Maori octopus (*Octopus maorum*) bycatch and southern rock lobster (*Jasus edwardsii*) mortality in the South Australian rock lobster fishery

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Abstract—Octopuses are commonly taken as bycatch in many trap fisheries for spiny lobsters (Decapoda: Palinuridae) and can cause significant levels of within-trap lobster mortality. This article describes spatiotemporal patterns for Maori octopus (*Octopus maorum*) catch rates and rock lobster (*Jasus edwardsii*) mortality rates and examines factors that are associated with within-trap lobster mortality in the South Australian rock lobster fishery (SARLF). Since 1983, between 38,000 and 119,000 octopuses per annum have been taken in SARLF traps. Catch rates have fluctuated between 2.2 and 6.2 octopus/100 trap-lifts each day. There is no evidence to suggest that catch rates have declined or that this level of bycatch is unsustainable. Over the last five years, approximately 240,000 lobsters per annum have been killed in traps, representing ~4% of the total catch. Field studies show that over 98% of within-trap lobster mortality is attributable to octopus predation. Lobster mortality rates are positively correlated with the catch rates of octopus. The highest octopus catch rates and lobster mortality rates are recorded during summer and in the more productive southern zone of the fishery. In the southern zone, within-trap lobster mortality rates have increased in recent years, apparently in response to the increase in the number of lobsters in traps and the resultant increase in the probability of octopus encountering traps containing one or more lobsters. Lobster mortality rates are also positively correlated with soak-times in the southern zone fishery and with lobster size. Minimizing trap soak-times is one method currently available for reducing lobster mortality rates. More significant reductions in the rates of within-trap lobster mortality may require a change in the design of lobster traps.

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Fishing traps are used throughout the world to target a wide range of crustaceans, fishes, and cephalopods. Commercial trap fisheries, especially those for decapod crustaceans, are often the most valuable fisheries within a region (Phillips et al., 1994). Traps are generally considered to be an efficient and benign form of fishing because they appear to cause relatively minor damage to benthic habitats, can be designed to target particular species and size ranges, and produce live catches in good condition while minimizing bycatch (Miller, 1990).

There are 49 species of spiny lobsters (Decapoda: Palinuridae) worldwide, 33 of which support commercial trap fisheries. The largest of these are in Cuba, South Africa, Mexico, Australia, and New Zealand (Williams, 1988). The main trap fisheries in Australia are for western rock lobster (*Panulirus cygnus*) in Western Australia and southern rock lobster (*Jasus edwardsii*) along the southern coastline. Octopuses constitute a significant component of the bycatch in both fisheries (Joll[1]; Knight et al.[2]) .

In South Australia, *J. edwardsii* supports the State's most valuable commercial fishery. *Octopus maorum* is a significant bycatch species and is thought to be the major cause of lobster mortality in traps (Prescott et al.[3]).

Although the octopus bycatch of the South Australian rock lobster fishery (SARLF) is saleable, the commercial value of this product does not offset the value of the large number of lobsters that are killed in traps by octopus. Many fishermen are convinced that incidental mortality of octopus resulting from lobster fishing acts to control octopus numbers and that if these rates were reduced, octopus abundance and levels of within trap predation would increase.

Despite the prevalence of octopus bycatch in lobster fisheries, there have been only a few studies on the interaction between octopus and lob-

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[1] Joll, L. 1977. The predation of trap-caught western rock lobster (*Panulirus Longipes cygnus*) by octopus. Department of Fisheries and Wildlife, Western Australia, Report 29, 58 p. [Available from Department of Fisheries, 168–170 St George's Terrace, Perth, Western Australia, 6000.]

[2] Knight, M. A., A. Tsolos, and A. M. Doonan. 2000. South Australian fisheries and aquaculture information and statistics report. Research Report Series 49, 69 p. [Available from SARDI Aquatic Science, 2 Hamra Avenue, West Beach, South Australia 5022.]

[3] Prescott, J., R. McGarvey, Y. Xiao, and D. Casement. 1999. Rock lobster. South Australian Fisheries Assessment Series 99/04, 35 p. [Available from SARDI Aquatic Science, 2 Hamra Avenue, West Beach, South Australia 5022.]

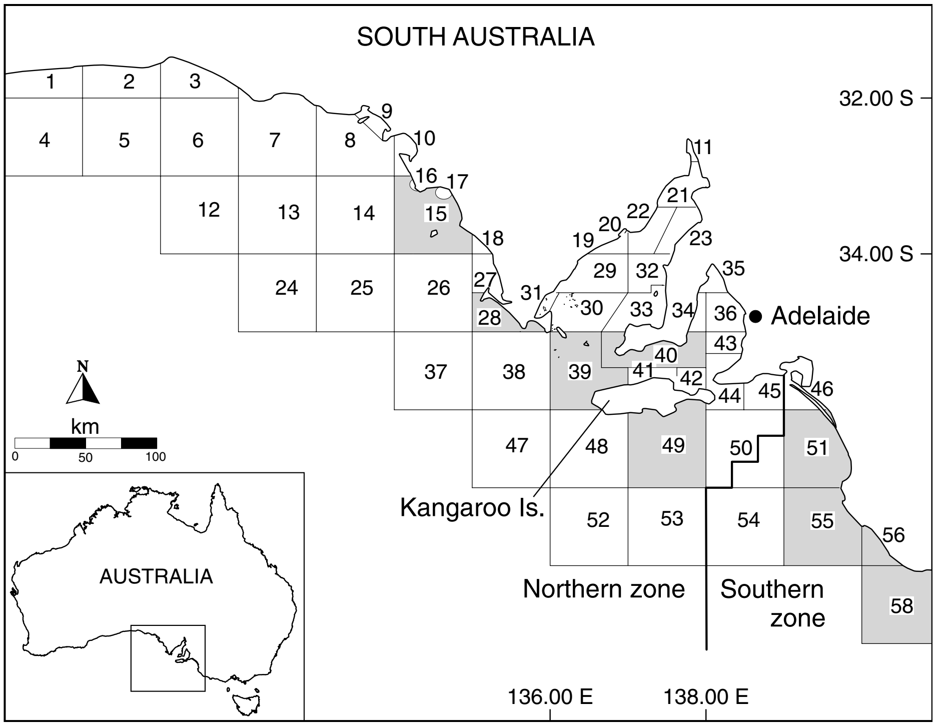

Figure 1

Map of the marine fishing areas (MFAs) of the South Australian rock lobster fishery. Shading shows the MFAs that were considered in this study and where most fishing effort is concentrated.

sters in traps (Joll[1]). Furthermore, there is a paucity of quantitative data on the impact of fishing on octopus populations, the proportion of lobster mortality that is attributable to octopus predation, or the long-term economic and ecological effects that octopus-induced mortality may have on lobster fisheries.

In this study, we examined the interaction between *O. maorum* and *J. edwardsii* in the South Australian rock lobster fishery (SARLF). The objectives were 1) to determine the number of lobsters and octopus caught and the number of lobsters killed in traps each year in the fishery; 2) to describe the interannual and seasonal patterns in lobster catch rate ($CPUE_L$), octopus catch rate ($CPUE_O$), and lobster mortality rate (M_L); 3) to examine some factors that may affect lobster mortality rates; 4) to estimate what proportion of the lobster mortality is attributable to octopus predation; and 5) to determine whether the rate of lobster mortality through octopus predation in traps is size dependent.

Materials and methods

South Australian rock lobster fishery

The SARLF is divided into a northern zone (NZ) and a southern zone (SZ), each of which is further divided into marine fishing areas (MFAs) for statistical purposes (Fig.1). There are 68 and 183 fishermen licensed to operate in the NZ and SZ respectively. The fishing season extends from November to May in the NZ and October to April in the SZ. A quota management system was introduced in the SZ in 1993, whereas the NZ is managed by gear restrictions and temporal closures.

Total annual catch and effort for the SARLF

Catch and effort data are recorded on a daily basis by all individual fishermen. Since 1983, a standardized logbook for recording catch and effort has been used across the fishery. Data provided by fishermen include MFA fished, average depth fished, number of trap-lifts, number and total weight of live lobsters, number of dead lobsters, and number and total weight of octopus. This information is stored in a South Australian rock lobster database that is managed by the South Australian Research and Development Institute, Aquatic Sciences.

Interannual and seasonal patterns in $CPUE_L$, $CPUE_O$, and M_L

Although commercial fishing for lobsters occurs along most of the South Australian coastline, the majority of effort is concentrated in only a few MFAs. In the NZ over the last 5 years about 72% of total trap-lifts were made in MFAs 15, 28, 39, 40, and 49. In the SZ over the same period 95% of trap-lifts were made in MFAs 51, 55, 56, and 58 (Fig. 1).

Data from the database were used to calculate catch rates of lobsters ($CPUE_L$), octopus ($CPUE_O$), and M_L on an annual and monthly basis for the nine major MFAs listed above. Catch rates from these MFAs for each fisherman were calculated according to the formula: *catch rate = catch number*/(*trap-lifts*/*day*). Annual and seasonal trends in $CPUE_L$, $CPUE_O$, and M_L were calculated for each zone and MFA.

Factors that affect within-trap lobster mortality

Potential factors that affect within-trap lobster mortality were analysed by using a general linear model (type-3 sums of squares) under the assumption that the number of dead lobsters follows a log-normal distribution.

The number of dead lobsters/trap-lift/day/license (with a ln+1 transformation) was used as the measure of lobster mortality. A model of the following structure was used to examine factors that affect the numbers of dead lobster:

$$\begin{gathered} \text{Dead lobster} = \text{License} + \text{MFA} + \text{Month} + \text{Year} \\ + \text{Effort} + \text{Depth} + \text{Octopus} + \text{Lobster catch} \\ + \text{Soak-time} + (\text{License} \times \text{Year}) + (\text{License} \times \text{Month}) \\ + (\text{Year} \times \text{Month}) + (\text{Year} \times \text{MFA}) + (\text{Soak-time} \times \text{Year}) \\ + (\text{Soak-time} \times \text{Month}). \end{gathered}$$

In the model, *License* represents an individual fisherman, *MFA* is the marine fishing area, *Month* accounts for seasonal variation and *Year* accounts for interannual variation, *Effort* is the number of trap-lifts/license each day, *Depth* is the average depth fished by each License on a particular day, *Octopus* and *Lobster* are the respective daily catches/license, and *Soak-time* is the number of days that the traps remained in the water since the previous trap-lift.

The interaction terms *License*×*Year* and *License*×*Month* account for variations in the catch characteristics of the individual licenses over time that result from changes in fishing practises and efficiency associated with different boats, license holders, and skippers. The interaction terms *Year*×*Month* and *Year*×*MFA* account for variation in the population dynamics of octopus and lobster over time in different locations that could result in differential trends in lobster mortality. The interaction terms *Soak-time*×*Year* and *Soak-time*×*Month* reflects the change in general fishing strategies over time. In quota-managed fisheries the average soak-time will be affected by a number of factors, for example, that may include price, weather, and the fishermen's perceived ability to catch their quota.

The analysis was run separately for the SZ (n=493,629 traps) and NZ (n=155,628 traps) because the respective zones have different fishing seasons and management structures. The relationship between the number of dead lobsters and the factors depth, soak-time,and number of octopuses and lobsters were presented graphically by the equation:

$$\text{Lobsters killed in traps} \propto \text{factor}^{-\alpha},$$

where α = the parameter estimated by use of the model.

Source of lobster mortality and size-dependent mortality

A sampling program was conducted on three commercial vessels from the SZ during the 2001–02 fishing season. Five days were spent on each vessel. All lobsters caught were measured (carapace length, mm), and the sex (male or female), maturity (mature or immature), status (dead or alive), and cause of death (octopus or other) were recorded.

The method used to distinguish between lobsters killed by octopus or other means followed that of Joll.[1] This suitability of this approach was confirmed through examination of the carcasses of over one hundred lobsters killed by octopus in aquarium trials (Brock et al.[4]). Lobsters with shells that were partly or completely separated at the juncture between abdomen and cephalothorax but were otherwise undamaged were deemed to have been killed by octopuses, whereas lobsters with shells without this separation and with evidence of bite marks were deemed to have been eaten by other predators (fish or cuttlefish).

Anecdotal evidence from fishermen suggests that larger lobsters are more susceptible to predation than smaller ones. The effect of CL on the probability of mortality was examined separately for males and females by generalized linear modeling. The probability of mortality at a given size was modeled with a logistic equation of the form:

$$P(sex, CL) = 1/(1+e^{-(a+bCL)}),$$

where P(sex, CL) = the probability of a lobster of a given sex at carapace length CL being dead; and

a and b are parameters to be estimated.

Results

Estimation of total lobster catch, octopus bycatch, and lobster mortality

In 1999, there were 1.6 million trap-lifts in the SARLF, and 70% of this total effort was in the SZ (Fig. 2). The number of traps-lifts in the SZ declined from 2.2 million in 1983 to 1.2 million in 1999 (Fig. 2A). In contrast, fishing effort in the NZ remained relatively consistent with 406,000 trap-lifts in 1983 and 480, 000 trap-lifts in 1999 (Fig 2B).

The total annual lobster catch has generally increased in each fishing zone since 1983 (Fig. 2, A and B).

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[4] Brock, D. J., T. M. Saunders, and T. M. Ward. In review. A two-chambered trap with potential for reducing within-trap predation by octopus on rock lobster. Can. J. Fish. Aquat. Sci., 19 p. [Available from SARDI Aquatic Science, 2 Hamra Avenue, West Beach, South Australia 5022.]

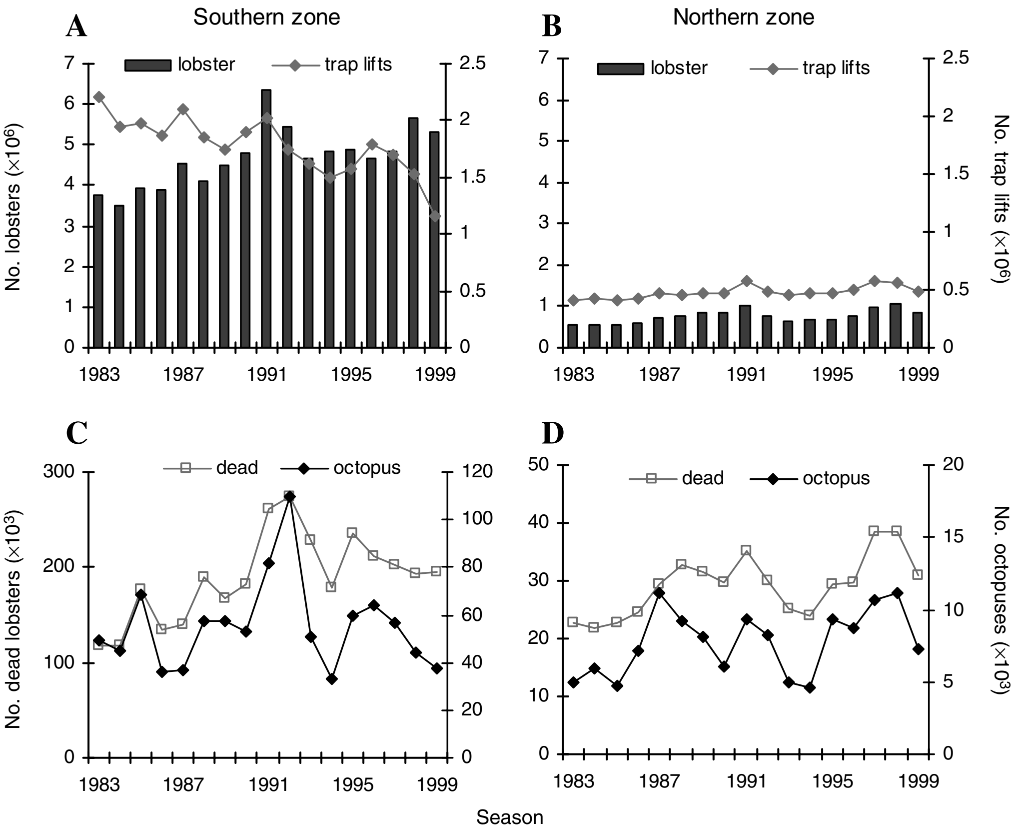

Figure 2

Annual total catch and effort for each zone of the South Australian rock lobster fishery for number of live lobsters caught (**A**), number of trap-lifts used (**B**), number of dead lobsters caught (**C**), and number of octopuses caught (**D**) (Note: change of scale in D).

In the SZ, the annual lobster catch rose from 3.8 million lobsters to a peak of 6.4 million lobsters in 1991 and was 5.4 million lobsters in 1999 (Fig. 2A). In the NZ, 560,000 lobsters were taken in 1983 compared to 850,000 in 1991 (Fig. 2B).

The total annual octopus catch varied among years in both zones, but between 70% and 90% of the total octopus catch were landed in the SZ (Fig. 2). The total number of octopus ranged from 36,000 in 1986 to 109,000 in 1992 (Fig. 2C) in the SZ, and from 4700 octopuses in 1985 to 11,200 in 1998 in the NZ (Fig. 2D).

In 1999, over 226,000 lobsters were killed in traps in the SARLF (Fig. 2). Since 1983, the mean proportion of dead lobsters out of the total catch has been approximately 4%. In the SZ, the number of lobsters killed in traps has generally increased from 118,000 in 1983 to 196,000 in 1999; a peak of 274,000 dead lobsters occurred in 1992 (Fig. 2C). In the NZ, there has also been a general increase in the number of lobster killed in traps each year; 24,000 dead lobsters were recorded in 1983, compared to 31,000 in 1999 and a peak of 39,000 dead lobsters recorded in 1998 (Fig. 2D).

Interannual and seasonal patterns in $CPUE_L$, $CPUE_O$, and M_L

Southern zone Mean annual $CPUE_L$ in the SZ increased from 175 to 466 lobsters/(100 trap-lifts/day) between 1983 and 1999, and the largest increase occurred between 1997 and 1999 (Fig. 3A). Mean annual $CPUE_O$ ranged from 1.8 to 6.2 octopus/(100 trap-lifts/day) in 1987 and 1992, respectively (Fig. 3C). Mean annual M_L rose from 5 to 17 dead lobster/(100 trap-lifts/day) between 1983 and 1999 (Fig. 3E). Peaks in both $CPUE_O$ and M_L occurred in 1985, 1992, and 1995.

Mean monthly $CPUE_L$ declined during the fishing season from 310 to 164 lobster/(100 trap-lifts/day) between October and April (Fig. 4A). In contrast, mean monthly $CPUE_O$ increased from 2.6 to 3.7 octopus/(100 trap-lifts/day) between October and December and declined to 1.8 octopus/(100 trap-lifts/day) in April (Fig. 4C). Similarly mean monthly M_L increased from 10.7 to 12.8 dead lobster/(100 trap-lifts/day) between October and November and declined to 6.7 dead lobster/(100 trap-lifts/day) in April (Fig. 4E).

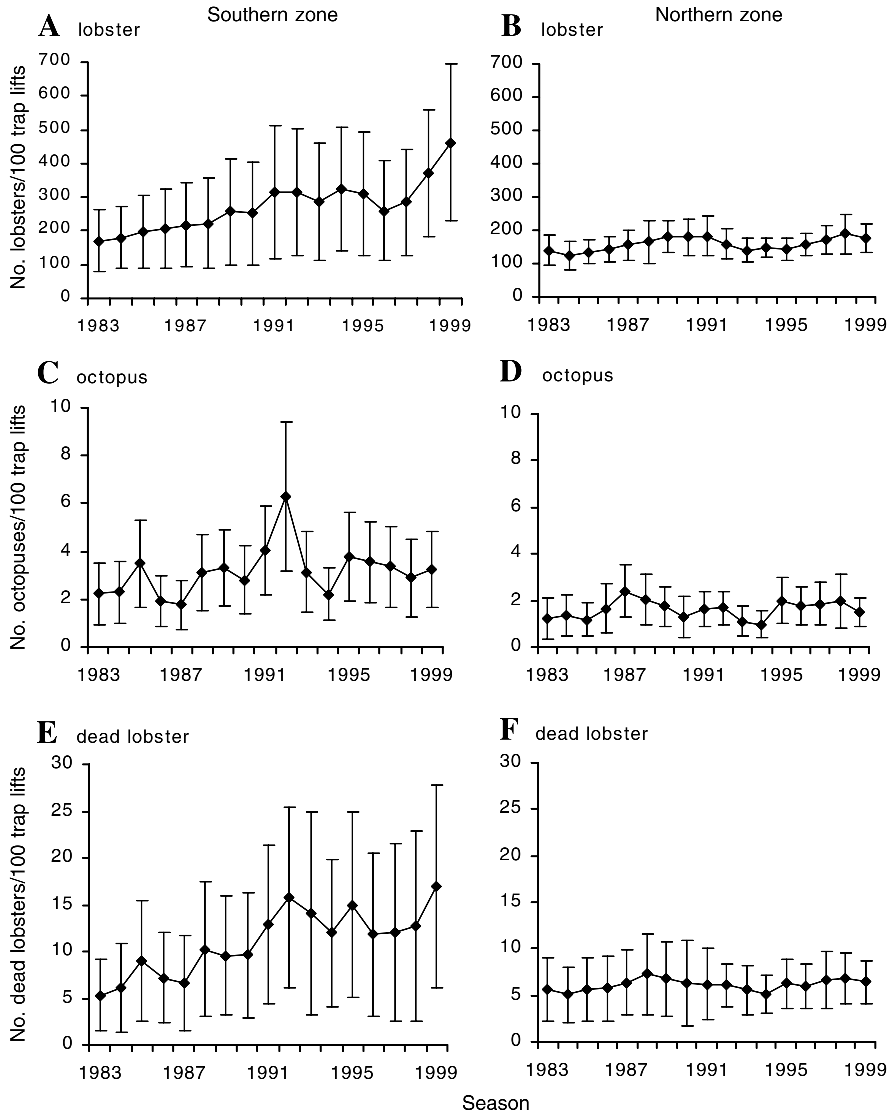

Figure 3

Annual catch rates in each fishing zone for lobsters ($CPUE_L$) (**A** and **B**), octopus ($CPUE_O$) (**C** and **D**), and dead lobsters (M_L) (**E** and **F**). Error bars are ±SD of mean.

Since 1983, mean annual $CPUE_L$ has increased in all MFAs, and has been consistently higher in MFAs 56 and 58 than in other areas (Fig. 5A). $CPUE_O$ has varied among years but has followed similar trends in different MFAs with consistent peaks in 1993 (Fig 5C). Prior to 1992, M_L was similar among MFAs but after 1992 was generally highest in MFAs 56 and 58 (Fig. 5E). M_L has increased over time in all MFAs.

Northern zone In the NZ, mean annual $CPUE_L$ rose from 135 to 179 lobsters/(100 trap-lifts/day) between 1983 and 1991, decreased to 138 lobsters/(100 trap-lifts/day) in 1993 and then rose again to 177 lobsters/(100 trap-lifts/day) in 1999 (Fig 3B). $CPUE_O$ ranged between 1.0 and 2.4 octopus/(100 trap-lifts/day) in 1987 and 1993 respectively (Fig. 3D). M_L ranged from 5.0 to 7.3 dead lobsters/(100 trap-lifts/day) in 1983 and 1988, respectively (Fig. 3F).

Mean monthly $CPUE_L$ declined from 196 to 88 lobster/100 trap-lifts/day between November and May (Fig. 4B). Mean monthly $CPUE_O$ was reasonably constant at between 1.43 and 1.7 octopus/100 trap-lifts/day for the first five months of the season before a decline to 1.0 octopus/100 trap-lifts/day in May (Fig. 4D). The mean monthly M_L declined from 7.5 to 3.4 dead lobster/100 trap-lifts/day between November and May (Fig. 4F).

Since 1983, mean annual $CPUE_L$ has been relatively low and stable in MFAs 15, 28, and 40 but has been

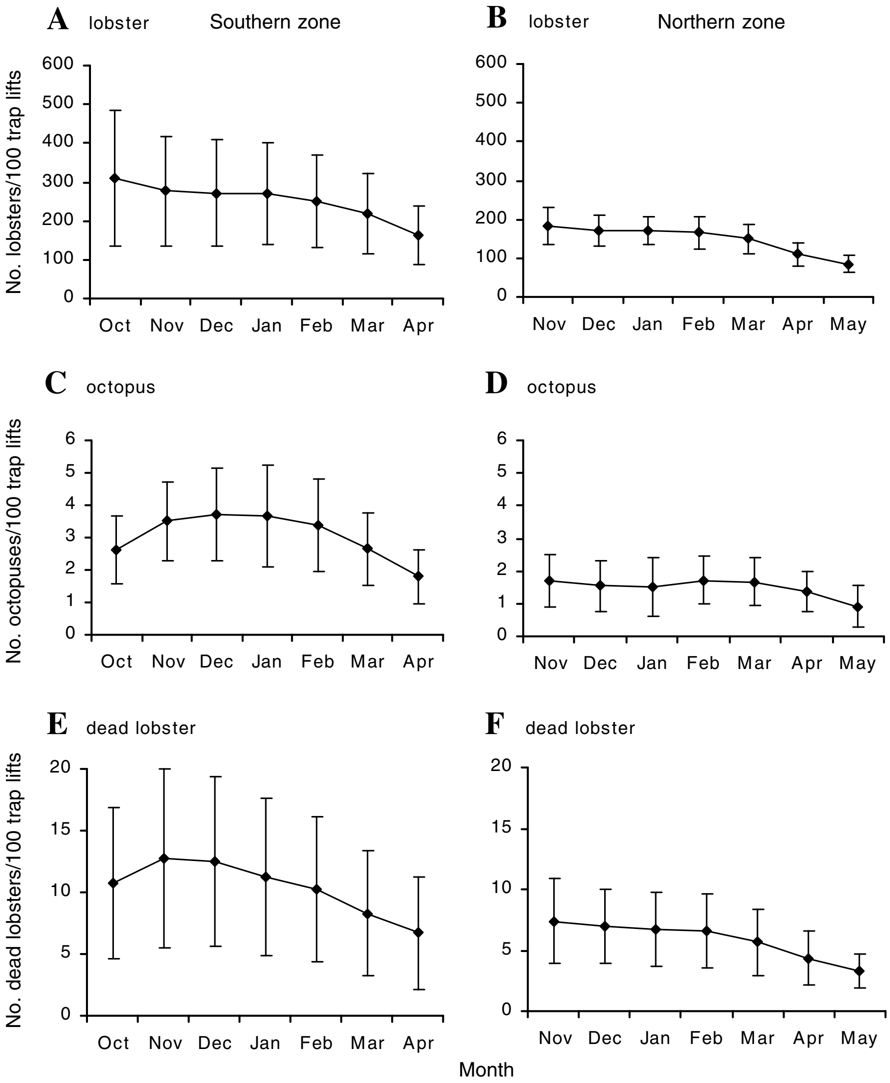

Figure 4

Mean monthly catch rates in each fishing zone for lobsters ($CPUE_L$) (**A** and **B**), octopus ($CPUE_O$) (**C** and **D**), and dead lobsters (M_L) (**E** and **F**). Error bars are ±SD of mean.

higher and more variable in MFAs 39 and 49 (Fig. 5B). There were large interannual fluctuations in $CPUE_O$ in each MFA, and these trends were similar among MFAs (Fig. 5D). M_L was highest in MFA 40, where a maximum of 12.5 dead lobsters/(100 traps lifts) was recorded 1998 and lowest in MFA 15 where the maximum was 5.2 dead lobsters/100 trap-lifts in 1997 (Fig. 5F). No clear long-term trends in M_L were apparent in any MFA.

Factors that affect within-trap lobster mortality

Based on the mean square values, the number of octopus had the greatest effect on lobster mortality in both zones (Table 1, A and B). The number of dead lobsters increased with both octopus and lobster catches and with soak-time and decreased as depth increased (Figs. 6 and 7). Based on the relative size of the mean square values, the factor with the greatest effect on the number of dead lobsters in the SZ was the number of octopus caught, followed by soak-time, number of lobsters caught, and depth. In the NZ, the number of octopus caught was also the most important factor, followed by the number of lobsters caught, depth, and soak-time.

Source of lobster mortality and size-dependent mortality

A total of 3627 lobsters from 635 trap-lifts were measured. In the sample there were 212 lobsters killed in traps of which 207 (98%) were killed by octopus and 5

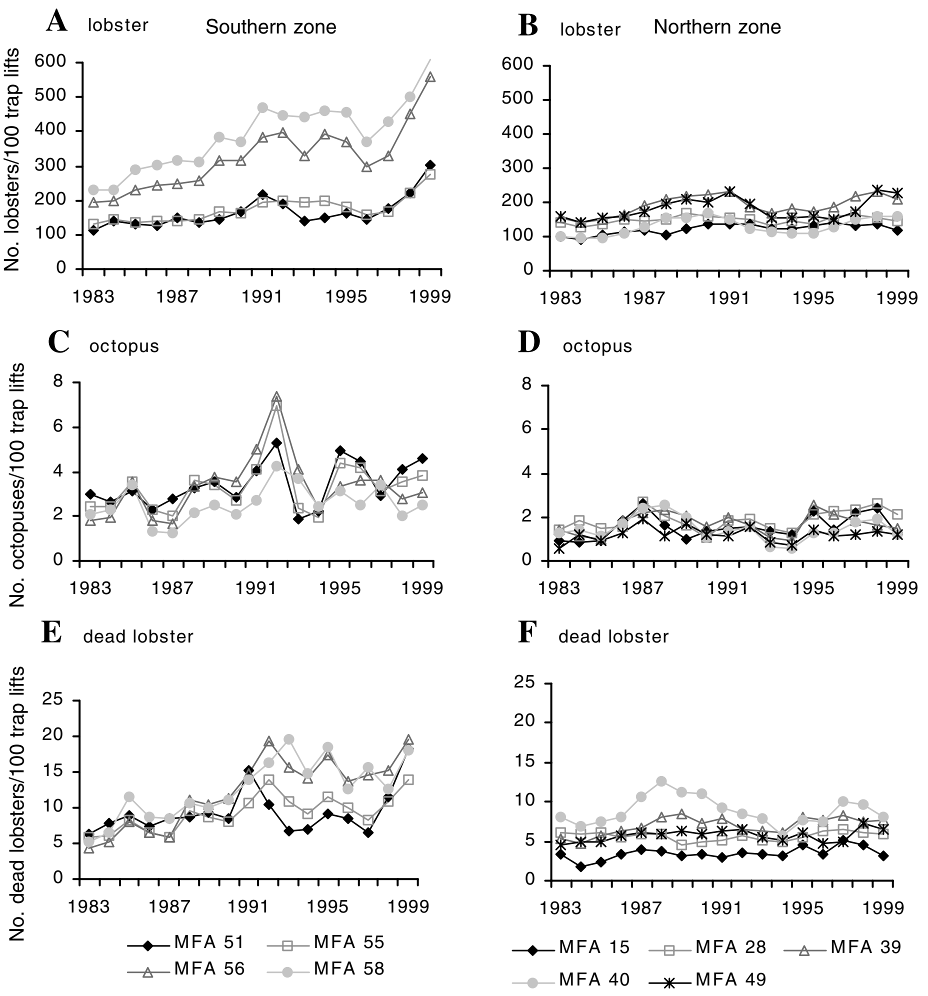

Figure 5

Annual catch rates of the major MFAs in each fishing zone for lobsters ($CPUE_L$) (**A** and **B**), octopus ($CPUE_O$) (**C** and **D**), and dead lobsters (M_L) (**E** and **F**).

by other predators. The mean CL of dead male lobsters was greater than live males (120 ±21.1(SD) vs. 110 ±18.3 (SD) mm, $P<0.001$). There was no significant difference in the mean size of live and dead female lobsters. For both sexes the probability of mortality increased with size according to the following relationships:

$$P\ (M_L,\ \text{males}) = 1/1+e^{-(-5.04+0.02CL)}$$
$$P\ (M_L,\ \text{females}) = 1/1+\mathrm{e}^{-(-4.18+0.01CL)}.$$

Above 100 mm CL, the probability of mortality increased more sharply for male lobsters than for female lobsters (Fig. 8).

Discussion

Logbook data from the SARLF show that over the last five years approximately 240,000 lobsters have been killed in traps each year. Although there are numerous predators of trapped lobsters—such as seals, conger eels, and several species of finfish—the impacts of these taxa appear to be minor compared to the effects of predation by *O. maorum*. The field-sampling program conducted in the SZ in 2001–02 suggested that over 98% of within-trap mortality was attributable to *O. maorum*. Although the sampling program was spatially and temporally restricted, this finding, in conjunction with the strong correlations between annual, seasonal and spatial trends in the $CPUE_O$ and M_L, clearly demonstrates that *O. maorum* is the major predator of lobsters in SARLF traps.

The results of this study suggest that about 4% of the total annual catch of the SARLF is lost to predation by *O. maorum* in traps. Mortality rates attributable to octopuses in other Australian lobster fisheries range from 1% in the Western Australian fishery for *Panulirus cygnus*[1] (*O. tetricus*) to 5% in the Tasmanian fishery for

Table 1

Results of the general linear model of factors that affect lobster mortality (all data log transformed) for (**A**) southern zone (r^2=0.62), (**B**) northern zone (r^2=0.38).

A

Source	df	Squares	Mean square	*F*-value	*P*>*F*
Model	5319	314,536	59.13	147.41	<0.0001
Error	483,961	194,140	0.401		
Corrected total	489,280	508,677			

Source	df	Type-3 SS	Mean square	*F*-value	*P*>*F*
License	245	49158.1	200.6	500.2	<0.0001
MFA	3	9.6	3.2	8.0	<0.0001
Year	17	2494.6	146.7	365.8	<0.0001
MFA×Year	51	233.0	4.7	11.6	<0.0001
Month	6	2830.7	471.8	1176.1	<0.0001
Effort	1	229.6	229.6	572.4	<0.0001
Lobster catch	1	6728.7	6728.7	16773.4	<0.0001
Depth	1	1335.0	1335.0	3327.9	<0.0001
Octopus	1	35930.5	35930.5	89568.8	<0.0001
Soak-time	1	6842.1	6842.1	17056.1	<0.0001
Soak-time×Year	17	286.9	16.9	42.1	<0.0001
License×Year	3415	53019.8	15.5	38.7	<0.0001
License×Month	1460	5900.2	4.0	10.1	<0.0001
Year×Month	94	3760.4	40.0	99.7	<0.0001
Soak-time×Month	6	310.2	51.7	128.9	<0.0001

B

Source	df	Squares	Mean square	*F*-value	*P*>*F*
Model	2159	39,217	18.17	41.75	<0.0001
Error	148,731	64,713	0.435		
Corrected total	150,890	103,931			

Source	df	Type-3 SS	Mean square	*F*-value	*P*>*F*
License	95	3361.5	35.4	81.3	<0.0001
MFA	4	174.8	43.7	100.4	<0.0001
Year	17	241.2	14.2	32.6	<0.0001
MFA×Year	68	175.4	2.6	5.9	<0.0001
Month	7	317.3	45.3	104.2	<0.0001
Effort	1	27.1	27.1	62.3	<0.0001
Lobster catch	1	1299.7	1299.7	2987.2	<0.0001
Depth	1	391.3	391.3	899.3	<0.0001
Octopus	1	6305.1	6305.1	14491.0	<0.0001
Soak-time	1	210.8	210.8	484.4	<0.0001
Soak-time×Year	17	117.7	6.9	15.9	<0.0001
License×Year	1287	7275.6	5.7	13.0	<0.0001
License×Month	553	1170.7	2.1	4.9	<0.0001
Year×Month	95	275.9	2.9	6.7	<0.0001
Soak-time×Month	6	2.8	0.5	1.1	0.3743

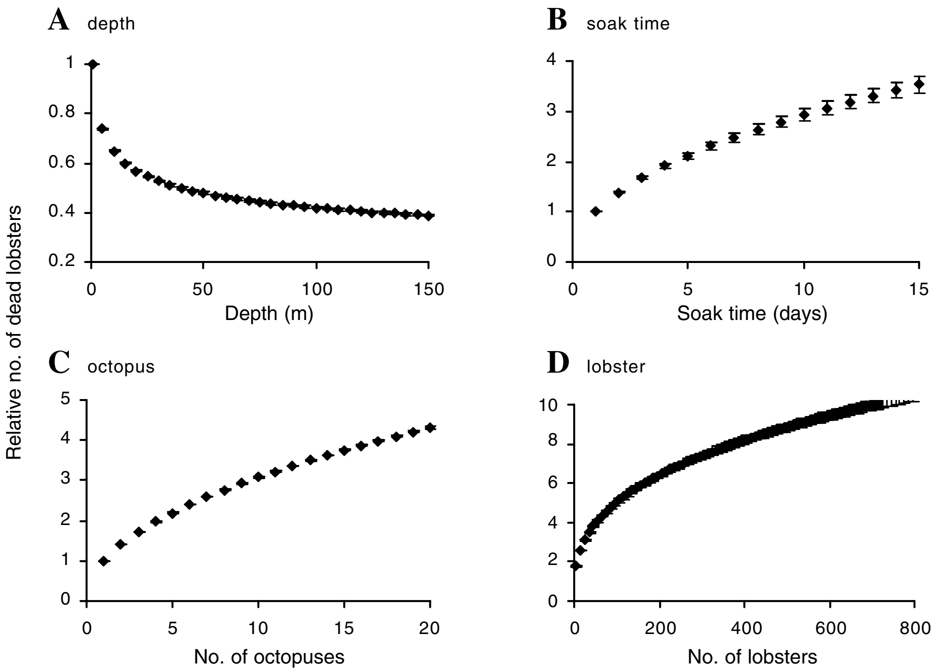

Figure 6

The relative number of dead lobster as a function of (**A**) depth, (**B**) soak-time, (**C**) number of octopus, and (**D**) no. of lobsters for the southern zone. Error bars are ±SD of mean.

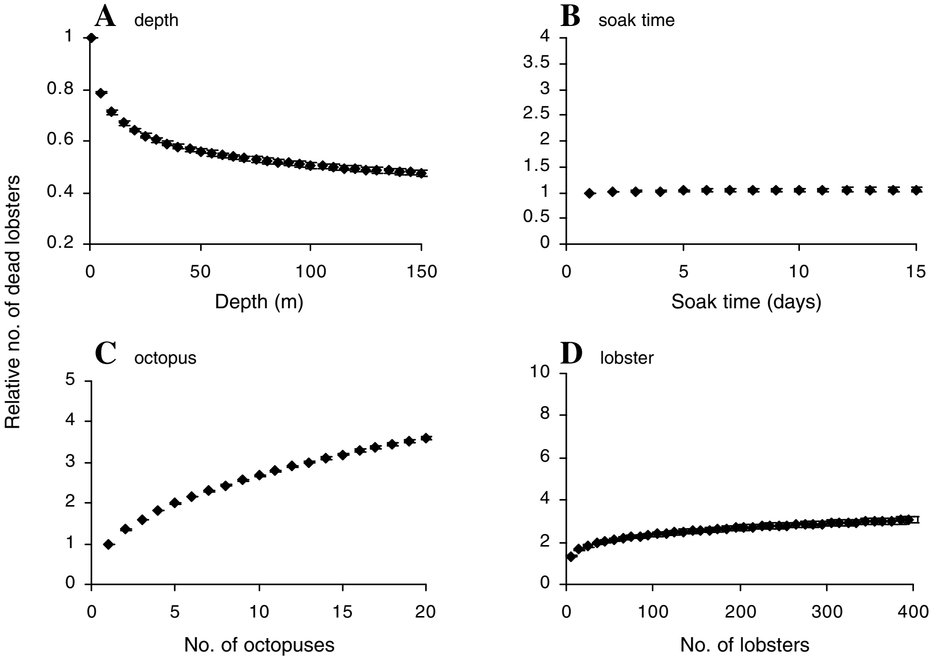

Figure 7

The relative number of dead lobster as a function of (**A**) depth, (**B**) soak-time, (**C**) number of octopus, and (**D**) number of lobsters for the northern zone. Error bars are ± SD of mean.

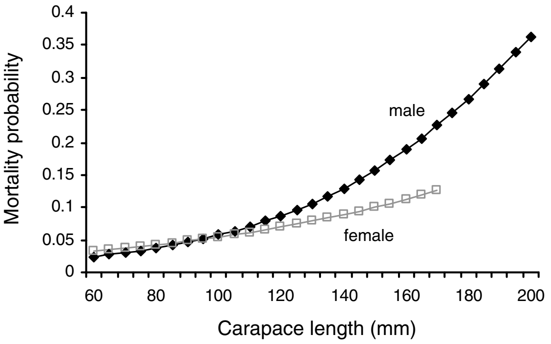

Figure 8

Size-dependent mortality of lobsters with respect to sex.

J. edwardsii (*O. maorum*), (Gardener[5]), and a localized study in the New Zealand fisheries for *J. edwardsii* (*O. maorum*) found the proportion of the lobster catch killed by octopus to be as high as 10% (Ritchie[6]). The estimates of lobster mortality from these other studies should be treated with caution however because the current study is the only one that documents within-trap lobster mortality from a fishery-wide data set.

The general linear modeling approach that we used to determine the factors associated with M_L has some limitations. For example, the logbook data for the SARLF, like the monitoring data for most other fisheries, are not completely independent, and interdependence among observations can bias estimates of parameters. Similarly, some of the factors in the model, notably $CPUE_L$ and $CPUE_O$ are partially correlated. In addition, the large number of observations and degrees of freedom tend to make most factors significant. We considered all of these issues when interpreting the results of the analyses and used the mean square (MS) values to rank the importance of factors.

In both zones, inter- and intra-annual fluctuations in M_L largely reflect the effects of $CPUE_O$ and $CPUE_L$. The broad trends in annual $CPUE_O$ have largely corresponded to those for M_L with peaks in both generally synchronous in both fishing zones. In the SZ, the general increase in M_L since 1983 appears to result from the increase in $CPUE_{L,}$ which has more than doubled over this period. This assessment is supported by catch-rate data from individual MFAs. The two MFAs in the SZ that have had the greatest increases in $CPUE_L$ over the last 5 years (56 and 58) have also had the highest corresponding increase in M_L. Increases in $CPUE_L$ are likely to elevate M_L by both increasing the probability of octopus encountering traps containing lobsters and the number of lobsters in traps entered by octopus.

However, M_L is also positively correlated with soak-time, especially in the SZ. This finding is consistent with patterns observed in the New Zealand fishery for *J. edwardsii*[6] and reflects the increased opportunities for octopus predation when pots containing lobsters remain in the water for longer periods. In the SZ, fishermen return to port each day and choose to fish or not to fish each day according to factors such as weather and price; therefore, although a 24-h soak period is still most common, soak times can range from one to five days. In the NZ, fishermen remain at sea for extended periods and consequently soak times longer than 24 hours are rare.

There was considerable variation in the fishery data, especially in the southern zone. It is likely that much of this variation is related to the large geographical extent of the fishery as opposed to fishing practises. Across the fishery lobster growth rates and subsequent catch rates vary greatly (McGarvey et al., 1999a). For example, since 1991, the $CPUE_L$ in MFAs 56 and 58 have been twice those of MFAs 51 and 55 in the SZ. Although the variation in $CPUE_O$ between the zones has been similar, the higher variability in $CPUE_L$ in the SZ is reflected in the variation in M_L.

Data spanning 17 years and covering about 50,000 km^2 represent one of the few long-term and large-scale data sets on the distribution and abundance of an octopus species (Hernandez-Garcia et al., 1998; Quetglas et al., 1998). The paucity of octopus studies on these scales reflects the logistical constraints of fishery-independent surveys of octopus populations and the poor and inconsistent methods generally used to record fishery catch and effort data (Boyle and Boletsky, 1996). The few data that are available on the distribution patterns of octopus have been obtained mainly from small commercial fisheries and $CPUE_O$ has been included as a measure of relative abundance (Defeo and Castilla, 1998; Hernandez-Garcia et al., 1998). This approach has proven useful, but several potential biases must be considered when $CPUE_O$ data are being interpreted: these include 1) changes in fishing methods and efficiency over time; 2) the distribution pattern (e.g., random or aggregated) of the species under consideration; and 3) spatiotemporal fluctuations in catchability (Richards and Schnute, 1986; Rose and Kulka, 1999). There are several reasons why the data from the SARLF may provide a useful measure of the relative abundance of octopus over these spatial and temporal scales. Most importantly, the basic unit of effort in the fishery, the trap, has remained unchanged since 1983. Furthermore, although *O. maorum* is retained as bycatch and kills *J. edwardsii* in traps, it is neither targeted nor avoided by fishermen, and fishing effort is thus relatively independent of its distribution patterns because the economic effects of both the sale of octopus bycatch and the costs of lobster predation are relatively small compared to the primary

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[5] Gardener, C. 2002. Personal commun. Tasmanian Aquaculture and Fisheries Institute, Private Bag 49, Hobart, Tasmania 7001.

[6] Ritchie, L. D. 1972. Octopus predation on trap-caught rock lobster—Hokianga area, N.Z. September–October 1972. New Zealand Marine Department. Fisheries Technical Report 81, 40 p. [Available from Ministry of Fisheries, 101–103 The Terrace, Wellington, New Zealand, 1020.]

economic driving force for the fishery, the lobster catch rates, and because the catch rates of octopus are difficult to predict. In addition, *O. maorum* is a solitary animal that tends to be dispersed randomly throughout areas of suitable habitat (Mather et al., 1985).

The higher total catches and catch rates of both lobster and octopus in the SZ, compared to the NZ, probably reflect the more extensive reef habitat and more intense nutrient-enrichment upwelling in this portion of the SARLF (Lewis, 1981). There have been large interannual fluctuations in CPUE_O in both zones since 1983. Such fluctuations in population size are common among other cephalopods, especially squid, and may result from life history strategies that are characterized by rapid growth, short lifespan (<two years) and almost universal mortality after a single spawning event (Boyle and Boletsky, 1996). Despite these fluctuations, CPUE_O has not declined noticeably in any MFA since 1983, which suggests that octopus mortality from fishing is consistent with little impact on octopus populations since the advent of fishing. This observation and the poor relationship between octopus catches and effort refute the belief of some SARLF fishermen that incidental fishing mortality acts to control octopus abundance.

This study, however, did confirm the view of fishermen that larger lobsters are killed more commonly by octopus than are smaller ones. This effect was most evident for male lobsters, which grow to larger sizes than females. There could be several reasons for the size-dependent mortality rates for rock lobsters. For example, octopus could actively select larger prey, or large lobsters could be captured more easily than small lobsters in traps by octopus. Because large lobsters can be worth more and produce more eggs than smaller lobsters, the increased mortality rates of large lobsters suggest that the total economic and ecological impacts of octopus predation in the SARLF are greater than indicated by the absolute number of lobsters killed.

Octopus predation of lobsters in traps is a significant problem in the SARLF. However, the economic effects vary between the zones. In the quota-managed SZ, additional lobsters are harvested to replace those killed in traps, which increases the time and costs of catch quotas, and imposes an impact on lobster abundance. In the input-controlled NZ, where there is no direct restriction on the quantity of lobsters taken, lobsters killed in traps represent both a direct economic loss and an impact on lobster abundance.

Like most fisheries for spiny lobsters, the SARLF is close to being fully exploited. Reducing rates of octopus predation provides one option available for increasing the value of the fishery. Some minor reductions in lobster mortality may be achieved by minimizing soak-times, especially in the SZ. More significant reductions in the rates of within-trap lobster mortality may be achieved by redesigning lobster traps (Brock et al.[4]).

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Literature cited

Boyle, R. F., and S. V. Boletsky.
1996. Cephalopod populations: definition and dynamics. Phil. Trans. R. Soc. Lond. 351:985–1002.

Defeo, O., and J. C. Castilla.
1998. Harvesting and economic patterns in the artisanal *Octopus mimus* (Cephalopoda) fishery in a northern Chile cove. Fish. Res. 38:121–130.

Hernandez-Garcia, V., J. L. Hernandez-Lopez, and J. J. Castro.
1998. The octopus (*Octopus vulgaris*) in the small-scale trap fishery off the Canary Islands (Central-East Atlantic). Fish. Res. 35:183–189.

Lewis, R. K.
1981. Seasonal upwelling along the south-eastern coastline of South Australia. Aust. J. Mar. Freshw. Res. 32:843–854.

Mather, J. A., S. Resler, and J. Cosgrove.
1985. Activity and movement patterns of *Octopus dofleini*. Mar. Behav. Physiol. 11:301–314.

McGarvey, R., G. Ferguson, and J. H. Prescott.
1999a. Spatial variation in mean growth rates of rock lobster, *Jasus edwardsii*, in South Australian waters. Mar. Freshw. Res. 50:333–342.

Phillips, B. F., J. S. Cobb, and J. Kittaka.
1994. Spiny lobster management, 550 p. Blackwell Scientific, London.

Quetglas, A., F. Alemany, A. Carbonell, P. Merella, and P. Sanchez.
1998. Biology and fishery of *Octopus vulgaris* Cuvier, 1797, caught by trawlers in Mallorca (Balearic Sea, Western Mediterranean). Fish. Res. 36:237–249.

Richards, L. J., and L. J. Schnute.
1986. An experimental and statistical approach to the question: Is CPUE an index of abundance? Can. J. Fish. Aquat. Sci. 43:1214–1227.

Rose, G. A., and D. W. Kulka.
1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua*) declined. Can. J. Fish. Aquat. Sci. 56(suppl. 1):118–127.

Williams, A. B.
1988. Lobsters of the world—an illustrated guide, 186 p. Osprey Books. New York, NY.