Predicting catches of the western rock lobster (Panulirus cygnus) based on indices of puerulus and juvenile abundance

Nicolavito Caputi, Rhys S. Brown, and Bruce F. Phillips


The western rock lobster fishery is one of the world's largest rock (spiny) lobster fisheries, averaging over 10000 t per year. There are two independent methods of predicting the catch. One is based on an index of abundance of puerulus (9-11 months) settling on collectors made of artificial seaweed. These collectors have been placed at two locations since 1969 and are checked monthly. The other method is based on an index of abundance of juveniles (pre-recruits), which is obtained using catch rates of undersize rock lobsters from a monitoring programme conducted onboard commercial fishing vessels. Indices of puerulus and juvenile abundance have been used in a multiple regression analysis to obtain a multiple correlation of 0.95 with catch and provide accurate predictions of catches. Separate predictions have been determined for the migratory (Nov-Jan) and non-migratory (Feb-Jun) phases of the fishery. Moulting occurs at the start of each of these phases, resulting in new recruits reaching legal size. An increase in the number of escape gaps in 1986 which affected the undersize catch rate is accounted for. The puerulus and juvenile indices complement each other, with the puerulus providing a long-term, up to four years, indication of the likely trends in catch, while the juvenile index provides a more accurate prediction of the catch a year ahead. These predictions have proved of immense value to fisheries managers and fishermen. They enable management to consider management options in response to fluctuations in recruitment before fishing operates on a year class. They also allow for improved financial planning by fishermen.

Introduction

The western rock lobster (Panulirus cygnus George) supports one of the world's largest rock lobster fisheries. It is also the most valuable single-species fishery in Australia, accounting for approximately 20% of the country's gross income from fisheries products. Australia is the largest exporter of rock (spiny) lobster in the world. The range of P. cygnus extends from North West Cape (23°44'S) to just south of Cape Leeuwin (34°24'S), while the fishery is concentrated between Kalbarri and Fremantle, a distance of 500 km (Fig. 1).

The 702 boats licensed for the fishery vary in length from 5 to 28 m, with the majority between 8 and 15 m. These boats operate 72 156 pots during a 7.5 month season (15 November to 30 June).

Since 1963 the fishery has been subjected to limited entry (Hancock, 1981) with the objectives of optimal utilization of the resource, reasonable economic return to the fishermen, and orderly exploitation to minimize conflicts among professional fishermen and between professional and recreational fishermen. The major regulations that support this management regime are a minimum size of 76 mm carapace length, escape gaps in each pot, return of undersize and berried females to the sea, closed seasons and restrictions on boat length, pot numbers and pot design (Phillips and Brown, 1989).

The predictions of the recruitment to the fishery and the catch have been closely monitored by scientists, managers, and fishermen since the first tentative predictions were made in the early 1970s based on indices of puerulus settlement. These predictions were based on the relationship between the index of puerulus settlement and the index of the recruitment during...
November–December four years later (Morgan et al., 1982). Later, Phillips (1986) related the puerulus index to the variation in recruitment and the total catch four years later, since the variation in recruitment during the migratory phase of the fishery in November–January can strongly influence the total catch of the year.

Caputi and Brown (1986) provided an independent method of predicting recruitment success using an index of juvenile abundance obtained from a monitoring programme carried out on the commercial vessels. This study combines both the index of puerulus settlement and the index of juvenile abundance to obtain an improved predictor of the catch. The study also demonstrates that significant numbers of rock lobsters reach legal size in the second half of the rock lobster season (after a moult in February) about 3 years after puerulus settlement, i.e., just after they reach four years of age. This information enables the prediction of the overall catch to be more accurate, and, in particular, the prediction of the catch of the second part of the season. The index of juvenile abundance obtained by Caputi and Brown (1986) has also been revised by determining the abundance of a size class in a given year which is likely to be reflected in the catch of the two parts of the fishing season, November–January and February–June, of the following year.

Life history

The main life history stages of the western rock lobster have been reviewed in detail in Phillips et al. (1980), Hancock (1981), and Morgan et al. (1982). Mating of the western rock lobster takes place during winter and spring (June–November) and the female carries the black spermatophore until October–December, when eggs are extruded, fertilized, and become attached to the pleopods, remaining there for up to nine weeks before hatching. After a 9- to 11-month planktonic phase, the puerulus stage completes the oceanic phase by settling in the shallow limestone reef areas along the coast. The peak settlement of puerulus occurs between September and January.

When juveniles are about 4 to 6 years of age (approx. 70–85 mm carapace), they migrate offshore as immature, pale, newly moulted animals (known locally as ‘whites’), from the shallow inshore reef areas to the outer continental shelf in depths of 40–150 m. The whites migration occurs regularly in November-January each year.

The minimum size for this fishery (76 mm) is generally less than the size at first breeding of females, except for the Abrolhos Islands, where the majority of breeding females are below the legal size (C. F. Chubb, pers. comm.).

Puerulus settlement

The level of settlement has been measured using artificial seaweed collectors (Phillips, 1972), and Phillips and Hall (1978) have shown that the puerulus caught on the collectors provide a measure of natural settlement which occurs along the coast each year. Settlement of the puerulus on the coastal reefs commences in August and continues through to April, with the peak settlement occurring during September to January (Morgan et al., 1982). The index of abundance of puerulus settlement used in this study is based on the average number of puerulus caught per collector per year at Seven Mile Beach (11 km north of Dongara) and Jurien Bay (Fig. 1).

Juveniles

The indices of juvenile abundance are based on length frequency data obtained from a commercial monitoring
Predicting catches of the western rock lobster

Table 1. A representation of the growth of the 68–71 and 72–75 mm size classes in year t−1 to legal size (76 mm) in the following year to illustrate the combination of size class and time periods used for prediction. November and February are the major moulting periods.

<table>
<thead>
<tr>
<th>Juvenile size class (t−1)</th>
<th>Whites catch (t)</th>
<th>Reds catch (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nov–Jan</td>
<td>Feb–Jun</td>
</tr>
<tr>
<td>72–75 mm</td>
<td>Legal size</td>
<td></td>
</tr>
<tr>
<td>68–71 mm</td>
<td>72–75 mm</td>
<td>Legal size</td>
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<tr>
<td></td>
<td>68–71 mm</td>
<td>72–75 mm</td>
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programme which commenced in the 1971/1972 season. Data collected onboard the commercial vessels include: number of pots sampled, carapace length (1-mm intervals) measurements for males and females, pot soak time, and pot type.

These data are obtained from four locations (Donnara, Jurien Bay, Lancelin, and Fremantle; see Fig. 1) for each month of the fishing season (currently 15 November to 30 June) and for four depth categories (0–18, 18–36, 36–54, over 54 m) at each of the four locations.

The catch rates, number caught per pot lift, of undersize animals with carapace length size ranges of 68–71 and 72–75 mm (each moult results in an increase of about 4 mm) provided the basis for an index of abundance of juveniles. Rock lobsters of these size classes are approximately 4 years old. The indices of juvenile abundance were calculated from a multiple regression of logarithmically transformed catch rates with the following factors: year, month, location, sub-locations, depth, soak time, and moon phase (Caputi and Brown, 1986).

Caputi and Brown (1986) determined the index of abundance of all rock lobsters in the size range 68–75 mm and related this to the recruitment and catch of the following year. This study takes into account that the rock lobsters of this size will generally have two moults in a year, during November and February. Thus, in order to predict the catch during November to January of any season, the abundance of juveniles in the size range 68–71 mm during November–January of the previous season and in the size range 72–75 mm during February–June of the previous season are used, as these animals would generally grow to legal size at the appropriate time (Table 1). Similarly, to predict the catch during February–June of a given season, the catch rate of juveniles in the size range 68–71 mm during February–June of the previous season is used. At the current high level of exploitation, the catch is strongly influenced by these newly recruited lobsters.

Because the escape gap used for the 1971/1972 season was 51 mm compared with the 54 mm used for 1972/1973 onward, the estimate of the abundance of four-year-old juveniles for 1971/1972 has not been used.

From the 1986/1987 season onwards, there has been another change to the escape gap configuration with an increase in the number of escape gaps required from one to at least three gaps. Brown and Caputi (1986) estimated that this change would result in a 40–60% decrease in the number of undersize being caught; this would thus affect the estimate of juvenile abundance obtained. A small increase in the subsequent catch may also occur due to an increase in survival and growth of undersize rock lobsters as a result of the changes in the escape gap and better handling of the undersize rock lobsters (Brown and Caputi, 1983, 1985, 1986).

Two approaches are possible to take account of this change in escape gap. The first method requires a correction factor to be obtained from escape gap trials so that the juvenile indices obtained during the multiple escape gap seasons can be adjusted. Separate correction factors would have to be obtained for the 68–71 and 72–75 mm size classes. The second approach would be not to correct the juvenile indices but to add a “dummy” variable in the catch–juvenile relationship, which would have a value of zero for the years when one escape gap was required and a value of 1 for the years requiring multiple escape gaps. This approach would then give an estimation of the effect of the changes in escape gaps on the juvenile catch rate and also take into account any increase in catch as a result of the escape gap change. The latter approach has been used in this study.

Recruitment to the fishery

The estimate of total catch used in this study is based on monthly processor receivals. Previous estimates of total catch have usually been based on fishermen’s catch records (e.g., Caputi and Brown, 1986; Phillips, 1986). Processor data provide a more reliable estimate of total catch as fishermen’s records underestimate the catch in nearly all years.

The rock lobster catch can be divided into two parts: (a) the November–January catch, during which many pale-coloured (“whites”), newly moulted, migratory rock lobsters are caught; and (b) the February–June catch, which is also influenced by the catch of newly
Table 2. Correlation between the catch in year $t$ with the puerulus abundance three and four years earlier for the year classes 1968/1969 to 1983/1984 ($n = 16$). The correlations of the variables selected for multiple regression analysis are indicated in bold. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

<table>
<thead>
<tr>
<th></th>
<th>Whites (t)</th>
<th>Reds (t)</th>
<th>Catch (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov-Jan</td>
<td>0.89***</td>
<td>0.60*</td>
<td>0.83***</td>
</tr>
<tr>
<td>Feb-Jun</td>
<td>0.57*</td>
<td>0.81***</td>
<td>0.71**</td>
</tr>
<tr>
<td>Mean</td>
<td>0.84***</td>
<td>0.78***</td>
<td>0.88***</td>
</tr>
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moulted rock lobsters that reach legal size for the first time. This catch would also include the surviving pale-coloured rock lobsters which have reverted back to their usual dark red colour at the next moult (this part of the fishery is locally referred to as the “reds” fishery).

At the start of both these phases of the fishery a moult occurs which allows a large number of undersize lobsters to grow to legal size and contribute to the catch. While the catch consists of at least three year classes, more than 70% of the catch is made up of animals which have moulted to become legal size during the season.

Results

Puerulus-catch relationship

Table 2 shows that the catch during November to January (whites) is highly correlated ($r = 0.89$) with puerulus abundance four years prior, and this has traditionally been the basis of prediction of the total catch. However, the correlation of this puerulus abundance with the catch during the rest of the year (reds) is fairly low ($r = 0.60$), i.e., only 36% of the variation explained. While the puerulus abundance three years prior does not correlate well with the catch in November-January, it does show a marked improvement in the correlation ($r = 0.81$) with the catch in February-June with 66% of the variation explained. This suggests that recruits may first reach legal size in significant quantities after the moult in February, just over three years after puerulus settlement (i.e., just after they reach four years of age), and most would probably reach legal size by the start of the following season in November. Thus when using the puerulus settlement data to predict the total catch, an average of the puerulus abundance three and four years prior ($P_{t-3,t-4}$) provides a good prediction for the total catch. The following relationship was fitted using a logarithmic transformation and linear regression and has a correlation of 0.88 ($r^2 = 0.77$):

$$\text{Catch}_t = 3.51 P_{t-3,t-4}^{0.245}$$

Juvenile-catch relationship

In the following analysis, unless otherwise specified, any reference to juvenile abundance refers to juvenile males in the size range 68–75 mm, which is just below legal size; most of these animals would be approximately 4 years old.

The relationship between the mean of the juvenile abundance of the 68–71 mm size class in the November–January period and the 72–75 mm size class in the February–June period ($J_{1,-1}$), and the catch in November–January of the following year (Whites) results in a correlation of 0.95 for the 14 years when one escape gap was used (Table 3). The juvenile abundance for the 68–71 mm size class in the February–June period ($J_{2,-1}$) results in a correlation of 0.83 with the catch in February–June of the following year (Reds) (Table 3). This compares with a correlation of 0.73 when using the abundance of juveniles of 68–75 mm for the whole year.

Puerulus–juvenile–catch relationship

Multiple regression analysis has been used to obtain the prediction of the catch for the whole year and for the two parts of the year, November–January and February–June, using both the puerulus and juvenile abundance and a “dummy” variable for a change in escape gaps (EG).

This resulted in a multiple correlation of 0.97 for the logarithmically transformed equation between the catch during November to January and the juvenile index ($J_{1,-1}$) for the previous season and the puerulus abundance index 4 years prior:

$$\text{Whites}_t = 11.7 P_{t-4}^{0.112} J_{t-1}^{0.602} \exp(0.327 \text{EG})$$

The estimates of the parameters of the puerulus abundance ($p < 0.05$), juvenile abundance ($p < 0.001$), and
escape gap variable \((p<0.01)\) were significant. The standard deviation about the regression equation was 0.072. An examination of the residuals showed that the Durbin–Watson statistic was 2.35, indicating no significant autocorrelation trend. The fishing seasons of greatest influence in the relationship were 1987/1988 and 1988/1989 (Cook's distance of 0.41) (Cook, 1977), as these are the two years on which the parameter associated with the escape gap is estimated, and 1973/1974 (Cook's distance of 0.16), the year with the lowest catch during the period.

Figure 2a shows that the catch during November–January since the 1973/1974 season is predicted quite well by the expected catch from the above model. The model correctly predicted that the 1986/1987 season would have the lowest November–January catch in 13 years and an improved catch of 4900 t was predicted for the 1987/1988 season, which compares well with the actual catch of 5200 t. The prediction for the November–January 1989/1990 is for a decrease in catch to 4400 t and preliminary information indicates that a decrease has occurred.

A multiple correlation of 0.87 was obtained for the relationship between the reds catch \((\text{Reds}_t)\), i.e. the catch from February to June, and the juvenile abundance \((\text{J}_{2t-1})\) and puerulus abundance 3 years prior \((\text{P}_{t-3})\):

\[
\text{Reds}_t = 7.08 \text{P}_{t-3}^{0.081} \text{J}_{2t-1}^{0.210} \exp(0.299 \text{EG}).
\]

The significance level of the overall relationship was 0.001 and the standard deviation about the regression was 0.070. The Durbin–Watson statistic of 1.97 indicated that there was no significant autocorrelation of the residuals.

Figure 2b indicates the low catch for the period February–June in 1985/1986 and the improved catches in the following three years were accurately predicted. The prediction for the 1989/1990 season is for a decrease in catch to 5400 t after the very high catches of 6800 and 6500 t for the previous two years. Preliminary data indicate that a decrease has occurred.

For the relationship with total catch, an average of the juvenile indices \((\text{J}_{1t}, \text{J}_{2t})\) used in the relationship with the two parts of the season was used. The relationship for the total catch with the juvenile index \((\text{J}_{12t-1})\) and the average of puerulus abundance index three and four years prior \((\text{P}_{t-3}, \text{P}_{t-4})\) resulted in a multiple correlation of 0.95:

\[
\text{Catch}_t = 22.9 \text{P}_{t-3}^{0.071} \text{J}_{12t-1}^{0.445} \exp(0.367 \text{EG}).
\]

The significance level for the estimates of parameters of both the juvenile abundance and the escape gap variable was 0.001, but the estimate of the puerulus parameter was not significant. The standard deviation about the

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**Figure 2.** The relationship between the catch (solid line) and its predicted value (broken line), based on indices of puerulus settlement and juvenile abundance, for the two parts of the season and the total catch.
relationship was 0.059. The Durbin–Watson statistic of 2.25 indicated no significant autocorrelation.

This relationship correctly indicated that the catches during the 1985/1986 and 1986/1987 seasons were the lowest in 13 years. A marked increase on an above-average catch was predicted for the 1987/1988 and 1988/1989 seasons, and this subsequently occurred. The prediction for the 1989/1990 season is for a decrease from the high catches in recent seasons to an average catch of 10,000 t.

The puerulus data for the more recent period suggest a couple of years of below-average catches in 1990/1991 and 1991/1992 and a return to above-average catches in 1993/1994. More precise predictions for these years will be available when the juvenile abundance index is obtained one year prior to the season.

Discussion

The revision of the juvenile index as used by Caputi and Brown (1986), which was based on all juveniles in the size range 68–75 mm caught and released during the fishing season to an index of the abundance of juveniles which are likely to grow to legal size in the following season, has resulted in a more accurate prediction of catch.

The use of both juvenile and puerulus data in a multiple regression analysis has helped in explaining more of the variation in catch. In previous studies juvenile and puerulus indices have been related separately to the recruitment to the fishery and total catch (Caputi and Brown, 1986; Phillips, 1986), and while providing a good relationship separately, their combined use leads to a more accurate prediction. The puerulus and juvenile indices complement each other, with the puerulus providing a long-term, up to four years, indication of the likely trends in catch, while the juvenile index provides a more accurate prediction of the catch one year ahead.

The number of undersize juveniles caught is, of course, dependent on the number and size of the escape gaps (305 × 54 mm) being used. An increase in the number of escape gaps occurred at the start of the 1986/1987 season, and an escape gap variable has been introduced into the relationship to estimate the correction factor due to the escape gap changes. At this stage only two years of data are available since the escape gap changes, so the estimate of this parameter may be unreliable. This could affect the precision of the catch predictions.

As identified by Caputi and Brown (1986), the use of the male juvenile index continues to result in a slightly stronger relationship with catch than it would if a combined male and female juvenile index is used. This may be due to the size classes chosen better reflecting the growth of males from undersize to legal size.

This study assumes that the growth of the rock lobsters is similar throughout the fishery. This will need further investigation, particularly if predictions are to be made on a regional basis, as is being requested by management.

The effect of fishing effort on the catch was not included in the above relationships, since this did not prove to be a significant factor in explaining the variation in catch since the 1973/1974 season. While there has been an increase of 10–15% in the number of pot lifts from the early 1970s to the early 1980s, this may have resulted in the catch being taken earlier in the season rather than in a marked increase in catch overall. However, the effect of increases in fishing power, and hence effective effort, still needs to be assessed.

It is interesting to note in Figure 2b that in two of the three years of high abundance, 1978/1979 and 1982/1983, the peak in the reds catch occurred four years after the peak in puerulus settlement and not three years after, as appears to be the more typical situation based on the observed data (Table 1). This could be an indication that there may be density-dependent growth occurring during periods of high pre-recruit abundance.

An extensive database on the various life history stages is now available for the rock lobster. The indices of juvenile abundance have provided an important link between the puerulus and recruitment to the fishery stage. The juvenile stage is the first stage in which rock lobsters may be sexed. Thus a prediction of the spawning stock may be possible using the index of female juvenile abundance.

Fisheries managers and fishermen consider the predictions in their consideration of management options in response to fluctuations in recruitment. When a low recruitment was expected in 1986/1987 (based on the 1982/1983 puerulus index and the 1985/1986 juvenile index), a 10% reduction in pot numbers was taken for the 1986/1987 season to protect the breeding stock (Phillips and Brown, 1989). Thus action was taken at the start of the season rather than waiting to the end of the season to obtain a measure of recruitment and taking action to protect the potential breeding stock. In addition, the ability to foresee recruitment accurately allows improved financial planning by fishermen and their financial advisers, who routinely seek information on prediction before major investment decisions are made.

The use of a pre-recruit juvenile abundance index has also been developed for the American lobster (Homarus americanus) fishery off Lower Argyle, southwestern Nova Scotia to enable prediction of the recruited yield one or two seasons later (Campbell, 1990). This fishery has recently experienced a threefold increase in landings such that the pre-recruit abundance will be useful in determining the future trend.

The reliability of the predictions over the years has
given fishermen confidence in the models used for the management of this fishery. This has helped in the acceptance of management decisions since they have been able to validate one aspect of the model prediction. Thus the usefulness of the ability to predict catches reliably should not be underestimated.

Acknowledgements

The authors thank Dr J. W. Penn, Mr N. G. Hall, and other research staff at the Western Australian Marine Research Laboratories for critically reading the manuscript and offering many helpful suggestions.

References