order to estimate these efficiencies, it was necessary to calculate, for each of the three trap-types, the catch per trap of each category of rock lobster within each of five fishing areas. The fishing areas were selected to correspond with those used in the management of the *J. lalandii* resource (Pollock 1986), but with the exception that samples taken within rock lobster sanctuaries were associated with the nearest commercial fishing ground. Thus, St Helena Bay represented Area 5 (4 longline sets), Jakobs Bay and Saldanha Bay represented Area 6 (8 longline sets), Dassen Island represented Area 7 (24 longline sets), Slangkop and Olifantsbosch represented Area 8 (23 longline sets) and Robben Island, Sea Point and The Knol represented Area 10 (55 longline sets). Because these four areas accounted for 93% of the traps deployed during the 1997/98 fishing season (MCM, unpublished data), it was assumed that trends observed within them would be representative of responses from the entire trap fishery. Therefore, the commercial catch in each of the respective areas was modelled by weighting area-specific catch per trap obtained during the survey by the number of traps deployed by the commercial fishery in each of the corresponding areas during the 1997/98 season. Response by the fishery was then approximated by the summed responses of the individual areas.

Given these assumptions, the effort required to land a unit mass of legal-sized (β = Legal) rock lobsters may be expressed as

$$Effort_{\alpha} = \frac{1}{Cpue_{\alpha}^{\beta=Legal}} \quad .$$

Furthermore, the magnitude of the catch of β-category rock lobsters relative to that of legal-sized rock lobsters may also be calculated for various levels of α:

$$\text{Relative catch}_{\alpha}^{\beta} = \frac{Cpue_{\alpha}^{\beta}}{Cpue_{\alpha}^{\beta=Legal}} \quad .$$

## RESULTS

Of the 114 longline sets, 93 provided data appropriate for analysis. Of the remainder, 16 caught no rock lobster and five caught rock lobsters only in the FIMS trap. None of the longlines deployed at either Jakob's Bay or St Helena Bay caught any rock lobsters, but the remaining stations each contributed at least two valid data points. All of the 19 longline sets that included top-entry experimental traps provided valid data.

Only two of the hypotheses tested (Table I) were not rejected at the 95% confidence level. The first was

Table II: Cumulative catches of various rock lobster categories using the four gear-types (percentage of total catch in parenthesis)

| Category | FIMS trap | Commercial trap | Bottom grid trap | Top-entry trap |
|---|---|---|---|---|
| Valid trap hauls | 93 | 93 | 93 | 19 |
| Mass (kg)$^{\text{Legal-sized}}$ | 802 | 559 | 305 | 71 |
| | (47.6) | (76.7) | (84.7) | (80.6) |
| Number$^{\text{Legal-sized}}$ | 2 729 | 1 763 | 968 | 231 |
| | (33.4) | (64.1) | (77.1) | (70.6) |
| Number$^{\text{75–80 mm } CL}$ | 1 571 | 731 | 404 | 108 |
| | (19.2) | (26.6) | (32.2) | (33.0) |
| Number$^{\text{Undersized}}$ | 5 441 | 986 | 288 | 96 |
| | (66.6) | (35.9) | (22.9) | (29.4) |
| Number$^{\text{Mature female}}$ | 2 128 | 500 | 214 | 33 |
| | (26.0) | (18.2) | (17.0) | (10.1) |
| Number$^{\text{Total}}$ | 8 170 | 2 749 | 1 256 | 327 |
| Mass (kg)$^{\text{Total}}$ | 1 684 | 728 | 360 | 88 |
| *Cpue*$^{\text{Total}}$(number trap$^{-1}$) | 87.8 | 29.6 | 13.5 | 17.2 |
| *Cpue*$^{\text{Total}}$(kg trap$^{-1}$) | 18.1 | 7.8 | 3.9 | 4.6 |
| Average size (mm *CL*) | 71.6 | 78.4 | 80.6 | 78.5 |

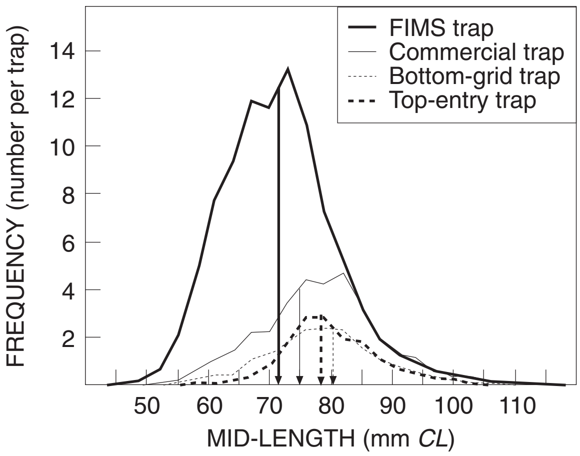


Fig. 2: Size distributions of the catches of *J. lalandii* by the different trap-types used during the survey. Vertical arrows indicate the sample means

that no significant difference could be detected between the number of undersized rock lobsters caught by top-entry experimental traps and that caught by the corresponding commercial traps. There was, however, a significant difference in the corresponding catch rates of legal-sized rock lobsters, with top-entry traps catching 42% less (by mass) than commercial traps. Because top-entry traps neither significantly reduced the rate at which undersized rock lobsters were caught nor increased (or at least maintained) the catch rates of legal-sized specimens, it is clear that they failed to achieve their designated goal. Further analyses were therefore deemed unnecessary.

The second hypothesis that could not be rejected related to catches in FIMS traps. This gear caught significantly more undersized and legal-sized animals than corresponding commercial traps (Tables I, II). However, the latter difference was restricted only to rock lobsters <80 mm *CL*. There was no significant difference between the number of rock lobsters >80 mm *CL* caught in FIMS traps and that caught in commercial traps (Table I).

Commercial traps caught more undersized and more legal-sized specimens than corresponding bottom-grid traps (Table II). However, these reductions in size-specific catch rates between FIMS, commercial and bottom-grid traps were not uniform. For every legal-sized rock lobster landed by FIMS traps, 1.99 undersized rock lobsters were also caught. For commercial traps, this ratio declined to 0.56, whereas bottom-grid traps caught 0.30 undersized rock lobsters for every legal-sized specimen. These trends are reflected by the sample size frequency distributions (Fig. 2), and also by gradients in catches of mature female rock lobsters, which were proportionately greatest for FIMS traps and least for bottom-grid experimental traps (Table II). Therefore, although the operation of each of these three trap-types seemed to be achieving some of their goals, further investigations were required to understand the mechanisms underlying their fishing characteristics and the consequences of these properties.

The selectivity curves generated by the SELECT procedure provided information regarding two fundamental aspects of trap performance. First, they estimated the fishing intensity ($p$) of the trap, which describes the relative likelihood that a rock lobster would enter the trap-type. Second, the SELECT curves defined the probability of captive specimens being retained in the trap as a function of length ($L_{50}$ and $SR$). Whereas this model fits the bottom-grid catch data fairly well (Fig. 3a, Table III), the curve for the complete commercial trap data-set (denoted Fit 1) was significantly over-dispersed (Table III). It was evident that catches from length-classes <70 mm *CL* did not conform to the symmetrical logistic selectivity model (Fig. 3a). Refitting the curve without these data (denoted Fit 2) yielded a substantially improved fit (Fig. 3a, Table III). Henceforth, unless otherwise stated, comments regarding selectivity of standard commercial traps will refer to Fit 2.

For both the commercial and the bottom-grid traps, the three-parameter model had a significantly better fit to the data than the two-parameter alternative, implying that the $p$-values of the two trap-types were significantly different from 0.5. For commercial traps, $p$ was estimated at 0.550, whereas a value of 0.366 was estimated for bottom-grid traps (Table III). Therefore, if confronted by a choice between a FIMS trap and a single trap of another type, a rock lobster would be 22% more likely to enter the alternative, if it was a commercial trap, and 42% less likely to enter the alternative, if it was a bottom-grid trap (Table III).

However, apart from fishing intensity ($p$), there were no marked differences in the selectivity parameters between commercial and bottom-grid traps (Table III). In fact, if approximate confidence limits are calculated for corresponding estimates of $L_{50}$ and $SR$ by adding and subtracting twice their asymptotic standard errors (provided in Table III), there is substantial overlap in both cases. This observation is supported by similarity in the curves presented in Figure 3b. These results imply that escapement from these two traps is similar, but that rock lobsters tend not to enter bottom-grid traps.

Because of the differences in catch rates (Wilcoxon

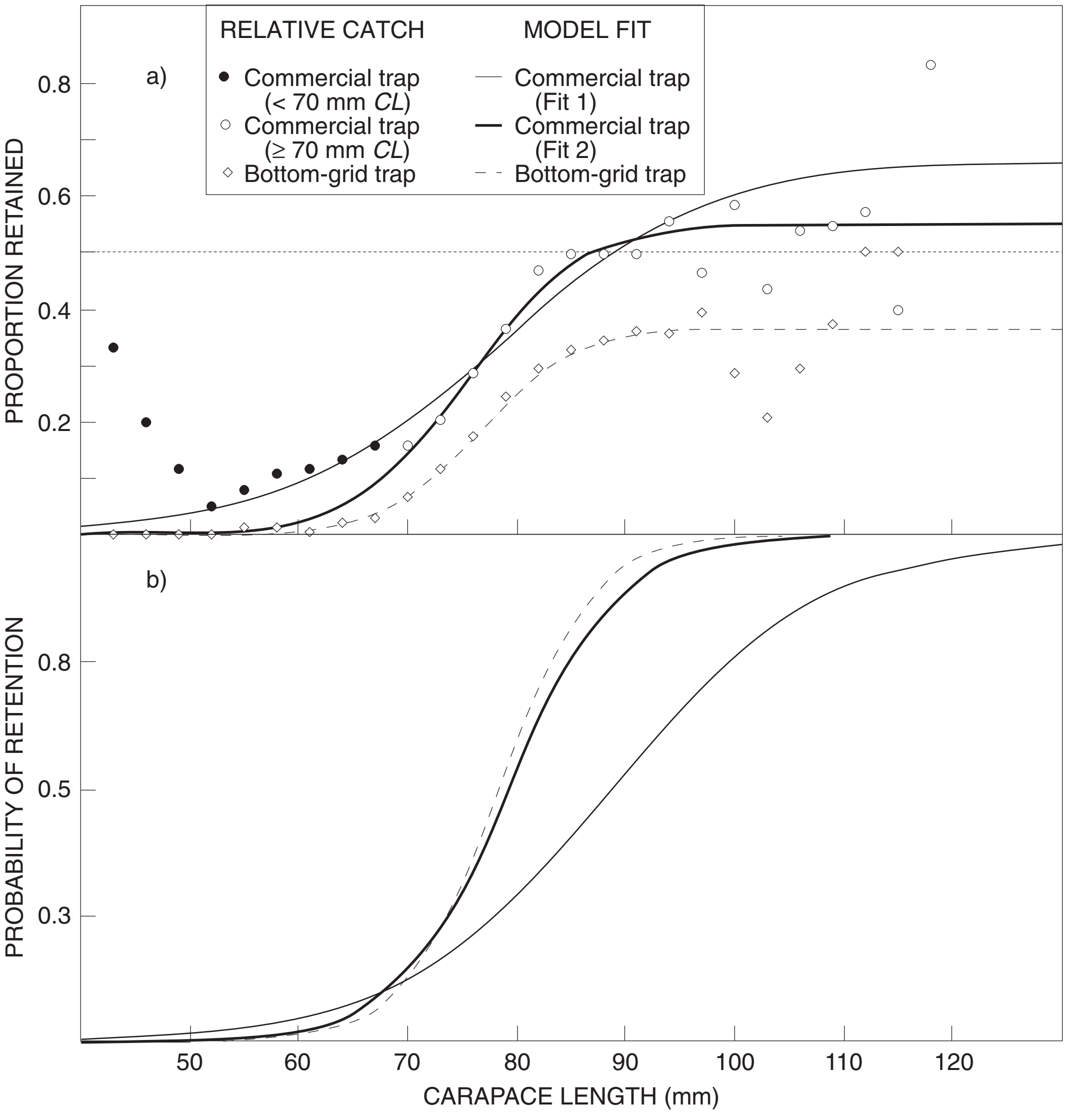


Fig. 3: Selectivity properties of commercial and bottom-grip traps in terms of (a) the proportion of the total catch retained in the experimental gear and (b) the probability of retention of captive specimens by the experimental gear

paired-sample tests – Table I), it may be assumed that the efficiency of bottom-grid or FIMS traps relative to commercial traps ($\gamma_{\beta}^{trap\text{-}type}$) can be approximated for any particular category ($\beta$) of rock lobster by their relative catch of that category accumulated during the 114 longline sets (Table II, Table IV).

Under this assumption, the present simple model indicates that, as the legislated proportion ($\alpha$) of bottom-grid traps in the industrial gear increases from 0 (commercial traps only) to 1 (bottom-grid traps only), the relative effort required to land a unit mass (*TAC*) of rock lobster increases (Fig. 4a). Simul-

Table III: Statistics from SELECT analysis. Values in parenthesis are asymptotic standard errors (*sensu* Millar 1993). These standard errors are provided only for the best model fits for each of the various categories of data

| Parameter | Commercial traps: all data (Fit 1) | | Commercial traps excluding size-classes < 70 mm *CL* (Fit 2) | | Bottom-grid traps | |
|---|---|---|---|---|---|---|
| | $p = 0.5$ | $p$ estimated | $p = 0.5$ | $p$ estimated | $p = 0.5$ | $p$ estimated |
| $a$ | -9.970 | -9.134 | -17.609 | -15.647 | -15.358 | -18.562 |
| $b$ | 0.128 | 0.103 | 0.228 | 0.197 | 0.183 | 0.237 |
| $p$ | 0.500 | 0.663 (0.083) | 0.500 | 0.550 (0.022) | 0.500 | 0.366 (0.017) |
| $L_{50}$ (mm) | 78.120 | 88.699 (6.503) | 77.164 | 79.243 (1.099) | 83.918 | 78.266 (0.743) |
| $SR$ (mm) | 17.216 | 21.337 (2.918) | 9.628 | 11.128 (1.061) | 12.006 | 9.264 (0.547) |
| Proportion of experimental traps ($\phi$) | | 0.500 | | 0.500 | | 0.500 |
| Relative fishing efficiency* | | 1.967 | | 1.222 | | 0.577 |
| *$H_0$: data have binomial distribution (i.e. data are not overdispersed)* | | | | | | |
| Deviance | 179.595 | 116.453 | 26.690 | 17.763 | 58.805 | 24.629 |
| $df$ | 24 | 23 | 15 | 14 | 24 | 23 |
| $p$-value | <0.001 | <0.001 | 0.031 | 0.218 | <0.001 | 0.370 |
| *$H_0$: 2-parameter model fits better* | | | | | | |
| Deviance | | 63.142 | | 8.928 | | 34.177 |
| $df$ | | 1 | | 1 | | 1 |
| $p$-value | | <0.001 | | 0.003 | | <0.001 |

* Relative likelihood that, given a choice between entering a FIMS trap or an alternative trap, a lobster will choose the alternative trap. Its value is calculated by: $(p/\phi)/[(1-p)/(1-\phi)]$

taneously, the relative catch of mature female and undersized rock lobsters decreases. At the current $\alpha$-level of 0.2, 9% more effort is required to land the *TAC* than would be necessary if bottom-grid traps were not used. In comparison, 6% less undersized and mature female animals are caught. If commercial and bottom-grid traps were used in a 1:1 ratio, a 27% increase in effort would be required to land the *TAC*, and this would be rewarded by a decrease of 17% in the catches of both undersized and mature female rock lobsters. A move to bottom-grid experimental traps only would mean an increase in effort of 75% and a decreased catch of undersized and mature female rock lobsters of 47 and 46% respectively.

As anticipated, if FIMS traps are considered as an alternative to regular commercial gear, the model indicates opposing trends. As more commercial traps are replaced by FIMS traps, the effort required to land any given *TAC* decreases, but the catches of undersized and mature female lobsters increases (Fig. 4b). If commercial and FIMS traps were used in a 1:1 ratio, the effort (relative to that using commercial traps only) would decrease by 18%, but catches of undersized and mature female rock lobsters would increase by 124 and 107% respectively. If FIMS traps replaced all standard commercial gear, the effort level would be reduced by 31%, whereas the catches of undersized specimens would rise by 210% and those of mature females by 181%.

## DISCUSSION

The mechanical selection of target organisms by traps is conventionally described primarily as a function of the greatest dimension of the trap's covering (Krouse 1989). Although this principle is not in question, the results of the present experiment illustrate that other factors may substantially modify the ability of *J. lalandii* to escape from traps. The South African fishery for *J. lalandii* is unusual in that standard commercial traps are covered with mesh having an aperture considerably wider ($L_{50}$ = 79.2 mm *CL*) than that required

Table IV: The efficiencies ($\gamma_\beta^{\text{trap-type}}$) with respect to various rock lobster categories ($\beta$) of bottom-grid and FIMS traps relative to commercial traps

| Category ($\beta$) | $\gamma_\beta^{\text{Bottom-grid}}$ | $\gamma_\beta^{\text{FIMS}}$ |
|---|---|---|
| Mass of legal-sized specimens | 0.57 | 1.42 |
| Number of undersized specimens | 0.29 | 5.01 |
| Number of mature females | 0.39 | 4.05 |

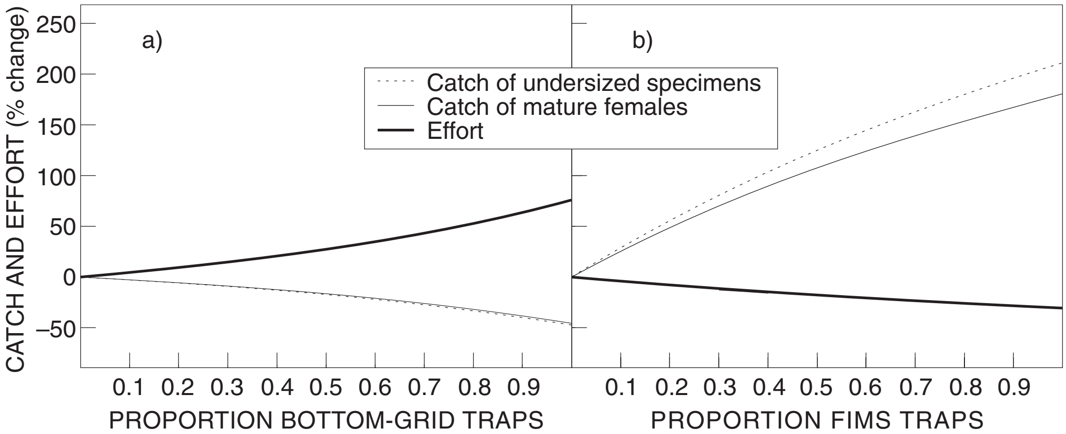


Fig. 4: Relative catch and effort estimates from the deterministic model for (a) bottom-grid traps and (b) FIMS traps

to retain rock lobsters of the current minimum legal size (75 mm *CL*). This is a consequence of recent changes in the management strategy for the resource (Schoeman *et al.* 2001), which stipulated a reduction in minimum legal size (from 89 mm *CL*) without altering the design of the trap. Therefore, it may be concluded that standard commercial traps are capable, without further modification, of achieving a reasonable level of sorting at the new minimum legal size. However, this applies only if the rock lobsters that enter the trap have both the opportunity and an incentive to try to escape before the trap is hauled aboard the fishing vessel.

The gear selectivity reflected by the catch data is likely composed of two separate processes: escape prior to hauling and escape while the trap is hauled through the water. The dimensions of the mesh aperture covering the trap panels regulate the former, whereas the structure and the dimensions of the openings in the codend (be it a mesh bag or a steel grid) influence the latter.

The relatively high estimates for $L_{50}$ (79.2 and 78.3 mm for commercial and bottom-grid traps respectively) imply that almost 50% of rock lobsters <80 mm *CL* can escape traps of both designs before hauling. Furthermore, the similarities of the corresponding selectivity curves suggest few differences in escapement rates at larger or smaller sizes. However, the selectivity properties of the two traps differ markedly during hauling. The codend of standard commercial traps (0.4 m long and 62-mm mesh – Schoeman *et al.* 2001) stretches under the weight of the catch once the trap is lifted from the sea floor. The captive specimens are therefore hauled in a tight mass within a fine-mesh bag, thereby preventing their escape, either through the codend or through the side panels of the trap. By contrast, the base of the bottom-grid trap remains rigid during hauling, affording captive rock lobsters the opportunity to escape through the side panels of the trap, even during hauling. Furthermore, the spacing (44 mm) of the bars in the escape grid corresponds closely with the carapace depth (smallest dimension) of rock lobsters of a carapace length of about 71 mm *CL* (MCM, unpublished data), allowing animals smaller than this an additional route of escape during hauling.

The above-mentioned suggests that the selectivity curve generated for bottom-grid traps is probably a good description of the theoretical selectivity of 100-mm mesh for *J. lalandii*. The similarities between this selectivity curve and that fitted for standard commercial traps (Fit 2) serves to justify the decision here to eliminate size-classes <70 mm *CL* from the latter data before refitting the SELECT curve. The appropriateness of this modified fit is further supported by the observation that catch rates of rock lobsters >80 mm *CL* (a length corresponding approximately to the estimate of $L_{50}$ of this curve) do not differ significantly between standard commercial and FIMS traps, whereas the catch rates of smaller specimens do. However, it should be noted that, by eliminating the smaller size-classes from the SELECT analysis, the utility of the fitted curve to the selectivity of *J. lalandii* is limited to rock lobsters >70 mm *CL* only.

Although the selectivity curves derived for commercial and bottom-grid traps were similar, with regard to the proportion of rock lobsters retained at various sizes, they differed substantially in their estimated relative fishing intensities. These estimates also differed significantly from those implied for FIMS traps. In fact, the SELECT models predict that, given a choice between a FIMS trap and another type of trap, a rock lobster would be 42% less likely to enter the alternative if it was a bottom-grid trap, and 22% more likely to enter the alternative if it was a commercial trap.

The poor performance of bottom-grid traps in attracting rock lobsters may be explained by problems in its design. The metal sorting grid at the base of the trap is secured at one end by steel hinges and at the other by a thin rope tied with a slipknot. Once the trap is deployed, the knot frequently works loose, allowing the grid to gape and close with passing swells. This results in the grid striking the base of the trap, so setting up vibrations that may deter rock lobsters from entering.

Explaining the differential fishing power of commercial and FIMS traps is, however, speculative. In such traps, entry by rock lobsters is theoretically unlimited; therefore, wherever rock lobster abundance is high, the traps fill rapidly and the bait is quickly consumed. Thus, there is little incentive for rock lobsters either to enter the trap or to remain there. Consequently, many animals can escape, either through the mesh or through the entrance funnels (Miller 1990). Nevertheless, some rock lobsters may remain in the trap even though they could easily escape, possibly as a result of the trap being used as a refuge from predators. In support of this hypothesis, a trap that was recovered after being on the seabed for at least a year contained a large number of rock lobsters that were theoretically small enough to pass through the mesh panels. This was despite the trap containing neither bait nor any signs of dead organisms that could have acted as an attractant (MCM, unpublished data). Assuming that the suitability of a trap as a refuge depends on the degree of shading provided by its mesh, it may be inferred that the fine-meshed FIMS traps would retain larger proportions of rock lobsters that could otherwise escape. However, even without this refuge effect, FIMS traps would retain a greater proportion of individuals <80 mm *CL* because of their mesh selectivity properties. The resultant crowding within FIMS traps that might be caused by these features could result in behavioural responses among captive rock lobsters that could deter additional animals from entering. Should this occur, it would suggest some level of trap saturation in FIMS gear, a phenomenon common in crustacean trap fisheries (Krouse 1989, Miller 1990), especially those that do not allow appreciable escapement.

An important implication of trap saturation is that catches made by the gear under consideration may not accurately reflect either the size distribution or abundance of *in situ* rock lobster populations, especially where abundances are high. This principle is supported by the earlier work of Pollock and Beyers (1979), who found that traps covered with 62-mm mesh caught relatively fewer small (<70 mm *CL*) *J. lalandii* than did divers sampling the same area.

The possibility that FIMS traps may become saturated has important implications for the management of the *J. lalandii* resource in South Africa. The operational management procedure currently employed uses both FIMS *cpue* and commercial *cpue* as indices of relative abundance (Johnston 1998, Cockcroft and Payne 1999). Although biases are acknowledged in both data sources, trap saturation is not explicitly considered. Therefore, should it occur, trap saturation may result in underestimates of population size, especially in areas where rock lobsters are abundant. However, an important assumption of the SELECT models used here is that FIMS traps do not allow rock lobsters >60 mm *CL* to escape. Crustaceans can escape through the entrance funnels of traps (Miller 1990), or even through gaps in the gear that are seemingly too small to allow passage (Treble *et al.* 1998). *J. lalandii* may behave likewise, which may provide an alternative explanation for the overdispersion of the SELECT model for the entire catch by commercial traps (Fit 1). It would also imply that the fishing power of both commercial (for both Fits 1 and 2) and bottom-grid traps could have been overestimated, because both the comparative fishing power and the rate of escapement from FIMS traps had been underestimated. This remains an important area of research with respect to the fishery ecology of *J. lalandii*, which could be evaluated by simple field and laboratory experiments.

Despite the above concerns, the present models, based purely on relative catch rates of various categories of rock lobster by the three trap-types, are free of troublesome assumptions. These calculations suggest that including bottom-grid traps in commercial gear may increase the effort required to land a *TAC* by as much as 75%. Corresponding decreases in the catch rates of undersized and mature female rock lobsters were estimated at 47 and 46% respectively. As mentioned previously, there is appreciable escapement from bottom-grid traps, probably through the grid during hauling; small rock lobsters may even be forced through the bottom-grid as the trap is hauled through the water. Because this sorting process is unlikely to be substantially less harmful than on-deck sorting in a deck-grid sorter (Schoeman *et al.* 2001), it is concluded that the use of bottom-grid traps has few significant benefits. Furthermore, given that bottom-grid traps are widely disliked by commercial fishers, because of the operational dangers associated with their greater mass and with emptying them in rough seas, there can be little justification for the continued enforced use of this gear.

It should be noted, however, that because of the experimental design, the comparison here between standard commercial traps and bottom-grid traps holds only for overnight soaks (average soak time >18 h). Currently, there is a tendency among local fishers to soak traps for considerably shorter periods (<4 h) during daylight. This practice results in decreased opportunities for captive rock lobsters to escape, which in turn means that larger proportions of undersized animals are brought to the surface in standard commercial traps than predicted by the SELECT model (MCM, unpublished data). Should this trend continue, future investigations should be designed to re-evaluate the efficiency of bottom-grid traps relative to commercial traps over the shorter soak times currently used.

The other alternative for changing the performance of commercial gear would be to revert to the mesh size used prior to 1984 (62 mm, stretched). This mesh size is used on FIMS traps, as well as on traps used in the Namibian *J. lalandii* fishery, albeit to catch rock lobsters at a smaller minimum legal size of 65 mm *CL* (Grobler and Noli-Peard 1997). If this mesh were used on all traps in the South African *J. lalandii* fishery at the current minimum legal size of 75 mm *CL*, the effort required to land any given *TAC* would be reduced by about 31%. However, the corresponding penalties in terms of catches of undersized and mature female rock lobsters would be unacceptably high. The disadvantages of changing to FIMS traps are compounded by a likely alteration in the catch size-structure. The average size would decrease, resulting in an increase in the time required to sort the legal-sized from the under-sized catch. Even if the use of deck-grid sorters were to be retained, the increased volume of catch per trap achieved by FIMS gear would probably result in the blockage of escape gaps in the grid, so necessitating laborious hand-sorting and increased processing time. Therefore, a reduction in mesh size also seems inappropriate.

Trials with top-entry traps showed that they failed to prevent a decline in the catch rate of legal-sized specimens. This trap design was also unsuccessful in achieving a decline in the catch rate of undersized rock lobsters, despite the presence of gaps large enough to allow almost all of them to escape. A possible reason for this failure was the positioning of the only entrance funnel below the point of attachment of the hauling rope. Any movement of the rope could have deterred rock lobsters from approaching this entrance, so explaining the low catch rates of legal-sized specimens. However, most rock lobsters smaller than about 80 mm *CL* would have been able to pass freely through the mesh panels at the sides of the trap. This would account for the similarities in catch rates of undersized specimens by top-entry and standard commercial traps in the present study.

It is concluded that those modifications to standard commercial gear tested here would not be beneficial to the fishery in the long-term, if overnight sets remain the most common fishing method. Relative to commercial gear, top-entry traps failed to reduce the catches of undesirable categories of rock lobster, while catching significantly fewer legal-sized specimens. Bottom-grid traps achieved better results, but the moderate decreases in catches of undersized and mature female rock lobsters by this gear were accompanied by unreasonably large increases in the effort required to land a commercial *TAC*. Similarly, although FIMS traps may enable commercial *TAC*s to be landed slightly more efficiently, this would be accompanied by massive increases in the catch rates of undersized and mature female rock lobsters.

Nevertheless, further investigations into the potential benefits of escape gaps should not be neglected. Future studies could concentrate on the potential advantages of alternative materials and trap designs. Of particular interest are the underlying mechanisms driving the low fishing power of bottom-grid traps, the possible saturation of FIMS traps and the influence of soak time on fishing performance.

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## LITERATURE CITED

ARANA, P. E. and S. V. ZILLER 1994 — Modelling the selectivity of traps in the capture of spiny rock lobster (*Jasus frontalis*), in the Juan Fernandez archipelago (Chile). *Investigación pesq., Santiago* **38**: 1–21.

BERGH, M. O. and S. J. JOHNSTON 1992 — A size-structured model for renewable resource management, with application to resources of rock lobster in the South-East Atlantic. In *Benguela Trophic Functioning*. Payne, A. I. L., Brink, K. H., Mann, K. H. and R. Hilborn (Eds). *S. Afr. J. mar. Sci.* **12**: 1005–1016.

BROWN, C. G. 1982 — The effect of escape gaps on trap selectivity in the United Kingdom crab (*Cancer pagurus* L.) and lobster (*Homarus gammarus* (L.)) fisheries. *J. Cons. int. Explor. Mer.* **40**: 127–134.

BROWN, R. S. and N. CAPUTI 1985 — Factors affecting the growth of undersize western rock lobster, *Panulirus cygnus* George, returned by fishermen to the sea. *Fishery Bull., Wash.* **83**(4): 567–574.

CHITTLEBOROUGH, R. G. 1975 — Environmental factors affecting growth and survival of juvenile western rock lobsters *Panulirus longipes* (Milne-Edwards). *Aust. J. mar. Freshwat. Res.* **26**(2): 177–196.

COCKCROFT, A. C. and P. C. GOOSEN 1995 — Shrinkage at moulting in the rock lobster *Jasus lalandii* and associated changes in reproductive parameters. *S. Afr. J. mar. Sci.* **16**: 195–203.

COCKCROFT, A. C. and A. I. L. PAYNE 1999 — A cautious fisheries management policy in South Africa: the fisheries for rock lobster. *Mar. Policy* **23**: 587–600.

CROUS, H. B. 1976 — A comparison of the efficiency of escape gaps and deck grid sorters for the selection of legal-sized rock lobsters *Jasus lalandii*. *Fish. Bull. S. Afr.* **8**: 5–12.

DAVIS, G. E. 1981 — Effects of injuries on spiny lobster, *Panulirus argus*, and implications for fishery management. *Fishery Bull., Wash.* **78**(4): 979–984.

EVERSON, A. R., SKILLMAN, R. A. and J. J. POLOVINA 1992 — Evaluation of rectangular and circular escape vents in the northwestern Hawaiian Islands lobster fishery. *N. Am. J. Fish. Mgmt* **12**: 161–171.

FOGARTY, M. J. and V. D. BORDEN 1980 — Effects of trap venting on gear selectivity in the inshore Rhode Island American lobster, *Homarus americanus*, fishery. *Fishery Bull., Wash.* **77**: 925–933.

GROBLER, C. A. F. and K. R. NOLI-PEARD 1997 — *Jasus lalandii* fishery in post-independence Namibia: monitoring population trends and stock recovery in relation to a variable environment. *Mar. Freshwat. Res.* **48**: 1015–1022.

HEYDORN, A. E. F. 1969 — Notes on the biology of *Panulirus homarus* and on length/weight relationships of *Jasus lalandii*. *Investl Rep. Div. Sea Fish. S. Afr.* **69**: 26 pp.

JOHNSTON, S. J. 1998 — The development of an operational management procedure for the South African west coast rock lobster fishery. Ph.D. thesis, University of Cape Town: 370 pp.

KROUSE, J. S. 1989 — Performance and selectivity of trap fisheries for crustaceans. In *Marine Invertebrate Fisheries: their Assessment and Management.* Caddy, J. F. (Ed.). New York; Wiley: 307–325.

MILLAR, R. B. 1993 — Analysis of trawl selectivity studies (addendum): implementation in SAS. *Fish. Res.* **17**: 373–377.

MILLAR, R. B. and S. J. WALSH 1992 — Analysis of trawl selectivity studies with an application to trouser trawls. *Fish. Res.* **13**: 205–220.

MILLER, R. J. 1990 — Effectiveness of crab and lobster traps. *Can. J. Fish. aquat. Sci.* **47**: 1228–1251.

NEWMAN, G. [G.] and D. [E.] POLLOCK 1969 — The efficiency of rock lobster fishing gear. *S. Afr. Shipp. News Fishg Ind. Rev*. **24**(6): 79, 81.

POLLOCK, D. E. 1986 — Review of the fishery for and biology of the Cape rock lobster *Jasus lalandii* with notes on larval recruitment. *Can. J. Fish. aquat. Sci*. **43**(11): 2107–2117.

POLLOCK, D. E. and C. J. DE B. BEYERS 1979 — Trap selectivity and seasonal catchability of rock lobster *Jasus lalandii* at Robben Island sanctuary, near Cape Town. *Fish. Bull. S. Afr*. **12**: 75–79.

POLLOCK, D. E., COCKCROFT, A. C. and P. C. GOOSEN 1997 — A note on reduced rock lobster growth rates and related environmental anomalies in the southern Benguela, 1988 –1995. *S. Afr. J. mar. Sci*. **18**: 287–293.

POLLOCK, D. E., COCKCROFT, A. C., GROENEVELD, J. C. and D. S. SCHOEMAN 2000 — The commercial fisheries for *Jasus* and *Palinurus* species in the South-East Atlantic and South-West Indian Oceans. In *Spiny Lobster Fisheries and Culture.* Phillips, B. F. and J. Kittaka (Eds). Oxford; Blackwell Scientific: 105–120.

ROSA-PACHECO, R. D. L. and M. RAMÍREZ-RODRÍGUEZ 1996 — Escape vents in traps for the fishery of the California spiny lobster, *Panulirus interruptus*, in Baja California Sur, Mexico. *Ciênc. mar., Baja Calif., Méx.* **22**: 235–243.

SCHOEMAN, D. S., COCKCROFT, A. C., VAN ZYL, D. L. and P. C. GOOSEN 2001 — Changes to regulations and the gear used in the South African commercial fishery for *Jasus lalandii*. *S. Afr. J. mar. Sci.* **24**: 365–369.

SPARRE, P. and S. C. VENEMA 1998 — Introduction to tropical fish stock assessment. *F.A.O. Fish. tech. Pap.* **360/1**: 407 pp.

TREBLE, R. J., MILLAR, R. B. and T. I. WALKER 1998 — Size-selectivity of lobster pots with escape-gaps: application of the SELECT method to the southern rock lobster (*Jasus edwardsii*) fishery in Victoria, Australia. *Fish. Res.* **34**: 289–305.

XU, X. and R. B. MILLAR 1993 — Estimation of trap selectivity for male snow crab (*Chionoecetes opilio*) using the SELECT modeling approach with unequal sampling effort. *Can. J. Fish. aquat. Sci.* **50**: 2485–2490.

ZAR, J. H. 1984 — *Biostatistical Analysis*, 2nd ed. Englewood Cliffs, New Jersey; Prentice-Hall: xiv + 718 pp.