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Contrasting sizes at sexual maturity of southern rock lobsters (*Jasus edwardsii*) in the two Victorian fishing zones: implications for total egg production and management

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Abstract. Fecundity (*F*) of *Jasus edwardsii* Hutton (Decapoda:Palinuridae) in the two Victorian fishing zones (Eastern and Western) was estimated from egg masses collected from 98 mature females (97–164 mm carapace length, CL) and was found to be related to carapace length (CL) by the equation $F = 0{\cdot}0316L^{3.359}$ ($r^2 = 0{\cdot}8539$; $n = 571$). Size at onset of sexual maturity (SOM), estimated from samples of the commercial catch ($n = 3891$) and analysed to determine the smallest size class in which 50% of females were carrying eggs or possessed ovigerous setae, was lower in the Western Zone (90 mm CL) than in the Eastern Zone (112 mm CL). Fecundity and SOM estimates and length frequencies in the commercial catch were used to estimate the relative reproductive potential (RRP) of each 5-mm-CL size class. The maximum RRP in the Western Zone was attributed to the size classes of 105 (38%) and 110 mm CL (25%), whereas the maximum RRP in the Eastern Zone was attributed to the size classes between 130 (40%) and 135 mm CL (16%). This study indicates that the current minimum legal size limits need to be reassessed and that separate management strategies for the two zones need to be considered.

Introduction

The current Victorian annual commercial catch of *Jasus edwardsii* is around 500 t, representing 10% of the south-east Australian fishery. The Victorian fishery is divided into an Eastern Zone and a Western Zone (Fig. 1), with over 80% of the catch being taken in the latter. Current management of the Victorian commercial fishery is based on input controls, with limited entry licences and pot numbers, closed seasons, minimum legal carapace lengths (110 and 105 mm CL for males and females respectively), and escape gaps in pots (Anon. 1994). However, a recommendation to move towards a quota management system was recently announced (Anon. 1996). Catch rates in the fishery have shown a steady decline from 2·5 kg pot-lift^{-1} in the 1950s to current values of 0·5 and 0·3 kg pot-lift^{-1} in the Western and Eastern Zones respectively (Hobday and Smith 1996).

A current management objective in Victoria is to maintain at least 25% of the virgin egg production. Size at onset of sexual maturity (SOM) and fecundity are key biological parameters used to assess egg production and the applicability of size limits in a fishery. However, no fecundity estimates have been published for *J. edwardsii* in Australian waters, and the only estimate of SOM in Victorian waters (96 mm CL) comes from a small area west of Apollo Bay (Treble 1996), near the boundary of the two fishing zones (Fig. 1).

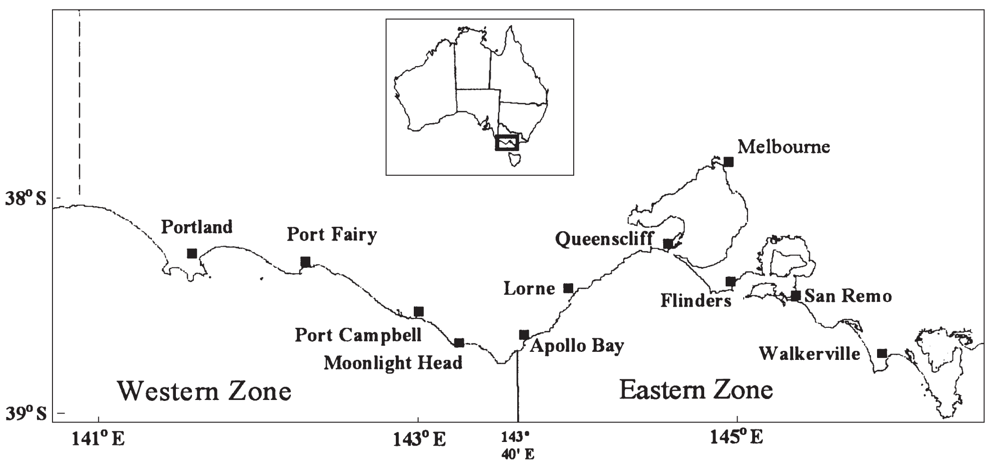

Fig. 1. Commercial fishing zones and major fishing ports mentioned in the text.

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Characteristics used to establish sexual maturity in lobsters include changes in morphometric relationships, dimorphism of pleopods, condition of ovaries, presence of eggs, presence of a spermatophoric mass, and changes in sternal plates (Aiken and Waddy 1980). Presence of ovigerous setae on the pleopods of *J. edwardsii* females has been shown to have a strong correlation with mature ovaries (Annala *et al.* 1980; MacDiarmid 1989*a*). Most maturity measurements of *J. edwardsii* have used the presence of eggs or ovigerose setae on females to establish size-related estimates. Throughout the present paper, estimates of SOM refer to the size class in which 50% of females are mature, determined by the presence of eggs or ovigerose setae as described in Wenner *et al.* (1974).

SOM is thought to vary because of a number of influences, including temperature, growth rate, age, metabolic rate, population density, food availability, and other environmental factors (Annala *et al.* 1980). Temperature has been implicated as a major influence on SOM of local populations of *J. edwardsii* (Bradstock 1950; Street 1969; Annala *et al.* 1980), with larger estimates of SOM in warmer areas with faster growth rates compared with colder environments.

SOM of *J. edwardsii* varies geographically. Females reach sexual maturity between 90 and 95 mm CL in waters off south-eastern South Australia, whereas sexual maturity in waters off western South Australia occurs between 112 and 114 mm CL (J. Prescott, SARDI, personal communication). In New Zealand waters, SOM in different areas varies by more than 30 mm CL: from 72 mm CL near Gisborne to 90 mm CL at Tauroa Point, 107 mm CL at Stewart Island, and 121 mm CL in eastern Foveaux Strait (Annala *et al.* 1980). Similarly, estimates of SOM for Tasmania have shown a marked variation, from 112 mm CL in the warmer northern waters near King Island to 41 mm CL in the colder south-western waters (R. Kennedy, Tasmanian DPIF, personal communication).

Size limits are often set to ensure that lobsters breed at least once before recruitment into the fishery (Annala *et al.* 1980). The minimum legal length (MLL) for females in Victorian waters (105 mm CL) should ensure reproductive opportunities before recruitment into the fishery. However, the proportion of eggs produced by the smaller size classes can be affected by their lower fecundity and lower proportion of mature females. In this paper, the relationships between fecundity, carapace length and SOM are presented. These data refine previous estimates of egg production and have implications for management of the Victorian fishery.

Materials and methods

Fecundity

In all, 124 females (97–164 mm CL) carrying eggs were collected from western and central Victorian waters between September 1994 and July 1996 (Fig. 1, Table 1). Sampling was conducted in such a way as to obtain a wide size range of females. As in previous work (Annala and Bycroft 1987), variability caused by locality was not considered important. Most of the smaller females were caught in the Western Zone and most of the larger ones in the Eastern Zone (Table 1), reflecting the size composition of the commercial catch in each zone (see Results). Most egg samples were collected during July, when the eggs were in an early to mid stage of development, to ensure minimal egg loss. An ice bath was used to pacify the females while the egg-bearing setae were cut from the pleopods with a sharp scalpel. Females were then placed in tanks to recover, and within several weeks they were tagged and returned to the fishing grounds. The carapace length and the weight of the females were recorded at the time of egg removal. Egg samples were placed in 98% ethanol and stored away from light.

Table 1. Sampling data for *Jasus edwardsii* fecundity
Sampling localities are shown in Fig. 1

Date	Sampling locality	Fishing zone	Carapace length range (mm)	*n*
5.ix.94	Queenscliff	East	118–139	7
28.x.94	Port Fairy	West	101–102	2
7.vii.95	Moonlight Head	West	97–123	46
9.vii.95	Walkerville	East	111–164	15
10.vii.95	San Remo	East	105–159	10
21.viii.95	Flinders	East	115–139	10
28.viii.95	Port Campbell	West	105–117	3
16.x.95	Lorne	East	119–146	5
28.xi.95	Portland	West	100–105	4
23.vii.96	Flinders	East	103–147	17
26.vii.96	San Remo	East	120–128	5

Eggs were prepared for counting by filtering off excess liquid and then drying the eggs in an oven at 40°C for at least 24 h. A sieve (mesh size, 7 μm) was used to remove foreign matter and to separate egg clumps. Total dry weight was determined, then three 0·04-g subsamples were taken and the number of eggs in each was counted twice under a dissecting microscope. Each subsample was ranked from 1 to 3 according to the following criteria: *(1)* well separated whole eggs, *(2)* small clusters of eggs that could be counted easily and that had a low proportion (<20%) of ruptured eggs, and *(3)* large clusters of eggs that were difficult to count and that had a large proportion (>20%) of ruptured eggs.

Fecundity (*F*) was estimated from all subsamples with rankings of 1 or 2 ($n = 98$) according to the equation

$$F = (W_t/W_s)E,$$

where W_t is the total dry weight, W_s is the subsample weight, and *E* is the egg count of the subsample. Data from all subsample estimates were then fitted, by means of an SAS non-linear modelling procedure, to the relationship

$$F = aL^b,$$

where *L* is the carapace length (mm) and *a* and *b* are constants (Kensler 1968; Annala *et al.* 1980; MacDiarmid 1989*b*).

SOM

Data used for SOM analysis were collected by observers aboard Victorian commercial rock lobster fishing vessels from January 1994 to October 1996. Biological data were collected on entire catches. Undersized or out-of-season female lobsters were tagged and returned to the water. Victorian rock lobster pots are required to contain escape gaps that are effective in reducing the proportion of undersized animals in the catch

(Treble *et al.*, in press). Thus, to sample undersized lobsters, a small number of pots without escape gaps were used under permit. The information collected for this study included carapace length (to the nearest 0.1 mm), sex (male or female), and sexual condition of females ('berried', carrying eggs; 'setose', ovigerous setae present; 'non-setose', ovigerous setae not present).

Data were divided into the two fishing zones (Fig. 1) and into 5-mm-CL size classes (e.g. the 105-mm-CL size class contains animals between 102·5 and 107·5 mm CL). The percentage of mature females (berried or setose) in each size class was determined and then fitted, by means of an SAS non-linear modelling procedure, to the logistic model

$$M = 1/[1 + \exp(-S \times L - L_{50})],$$

where M is the percentage of mature females in a size class, S is the parameter controlling the slope of the curve at the inflection point, L is the carapace length (mm), and L_{50} is the length at which 50% of females are mature (SOM).

Relative reproductive potential

Morgan (1972) calculated the relative reproductive potential for *Panulirus cygnus* in Western Australian waters by combining the fecundity of individuals of different carapace lengths with their corresponding relative numbers in the population. In the present paper, Morgan's (1972) calculation method is modified by inclusion of the proportion of individuals that are mature in the size classes above the MLL by means of the relationship

$$P_i = C_i M_i F_i,$$

where P_i is the relative egg production or reproductive potential for each size class i above the MLL, C_i is the proportion by number of the size class i in the commercial catch, M_i is the percentage of mature individuals, and F_i is the fecundity.

Results

Fecundity

Fecundity estimated from replicate counts (n = 571) from the 98 samples with ranks of 1 and 2 was found to vary with carapace length (Fig. 2) according to the relationship

$$F = 0{\cdot}0316\ L^{3.359}\ (r^2 = 0{\cdot}8539;\ n = 571).$$

The maximum number of eggs ranged from 152 450 for a 97-mm-CL female to 682 544 for a 150-mm-CL female.

SOM

Eastern Zone. In this zone, 1430 female lobsters were measured. The length–frequency distribution of the commercial catch showed that, as expected, length frequencies increased substantially at the MLL of 105 mm CL for female rock lobsters in Victorian waters (Fig. 3). The size distribution of females in the Eastern Zone is quite broad, with size classes from 105 to 135 mm CL being well represented in samples.

No ovigerous setae were observed on females ≤85 mm CL. The smallest setose female observed was 89 mm CL. The percentage of mature females increased rapidly between 105 and 120 mm CL, with all females >145 mm CL having ovigerous setae (Fig. 3). The fitting of the logistic model to the proportion of mature females in each 5-mm-CL size class in the Eastern Zone resulted in an estimated SOM of 112 mm CL (r^2 = 0·998; n = 23 size classes) (Fig. 3).

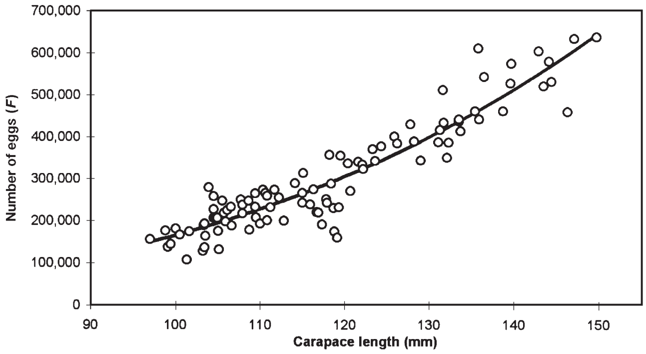

Fig. 2. Relationship between size of female lobsters and number of eggs carried.

Western Zone. In this zone, 2461 females were measured. The length–frequency distribution of the commercial catch in the Western Zone was distinctly different from that in the Eastern Zone, with the highest length frequencies occurring at 105 mm CL and with lobsters >120 mm CL being poorly represented in all samples (Fig. 4).

The percentage of mature females in the Western Zone increased at smaller sizes than did that in the Eastern Zone; the smallest setose female was 75 mm CL. At the MLL of 105 mm CL, more than 90% were mature (Fig. 4), with SOM being estimated at 90 mm CL (r^2 = 0·995; n = 17 size classes) (Fig. 4).

Relative reproductive potential

Relative reproductive potential (RRP) had different characteristics in the two fishing zones. The RRP in the Eastern Zone had significant contributions from larger size classes, whereas that in the Western Zone came predominantly from the smaller size classes above MLL.

Eastern Zone. The size class with the highest RRP in the Eastern Zone was 135 mm CL (Fig. 5), resulting from the large SOM and the high proportion of large females in the catch. More than 50% of the female commercial catch is ≤115 mm CL, but the RRP for these size classes is only 20% (Fig. 5).

Western Zone. The RRP in the Western Zone followed the length distribution of the commercial catch (Fig. 6). The 105-mm-CL size class contains more than 45% of the total commercial catch, and approximately 75% of the female catch is taken in the two size classes of 105 and 110 mm CL. More than 60% of the potential egg production in the Western Zone comes from these two size classes, and more than 37% comes from the 105-mm-CL size class alone.

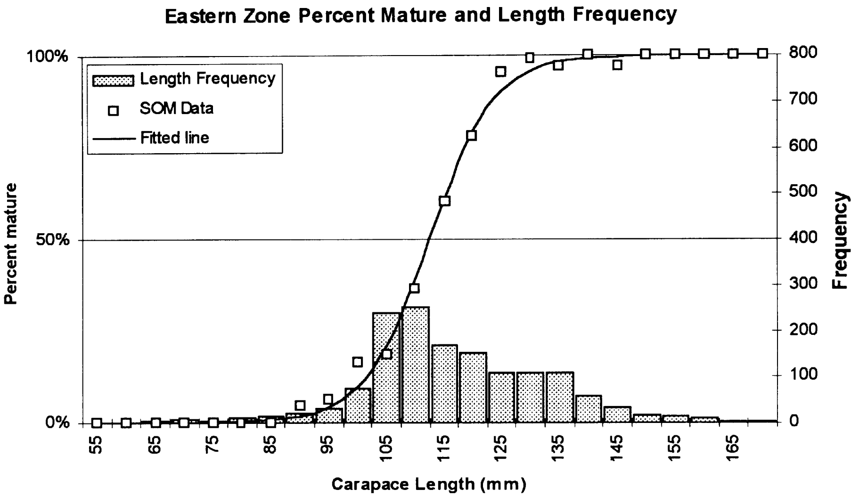

Fig. 3. SOM data and length frequencies for the commercial catch in the Eastern Zone.

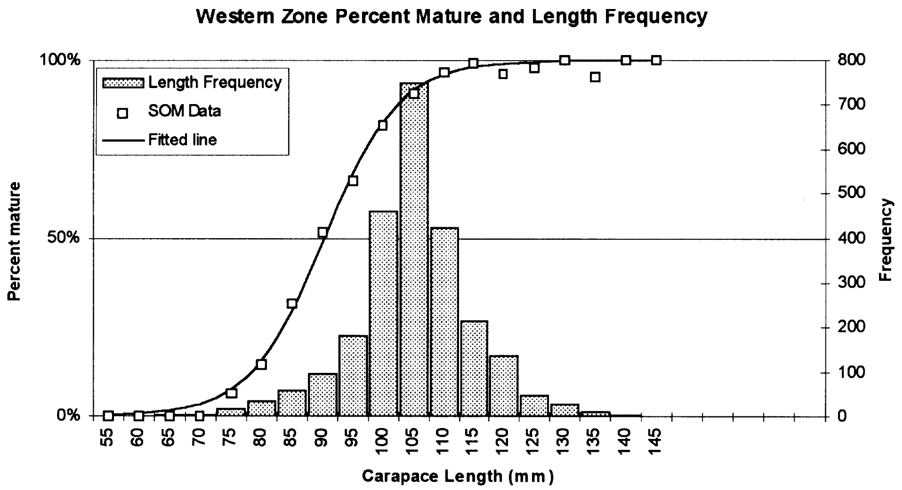

Fig. 4. SOM data and length frequencies for the commercial catch in the Western Zone.

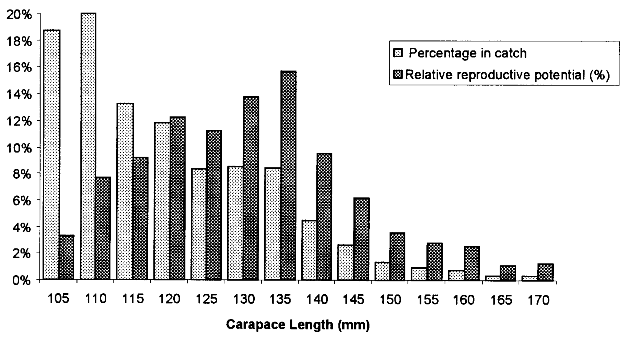

Fig. 5. RRP and the corresponding percentage of the commercial catch in the Eastern Zone, by 5-mm size classes above the MLL.

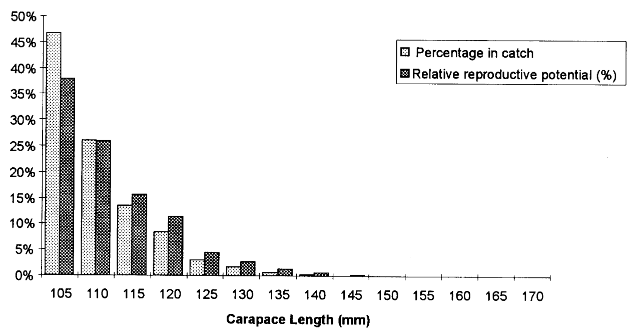

Fig. 6. RRP and the corresponding percentage of the commercial catch in the Western Zone, by 5-mm size classes above the MLL.

Discussion

Although fecundity relationships for *J. edwardsii* have varied in specific studies (Table 2), possibly because of factors such as food availability (Melville-Smith *et al.* 1995), population density (Chittleborough 1979; Beyers and Goosen 1987; MacDiarmid 1989*b*) and water temperature (Annala and Bycroft 1987), no significant correlations have been found within studies relating fecundity to locality or any broad-scale biological or environmental variables (e.g. Annala and Bycroft 1987).

The fecundity estimated in the present study for *J. edwardsii* in Victorian waters is similar to that estimated by other workers for *J. edwardsii* in the same general region (Table 2). Because of this similarity, further refinement of the fecundity relationship by fishing zone in Victoria is probably not necessary. The consistency in the fecundity relationship suggests that environmental conditions are not important in determining the number of eggs produced by a female. Because eggs are adherent to setae, fecundity may be determined by the physical limitation of pleopod size. If so, individuals from areas with higher growth rates would have larger pleopods, enabling them to carry a larger number of eggs.

Some authors argue that the presence of setae on a female is not an absolute guarantee that the animal will produce eggs during the season (Booth 1984; MacDiarmid 1989*b*). Also, setae may be lost during a moult in late spring or summer (October to December) and hence an otherwise mature female may be recorded as immature on the basis that ovigerous setae are absent (Fielder 1964; Annala *et al.* 1980; MacDiarmid 1989*b*). For these reasons, SOM estimates using setae as an indicator of maturity may lead to underestimates of egg production. Furthermore, because smaller females are more likely to moult in late spring or summer, SOM estimates could be biased toward larger size classes.

The present study provides a preliminary picture of SOM in the two Victorian fishing zones. Treble's (1996) SOM estimate of 96 mm CL is consistent with the present findings, as it was derived from an area near the eastern limit of the Western Zone and falls between the present SOM estimates for the two zones (90 mm CL in the Western Zone, 112 mm CL in the Eastern Zone). However, as SOM for *J. edwardsii* has been found to vary geographically (Annala *et al.* 1980), estimation of SOM at a finer geographical resolution within each Victorian fishing zone needs to be investigated.

Egg-per-recruit analysis has estimated current egg production in both Victorian fishing zones at 6–20% of the virgin, unfished stock (Hobday and Smith 1996), which is well below the management target of 25%. The effect of local recruitment resulting from Victorian egg production is unknown, but until recruitment processes are defined, each of the States in the south-eastern fishery (South Australia, Victoria and Tasmania) should aim to maintain suitable levels of egg production.

Options for achieving higher egg production in the Victorian component of the south-eastern fishery include reducing fishing mortality and increasing the MLL. Reducing fishing mortality would in time increase the mean size of individuals in the population, resulting in higher egg production. Protection of setose females as practised in Western Australia may not be appropriate in Victoria because the long closed season on females (June to November) spans the main reproductive period. Increasing the MLL for females from 105 to 110 mm CL (equivalent to the MLL for males) would increase egg production, particularly in the Western Zone, where the maximum RRP currently occurs at the present MLL. However, this would make the MLL 20 mm more than the SOM, which may be overcautious in the long term. Such an increase in MLL in the Eastern Zone would have less effect on overall egg production because of the low RRP of animals at the current MLL and the smaller size of the fishery compared with that in the Western Zone. However, an increase in MLL in the Eastern Zone is necessary, given the low percentage of mature females at the current MLL. Introduction of a maximum legal length may be more appropriate in this zone, where the RRP for size classes of ≥145 mm CL is 17%, representing only 6% of the catch (Fig. 5). However, such a

Table 2. Summary of fecundity studies on *Jasus edwardsii*
F, fecundity; *L*, carapace length

Study	Fecundity relationship	Estimated fecundity at 104 and 120 mm CL	Estimation method	Sampling area
Hickman (1946)	Geometric		2-g wet subsample	Wedge Bay, Tasmania
Kensler (1968)	$F = 0.6921L^{2.69}$	184497 and 271123	2-g wet subsample	Chatham Islands, New Zealand
MacDiarmid (1989*b*)	$F = 0.169L^{3.0091}$	198309 and 305036	Bycroft (1986)	North-eastern New Zealand
Annala and Bycroft (1987)				
Highest	$F = 9.2999L^{2.11}$	166378 and 225023	Bycroft (1986)	New Zealand (various sites)
Lowest	$F = 0.0050L^{3.75}$	183166 and 313256	Bycroft (1986)	New Zealand (various sites)
Present study	$F = 0.0316L^{3.359}$	188322 and 304549	Dry subsample	Western and central Victoria

strategy may not be beneficial, owing to likely increased exploitation of the remaining legal-sized females that, if high enough, could prevent sufficient numbers reaching the maximum legal length.

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