Development and assessment of methods to reduce predation of 'pot caught' southern rock lobster (*Jasus edwardsii*) by maori octopus (*Octopus maorum*)

June 2003

Project No. 1998/150

D. Brock, T. Saunders and T.M. Ward

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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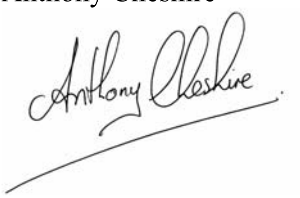

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Development and assessment of methods to reduce the predation of 'pot caught' southern rock lobster (*Jasus edwardsii*) by maori octopus (*Octopus maorum*).

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Objectives

1. Describe the spatial and temporal changes that have occurred in octopus predation level over the last 15 years.
2. Determine how environmental factors influence octopus predation over a fishing season.
3. Identify pot modifications that have the potential to prevent/reduce octopus predation of pot caught southern rock lobster.
4. Trial pot designs to prevent/reduce octopus predation under laboratory conditions.
5. Develop a pot that under commercial fishing conditions, prevent/reduces octopus predation, maintains lobster catch rates and is cost effective.
6. Ensure industry participation and consultation at all stages of the project.
7. Ensure adoption of modified pot by industry where appropriate.

OUTCOMES ACHIEVED

This project quantified the level of octopus by-catch and effects of octopus predation on the mortality rates of rock lobster in the South Australian Rock Lobster Fishery (SARLF). It showed that current octopus bycatch levels appear to be sustainable and that approximately 4% of the annual lobster catch of the SARLF is killed by octopus in pots. Findings suggested that small reductions in lobster mortality rates may be achieved by minimising soak times, but that more significant reductions will depend on reducing the rates of octopus entry into pots. Observations of octopus entering pots in aquaria indicated that octopus were attracted to the bait in traps rather than the lobsters. A two-chambered pot was developed, which consisted of an outer chamber that was accessible to octopus but not lobsters, and an inner chamber that both could access. Aquarium trials showed that most octopus entered the outer chamber containing bait rather than the inner chamber containing lobsters, which reduced lobster mortality rates by ~70% compared to a conventional pot. In field trials aboard SARLF vessels, the two-chambered pot reduced lobster mortality rates by 45-48% but also reduced lobster catch rates by 28%. The effectiveness of escape gaps in reducing the level of octopus predation on undersize lobsters was also tested. The presence of escape gaps in pots significantly reduced the retention of undersize lobsters in pots which lowered undersize mortality by approx. 65% when compared to pots without escape gaps. The mortality rate of legal sized lobsters was unaffected. The two-chambered concept is a new and innovative concept with great potential to reduce lobster mortality in pot fisheries with significant octopus bycatch. If the design can be refined to maintain lobster catch rates, the introduction of a two-chambered pot incorporating escape gaps would result in approximately 100,000 ($>2 million) fewer lobsters being killed each year in the SARLF.

The SARLF is the State's most valuable wild fishery with estimated export earnings of >$100 million in 2002. The fishery is a closed entry fishery with 250 licence-holders and is divided into the Northern and Southern Zones. Lobsters are caught in baited pots that are generally set for 24 hours prior to hauling.

Mortality of lobsters due to predation in pots, especially by maori octopus is a significant problem in the SARLF, but has generally been considered to be unavoidable, and minimal effort has been expended determining the scale of the problem or investigating a solution. This project was initiated in 1998 to develop methods for reducing rates of octopus predation on lobsters in pots.

Over the last 5 years, an average of 240,000 lobsters have been killed each year in SARLF pots. This represents approximately 4 % of the total commercial catch with the highest levels of mortality occurring in the Southern Zone. Whilst cuttlefish and scale-fishes, such as leatherjackets and grouper, are known to kill lobsters in pots over 97% of all lobster mortality is attributable to octopus predation. Trends in octopus catch rates suggest that lobster fishing has had minimal impact on octopus abundance.

Aquarium trials showed that octopus most commonly enter pots via the neck, but also enter through the bottom and the 50 mm mesh covering the sides of pots. Regardless of location, entry always occurred within a few minutes of the octopus's first contact with the pot. Lobsters in pots were always killed, however octopus were primarily attracted to pots by the presence of bait rather than the presence of lobsters.

On observation of octopus behaviour in the aquarium trials it was apparent that preventing octopus from entering pots was highly unlikely. Therefore the research focused on reducing the number of lobsters killed once octopus had entered pots. Two possible approaches were examined, the use of escape gaps to minimise the retention of undersize lobsters and thus their exposure to predation risk, and the development of a "two-chambered" pot to catch octopus and lobsters in separate compartments of the same pot to reduce their interaction and thus potential lobster mortality.

The two-chambered pot consisted of an outer chamber that was accessible (from the side) to octopus, but not to lobsters, and an inner chamber that both octopus and lobsters could enter via a conventional neck on the top of the pot. The two-chambered pot was based on the principle that octopus would enter the first chamber containing bait (i.e. the outer chamber) that they encountered and would feed on the bait and leave without entering the inner chamber containing lobsters. Further aquarium trials demonstrated that this two-chambered pot reduced lobster mortality by 70% compared to a conventional pot.

The two-chambered pot design was further developed for testing in the commercial fishery. In 2000/01 field trials of the two-chambered pot were conducted from two boats in the Southern Zone. The results of the field trials showed that the two-chambered pot reduced lobster mortality by 48% compared to conventional pots, but that the catch rate of lobsters was also reduced by 28%.

The information gained from the 2000/01 field trials was used to further develop the two-chambered design. Field trials in 2001/02 showed that lobster mortality was reduced by 45% in the two-chambered pot but that the catches of lobsters were also lower (28%).

As part of the 2000/01 field trial the effectiveness of escape gaps in reducing the level of octopus predation on undersize lobsters was also tested. The presence of escape gaps did not affect the catch rate or mortality rate of legal sized lobsters but the catch rate of undersize lobsters by was significantly lower in pots with escape gaps compared to conventional pots without escape gaps (0.84 undersize/pot lift vs 2.08). This lead to a 60% reduction in the mortality rate of undersize in pots with escape gaps. Extrapolation of the results obtained in this study indicate that the introduction of escape gaps into the fishery could reduce undersize lobster mortality by approximately 40,000 lobsters.

Results of this study show that a two-chambered pot design reduces the level of octopus predation on lobsters caught in pots. Unfortunately, the reduction in lobster catch rates limits the commerical use of the current design. However, given the potential benefits in economic terms for individual fishers and for lobster stocks to be gained from a reduction in octous predation, lobster fishers may wish to consider investigating options for enhancing the catching efficiency of two-chambered traps.

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CHAPTER 1. GENERAL INTRODUCTION

Background

The southern rock lobster (*Jasus edwardsii*) is widely distributed throughout southern Australia and supports commercial fisheries in Western Australia, South Australia, Victoria and Tasmania. The fishery is of major economic importance to South Australia. In 2001/02, the South Australian fishery landed 2,367 tonnes of rock lobster, which sold for over $100 million on export markets.

The South Australian commercial rock lobster fishery (SARLF) is divided into the Northern Zone (NZ) and Southern Zone (SZ). Currently, the NZ fishery is managed by input controls that include pot and size restrictions and seasonal closures, while the SZ is managed under a Total Allowable Commercial Catch (TACC) system introduced in 1993 (Zacharin 1997). Fishing in the NZ is conducted from 1 November until the 31 May and in the SZ from the 1 October until the 30 April.

Commercial fishers predominantly harvest lobsters using steel-framed pots covered with wire mesh and incorporating a moulded plastic neck. Pots are generally set overnight and retrieved the following day. The catch is initially stored live in holding wells on boats and then transferred to holding tanks at numerous processing factories.

A significant problem affecting the SARLF is predation by the maori octopus (*Octopus maorum*) on lobsters in pots. Octopus enter pots and kill lobsters that could otherwise be sold by fishers, or in the case of undersized lobsters, returned to the fishery. Octopus predation is widespread throughout the fishery and it has been estimated that lobster mortality attributable to octopus is about 5% of the total catch (J. Prescott pers. com.). In addition, surviving lobsters from a pot that has been attacked by an octopus are often damaged and thus have a reduced landed price.

Currently, there has been limited research into the issue of octopus predation. A survey of octopus predation in the Southern Zone fishery by Medeenya (1991) found that on average 10% of pots were attacked by octopus and that 96% of within-pot lobster mortality was attributable to octopus. Other pot predators included leatherjackets and cuttlefish. Ritchie (1972) in a study at Hokianga, New Zealand showed that for 24-hour soak periods, octopus killed 12.6% of the total catch.

Very little effort has been expended on overcoming the problem of octopus predation considering its significant impacts on major commercial lobster fisheries in the Southern Hemisphere. To our knowledge, Joll's (1977) work on the western rock lobster (*Panulirus cygnus*) and the gloomy octopus (*Octopus tetricus*) in the Western Australian commercial lobster fishery is the only study of methods to mitigate octopus predation. Joll (1977), found that octopus could locate baits by olfaction from a distance of at least 1.5 m, rapidly entered pots and were not deterred by the use of octopus as bait or by the slime or skin extracts of known predators.

Need

The predation of rock lobsters in pots by octopus is the major cause of direct loss to commercial fishers in South Australia. It is estimated that on average, between 5-10% of the total lobster catch in the SARLF is killed by octopus, representing a total annual loss of between 200-250,000 lobsters (Prescott 2001, Medeenya 1991).

In the input-regulated NZ fishery octopus predation results in a direct financial cost to fishers associated with the loss of saleable lobsters. In the output-regulated SZ fishery predation results in indirect costs associated with increased time and effort expended to catch quota. In both fisheries the loss of undersized lobsters hampers efforts to manage these fisheries sustainably. Prevention or reduction of octopus predation of lobsters in pots could significantly increase the value of the SARLF while at the same time improving the status of the lobster stock.

Objectives

1. Describe the spatial and temporal changes that have occurred in octopus predation level over the last 15 years.
2. Determine how environmental factors influence octopus predation over a fishing season.
3. Identify pot modifications that have the potential to prevent/reduce octopus predation of pot caught southern rock lobster.

4. Trial pot designs to prevent/reduce octopus predation under laboratory conditions.
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6. Ensure industry participation and consultation at all stages of the project.
7. Ensure adoption of modified pot by industry where appropriate.

CHAPTER 2. OCTOPUS *(OCTOPUS MAORUM)* BYCATCH AND LOBSTER (*JASUS EDWARDSII*) MORTALITY IN THE SOUTH AUSTRALIAN ROCK LOBSTER FISHERY.

Objective 1: Describe the spatial and temporal changes that have occurred in octopus predation level over the last 15 years.
Objective 2: Determine how environmental factors influence octopus predation over a fishing season.
These objectives were achieved by analysis of commercial catch data from the SARLF since 1983, in conjunction with sampling on-board commercial vessels. The number of dead lobsters but not the cause of mortality is recorded by fishers in their logbooks. Over the last 5 years, approximately 240,000 lobsters per annum were killed in pots, representing ~4% of the total catch. The on-board sampling program showed that over 97% of lobster mortality in pots was attributable to predation by octopus. Since 1983 the level of lobster mortality has varied in response to large inter-annual fluctuations in octopus abundance. The absence of a decline in the catch rates of octopus over this period, suggests that lobster fishing may not have significantly affected the abundance of octopus. The highest octopus catch rates and lobster mortality rates were recorded during summer and in the SZ of the fishery. In the SZ, within-pot lobster mortality rates have increased in recent years, apparently in response to the increase in lobster abundance and the resultant increase in the probability of octopus encountering pots containing one or more lobsters. In the NZ there are no clear long-term trends in octopus predation levels. Lobster mortality rates were positively correlated with soak times (the period between placing and lifting of a pot) and lobster size, and were negatively correlated with fishing depth.

Introduction

There are 49 species of spiny lobsters (Decapoda: Palinuridae) worldwide, 33 of which support commercial pot fisheries. The largest of these are in Cuba, South Africa, Mexico, Australia and New Zealand (Williams 1988). The main pot fisheries in Australia are for western rock lobster, *Panulirus cygnus*, in Western Australia and southern rock lobster, *Jasus edwardsii*, along the southern coastline. Octopus constitute a significant component of the bycatch in both fisheries (Joll 1977, Knight *et al*. 2000).

O. maorum is a large (up to 15 kg), sub-tidal, benthic octopus that is commonly found along the southern coasts of Australia and New Zealand at depths ranging from 5-120m (Stranks 1996). The species is semelparous, ie. males die at the end of the mating period, females die after laying and brooding a clutch of several thousand eggs (Anderson 1999, Grubert and Wadley 2000). Larvae are planktonic for 2-3 months before metamorphosing and becoming demersal. No data have been published on the large-scale or long-term patterns of distribution and abundance of this species.

Whilst the octopus bycatch of the South Australian Rock Lobster Fishery (SARLF) may be sold, the commercial value of this product does not offset the value of lobsters lost due to predation by octopus. Many fishers are convinced that incidental mortality resulting from lobster fishing acts to control octopus numbers and that if rates of incidental mortality were reduced octopus abundance and levels of within pot predation would increase (S. Sloan, Primary Industries and Resources of South Australia, pers. comm.).

In this chapter, we examine the interaction between *O. maorum* and *J. edwardsii* in the South Australian Rock Lobster Fishery (SARLF). The aims were: (1) to determine the number of lobsters and octopus caught and the number of lobsters killed each year in the fishery; (2) to describe the inter-annual and seasonal patterns in lobster catch rate ($CPUE_L$), octopus catch rate ($CPUE_O$), and lobster mortality rate (M_L); (3) to examine the factors that 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 pots is size-dependent.

Materials and methods

South Australian rock lobster fishery

The NZ and SZ are divided into Marine Fishing Areas (MFA) for statistical purposes. There are 68 and 183 fishers licensed to operate in the NZ and SZ respectively.

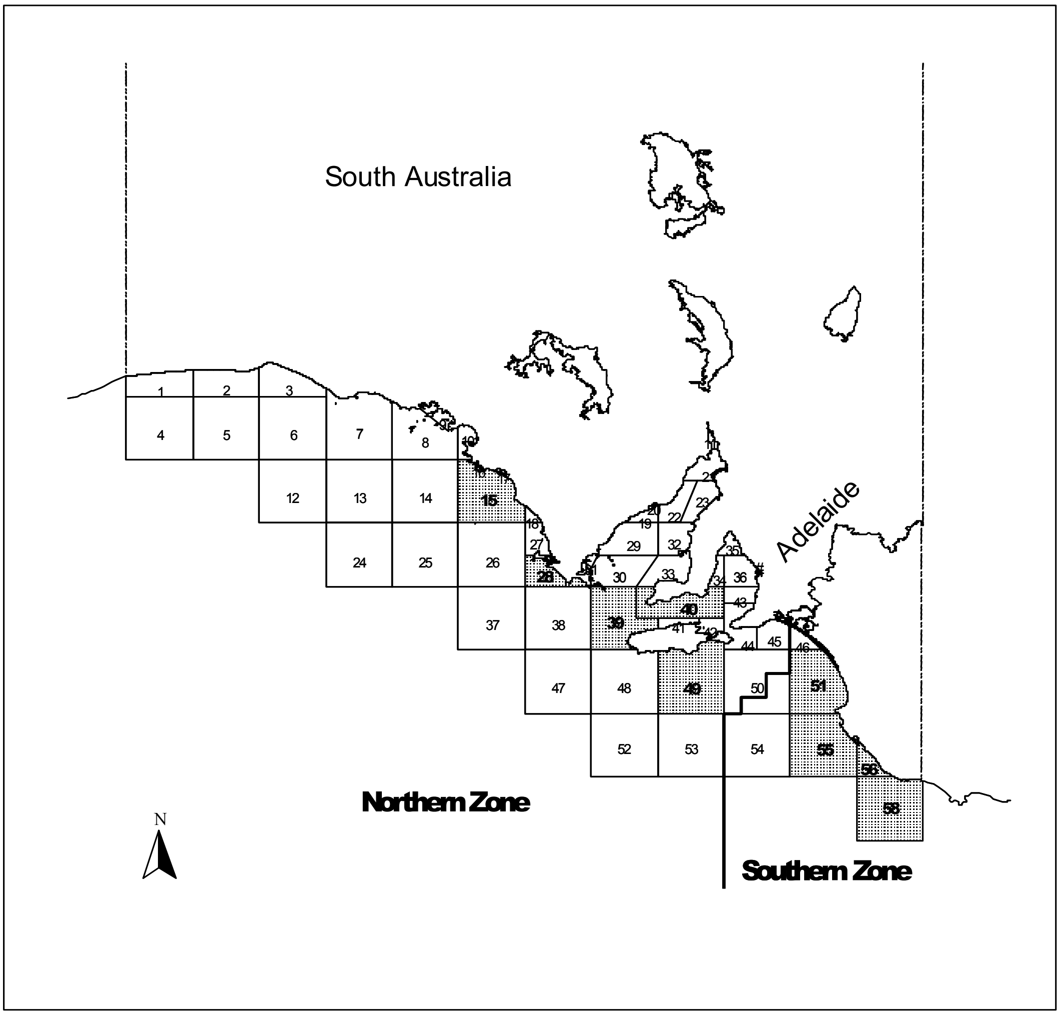

Figure 1.1. Map of the Northern and Southern Zones of the South Australian Rock Lobster Fishery (shading shows the MFAs where most fishing effort is concentrated and that are considered in this chapter).

Total annual catch and effort for the SARLF

Catch and effort data are recorded on a daily basis by all individual fishers. Since 1983, a standardised logbook for recording catch and effort has been used across the fishery. Data provided by fishers include: MFA fished, average depth fished, number of pot-lifts, number and total weight of live lobsters, number of dead lobsters, and number and total weight of octopus. The recording of these catch statistics has been compulsory and given that the fishery has been limited entry over this time period it is assumed that potential biases in the data due to changes in recording practises have been negligible. This information is stored in a South Australian Rock Lobster database that is managed by the South Australian Research and Development Institute, Aquatic Sciences. Information on the number of pot-lifts, lobster and octopus catches and lobsters killed in the SARLF presented in this study were obtained from the database.

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

Whilst commercial fishing for lobsters occurs along most of the oceanic component 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 pot-lifts were made in MFAs 15, 28, 39, 40, 49. In the SZ over the same period 95% of pot-lifts were made in MFAs 51, 55, 56 and 58 (Fig. 1.1).

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

Factors that affect within pot lobster mortality

The factors that affect within pot lobster mortality were analysed using a general linear model (Type III sums of squares) under the assumption that the number of dead lobsters follows a log-normal distribution. The number of dead lobsters/pot-lift/day/licence (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:

DEAD LOBSTER = LICENCE + MFA + MONTH + YEAR + EFFORT + DEPTH + OCTOPUS + LOBSTER CATCH + SOAK-TIME + LICENCE*YEAR + LICENCE*MONTH + YEAR*MONTH + YEAR*MFA + SOAK-TIME*YEAR + SOAK- TIME*MONTH.

In the model, LICENCE is for the individual fishers, MFA is the Marine Fishing Area, MONTH accounts for seasonal variation and YEAR accounts for inter-annual variation, EFFORT is the number of pot-lifts/licence/day, DEPTH is the average depth fished by each licence on a particular day, OCTOPUS and LOBSTER are the respective daily catches/licence and SOAK-TIME is the number of days that the pots remained in the water since the previous pot-lift.

The interaction terms LICENCE*YEAR and LICENCE*MONTH account for variations in the catch characteristics of the individual licences over time that result from changes in fishing practises and efficiency associated with different boats, licence 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, which 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 that may include price, weather and fishers' perceived ability to catch their quota.

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

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

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

Source of lobster mortality and size-dependent mortality

A sampling program was conducted on 3 commercial vessels from the SZ during the 2001/2002 fishing season. Five days were spent on each vessel. All lobsters caught were measured (carapace length, mm), and the sex (male/female), maturity (mature/immature), status (dead/alive) and cause of death (lobster/other) were recorded.

The method used to distinguish between lobsters killed by octopus or other means followed that of Joll (1977). The suitability of this approach was confirmed through examination of the carcases of over one hundred lobsters killed by octopus in aquarium trials (D. Brock unpubl.). 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 octopus, whereas lobster with shells without this separation and evidence of bite marks were deemed to have been eaten by other predators (fish or cuttlefish).

Anecdotal evidence from fishers suggests that larger lobsters are more susceptible to predation than smaller ones. The mean carapace lengths (CL) of dead and live male and female lobsters were compared using an ANOVA. In addition, the effect of CL on the probability of mortality was examined separately for males and females by generalised linear modelling. The probability of mortality at a given size was modelled with a logistic equation of the form:

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

where P(sex, CL) is 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 pot-lifts in the SARLF, and 70% of this total effort was in the SZ (Fig. 1.2). The number of pots lifts in the SZ declined from 2.2 million in 1983 to 1.2 million in 1999 (Fig. 1.2a). In contrast, fishing effort in the NZ remained relatively consistent with 406,000 pot-lifts in 1983 and 480, 000 pot-lifts in 1999 (Fig 1.2b).

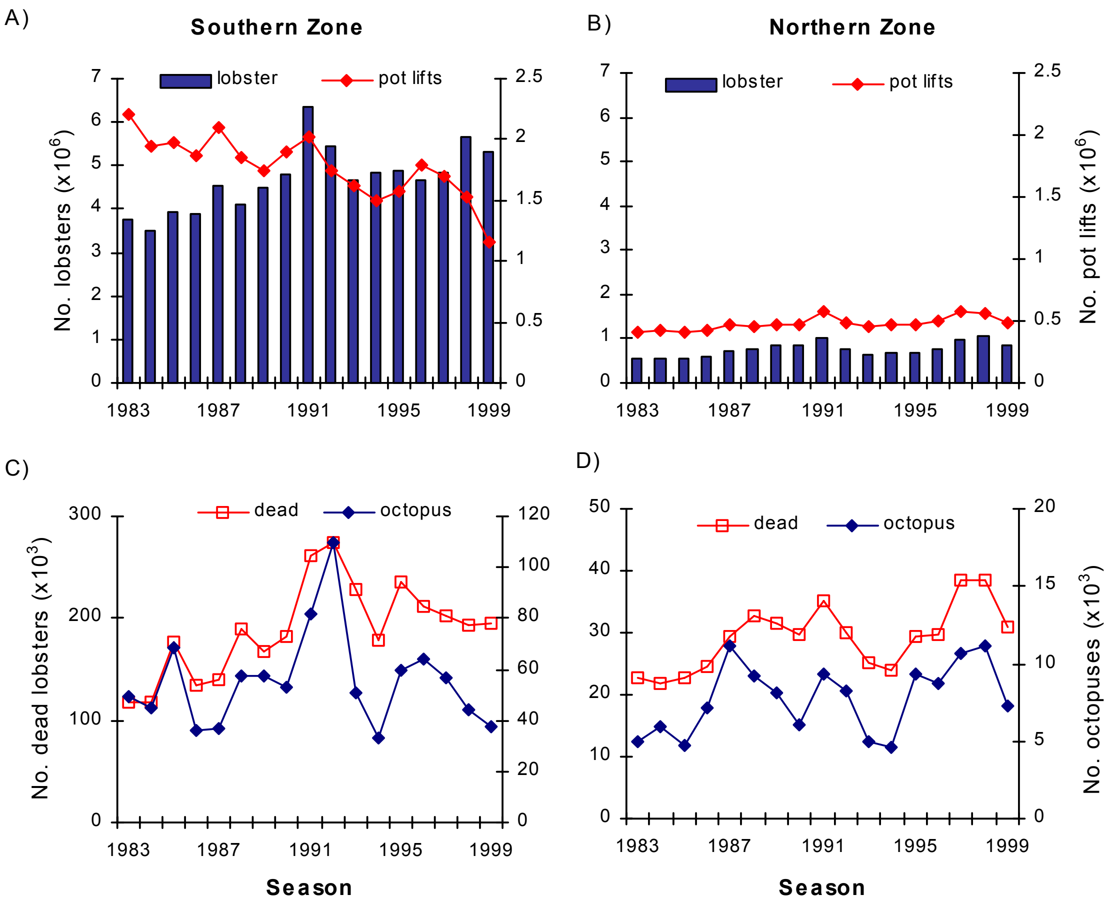

Figure 1.2. Annual total catch and effort for each zone of the SARLF of (a) & (b) number of pot lifts and lobsters caught, and (c) & (d) number of octopus caught and lobsters killed in pots (y axis range differs between SZ and NZ graphs).

The total annual lobster catch has generally increased in both fishing zones since 1983 (Fig. 1.2 a & b). In the SZ, the annual lobster catch rose from 3.8 million to a peak of 6.4 million in 1991 and was 5.4 million in 1999 (Fig. 1.2a). In the NZ, 560,000 million lobsters were taken in 1983 compared to 850,000 million in 1991 (Fig. 1.2b).

The total annual octopus catch varied among years in both zones, with between 70 and 90% of the total octopus catch being landed in the SZ (Fig. 1.2). In the SZ, the total number of octopus ranged from 36,000 in 1986 to 109,000 in 1992 (Fig. 1.2c) and in the NZ from 4,700 octopus in 1985 to 11,200 in 1998 (Fig. 1.2d).

In 1999, over 226,000 lobsters were killed in pots in the SARLF (Fig. 1.2). 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 pots has generally increased from 118,000 in 1983 to 196,000 in 1999 with a peak of 270,000 dead lobsters in 1992 (Fig. 1.2c). In the NZ, there has also been a general increase in the number of lobsters killed per year from 24,000 in 1983 to 31,000 in 1999 (Fig. 1.2d).

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 pot-lifts/day between 1983 and 1999, with the largest increase occurring between 1997 and 1999 (Fig. 1.3a). Mean annual $CPUE_O$ ranged from 1.8 to 6.2 octopus/100 pot-lifts/day in 1987 and 1992, respectively (Fig. 1.3c). Mean annual M_L rose from 5 to 17 dead lobster/100 pot-lifts/day between 1983 and 1999 (Fig. 1.3e). 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 pot-lifts/day between October and April (Fig. 1.4a). In contrast, mean monthly $CPUE_O$ increased from 2.6 to 3.7 octopus/100 pot-lifts/day between October and December, and declined to 1.8 octopus/100 pot-lifts/day in April (Fig. 1.4c). Similarly mean monthly M_L increased from 10.7 to 12.8 dead lobster/100 pot-lifts/day between October and November and declined to 6.7 dead lobster/100 pot-lifts/day in April (Fig. 1.4e).

Since 1983, mean annual $CPUE_L$ increased in all MFAs, and was consistently higher in MFAs 56 and 58 than other areas (Fig. 1.5a). $CPUE_O$ varied among years, but followed similar trends in different MFAs with consistent peaks in 1993 (Fig 1.5c). Prior to 1992, M_L was similar among MFAs but after 1992, was highest in MFAs 56 and 58 (Fig. 1.5e). M_L has increased over time in all MFAs.

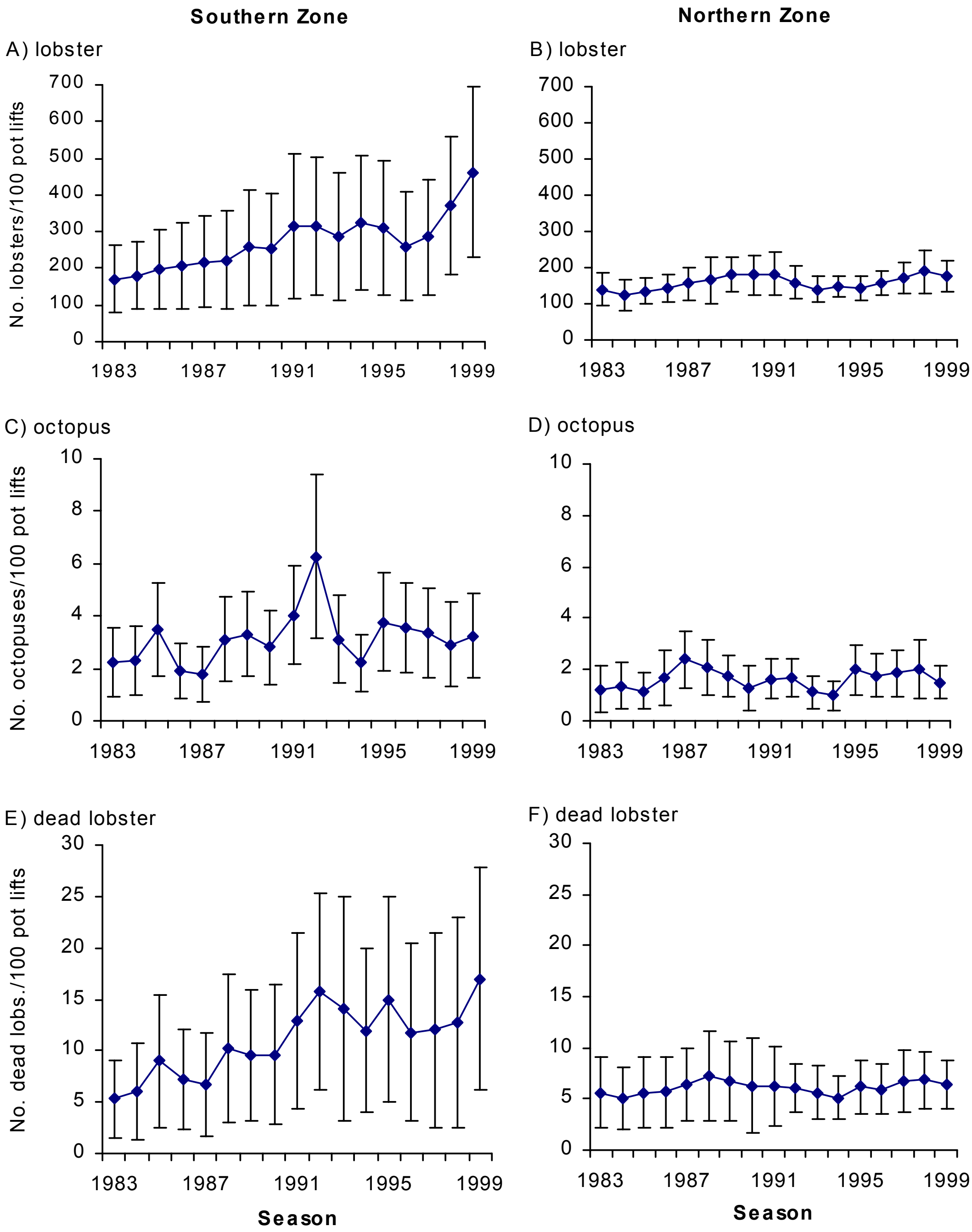

Figure 1.3. Annual catch rates (per 100 pot lifts, pl) in each fishing zone of (a) & (b) lobsters ($CPUE_L$), (c) & (d) octopus ($CPUE_O$), and (e) & (f) dead lobsters (M_L) (error bars ± SD of mean, y axis differs between NZ and SZ).

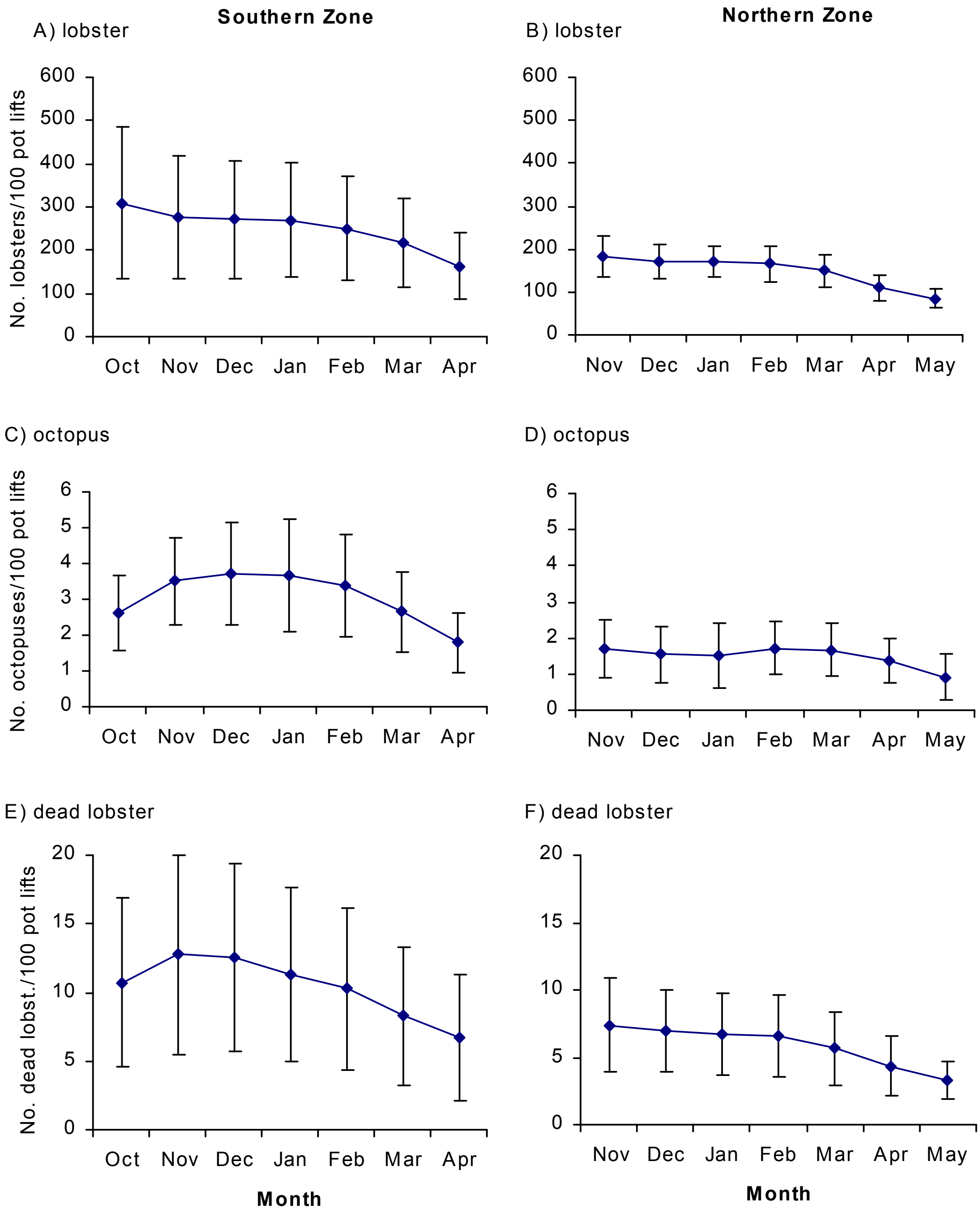

Figure 1.4. Mean monthly catch rates (per 100 pot lifts, pl) in each fishing zone of (a) & (b) lobsters ($CPUE_L$), (c) & (d) octopus ($CPUE_O$), and (e) & (f) dead lobsters (M_L) (error bars ± SD of mean).

Northern Zone

In the NZ, mean annual $CPUE_L$ rose from 135 to 179 lobsters/100 pot-lifts/day between 1983 and 1991, decreased to 138 lobsters/100 pot-lifts/day in 1993 and then rose again to 177 lobsters/100 pot-lifts/day in 1999 (Fig 1.3b). $CPUE_O$ ranged between 1.0 and 2.4 octopus/100 pot-lifts/day in 1987 and 1993 respectively (Fig. 1.3d). M_L ranged from 5.0 to 7.3 dead lobsters/100 pot-lifts/day in 1983 and 1988 respectively (Fig. 1.3f).

Mean monthly $CPUE_L$ declined from 196 to 88 lobster/100 pot-lifts/day between November and May (Fig. 1.4b). Mean monthly $CPUE_O$ was 1.9 octopus/100 pot-lifts/day at the start of the season, then dropped to 1.6 octopus/100 pot-lifts/day in January before rising to 1.8 octopus/100 pot-lifts/day in February and then declining to 1.0 in May (Fig. 1.4d). The mean monthly M_L declined from 7.5 to 3.4 dead lobster/100 pot-lifts/day between November and May (Fig 1.4f).

Since 1983, mean annual $CPUE_L$ has been relatively low and stable in all MFAs 15, 28 and 40, but has been higher and more variable in MFAs 39 and 49 (Fig. 1.5b). There were large interannual fluctuations in $CPUE_O$ in each MFA, and these trends were similar among MFAs (Fig. 1.5d). M_L was highest in MFA 40, where a maximum of 12.5 dead lobsters/100 pots lifts was recorded 1998 and lowest in MFA 15 where the maximum was 5.2 dead lobsters/100 pot-lifts in 1997 (Fig. 1.5f). No clear long-term trends in M_L were apparent in any MFA.

Factors that affect within pot lobster mortality

All of the individual factors and all of the interaction terms in the model (except for SOAK*MONTH for the NZ) had a significant effect on the number of dead lobsters/licence/day in each of the zones (Table 1.1a & b). The number of dead lobsters increased with both octopus and lobster catches and with soak-time, and decreased as depth increased (Fig. 1.6 & 1.7). 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 the 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.

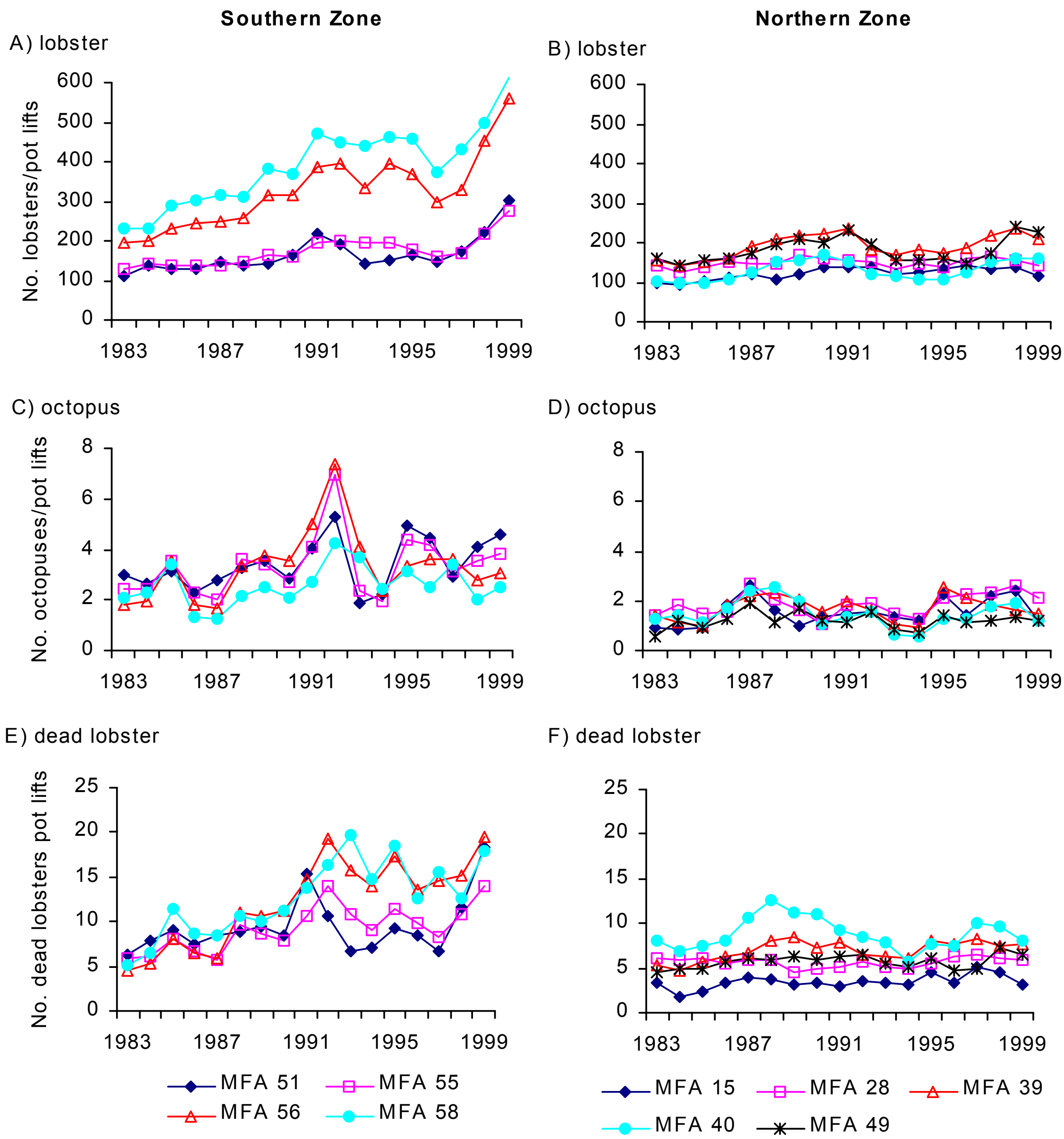

Figure 1.5. Annual catch rates of the major MFAs in each fishing zone of (a) & (b) lobsters ($CPUE_L$), (c) & (d) octopus ($CPUE_O$) and (e) & (f) dead lobsters (M_L).

Table 1.1 Results of the General Linear Model of factors that affect lobster mortality using a log-normal transformation, (a) Southern Zone, (b) Northern Zone

(a)

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5319	314,536	59.13	147.41	<0.0001
Error	483,961	194,140	0.401		
Corrected Total	489,280	508,677			

R-Square = 0.62

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LICENCE	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
LICENCE*YEAR	3415	53019.8	15.5	38.7	<0.0001
LICENCE*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	Pr > F
Model	2159	39,217	18.17	41.75	<0.0001
Error	148,731	64,713	0.435		
Corrected Total	150,890	103,931			

R-Square = 0.38

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LICENCE	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
LICENCE*YEAR	1287	7275.6	5.7	13.0	<0.0001
LICENCE*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

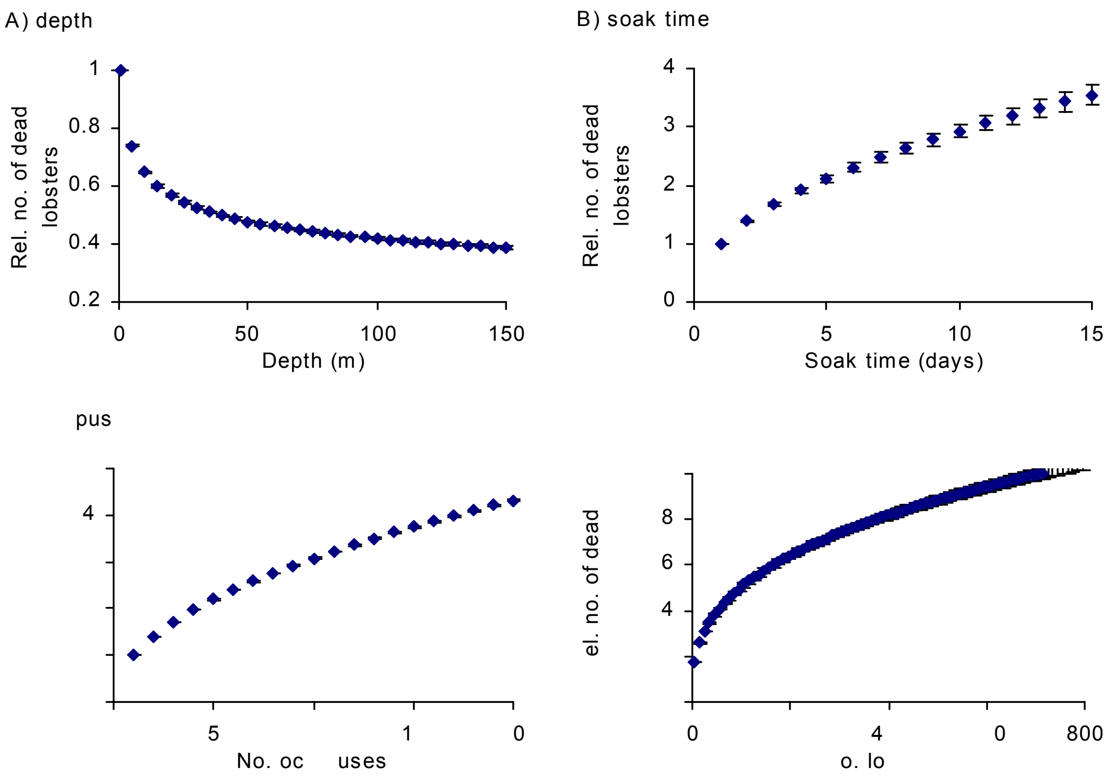

Figure 1.6. The relative number of dead lobster as a function of (a) depth, (b) soak time, (c) no. octopus, and (d) no. of lobsters for the Southern Zone.

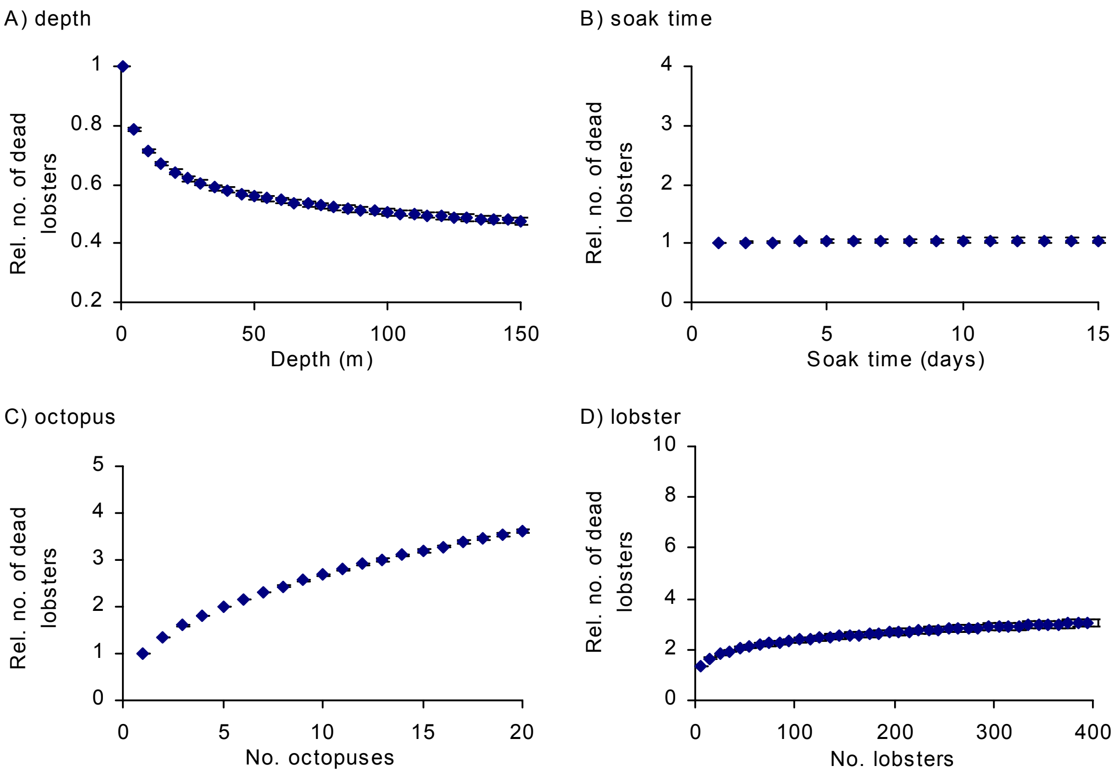

Figure 1.7. The relative number of dead lobster as a function of (a) depth, (b) soak time, (c) no. octopus, and (d) no. of lobsters for the Northern Zone.

Source of lobster mortality and size-dependent mortality

A total of 3627 lobsters from 635 pot-lifts was measured. The mean CL of dead male lobsters was greater than live males (118 vs. 110 mm, $p < 0.001$, Fig. 1.8). There was no significant difference in the mean size of live and dead female lobsters (Fig 1.8).

There were 212 dead lobsters recorded from the total catch, of which 207 (98%) were killed by octopus and 5 by other predators. For both sexes the probability of mortality increased with size according to the following relationships:

$P(M_L, \text{males}) = 1/1+e^{-(-5.04+0.0224*CL)}$

$P(M_L, \text{females}) = 1/1+e^{-(-4.18+0.0132*CL)}$

Above 100 mm CL the probability of mortality increased more sharply in male lobsters than female lobsters (Fig. 1.9).

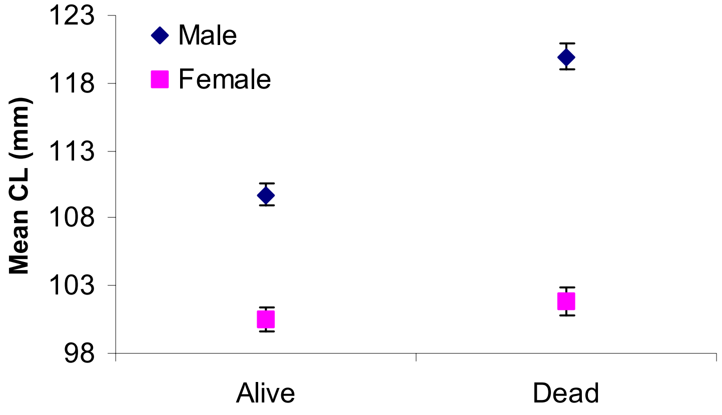

Figure 1.8. Comparison of mean carapace length for live and dead lobsters with respect to sex (error bars ± SE of mean).

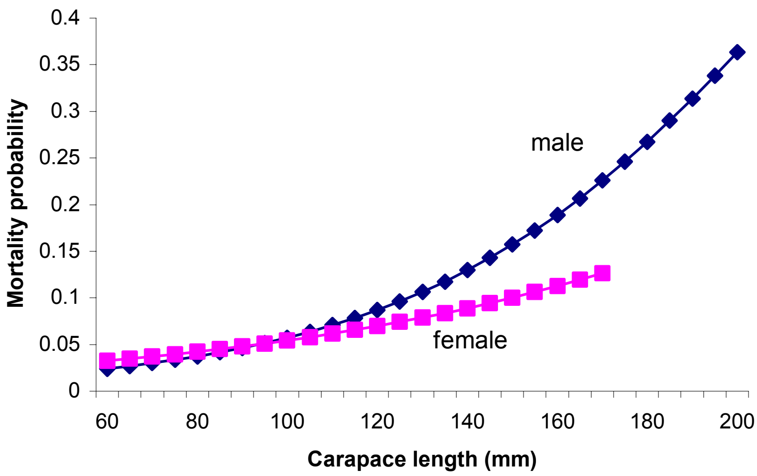

Figure 1.9. Size-dependent mortality of lobsters with respect to sex.

Discussion

Logbook data from the SARLF suggest that over the last five years approximately 240,000 lobsters have been killed within pots each year. Whilst field observations suggest that there are numerous predators of trapped lobsters, including 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 indicated that over 97% of within-pot 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, demonstrates that *O. maorum* is the major predator of lobster in SARLF pots.

The results showed that approximately 4% of the total annual catch of the SARLF is lost to predation by *O. maorum* in pots. This is similar to the mortality rates caused by this species in the Tasmanian fishery (5%), lower than those recorded in some parts of the New Zealand fisheries (10%) for *J. edwardsii* (C. Gardner pers. comm. 1999, Ritchie 1972), but higher than the level (1%) caused by *O. tetricus* in the Western Australian fishery for *Panulirus cygnus* (Joll 1977).

The general linear modelling (GLM) approach that we used to determine the factors associated with M_L has some limitations. For example, we could have adopted a more formal (bottom-up or top-down) approach to developing the model structure, but decided that constraints in the data combined with the need to address the original objectives of the chapter virtually defined the model structure *a priori*. Similarly, we acknowledge that some of the factors in the model, notably $CPUE_L$ and $CPUE_O$ (which are the major factors associated with M_L) are partially correlated, but note that this issue would also affect most other types of analyses and consider that the most appropriate response is to simply acknowledge the problem. We also acknowledge that the logbook data for the SARLF, like most other fisheries monitoring data, are not completely independent and that interdependence among observations can bias estimates of parameters and hence conclusions. To address this issue, we tried aggregating the data at a variety of levels, but found that this did not resolve the problem and significantly reduced the information that could be gleaned from the analyses. Hence, we decided to use the data in its least aggregated form. Another perceived problem with the analyses we undertook is that the large number of observations and degrees of freedom tend to make most factors significant. We dealt with this issue by using the MS values to rank the importance of factors. To summarise, the dataset that we used in this chapter was large and complex, and we could have used a wide range of analyses, but we consider that the GLM approach that we took is suitable for addressing the objectives of the chapter.

In both zones, inter- and intra-annual fluctuations in M_L appear to largely reflect the effects of $CPUE_L$ and $CPUE_O$. For example, the general increase in M_L in the SZ since 1983 appears to result from the increase in $CPUE_{L,}$ which has more than doubled over this period, whereas short-term inter-annual fluctuations in M_L appear to correspond with changes in $CPUE_O$. 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.

The links between M_L, $CPUE_L$ and $CPUE_O$ in both zones can be readily explained. Increases in $CPUE_L$ are likely to elevate M_L by (i) increasing the probability of octopus encountering pots containing lobsters and (ii) increasing the number of lobsters in pots entered by octopus. Variations in $CPUE_O$ are likely to reflect changes in octopus abundance, and increased octopus abundance is likely to be reflected in elevated $M_{L.}$

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* (Ritchie 1972) and reflects the increased opportunities for octopus predation when pots containing lobsters remain in the water for longer periods. The effect of soak-time on M_L in the SZ is related to fishing practices, management arrangements and lobster abundance in that zone. SZ fishers return to port each day and choose to fish or not to fish each day based on factors such as weather and price. Hence, while the majority of pots are retrieved by fishers after a 1 day soak time, a range of soak times times are pots are commonly fished for a wide range of soak-times. As lobster abundance and $CPUE_L$ have increased in recent years, fishers who are confident of catching their quota before the end of the season have become more selective about the price and weather conditions in which they will fish and soak-times have tended to increase. Hence, the effect of soak-time on M_L is related to the increase in $CPUE_L$ in the SZ.

Soak-times longer than one day occur less frequently in the NZ than the SZ. This is because fishing trips in the large NZ usually extend for one to two weeks and fishers usually pull their pots each day. Furthermore, as the NZ is managed through input controls including limits on the number of days fished, NZ fishers are more likely to go fishing in poor weather conditions than their SZ counterparts. Also lobsters taken by octopus in the NZ cannot be replaced as they can in the quota-managed SZ. In the NZ, $CPUE_L$ has been relatively stable and M_L has followed a similar pattern to $CPUE_O$, which has also been relatively stable compared with the scale of the fluctuations in the SZ.

Data presented in this paper were collected over a period of 17 years from an area covering approximately 50,000 km^2. Hence, this is one of the few long-term and large-scale datasets that provides insights into the distribution and abundance of an octopus species (Quetglas *et al.* 1998, Hernandez-Garcia *et al.* 1998). The paucity of studies on these scales reflects the logistical constraints associated with conducting fishery-independent surveys of octopus populations, and the artisanal and/or multispecies nature of most octopus fisheries and the correspondingly poor and inconsistent methods generally used to record 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 have used $CPUE_O$ 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) spatio-temporal 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, i.e. the pot, has remained unchanged since 1983. Furthermore, although *O. maorum* is retained as bycatch and kills *J. edwardsii* in pots it is neither targeted nor avoided by fishers, and fishing effort is thus relatively independent of its distribution patterns. This is because the economic effects of both the sale of octopus by-catch and the costs of lobster predation are relatively small compared to the primary economic driver for the fishery, i.e. lobster catch rates, and because the catch rates of octopus are difficult to predict. It is also relevant that *O. maorum* is a solitary animal that tends to be dispersed randomly throughout areas of suitable habitat (Mather *et al.*1985).

One aspect of the biology of *O. maorum* that should be considered when $CPUE_O$ data from the SARLF are being interpreted is the brooding behaviour of females. This effect could potentially explain the decline in $CPUE_O$ over the course of the fishing season, but this trend could also be associated with a seasonal decline in $CPUE_L$ or reductions in octopus abundance resulting from fishing pressure. However, the data required to determine why $CPUE_O$ declines over the course of the season in the SARLF are not currently available. Information on the life history characteristics of *O. maorum* in South Australia is needed to resolve this issue.

The higher total catches and catch rates of both lobster and octopus in the SZ compared to the NZ are likely to higher levels of abundance and the more extensive reef habitat and intense nutrient-enrichment through upwelling in this portion of the SARLF (Lewis 1981). There have been large inter-annual fluctuations in $CPUE_O$ in both zones since 1983, suggesting that octopus abundance may have varied significantly over this period. Large fluctuations in population size are common among other cephalopods, especially squid, and may result from life history patterns that are characterised by rapid growth, short lifespan (<2 years) and almost universal mortality after a single spawning event (Boyle and Boletsky 1996).

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 through upwelling in this portion of the SARLF (Lewis, 1981). There have been large inter-annual 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 characterised by rapid growth, short lifespan (<2 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 has been consistent over time. Given that fishers retain less than 50% of all octopus that enter pots (pers. obs.) and the poor correlations between octopus catch and effort it does not appear that current levels of octopus bycatch in the fishery are unsustainable.

This study confirmed the view of fishers that larger lobsters are killed more commonly by octopus than 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 of lobsters. For example, octopus could actively select larger prey, or large lobsters could be captured more easily in pots by octopus than small lobsters. As 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 numbers of lobster killed.

There are several other reasons why estimates of lobster mortality presented in this paper may underestimate the effects of octopus predation on the SARLF. Firstly, the remains of dead lobster can be washed out of pots and these mortalities are not recorded in logbooks. Secondly, pots containing octopus and dead lobsters often include lobsters with missing limbs and other damage, which are usually returned to the water because they attract lower prices. Previous studies have shown that injured lobsters that are returned to the water have reduced rates of somatic growth and reproductive output (Brown and Caputi 1985, Lyons 1991), and it seems likely that may also have reduced rates of survival.

This study shows that octopus predation of lobsters in pots 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 pots, which increases the time (and costs) of catching quotas, and imposes a non-productive impact on lobster abundance. In the input-controlled NZ, where there is no direct restriction on the quantity of lobsters taken, lobsters killed in pots represent both a direct economic loss and a non-productive impact on lobster abundance.

Like most fisheries for spiny lobsters, the SARLF is close to fully exploited under current management arrangements. Reducing rates of octopus predation provides one option for increasing productivity of the fishery. Some reductions in lobster mortality may be achieved by minimising soak-times, especially in the SZ. However, this approach only offers minor advantages. More significant reductions in the rates of within-pot lobster mortality may only be achieved by reducing rates at which octopus enter pots.

CHAPTER 3: A TWO-CHAMBERED POT REDUCES WITHIN-POT PREDATION BY OCTOPUS ON ROCK LOBSTERS IN AQUARIUM TRIALS.

Objective 3: Identify pot modifications that have the potential to prevent/reduce octopus predation of pot caught southern rock lobster.

Objective 4: Trial pot designs to prevent/reduce octopus predation under laboratory conditions.

The first objective was achieved by direct observation of the interaction of octopus and lobsters in conventional lobster pots. In a large aquarium, a video camera was used to record the approach, entry and exit of octopus from pots and determine how the presence of bait versus the presence of lobsters affected their behaviour. Octopus were primarily attracted to pots by the presence of bait as opposed to lobsters and octopus entry into pots was mediated by exploration. Octopus most frequently entered pots through the neck but were also able to enter through the mesh covering the side of pots and the bottom of conventional pots. Potential pot modifications identified included: deterring octopus from entering through the neck; placement of a shelter inside the pot and the redesign of pots to contain two chambers to keep octopus and lobsters separate.

The second objective was achieved by testing pot modifications under the same conditions used to address objective 1. Preliminary trials showed that the two-chambered concept had the greatest potential to mitigate octopus predation. The pot had an outer chamber that contained bait and allowed entry by octopus but not lobster and an inner chamber that allowed access to both animals. The two-chambered pot was designed on the principle that octopus enter the outer chamber containing bait through a side entrance in preference to entering the inner chamber containing lobsters through the neck. Results showed that lobster mortality was 70% lower in the two-chambered pot than in a conventional pot.

Introduction

Joll's (1977) study of within-pot predation of *P. argus* by *O. tetricus* in Western Australia is, to our knowledge, the only published attempt to understand and resolve this problem. Joll showed that *O. tetricus* enters pots rapidly via several locations and can locate bait solely by olfactory means. The use of octopus as bait, or the presence of tissue extracts or visual models of known predators was not found to deter octopus entry into pots. Joll concluded that "with the necessity of pots to have an entry port for rock lobsters …. it is difficult to conceive of any changes in pot design which could make pots octopus proof".

Although a pot design that could prevent octopus entry entirely seems unrealistic, pots have proven to be one of the most versatile types of fishing gear and have been modified to catch particular species and size ranges (Miller 1990) and to exclude or reduce the entry of animals very similar to the target species (Carlile 1997). The significant morphological and behavioural differences between (shelled) lobsters and (soft-bodied) octopus suggest that it may be possible to design a pot that exploits these differences to inhibit octopus entry into pots and hence, lobster predation.

Identification of pot modifications that may potentially mitigate octopus predation on lobsters within pots requires a comprehensive understanding of the behaviour of octopus on and within pots. The aims of this chapter were (1) to investigate the behaviour of *O. maorum* with the pots typically used in the South Australian Rock Lobster Fishery, and to compare these results with findings of Joll (1977) for *O. tetricus,* and (2) to use these observations to develop and test pot designs that have the potential to reduce octopus predation.

Methods

Octopus behaviour in and around pots

The behaviour of *O. maorum* in and around pots was observed in trials conducted in a large circular tank (5 m diameter, 2 m high, 40 000 l) with constant seawater flow located at the SARDI Aquatic Science Centre, Adelaide.

Octopus ranging between 1.5-8 kg and legal-sized rock lobsters were caught in pots by commercial fishers off Cape Jaffa, South Australia. Prior to transportation, octopus were 'rested' overnight in shallow water in 20 litre screw top containers with small holes that allowed water exchange. Octopus were transported in 25 l buckets with securely fitting lids filled with fresh seawater. Each container was aerated with a portable air pump.

Octopus were maintained in square fibreglass tanks (1 m × 1 m × 0.5 m deep) linked to a flow through seawater circulation system. Water temperature was maintained at 19 ± 1°C and a suitable den was provided. Octopus were fed sufficient rock crabs (*Nectocarcinus integrifrons*) to maintain body weight (Joll 1977). Octopus were kept in captivity for a period of 2-5 days before the commencement of their first trial.

Trials were conducted between October 1999 and February 2000. A 'trial" consisted of the behaviour of one octopus around and within a conventional lobster pot as used in the SARLF (Fig. 2.1) over a 20 hour period.

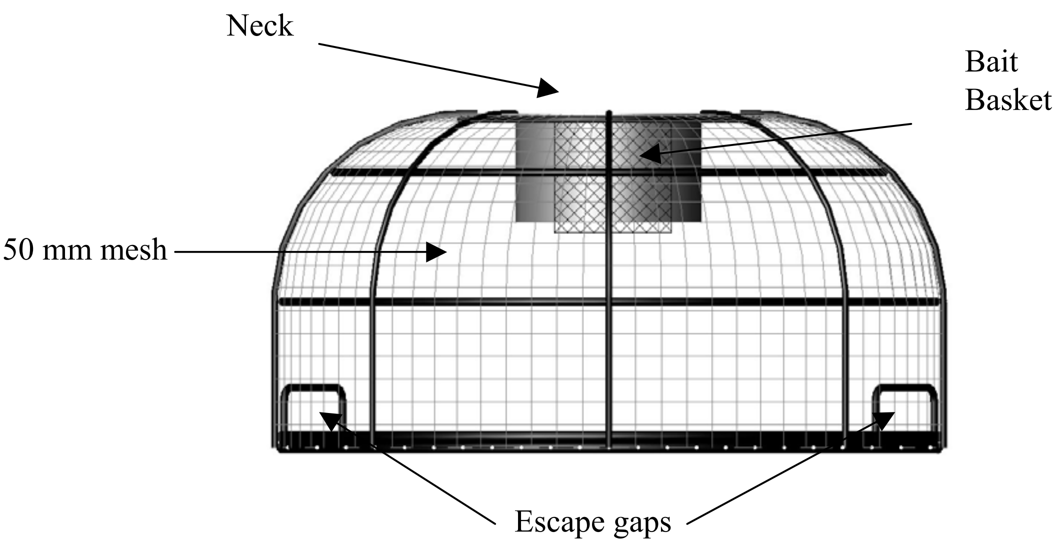

Figure 2.1. Conventional lobster pot as used in the SARLF.

The pot contained two escape gaps (55 by 150 mm) located on opposite sides of the pot. Escape gaps are not mandatory in the SARLF yet, but more escape gaps are fitted to pots each year and are therefore included to determine what effect, if any, their presence has on octopus entry and exit from pots. Diurnal variations in the behaviour of octopus were examined by commencing trials in the (i) morning and (ii) evening. The effects of the presence/absence of lobsters in pots on the behaviour of octopus was investigated by presenting octopus with, (i) pots containing two baskets of bait (Australian salmon, *Arripis trutacea*) or (ii) pots containing two baskets of bait plus three legal-sized rock lobsters.

The lack of readily available octopus and difficulties associated with feeding and maintaining large numbers of octopus meant that it was not possible to ensure each octopus underwent only one trial. While repeated trials with the same octopus represents a form of pseudo-replication we feel that as the maximum number of trials performed by any one octopus was three and that this is well below the number usually associated with learned behaviour in octopus (Messenger and Sanders 1972, Muntz and Gwyther 1988 a, b) that this was unlikely to bias our results.

Each trial was run as follows. An octopus was introduced to the large circular tank containing a den and allowed to acclimatise for 24 hours. At the commencement of the trial a lobster pot containing either bait or bait and lobster was placed centrally in the tank 1.5 m from the octopus den. The pot was placed on a rough surface of bricks to simulate field conditions (pots are set over reef areas and therefore rarely sit flat on the bottom). The pot was orientated so that the two bait baskets were in a plane perpendicular to the line of sight from the den to the pot.

Recording began as soon as the pot was placed in the tank. The tank was enclosed so that octopus remained undisturbed for the duration of the trial. Two red lights (680nm) on timers were used to provide enough illumination to record on video the behaviour of the octopus during the night, with tank lids open during the day. Given that the spectral sensitivity maxima of cephalopods is around 480 nm (Hara and Takeuchi 1967, Hubbard and George 1958) it was assumed that the presence of the red light would have minimal effect on the ambient light environment perceived by the octopus.

All interactions between the octopus and lobster were recorded using a Canon MV1 digital camera in an underwater housing. The camera housing was fitted with external power and coaxial plugs to allow constant power and footage to be recorded on normal analogue video recorders with “long play” capability. The use of two video recorders and 5-hour videotapes gave a maximum of 20 hours continuous footage.

Once the trials were completed, the videotapes were examined. Information that was recorded included: a description of the octopus's behaviour; the time (mins) elapsed from the commencement of a trial to first contact; entry and exit from the pot; the location of entry into and exit from the pot; and the number and size of lobsters killed.

Modified pot design, development and trial

Using information obtained during the current study and that by Joll (1977) the effect of three pot modifications on lobster mortality rates were tested under the same conditions as the original tank trials. The modifications encompassed:

1. Provision of a shelter for octopus inside the pot to minimize the chance of multiple lobster kills by octopus and reduce lobster exposure to octopus. The shelter was an earthenware container secured inside the pot.
2. Insertion of sharp spikes in the neck of the pot to deter octopus entry. The spikes consisted of 40 industrial sowing needles fixed inside the neck so that their points faced the direction of animals entering pots via the neck.
3. Construction of a two-chambered pot to separate octopus from lobsters and thus reduce mortality (Fig. 2.2). Two continuous gaps, 40 mm high, running around the side of the pot provided access to the outer chamber while a standard 'neck' opening provided access to the inner chamber. Bait is placed in the outer chamber with the aim that octopus will enter this chamber in preference to the inner chamber. A gap height of 40 mm was chosen because (1) anecdotal information suggests that lobsters small enough to pass through a 40 mm gap rarely enter pots, and (2) tank trials demonstrated that octopus ranging between 1 – 7 kg could pass through a gap 150 mm wide and 25 mm high. As *O. maorum* above 7 kg are encountered rarely (Brock, unpublished data), most will pass easily through a gap of 40 mm.

After 6-8 trials of each pot modification it was clear that modifications 1 and 2 were not successful in reducing lobster mortality, so no further trials of these pot modifications were conducted (Table 2.1). In no instance were octopus ever seen to use the shelter and lobsters were killed in every trial containing a shelter. Lobsters were also killed in 6 out of 7 trials of the modified pot containing inserted spikes around the neck. However, lobster mortality only occurred in 2 out of 6 trials of the two-chambered pot and therefore further testing was conducted on this modification.

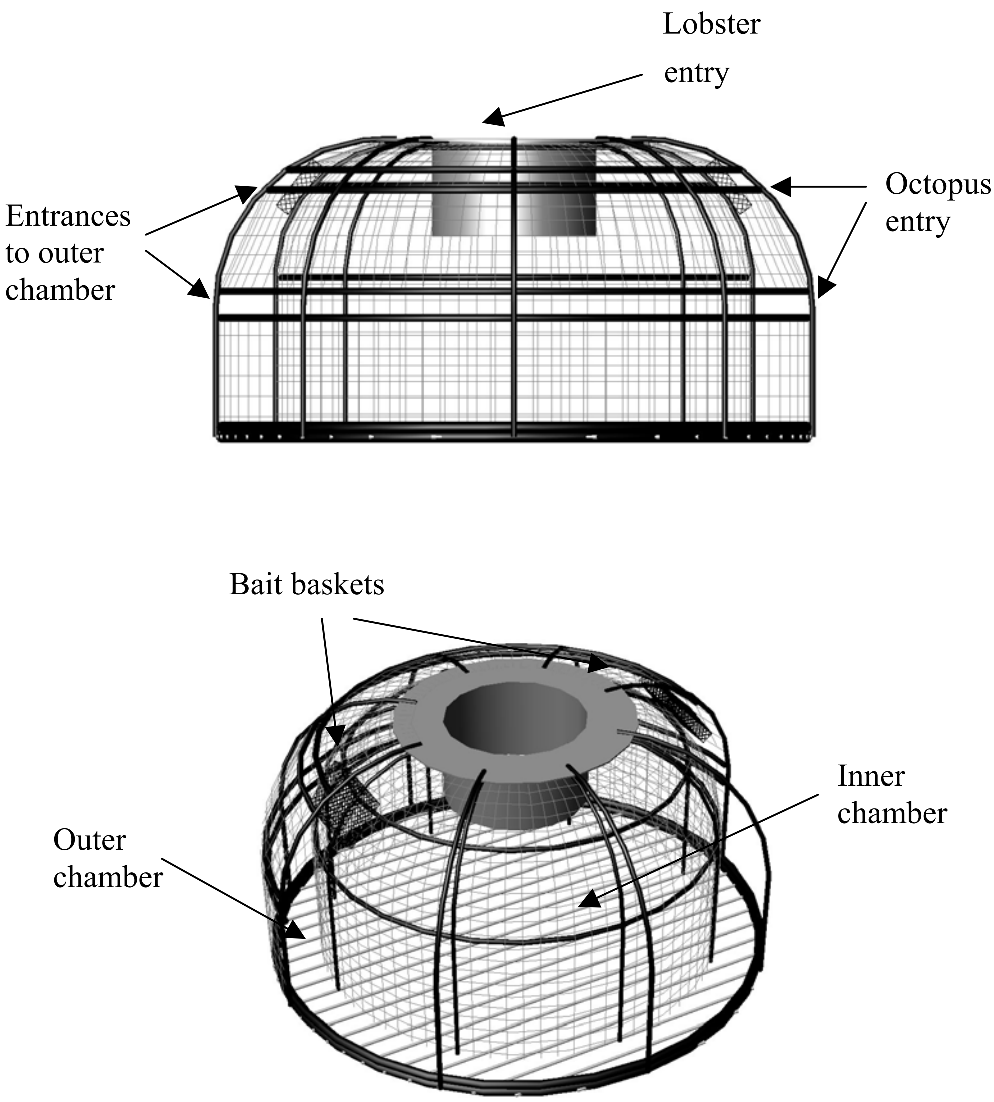

Figure 2.2. Side view (top) and top view with front section of mesh on outer chamber removed (bottom) of the two-chambered pot.

Table 2.1. Results of preliminary trial of three techniques to reduce octopus predation

Method	No. Trials	% of trials in which lobsters were killed
Provision of shelter	15	100
Deterrent spikes	7	87
Two chambers	6	33

Data Analysis

The effect of trial commencement time (morning/ evening) and presence/absence of lobsters in pots on the likelihood of pot entry, lobster mortality rate and timing of events were analysed by the Fisher exact test, Mann-Whitney test and Analysis of Variance respectively. The distribution of octopus entries and exits from pots was tested by Chi-square analysis of contingency tables.

Results

Interactions of octopus with pots

A total of 104 trials were conducted. However, 29 trials were not completed and excluded from the analysis due to problems such as recording failure, movement of the camera by the octopus and lobsters escaping from the pot. Octopus entered pots in 65 of the 75 completed trials (Table 2.2). The proportion of successful pot entries was independent of the time of trial commencement or the contents of the pot (Fisher exact test, $p > 0.5$ for both treatments).

Table 2.2. Number of trials and octopus entries for each treatment combination

	Pot Contents			
	2 bait baskets of salmon		2 bait baskets of salmon + 3 legal-sized lobsters	
	Morning Start	Evening Start	Morning Start	Evening Start
No. Trials	19	18	20	18
No. Entries	16	15	17	17

Octopus approached the pot by either slow swimming or crawling. The most common point of first contact with the pot was at the side with the octopus inspecting the pot with their arms. Less frequently, octopus swam towards the pot and then 'parachuted' onto the top and enveloped it with its arms.

Octopus took on average 2.5 hours from the commencement of trial to first contact the pot (Fig 2.3a). The time of day octopus entered pots was dependent on the time of trial commencement, i.e. octopus were more likely to enter pots during the day in trials that commenced in the morning and more likely to enter pots during the night in trials commenced during the evening (Fishers exact test $p < 0.01$). Neither the presence/absence of lobsters in the pot (ANOVA $p > 0.5$) nor the time the trial commenced (ANOVA $p > 0.5$) significantly affected the time it took an octopus to first contact the pot.

Once in contact with the pot, octopus investigated it with exploratory movements of the arms, often inserting several through the mesh into the interior of the pot. Examination of the pot appeared to be mediated mainly by tactile exploration. However, in some trials containing lobsters, it was apparent that octopus could 'see' the lobsters as they circled around the pot following the lobsters inside.

Octopus generally entered pots within a few minutes (<3) of first contact (Fig. 2.3b). Neither the presence/absence of lobsters (ANOVA $p > 0.5$) nor the time of trial commencement (ANOVA $p > 0.5$) affected the time taken to enter pots from first contact.

Octopus most commonly entered pots through the neck (Chi-square $p < 0.01$), but also entered via the base, steel mesh on the sides and escape gaps (Table 2.3. Complete entry into pots generally occurred within a few seconds of initiation of the entry, with the exception of entries through the 50 mm diameter mesh, which took longer. For example, one 6.5 kg octopus took over eight minutes to enter through the mesh.

After entry into pots containing bait only, the octopus enveloped and fed from the bait basket until ready to exit the pot. In pots containing both bait and lobsters, the octopus usually targeted lobsters, although on a few occasions the octopus fed initially on the bait before capturing and consuming the lobsters. Octopus generally caught one or more lobsters within 5 minutes of entering and began to feed. Some octopus consumed all three lobsters during the trial, more commonly though only one lobster was consumed. There was no significant difference in the number of lobsters consumed per trials that commenced during the morning or evening (Mann-Whitney $p > 0.5$).

When an octopus had finished feeding, generally after about 3 hours (Fig. 2.3c), it began to search for an exit from the pot. The most common point of exit was through the escape gap (Table 2.3, Chi-square $p < 0.01$). Exits appeared to be mediated by tactile examination of the pot as octopus often crawled past escape gaps several times before finally exiting. The dimensions of the escape gap impeded none of the octopus. The period for which octopus remained in pots was not affected by the contents of the pot (ANOVA, $p > 0.5$) or by the time that the trial commenced (ANOVA, $p > 0.5$).

A comparison of the percentage of octopus outside their dens at half hourly intervals showed that octopus were more active at night in trials that commencement during both day and night (Fig.2.4a & b). The percentage of octopus 'out' of their dens during the day ranged between 0 – 55% during the day and 30 – 76% during the night.

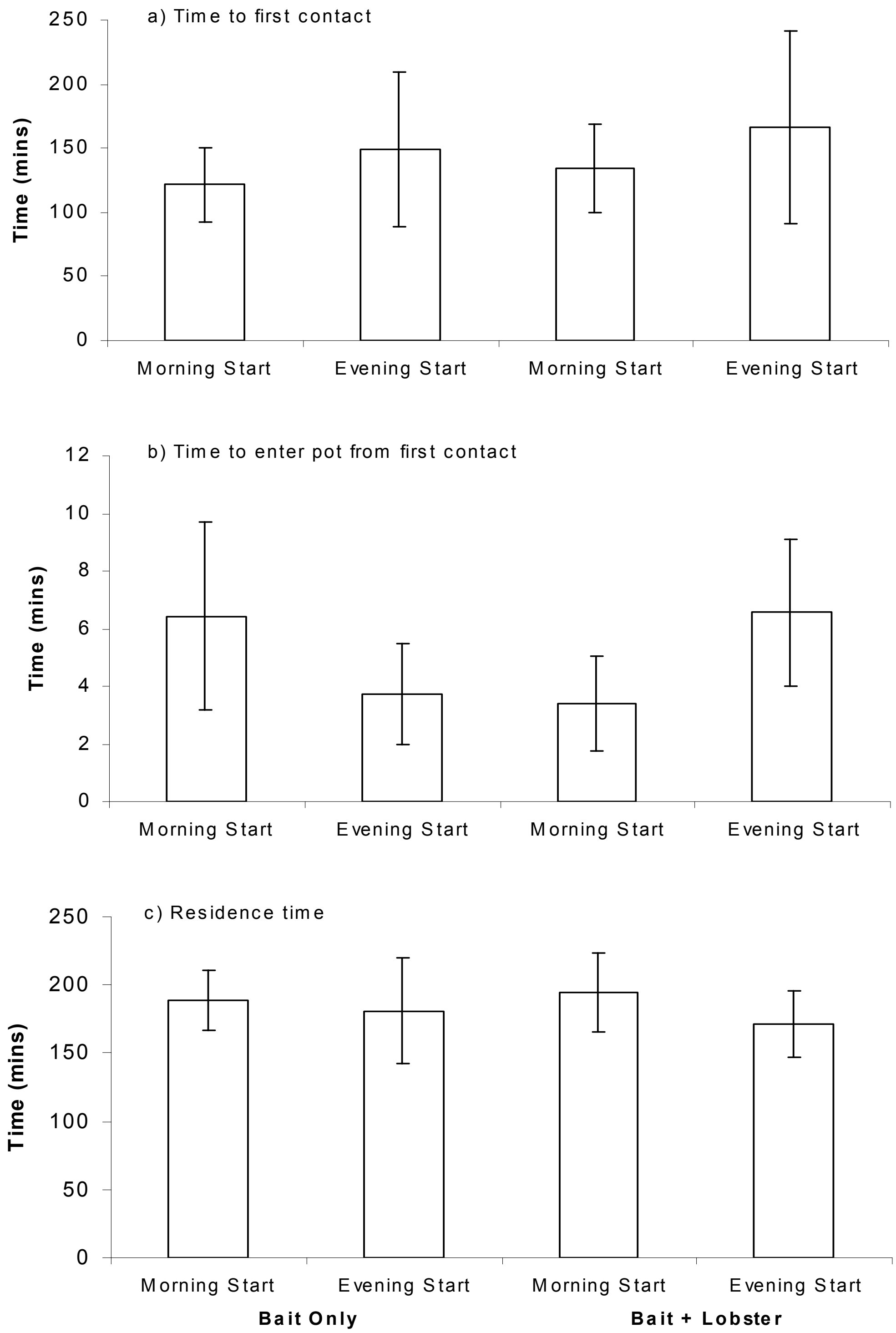

Figure 2.3. Comparison of the time for octopus: a) to contact pots from trial commencement, b) to enter pots from first contact, and c) spent inside pots before leaving (error bars ± SE of mean).

Table 2.3. Number and location of entry and exit of octopus from pots.

	Neck	**Bottom**	**Side**	**Escape Gap**
No. of entries	32	15	7	7
No. of exits	6	11	6	36

Table 2.4. Entry locations and predation frequency in two-chambered pots and conventional pots. [1]Entries via the escape gap included in side entries. [2]Residence times in the outer chamber only

	Location of Entry				
	Side	Neck	Bottom	% Trials in which lobster killed	Residence Time
Two-chambered pot	15	4	2	29	150[2]
Conventional pot	11[1]	16	7	100	184

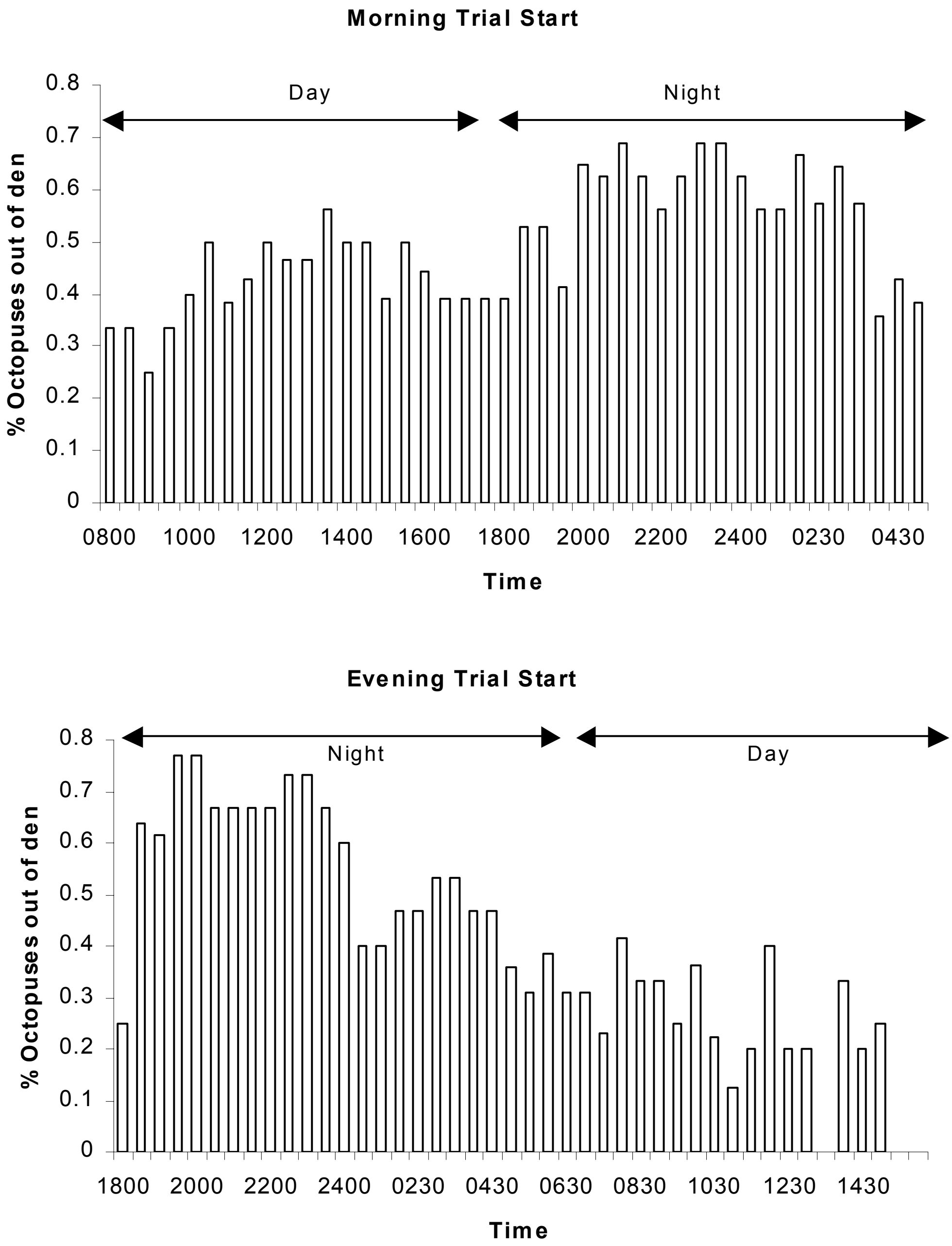

Figure 2.4. Percentage of all octopus active (out of dens) in half hourly intervals for trials started (a) in the morning, and (b) in the evening.

Two-Chambered Pot

Octopus predation was significantly lower in trials with the two-chambered pot compared to those with conventional pots (Table 2.4, Chi-square $p < 0.01$). Octopus entered the outer chamber in 15 of the 21 trials of the two-chambered pot. When an octopus entered the outer chamber, it fed on the bait and then exited the pot without entering the inner chamber. In trials utilising a conventional pot, every time an octopus contacted a pot at least one lobster was killed.

The general behaviour of octopus on and within the two-chambered pot was similar to that of octopus on and within conventional pots. Octopus entry into the outer chamber was rapid and once in the outer chamber octopus generally fed on the bait for between 2-3 hours before leaving the pot. In trials where the octopus entered the outer chamber, on no occasion did the octopus return to the pot, enter the inner chamber and kill lobsters.

Discussion

O. maorum was observed outside its den more often during the night than during the day, however the rates of entry into pots and lobster mortality during the day and the night were not significantly different. Anderson (1999) also noted that *O. maorum* in captivity was frequently active during both the day and night, and divers in South Australia commonly observe *O. maorum* foraging during the day (D. Brock, pers. obs.). Although several species of octopus have been described as nocturnal (eg. *O. vulgaris*, Kayes, 1974) or crepuscular (eg. *O. cyanea*, Yarnall, 1969, Forsythe and Hanlon 1997), many species (eg. *O. dofelini*, Mather 1988) appear to have flexible activity patterns that are affected by a range of environmental cues, including prey availability, as well as time of day and/or light levels. For example, Wells *et al.* (1983) demonstrated that the (nocturnal) activity pattern of *O. vulgaris* in captivity could be altered by changing the feeding regime, and that specimens fed during the day or irregularly were equally active during the day and night. The findings of this study show that *O. maorum* has a flexible activity pattern that is essentially opportunistic, and support the industry view that temporal adjustments to fishing patterns are unlikely to reduce levels of octopus predation on lobsters.

Given the well-developed visual capabilities of octopus and the significant rates of octopus predation on lobster in the SARL, it was expected that *O. maorum* would enter pots containing lobsters more quickly or more often than pots containing bait only. However, the presence/absence of lobsters did not significantly affect the behaviour of octopus and *O. maorum* appeared to be primarily attracted to pots by the presence of bait rather than the presence of lobsters. This result may indicate that *O. maorum* primarily uses olfaction rather than vision to locate pots, and is consistent with the results of Joll (1977) that indicate *O. tetricus* located baits solely by olfaction.

Vision appeared to play only a limited role in the exploration of pots by *O. maorum*. After swimming or crawling onto the side of a pot, *O. maorum* usually crawled around and over the pot and used its arms to explore and probe openings. This observation is consistent with field studies of other species of octopus, which suggest that vision may not be as important in the prey capture as indicated by some laboratory experiments (Forsythe & Hanlon, 1997). For example, direct field observations of *O. cyanea*, *O. vulgaris* and *O. dofelini* indicate that successful foraging and feeding is usually the result of tactile exploration rather than visual detection of prey (Hartwick *et al.* 1984, Mather 1991a, Mather and O'Dor 1991, Forsythe and Hanlon 1997).

The patterns of entry into and exit from pots also reflect the tactile nature of the exploration of pots by *O. maorum*. Octopus usually entered pots through the neck, which is the largest opening, but commonly exited through the escape gaps, which are the openings that are most accessible from the floor of a pot. Joll (1977) recorded similar patterns of entry and exits for *O. tetricus* in wire pots for *Panulirus argus* similar to those used in the SARLF. The findings of the present study support the conclusions of Joll (1977) that entry through various openings is 'fortuitous' and directed by tactile examination of the pot rather than 'recognition' of a potential access point.

Tactile exploration is effective for locating access points to pots. Octopus successfully entered every pot that they contacted and entry was generally completed within a few minutes of the first contact. Similarly, Joll (1977) suggested that the average time between first contact and entry for *O. tetricus* was 3.16 minutes. These findings do not support assertions by fishers that the presence of escape gaps in pots increases the likelihood of octopus predation on lobsters by providing more rapid access. Ritchie (1972) showed that the presence of escape gaps did not increase the numbers of *J. edwardsii* killed by *O. maorum* in the New Zealand pot fishery.

The ease with which *O. maorum* entered pots in this study supports the conclusion by Joll (1977) that given the need for a fixed opening to catch lobsters it will be difficult to exclude octopus from pots entirely. However, our observations of *O. maorum*, showed that differences in the behaviour and morphology of lobsters and octopus could potentially be used to reduce the rates of octopus predation on lobsters. Specifically, (i) the attraction of octopus to bait rather than lobsters and (ii) the tendency for octopus to enter pots through the first appropriate opening that they encountered (iii) and the ability of octopus to enter pots through smaller openings than legal-sized lobsters, led us to test a pot design that allowed lobsters and octopus to be caught in separate compartments of the same pot. As octopus generally approach pots from the side, we built a two-chambered pot (Fig. 2.2) with openings (large enough for octopus but too small for legal-sized lobsters) to the outer chamber (containing bait) located between the side of the pot and the neck (so that octopus would encounter the openings to the outer chamber before encountering the opening to the inner chamber). Experiments in an aquarium confirmed that lobster mortality in two-chambered pots were 72% lower than in conventional pots. Octopus that entered the "outer" chamber containing bait only, never subsequently entered the "inner" chamber containing bait and lobsters.

To our knowledge this is the first time that a pot has been developed that has the potential to reduce the rates of within-pot predation by octopus on lobster. The success of the aquarium experiments suggests that field trials are warranted to determine whether the concept works in a commercial context. In addition, no attempt was made to determine how the presence of two chambers affects the catch rate of lobsters, which will affect the economic viability of any modified pot. If the reductions in the lobster mortality rates achieved in the aquarium trials could be translated to the fishery, approximately 155,000 fewer lobsters would be killed by octopus in the SARLF each year.

CHAPTER 4. FIELD PERFORMANCE OF POTS DESIGNED TO REDUCE OCTOPUS PREDATION ON ROCK LOBSTER.

Objective 5: Develop a pot that under commercial fishing conditions, prevents/reduces octopus predation, maintains lobster catch rates and is cost effective. The performance of a two-chambered pot was compared to conventional pots during commercial fishing in 2000/01 (Pot A). Trials of this pot were conducted from two licensed commercial fishers from the port of Southend in the SZ of the SARLF. Pot A reduced lobster mortality by 48% but also reduced the catch of legal-sized lobsters by 28%. A refined two-chambered pot (Pot B) was tested in 2001/2 from three commercial vessels. The effectiveness of escape gaps in reducing octopus predation on undersized lobsters was also examined. Lobster mortality was 45% lower in Pot B than in conventional pots but there was still a 28% reduction in the catch rate of lobsters. The presence of escape gaps reduced undersized mortality by 66% compared to pots without escape gaps. The objective of developing a pot that was effective under commercial fishing conditions was achieved only partially as the reduction in the lobster catch rate made the current two-chambered pot less attractive from a commercial perspective. However, as reducing octopus predation offers one of the few opportunities for increasing long-term yields in the SARLF, and for fishers and scientists to investigate design options for enhancing the catching efficiency of two-chambered traps.

Introduction

Escape gaps that allow undersized lobsters to exit pots are mandatory in most lobster fisheries, but not in the SARLF (Prescott 1999). Reductions in the catch rates of undersized lobsters resulting from the use of escape gaps are well documented (Brown and Caputi 1986, Krouse 1989, Treble *et al*. 1998), but the effects of escape gaps on octopus predation on lobsters in pots have not been investigated. Escape gaps could conceivably reduce octopus predation on small lobsters by providing additonal opportunities to escape, but could increase predation of large lobsters by providing additional access points for octopus.

In this chapter we compare the effectiveness of two-chambered pots and escape gaps in reducing octopus predation on lobsters by comparing lobster mortality, and the catch rates of octopus and lobster, in conventional and two-chambered pots with and without escape gaps under commercial fishing conditions in the SARLF.

Methods

Pot Design

The pots most commonly used in the SARL are 'beehive' in shape with a base diameter of 900 mm and a height of 400 mm (Fig. 3.1). The pots are covered by 50 mm stainless mesh and the base is constructed of steel bars spaced at 50 mm. A round plastic neck (250 mm diameter) that extends into the pot allows lobsters to enter. Two bait baskets are positioned inside the pot on either side of the neck. This pot design will be referred to as a conventional pot.

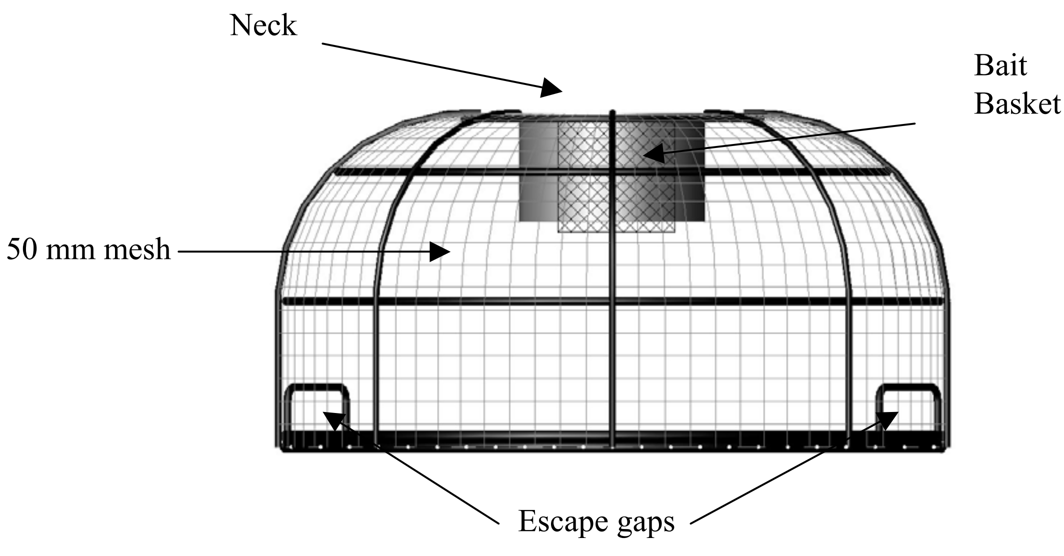

Figure 3.1. Conventional pot used in the South Australian commercial rock lobster fishery

The concept of the two-chambered pot described in the previous chapter was used to build a modified pot that will be referred to as Pot A (Fig. 3.2). Field trials of Pot A were conducted in the 2000/01 fishing season. Information gained from these trials was used to identify design modifications, including the fitting of escape gaps, that were used to construct Pot B. Field trials for Pot B (Fig. 3.3) were conducted in the 2001/02 fishing season.

Pot A was the same basic design as a conventional pot, except the spacing of the bars in the base of pot A were 20 mm compared with 50 mm for a conventional pot. Pot B was square and made from 50 mm square steel mesh, the dimensions of the pot were 900 × 900 × 450 mm. Both pots had an internal wall that divided the pot into two chambers, an outer and an inner chamber. Access to the outer chamber in Pot A was via two parallel entrances with gaps 50 mm wide that encircled the pot. In Pot B access was via four vented 40 mm wide entrances in each side of the pot. Access to the inner chamber in both pots was via a plastic neck as used in conventional pots. In both pots the neck was on a hinged mechanism that enabled the top of the pot to open to allow access to both the inner and outer chambers. In Pot A, two bait baskets were used with one positioned in the inner chamber near the neck and the other in the outer chamber near the neck. In Pot B, two bait baskets were situated adjacent to the neck so that they extended into both the inner and outer chamber.

Year 1

Fishing trials were conducted on two commercial vessels from the port of Southend in the Southern Zone of the SARL. Pots were generally set for a 24 hour soak period. Twelve Pot As without escape gaps were set from each boat and their performance compared to 12 of the fishers conventional pots without escape gaps. The first vessel fished the pots for 11 days during November and December 2000. The second vessel fished the pots for 11 days during January 2001. A total of 228 lifts were monitored for each pot type.

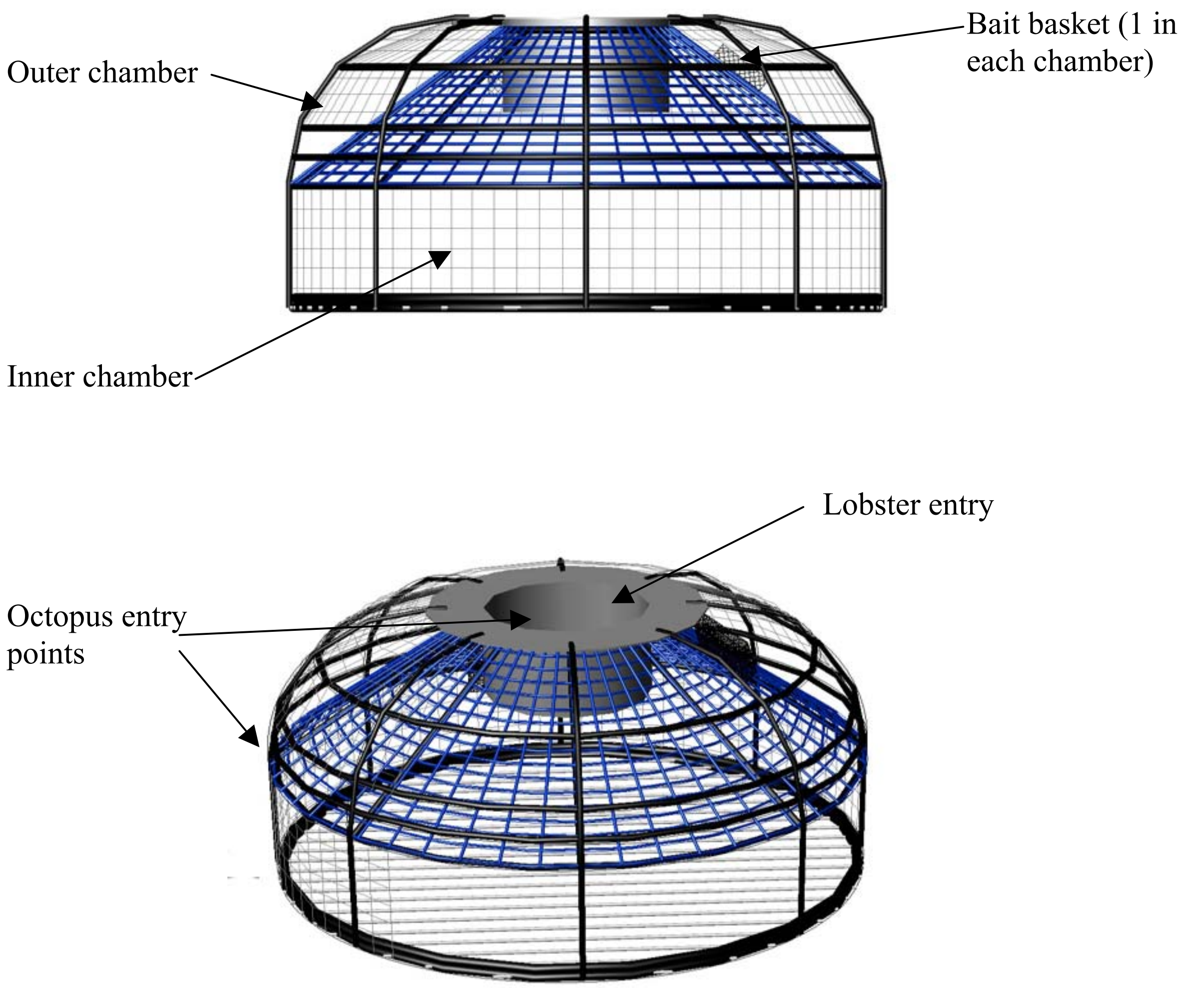

Figure 3.2. Pot A showing side view (above) and top view (below)

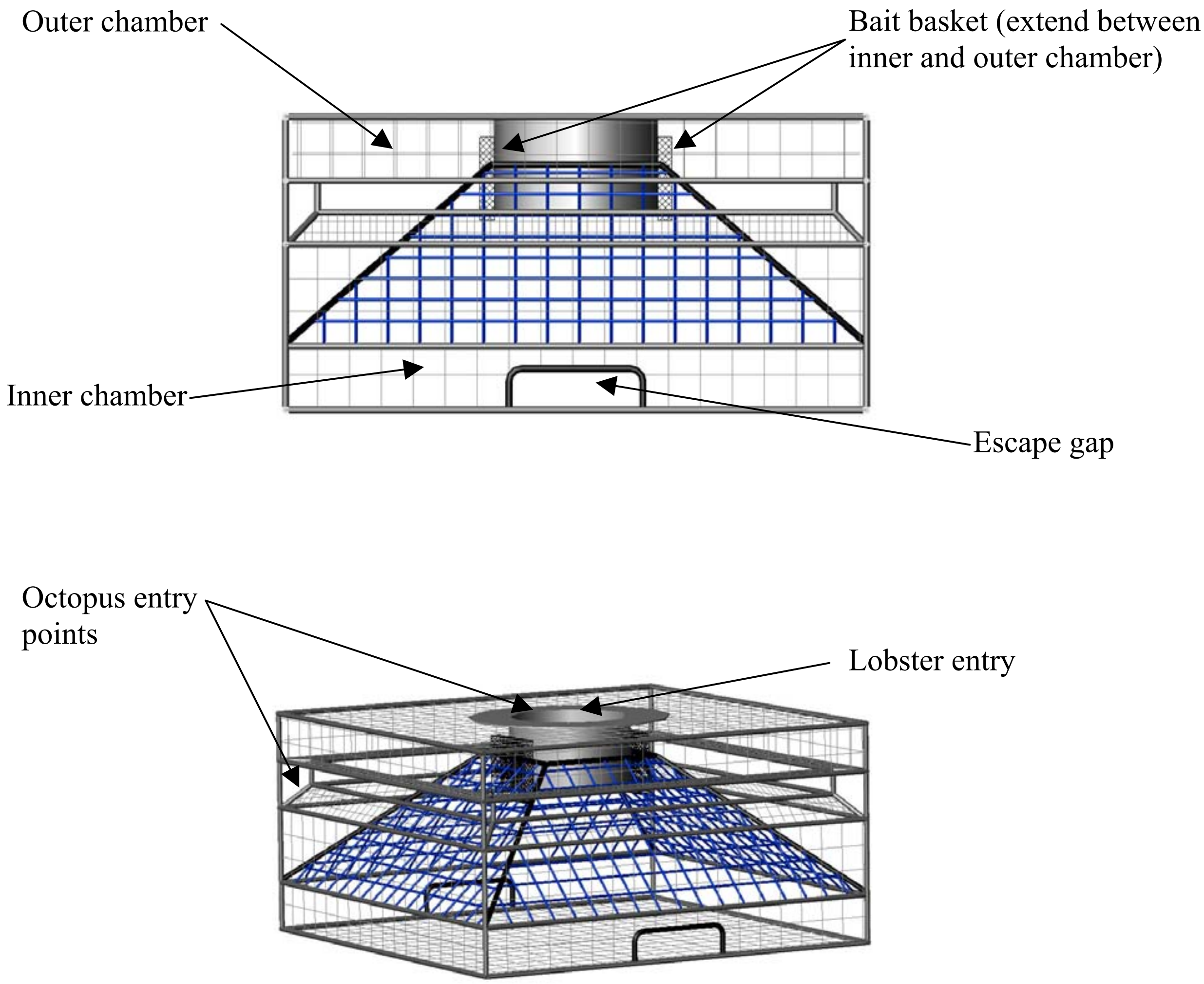

Figure 3.3 Pot B showing side view (above) and top view (below)

The twelve Pot As were haphazardly distributed among the two fishers total pot allocations (71 and 80 pots). The conventional pots chosen for comparison were those set immediately after each Pot A in the fishing line. For every lift of a Pot A and conventional pot, the date and time of pot lift, fishing depth, pot number, number and size (carapace length in mm) of lobsters and the number of octopus caught was recorded. When dead lobsters were present only those killed by octopus were included in the analysis.

Year 2

The 2001/02 fishing trials compared the performance of Pot B with and without escape gaps and conventional pots with and without escape gaps. Two escape gaps (200 cm wide × 55 cm high) were placed at the base and on opposite sides of pots. Fishing trials were conducted using three commercial vessels operating in the same area used for the field trials of Pot A. On each vessel, 10 Pot B, 10 Pot B with escape gaps, 10 conventional pots and 10 conventional pot with escape gaps were used. Trials were conducted for 12, 12 and 11 days, respectively, from the three vessels in turn between November 2001 and January 2002. A total of 350 lifts were monitored for each pot type.

As in the trials of Pot A, the Pot Bs were haphazardly distributed among the other pots. Conventional pots used for comparison were located adjacent to each Pot B. For each pot lift, the same data as for the Pot A trials plus lobster sex were collected.

Data Analysis

The relative performance of Pots A and B were compared to conventional pots on the basis of catch variables associated with (1) octopus predation, (2) octopus catch, and (3) lobster catch. Catch rate data was analysed by a combination of parametric (ANOVA, t-test) and non-parametric (Wilcoxon pair-wise comparisons) methods. Proportional data were analysed by the use of contingency tables (Zar 1984).

Octopus Predation

The octopus entry rate was defined as the proportion of pots that contained dead lobsters killed by octopus out of the total number of pots containing lobsters. For the two-chambered pot this applied to the inner chamber only as this is the lobster catching portion of the pot.

Lobster mortality rate was defined as the proportion of dead lobsters out of the total lobster catch for each pot type. The total number of live and dead lobster for each pot type on each day was summed and the proportion of the total catch that was killed was analysed for each pot type.

To compare the proportional distribution of the size of dead lobsters in the different pot types, the ratio of dead undersized lobsters (carapace length < 98.5mm) to dead legal-sized lobsters was also tested.

Octopus Catch

Octopus catch rate for each pot type was defined as the total number of octopus caught per day per pot. Octopus retention rate was defined as the number of pots containing octopus out of the number of pots containing dead lobsters killed by octopus (a large proportion of octopus have exited from pots at the time of pot hauling). As more than one octopus may enter and leave pots over a 24 hour soak period the retention rate is not an exact measure of the number of octopus caught from the total number that entered pots.

Lobster Catch

The lobster catch consisted of undersized lobsters (carapace length < 98.5), which are returned to the water and legal-sized lobsters (CL > 98.5) that are retained as the landed catch. The live legal lobster catch rate and live undersized catch rate were defined as the total number of lobsters of each type caught per day per pot lift and the effect of pot type on catch rates were compared by analysis of variance. Lobster size selectivity for the different pots was compared by analysis of variance.

Results

Year 1

Octopus Predation

The proportion of conventional traps entered by octopus (28%) was significantly higher than for the inner chamber for Trap A (16%) (Fig. 3.4a, contingency table analysis of proportions, $p < 0.05$).

The lobster mortality rate in Trap A (6%) was significantly lower than conventional traps (13%) (Fig. 3.4b, Wilcoxon paired-sample test, $p < 0.001$). The ratio of dead legal-sized lobster to dead undersize lobster was the same for both trap types (Fig. 3.4c, contingency table analysis of proportions, $p > 0.5$).

Octopus Catch

The octopus catch rate in Trap A of 0.08 octopus. $traplift^{-1}.day^{-1}$ was significantly lower than the rate in conventional traps of 0.13 octopus. $traplift^{-1}.day^{-1}$ (Fig. 3.5a, Wilcoxon paired sample test, $p < 0.05$). There was no difference between traps in the proportion of octopus retained in traps, which was 54% for both trap types ($p > 0.5$, Fig. 3.5b).

Lobster Catch

The catch rate of legal-sized lobster was significantly lower in Trap A (1.5 live legal $lobsters.traplift^{-1}.day^{-1}$) compared to conventional traps (2.1 live legal $lobsters.traplift^{-1}.day^{-1}$) (Fig. 3.6a, t-test, $p < 0.01$). However, there was no difference between trap types in the undersize lobster catch rate, which were 1.1 and 1.2 undersize $lobsters.traplift^{-1}.day^{-1}$ in Trap As and conventional traps respectively (Fig. 3.6b, t-test, $p > 0.2$).

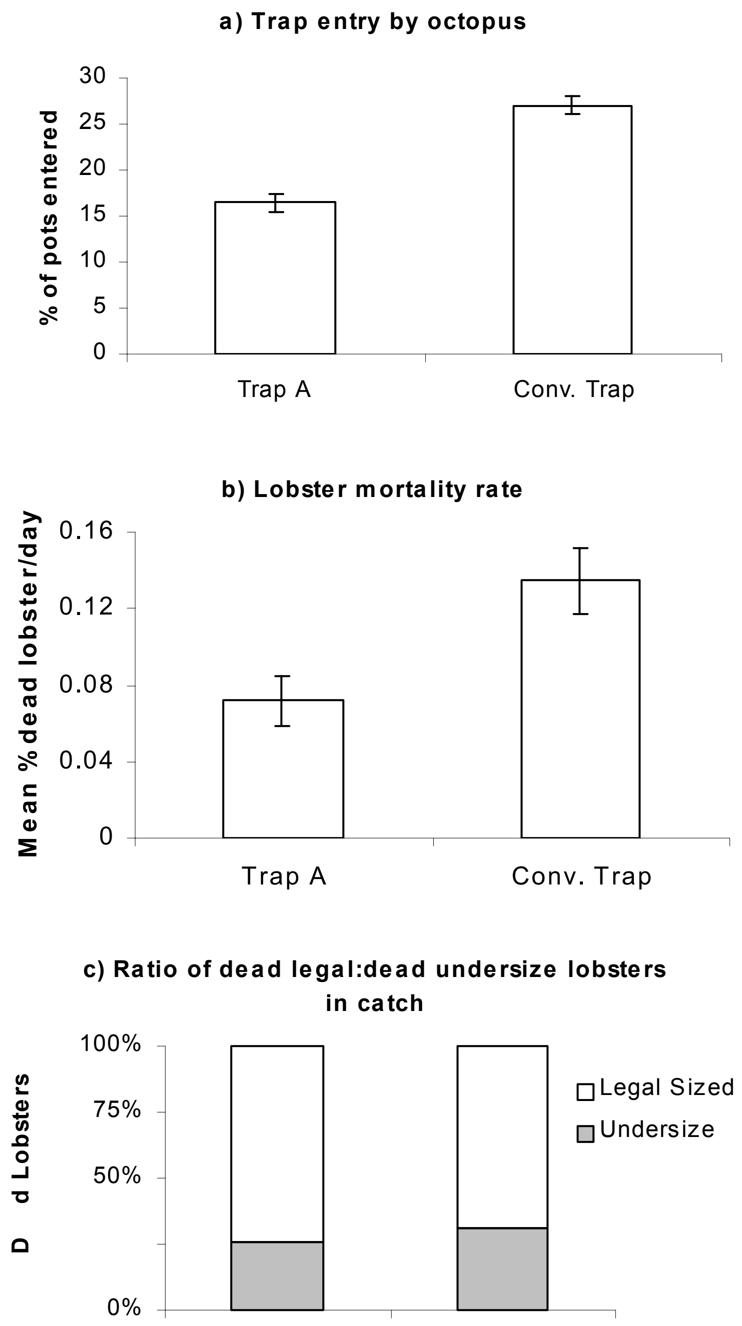

Figure 3.4. Comparison between Pot A and conventional pot of (a) octopus entry rate, (b) lobster mortality rate, and (c) ratio of dead legal: undersized lobsters (error bars ± SE of mean).

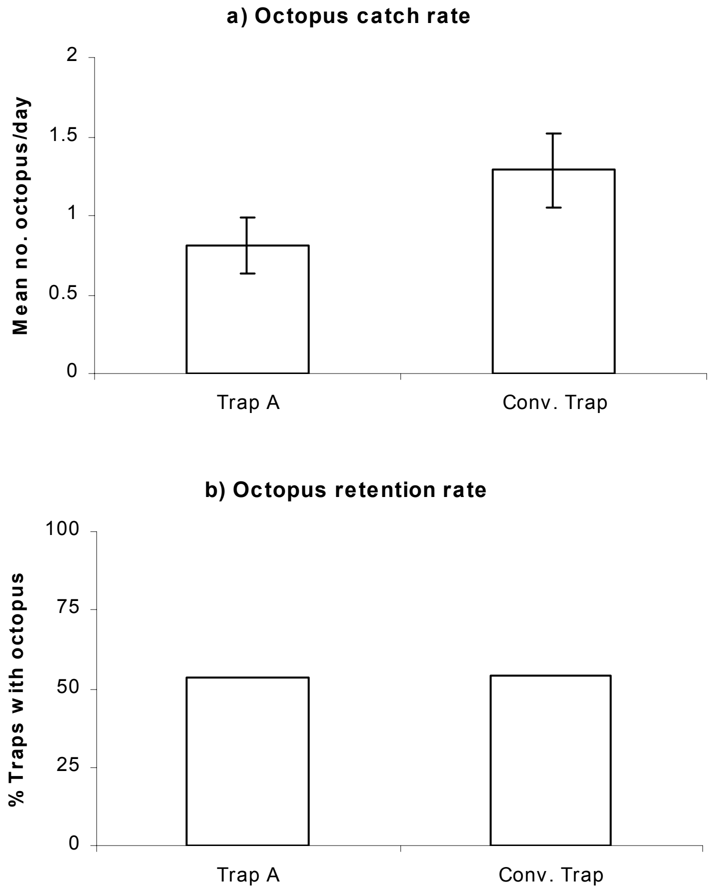

Figure 3.5. Comparison between Pot A and conventional pot of (a) octopus catch rate, and (b) octopus retention rate, (error bars ± SE of mean).

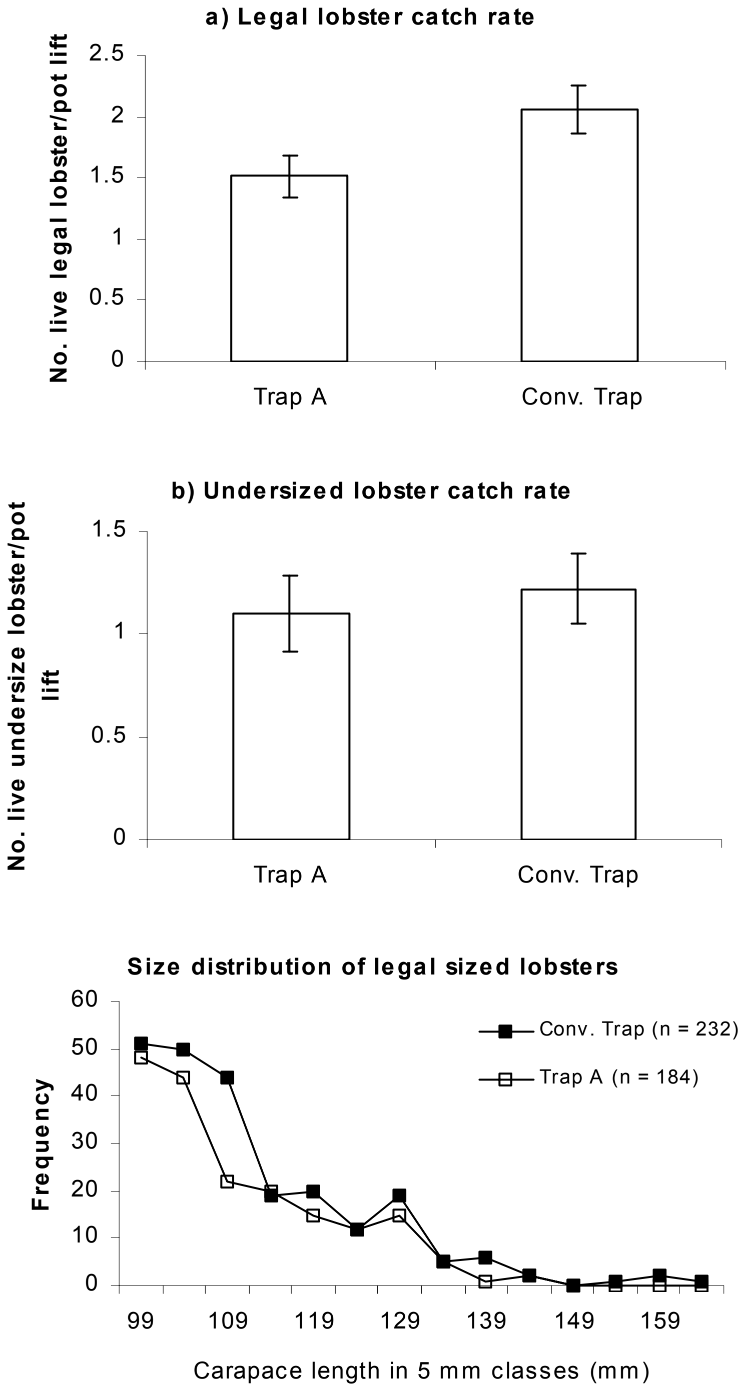

Figure 3.6. Comparison between Pot A and conventional pot of (a) live legal-sized lobster catch rate, (b) live undersized lobster catch rate, and (c) size distribution of legal-sized lobsters, (error bars ± SE of mean).

The mean size of live legal-sized lobsters in conventional traps was 112 mm carapace length (CL), which was not significantly different to the 110 mm CL for Trap A (Fig. 3.6c, t-test, $p > 0.2$).

Year 2

Octopus Predation

Trap type had a significant effect on the proportion of traps entered by octopus (Fig. 3.7a, contingency table analysis of proportions, $p < 0.05$). The proportion of octopus entries into the inner chamber of Trap B with or without escape gaps was lower than conventional traps with and without escape gaps. The presence of escape gaps did not affect the proportion of traps entered by octopus (Tukey type multiple comparison, $p < 0.05$).

The lobster mortality rate ranged from 3.7% in Trap B (escape gaps) to 6.8% in conventional traps (Fig. 3.7b). The lobster mortality rates in both Trap B and Trap B with escape gaps were significantly lower than for conventional traps but not for conventional traps with escape gaps (Wilcoxon paired sample test, $p < 0.01$). The ratio of dead undersize to dead legal-sized lobsters was significantly different between trap types (contingency table analysis of proportions, $p < 0.01$). Traps with escape gaps had a significantly lower proportion of dead undersize lobsters than traps without escape gaps (Fig. 3.7c, Tukey-type multiple comparisons, $p < 0.05$).

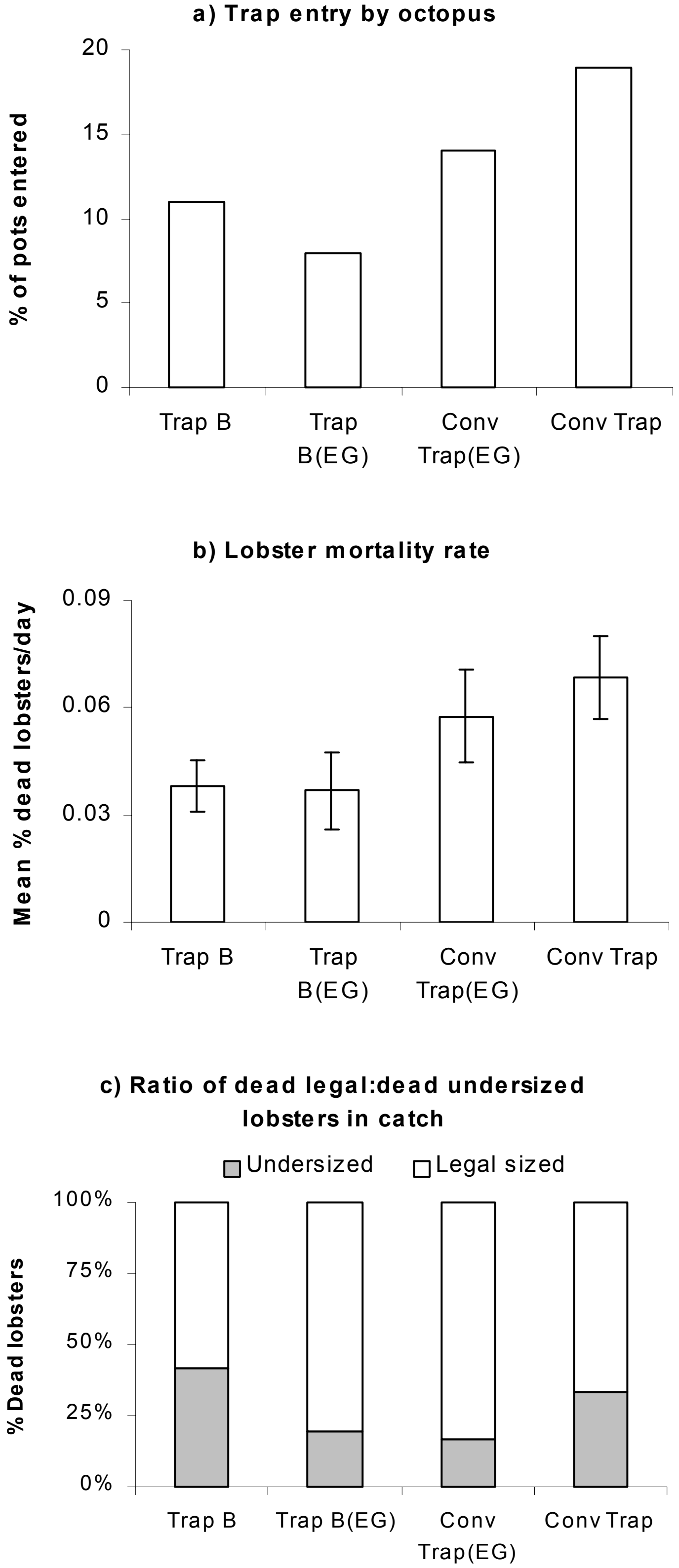

Figure 3.7. Comparison between Pot B and conventional pot of (a) octopus entry rate, (b) lobster mortality rate, and (c) ratio of dead legal: undersized lobsters (error bars ± SE of mean).

Octopus Catch

The octopus catch rate was low for the trials of Trap B ranging from 0.047 octopus.traplift^{-1}day^{-1} for conventional traps to less than 0.01 octopus.traplift^{-1}day^{-1} for Trap B (escape gaps) (Fig. 3.8a). The octopus retention rates were significantly affected by the presence of escape gaps (contingency table analysis of proportions, $p < 0.01$) and varied between 30-40% for Trap Bs and conventional traps without escape gaps to approximately 14 % for Trap Bs and conventional traps with escape gaps (Fig. 3.8b). Traps with escape gaps retained significantly fewer octopus than those without escape gaps (Tukey-type multiple comparisons, $p < 0.05$).

Lobster Catch

There were significant differences between trap types in both legal and undersized lobster catch rates (ANOVA, $p < 0.001$ for legal, $p < 0.01$ for undersized). The catch rates of legal-sized lobsters were significantly higher in conventional traps (3.1 legal-sized lobsters.trap lift^{-1}day^{-1}) than Trap B's (2.3 legal-sized lobsters.trap lift^{-1}day^{-1}) (Tukeys test, $p < 0.05$). The presence of escape gaps did not affect the catch rates of legal-sized lobsters (Fig 3.9a).

The catch rate of undersized lobsters ranged from 2.8 to 0.5 undersized lobsters.trap lift^{-1}day^{-1} in Trap Bs and Trap Bs with escape gaps respectively (Fig. 3.9b). Traps with escape gaps caught significantly fewer undersized lobsters than those without. Trap Bs caught significantly more undersized lobsters compared to the conventional traps (Tukeys test, $p < 0.05$).

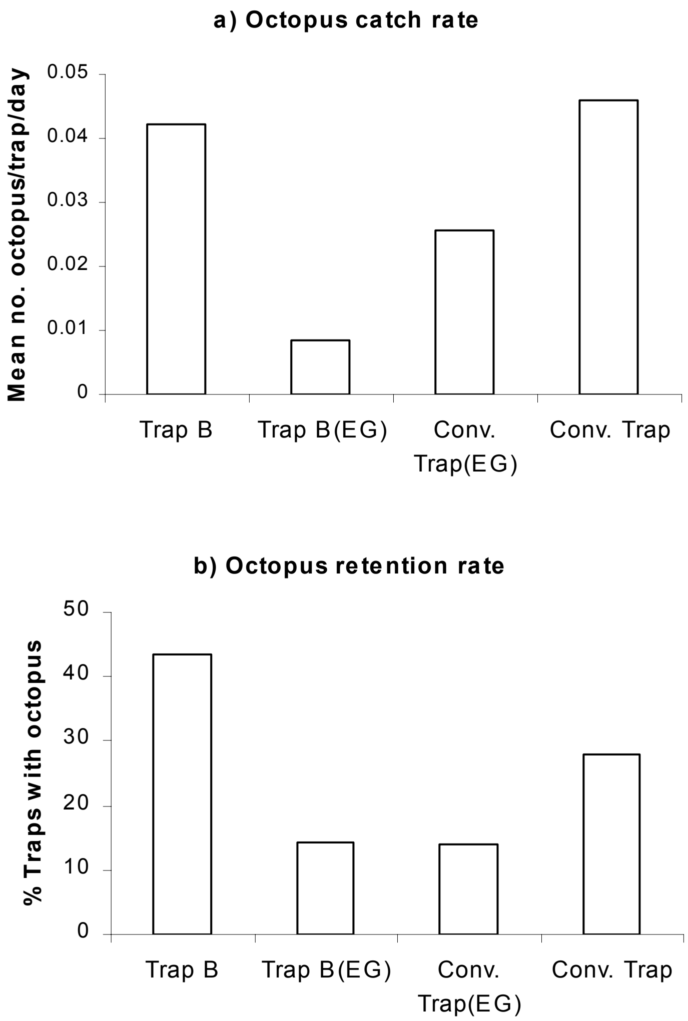

Figure 3.8. Comparison between Pot B and conventional pot of (a) octopus catch rate, and (b) octopus retention rate.

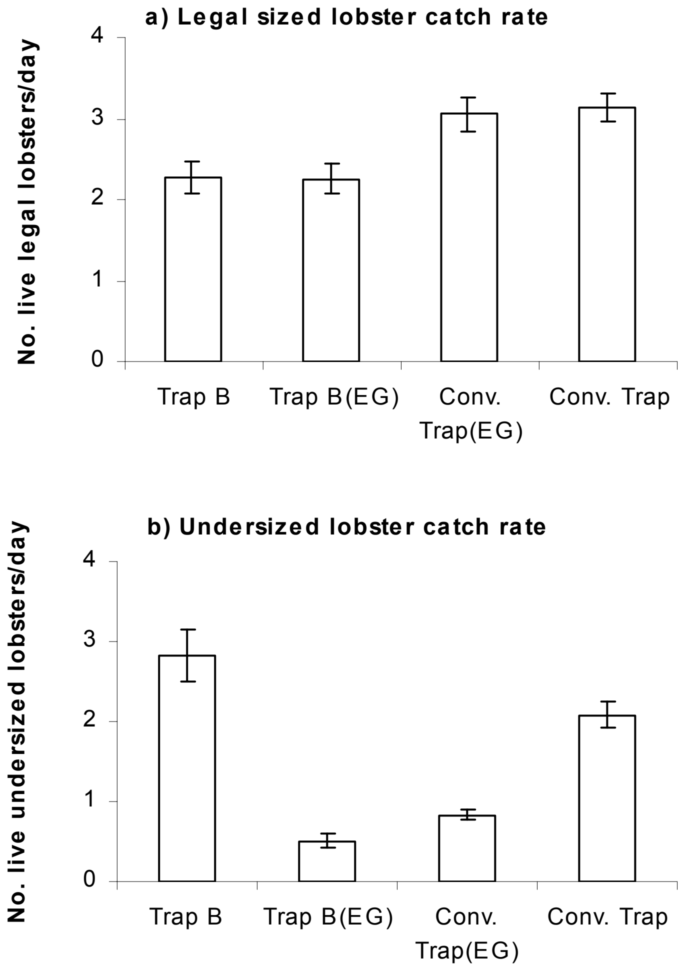

Figure 3.9. Comparison between Pot B and conventional pot of (a) live legal-sized lobster catch rate, and (b) live undersized lobster catch rate (error bars ± SE of mean).

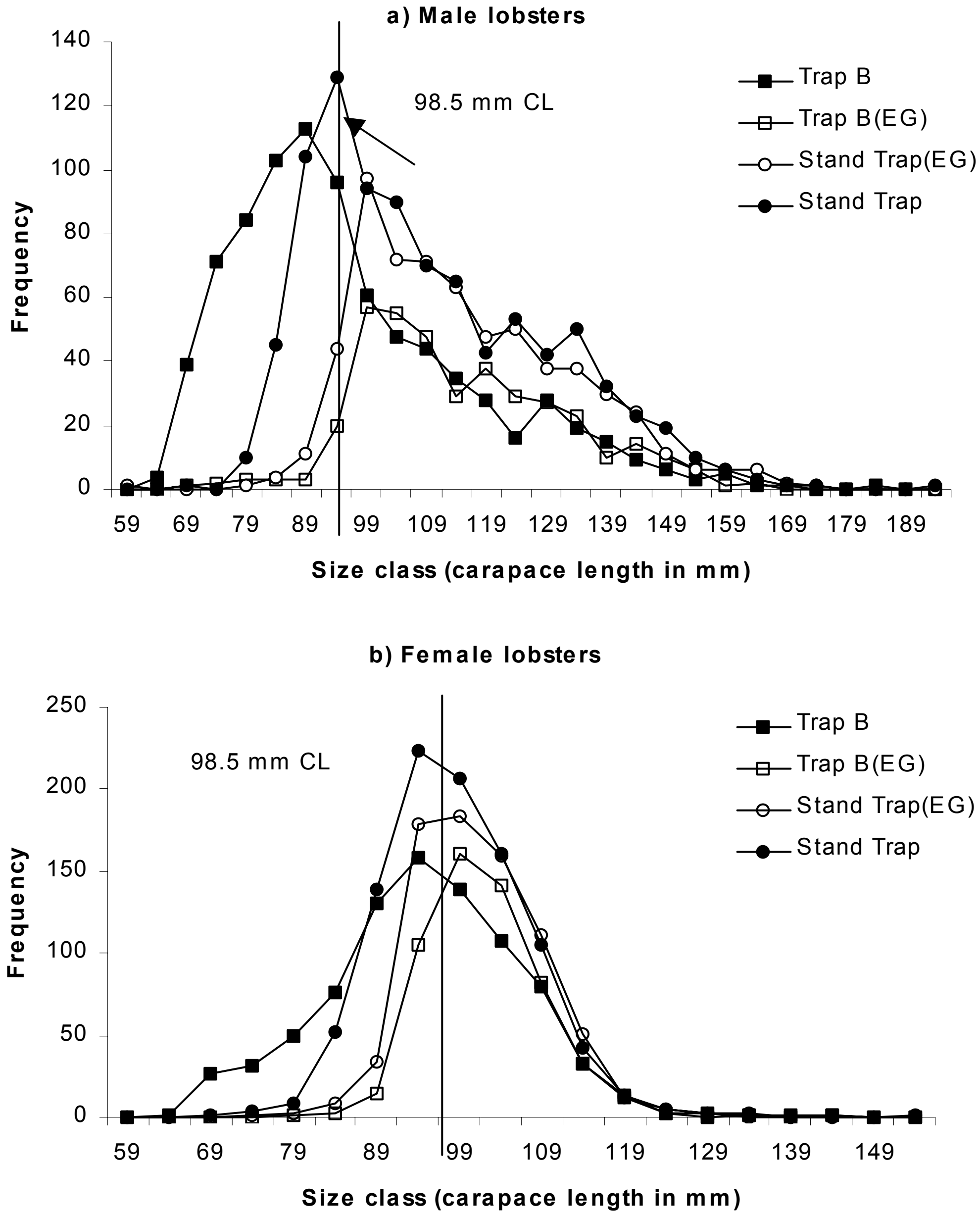

Figure 3.10. Comparison of the size frequency distributions of a) male lobsters, and (b) females lobsters for the different pot types.

The sizes of legal-sized male and female lobsters were not significantly different between trap types (ANOVA, $p > 0.05$ for both sexes, Fig. 3.10a). However, trap type had a significant effect on the mean size of undersize male and female lobsters (Fig. 3.10b, ANOVA, $p < 0.01$, for both sexes). Traps without escape gaps retained a greater proportion of undersized lobsters from the smaller size classes. For undersized male lobsters the mean size in Trap B was lower than all other traps (Tukeys test, $p < 0.01$). The mean size of undersized female lobsters in traps in order from smallest to largest was; Trap B < conventional traps < Trap B (escape gaps) = conventional traps (Tukeys test, $p < 0.01$).

Discussion

This study shows that the concept of a two-chambered pot has the potential to mitigate octopus predation of lobsters in commercial pot fisheries. Traps A and B reduced octopus predation on lobsters in traps by 48 and 45%, respectively. Evidence of the presence of octopus in the outer chamber showed that the traps reduce lobster mortality because some octopus entered the outer chamber, which lobsters could not access, rather than the inner chamber where the lobsters were retained.

The 40-45% reduction in lobster mortality rate observed in the field trials of the two-chambered trap designs was lower than the 75% reduction achieved in the aquarium trials (Brock *et al.* in review). This may be because the trap design used in the aquarium trials was not constrained by the need to maintain lobster catch rates. In contrast, the traps used in the field experiments were designed to maintain lobster catch rates whilst still reducing the rates of octopus entry into the inner chamber and minimizing lobster mortality rates.

The outer chambers of the two traps used in the field trials had fewer and smaller entry points than those used in the aquarium trials, which may have reduced the rate of octopus entry into the outer chambers relative to the inner chamber. Furthermore, the traps were placed upright on the level surface of the aquarium in the initial trials, which ensured that octopus first contacted traps from the side near the entrances to the outer chamber, rather than the from the top near the entrance to the inner chamber. In contrast, during the field trials commercial fishers could not control the orientation of

Traps A and B on the irregular surface of the limestone reefs on which they fished, so that octopus did not necessarily contact the side of the trap first. As octopus can enter both the outer and inner chambers of traps, this may have reduced the effectiveness of the two chambered trap in the field.

The finding that escape gaps do not increase the rate of octopus predation on legal-sized lobsters in either two-chambered or conventional traps supports the conclusion of Ritchie (1972) that predation rates are not affected by the presence of escape gaps. Direct observation in aquarium trials of octopus entering traps without escape gaps within minutes suggest that the presence of escape gaps is unlikely to increase the rate of octopus entry into traps or lobster predation (Joll 1977, Brock *et al*. in review).

The >50% reduction in the catch rates of undersize lobsters in both two-chambered and conventional traps with escape gaps is consistent with the findings of Treble *et al*. (1988) and Schoeman *et al*. (2002). As indicated by these authors, escape gaps may decrease the number of undersized lobsters caught in traps and hence exposed to the damage, stress and mortality associated with handling and displacement (Chittleborough 1975, Brown and Caputi 1984, Schoeman *et al.* 2002). The lower number of undersized lobsters killed by octopus in both two-chambered (66%) and conventional traps (68%) with escape gaps suggests that the presence of escape gaps can assist to control octopus predation.

The lobster mortality rate was significantly ($p < 0.01$) lower in the two-chambered traps (with or without escape gaps) than conventional traps without escape gaps. Mortality rates in two-chambered traps with escape gaps were also 38% lower than in conventional traps with escape gaps, but this difference was not statistically significant at the $p = 0.01$ level which was used because successive pair-wise comparative tests were used thus increasing the probability of a Type I error. However, we suspect that if the sample sizes had been larger the results would have shown that two-chambered traps with escape gaps are more effective than two-chambered traps without escape gaps.

The octopus catch rates in Trap A were lower than for conventional traps without escape gaps. The presence of tampered baits and dead crabs in the outer chamber, combined with the reduced lobster mortality rates compared with conventional traps, suggest that octopus entered the outer chamber of the modified traps but exited before the trap was lifted to the surface. In an attempt to increase the octopus catch rates, the outer chamber of Trap B was enlarged and the entrance was vented (Fig. 3.3). This was unsuccessful and only one octopus was caught in the outer chamber of Trap B. The low residence time in the outer chamber compared to the inner chamber may reflect the additional time required for octopus to capture and consume lobsters (3-8 hours, Joll 1977) compared to bait.

The presence of escape gaps was associated with a decrease in octopus catch rate in both two-chambered and conventional traps. Ritchie (1972) also found that traps with escape gaps retained fewer octopus. Whilst escape gaps do not affect the rate of octopus entry into traps, they do appear to faciliate more rapid exits and thus shorter residence time in traps. In aquarium trials, octopus were observed to take longer to exit traps through the neck than through escape gaps (D. Brock, unpublished data). This may have been because the neck of traps impedes the exit of octopus as it is designed to impede the exit of lobsters.

The 28% reduction in the catch rates of legal-sized lobsters in Traps A and B compared to conventional traps, could be attributable to either reductions in the rate of lobsters entering or increases in the rate of lobsters leaving two chambered traps. The latter explanation may be more likely as the shape of the trap and the entrance (to the inner chamber) of Trap A were similar to the shape and entrance to conventional traps, and should not have impeded lobster entry. In contrast, the internal wall separating the two chambers of Traps A and B form a funnel towards the neck and may assist lobsters to crawl out through the neck of the trap.

This study shows that the concept of a two-chambered trap has potential to mitigate octopus predation on lobsters in traps, however the current design reduces the catch rates of legal-sized lobster and would require fishers to expend an additional 30% of fishing effort to catch their annual quota (SZ). If the the two-chambered trap can be redesigned to improve lobster catch rates whilst maintaining the effect on mortality rates, approximately 100,000 fewer lobsters would be killed in the SZ of SARLF each year, or the size of the landed catch could be increased by 2+% without affecting the harvest rate.

Improved two-chambered traps should include escape gaps as these reduce the mortality rates of under-sized lobsters but do not reduce significantly the catch rates of legal-sized lobsters. Even if improved two-chambered traps that maintain high catch rates of legal-sized lobsters cannot be developed, the use of escape gaps in the southern zone of the SARLF should be encouraged as these devices alone would reduce the number of undersize lobsters killed by octopus from >80,000 to <40,000 per year (Ward *et al*. 2002).

CHAPTER 5. INDUSTRY CONSULTATION AND ADOPTION OF A MODIFIED POT.

Objective 6: Ensure industry participation and consultation at all stages of the project.

Objective 7: Ensure adoption of modified pot by industry where appropriate.

Objective 6 was achieved by developing and maintaining a close interaction with industry at a number of levels. Information on the progress of ongoing research was disseminated to industry through meetings with the peak industry bodies, annual presentations at the major fishing ports and reports and articles in a range of print media. Industry consultation was achieved by an initial survey of the views of all licence holders, regular meetings with a committee of industry leaders and interaction with individual fishers. The provision of animals for trial purposes, design and construction of pots and trial on boats were undertaken with industry ensuring that a large number of fishers participated directly in the project.

Objective 7 was not achieved, as the two-chambered pot in its current form is not a commercially viable alternative to conventional pots due to the reduced catch rates of legal-sized lobsters. However, the extension to industry of the results of the escape gap trials directly contributed to an increase in their use in the Southern Zone. The study did, however, demonstrate that the concept of a two-chambered pot has the potential to reduce rates of octopus predation on lobsters caught in pots. As reducing octopus predation offers one of the few opportunities for increasing yields in the SARLF, fishers may wish to consider investigating options for enhancing the catching efficiency of two-chambered traps.

Industry Questionnaire

Prior to commencement of the research an extensive questionnaire was sent out to all licence holders seeking their views on a range of issues associated with octopus predation in the fishery The response was excellent with 120 (46%) fishers returning completed questionnaires.

The following details the questions contained in the survey and a summary of the responses received. The figures have been calculated as a percent of the total respondents (i.e. as a percent of 120). Where the figures for each question do not add up to 100%, the remaining fishers did not answer the question.

Fisher Questionnaire

General Information

1. Do you fish above or below 50 metres depth (on average)?

Above	***Below***
30.1%	50.4%

2. Are octopus the major cause of lobster death in your pots?

Yes	***no***	***sometimes***
83.2%	0.9%	15.0%

If yes, what % of dead lobster are the result of octopus predation?

<50%	***50-60%***	***60-70%***	***70-80%***	***80-90%***	***100%***
8.0%	7.1%	2.7%	17.7%	46.0%	8.0%

3. Do you think octopus predation has increased or decreased in the last 10-20 years?

Increased	***Decreased***	***unchanged***	***unsure***
34.5%	1.8%	47.8%	12.4%

5. Do you think octopus are major predators of lobster in natural conditions? (i.e. Outside of pots)

Yes	***No***
59.3%	11.5%

6. Does octopus predation increase or decrease with increasing depth?

Increase	***decrease***	***unsure***
6.2%	56.6%	23.0%

7. Do octopus usually kill all the lobster in a pot, or only some?

All	***some***
15.9%	60.2%

8. If there are live lobsters left in a pot that contains an octopus, are they usually damaged in any way?

Yes	***no***
92.0%	0.9%

9 What percentage of octopus entering pots do you think you actually catch?

<25%	***50%***	***75%***	***100%***
50.4%	32.7%	11.5%	0%

10. Are octopus more attracted to the bait or lobster or a combination of both? (i.e. What do you think attracts octopus to pots?)

Bait	***lobster***	***bait & lobster***	***unsure***
9.7%	12.4%	75.2%	0.9%

12. When an octopus is caught how often are there no lobster (dead or alive) also present in the pot?

<25%	***50%***	***75%***	***100%***
75.2%	10.6%	4.4%	2.7%

13. When do octopus most commonly enter pots? (i.e. When do you think octopus are the most active?)

Dawn	***day***	***dusk***	***night***	***not sure***
5.3%	0.9%	1.8%	32.7%	31.0%

14. When do the majority of lobsters enter pots? (i.e. When do you think lobsters are the most active?)

Dawn	***day***	***dusk***	***night***	***not sure***
0.9%	0%	8.8%	45.1%	7.1%

15. Are you more likely to catch octopus in pots pulled at the start of the day, end of the day or any time during lifting?

Start	***end***	***anytime***	***unsure***
24.8%	3.5%	68.1%	1.8%

17. Are octopus more likely to eat larger or smaller lobsters?

Larger	***Smaller***	***Unsure***
65.5%	10.6%	8.8%

18. Do you think octopus enter pots through 50mm mesh on the side of a pot or through the neck of the pot in the majority of cases?

Side of pot	***Neck of pot***
1.8%	79.6%

19. Are less octopus caught in pots that have been left for a period of more than a day (i.e. Longer than 24 hour pot soaks)?

Yes	***no***
61.1%	29.2%

20. Do you think escape gaps are a good idea?

Yes	***no***	***don't care***
12.4%	70.8%	11.5%

21. Do you think the 50mm wire mesh is as effective in letting undersized out as escape gaps are?

Yes	***no***
63.7%	26.5%

22. Do you think the presence of escape gaps increases the chance of octopus entry?

Yes	***no***
64.6%	23.9%

23. Do you think escape gaps reduce the catch of octopus?

Yes	***no***
61.1%	27.4%

24. Do you think survival of undersized lobsters returned to the water is of major concern?

Yes	***no***
41.6%	49.6%

25. Do you think more research is needed into escape gaps?

Yes	***no***
29.2%	59.3%

26. Would you like a copy of the findings of the survey?

Yes	***no***
77.9%	6.2%

27. Would you like a summary report showing statistics associated with Catch and Effort and Octopus Predation in your fishing block since 1983?

Yes	***no***
65.5%	15.9%

28. Would you consider assisting in collection of data about octopus predation in the 98/99 fishing season?

Yes	***no***
43.4%	30.1%

Summary of Survey Findings

- Most fishers believe that octopus are the major cause of lobster death in their pots (83.2%), and most believe they are responsible for 80-90% mortality (46%).

- Fishers were divided as to whether octopus predation levels have remained unchanged or increased over the last 10-20 years, however only 1.8% thought it had decreased.
- Most fishers find octopus in pots with no lobster less than 25% of the time (75.2%).
- Questions 13 and 14 addressed the timing of lobster and octopus entry to pots. In both cases, a large number of responses (38% and 28% respectively) could not be analysed easily because fishers encircled multiple answers or wrote their response in the comments section. However, of those fishers that circled one answer, most believed that lobsters and octopus enter pots mainly at night, though many were less certain of timing of octopus entry. Also, from question 15 it seems that most believed octopus are likely to be caught any time of day.
- The majority of fishers stated that octopus have a preference for the biggest lobsters in the pot.
- Most believe octopus enter more from the neck of the pot than through the side, but many commented that they also enter through the base.
- Most fishers noticed that they catch fewer octopus when the pots have been soaking for longer than 24 hours and many commented that this was due to octopus having more time to leave the pot after eating the captured lobsters.
- Most fishers did not think that escape gaps were a good idea and did not think more research was needed. This was mostly because fishers believed that escape gaps allow octopus easier entry and allow them to escape more easily when pots are pulled.
- 77.9% of the fishers requested a final copy of the results of this survey and a smaller number (65.5%) requested a summary of their historical catch and effort data.
- 43% of fishers indicated that they would assist in data collection for this research.

Consultation

Consultation with Industry was maintained through a number of forums. A small committee of representatives from the industry consisting of Terry Moran (SZ fisher), Steve Hinge (NZ fisher) and Roger Edwards (SARLAC) was formed to oversee the research. Regular meetings were held with this committee to assess research progress and directions.

In 2001 and 2002 formal presentations were made at each of the major ports in the Southern and Northern Zones. At these talks the results of the previous 12 months research was presented to the industry. An integral part of this process was to provide a forum for fishers to ask questions and express concerns over a range of issues, which provided valuable information and feedback that helped focus the research.

Other presentations were made during the course of the project at various forums including: the Rock Lobster Congress in 2001 and 2002, Fisheries Management Committees meetings and general talks presented at SARDI Aquatic Sciences. Displays showing live octopus and pot designs were also demonstrated at various events including, Mt Gambier Field Day, Cape Jaffa Food and Wine Festival and SARDI Aquatic Sciences Open Days. Articles and research updates were published in magazines, newsletters and newspapers including Southern Fisheries, Port MacDonnell Newsletter, SA Rock Lobster Newsletter, The Adelaide Advertiser, and The Canberra Times.

Industry Participation

Industry participation was frequent and fundamental to the success of this research. Fishers from at least four different ports donated over 40 octopus and 100 lobsters for the project. Effective working relationships were established with numerous individual fishers over the course of the project. In particular these fishers provided advice and assistance in the design and construction of pots and provided their boats and equipment for a total of 70 days of fishing trials.

CHAPTER 6. GENERAL DISCUSSSION

Benefits

The analyses of the fishery data for octopus conducted in this study suggested that the retention of octopus by fishers at current levels is sustainable.

The project also provided the first comprehensive investigation of the scale and causes of lobster mortality in pots in the SARLF, and provides a baseline for future studies of the issue.

The project identified two design modifications that reduced the rates of octopus predation on lobsters. These were the innovative new concept of a two-chambered pot, and the use of escape gaps to reduce octopus predation on undersized lobsters.

The project also identified the objectives of design modifications (i.e. increased in catching efficiency of lobsters) that are required to make the two-chambered pot commercially viable.

Extension to industry of results regarding the effectiveness of escape gaps in reducing lobster mortality is expected to increase their usage in the SZ over the next few years. We estimate that the introduction of escape gaps to all pots in the SZ would reduce the number of undersized lobsters caught from >2 million to <1 million annually and reduce the number of undersized lobsters killed by octopus in pots by approximately 40,000. The successful introduction of modified two-chambered pots with escape gaps into the SARLF could potentially reduce lobster mortality by 100,000 lobsters worth >$2 million each year. The results of this research is applicable to all commercial lobster fisheries in which octopus is a significant by catch species.

Further Development

This study showed that lobster mortality in pots can be reduced by diverting a proportion of octopus into an outer chamber containing bait that is not accessible to lobsters. This is a significant achievement as in the past both researchers and fishers have generally considered the problem of octopus predation insoluble. The two-chambered pot in conjunction with escape gaps presents and opportunity of the

Industry to significantly increase the long term yield of the SARLF with potential extension to other commercial fisheries. On this basis further development is warranted. The catch rate of legal sized lobsters was lower in both Pot A and B compared to conventional pots. The re-design of the two-chambered concept to improve legal lobster catch rates should be the main focus of any future development as this is the main impediment to their introduction into the fishery at the present time. This development should be undertaken by fishers – i.e. the proven experts in refining methods for catching lobsters.

Summary and conclusions

Factors affecting spatial and temporal patterns in octopus abundance and lobster mortality rates

The second chapter of this report examined the effects of environmental factors, fishing activities and lobster abundance on the spatial and temporal patterns in octopus catch rates and lobster mortality rates. The analyses showed that since 1983, between 38,000 and 119,000 octopus per annum have been taken in SARLF pots. Catch rates fluctuated between 2.2 and 6.2 octopus/100 pot lifts/day, but there is no evidence to suggest that catch rates have declined or that this level of bycatch is unsustainable. Over the last 5 years, approximately 240,000 lobsters per annum were killed in pots, representing ~4% of the total catch.

Field studies showed that over 97% of within-pot lobster mortality was attributable to octopus predation. Lobster mortality rates were positively correlated with the catch rates of octopus and lobster. The highest octopus catch rates and lobster mortality rates were recorded during summer and in the more productive SZ of the fishery. In the SZ, within-pot lobster mortality rates have increased in recent years, apparently in response to the increase in lobster abundance and the resultant increase in the probability of octopus encountering pots containing one or more lobsters. Lobster mortality rates were also positively correlated with soak times (i.e. the period between placement and collection of a pot) and lobster size.

Minimizing soak times is one of the few methods currently available for reducing lobster mortality rates. More significant reductions in the rates of within-pot lobster mortality will require the development methods for reducing the rates at which octopus enter pots.

Identification and testing of pot designs with potential for reducing octopus predation

The third chapter of this report documents the results of aquarium studies designed to identify and assess pot designs with the potential for reducing octopus predation on pot-caught lobster. This investigation of the behavioural interactions of octopus with pots used in the SARLF showed that octopus were primarily attracted to pots by the presence of bait rather than lobsters and that octopus entry into pots was 'fortuitous' and mediated by speculative exploration. A two-chambered pot was developed that consisted of an outer chamber containing bait that octopus could enter but lobsters could not and inner chamber that both animals could access. The concept behind this design was that octopus would enter the outer chamber containing bait more often than the inner chamber containing lobsters. In aquarium trials, lobster mortality was 70% lower in the two-chambered pot than a conventional pot.

Effectiveness of escape gaps and a two-chambered pot in a commercial context

The fourth chapter of this report describes the results of field trials undertaken on commercial vessels in 2000/01 and 2001/02. This study compared the effectiveness of two-chambered pots (with and without escape gaps) and conventional pots in terms of lobster mortality rates, and octopus and lobster catch rates. The trials showed that lobster mortality rates were 45-48% lower in two-chambered pots than conventional pots. However, the commerical viability of the design was limited by the 28% reduction in the catch rates of legal-sized lobsters compared to conventional traps.

In addition, the presence of escape gaps did not increase the predation rates of lobsters above the minimum legal size, but significantly reduced the catch rates and mortality rates of under-sized lobsters. The presence of escape gaps did not affect the catch rate of legal sized lobsters but the catch rate of undersize lobsters by was significantly lower in pots with escape gaps compared to conventional pots without escape gaps (0.84 undersize/pot lift vs 2.08). This lead to a 60% reduction in the mortality rate of undersize in pots with escape gaps. Extrapolation of the results obtained in this study indicate that the introduction of escape gaps into the fishery could reduce undersize lobster mortality by approximately 40,000 lobsters.

The pot modifications (ie. escape gaps and two-chambers) work in a complimentary manner to reduce lobster mortality and as such the incorporation of both in the same pot increases the effectiveness of pots in minimising the number of lobsters killed by octopus. It is estimated that a two-chambered trap fitted with escape gaps has the potential to reduce annual lobster mortality in the SARLF by 100,000 lobsters.

Industry participation and adoption of the pot modifications

Chapter four described the extensive industry participation and consultation involved in this project. It suggested that future research into improving the catching efficiency of two-chambered traps – if it is required – should be conducted by experts, i.e. fishers.

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APPENDIX 1: INTELLECTUAL PROPERTY

The FRDC's share of intellectual property based on inputs is 52%.

APPENDIX 2: PROJECT STAFF

SARDI Aquatic Sciences:	Tim Ward
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