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THE PREDATION OF POT-CAUGHT WESTERN ROCK LOBSTER (*PANULIRUS LONGIPES CYGNUS*) BY OCTOPUS

BY

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CONTENTS

			Page
	SUMMARY		
I	INTRODUCTION		7
II	THE WESTERN ROCK LOBSTER FISHERY		8
III	PREDATORS OF POT-CAUGHT WESTERN ROCK LOBSTER		11
IV	ESTIMATION OF THE LOSS OF WESTERN ROCK LOBSTERS THROUGH PREDATION		11
	METHODS		11
	RESULTS		13
	(i)	Total predation	13
	(ii)	Predation by various species	21
	(iii)	Size and sex of predated rock lobsters	22
	(iv)	Loss of commercially-sized rock lobsters	24
	(v)	Financial loss to the fishery	25
	(vi)	Estimate of the number of octopus caught	26
	DISCUSSION		27
V	ASPECTS OF OCTOPUS PREDATION		28
	A.	THE ATTRACTION OF OCTOPUS TO ROCK LOBSTER POTS	28
		METHODS	30
		(i) Aquarium experiments	30
		(ii) Field experiments	32
		RESULTS	33
		(a) Bait location trials	33
		(b) Sensitivity trials	35
		(c) Pot location trials	35
		DISCUSSION	36
	B.	REPULSION OF OCTOPUSES FROM ROCK LOBSTER POTS	37
	C.	ENTRY INTO AND ESCAPE FROM ROCK LOBSTER POTS BY OCTOPUS	39
		METHODS	39
		RESULTS	39

CONTENTS (Contd.)

		Page
	DISCUSSION	42
D.	THE BEHAVIOUR OF OCTOPUSES AND ROCK LOBSTERS IN POTS	43
E.	REDUCTION OF THE ESCAPE OF OCTOPUSES FROM ROCK LOBSTER POTS	47
	METHODS	48
	(i) Field trials	48
	(ii) Aquarium trials	48
	RESULTS	48
	DISCUSSION	52
VI	GENERAL DISCUSSION	53
VII	ACKNOWLEDGEMENTS	55
VIII	REFERENCES	55

TABLES

1.	COMMERCIAL CATCH SAMPLES 1972/73 - 1975/76	
	(a) 1972/73 season	14
	(b) 1973/74 season	15
	(c) 1974/75 season	16
	(d) 1975/76 season	17
2.	EFFORT (POT LIFTS) BY BLOCK AND MONTH 1972/73 - 1974/75	
	(a) 1972/73 season	18
	(b) 1973/74 season	19
	(c) 1974/75 season	20
3.	ESTIMATED TOTAL NUMBER OF PREDATED ROCK LOBSTERS IN THE SEASONS 1972/73 - 1975/76	21
4.	ESTIMATED NUMBER OF ROCK LOBSTERS PREDATED BY OCTOPUS, CUTTLEFISH AND FISH IN THE 1974/75 AND 1975/76 SEASONS	22

TABLES (Contd.)

		Page
5.	SIZE (CARAPACE LENGTH) OF PREDATED ROCK LOBSTERS IN COMMERCIAL CATCH SAMPLES	22
6.	SEXES OF PREDATED ROCK LOBSTERS IN COMMERCIAL CATCH SAMPLES	24
7.	ESTIMATED NUMBER OF LEGAL-SIZED ROCK LOBSTERS PREDATED	24
8.	MEAN WEIGHTS (g) OF PREDATED, LEGAL-SIZED ROCK LOBSTERS	25
9.	ESTIMATED WEIGHT LOSS (kg) THROUGH PREDATION	26
10.	ESTIMATED FINANCIAL LOSS THROUGH PREDATION	26
11.	ESTIMATED NUMBER AND WEIGHT OF OCTOPUS CAUGHT	26
12.	LOCATION OF HIDDEN BAITS BY OCTOPUS	34
13.	SENSITIVITY OF OCTOPUS AND ROCK LOBSTER TO DILUTIONS OF ABALONE FOOT MUSCLE HOMOGENATE	35
14.	NUMBER OF POTS ENTERED BY OCTOPUSES IN POT LOCATION TRIALS	36
15.	EFFECT OF USING OCTOPUS AS A COMPONENT OF ROCK LOBSTER BAIT	38
16.	AREAS OF ENTRY INTO ROCK LOBSTER POTS BY OCTOPUSES	42
17.	AREAS OF EXIT OF OCTOPUSES FROM ROCK LOBSTER POTS	42
18.	SEXES OF ROCK LOBSTERS PREDATED IN POT ENTRY TRIALS	44
19.	CATCHES OF NORMAL COMMERCIAL ROCK LOBSTER POTS AND POTS FITTED WITH OCTOPUS TRAPS	49
	(a) Cane beehive pots (Fremantle)	49
	(b) Batten pots (Dongara)	50
20.	COMBINED RESULTS OF COMMERCIAL FISHING TRIALS AT DONGARA AND FREMANTLE USING NORMAL ROCK LOBSTER POTS AND POTS FITTED WITH OCTOPUS TRAPS	51
21.	PERIOD OF RESIDENCY BY OCTOPUS IN ROCK LOBSTER POTS CONTAINING OCTOPUS TRAPS (AQUARIUM TRIALS)	51

FIGURES

		Page
1.	ROCK LOBSTER FISHING AREAS	9
2.	PRINCIPAL POT TYPES USED IN THE ROCK LOBSTER FISHERY	10
3.	TYPICAL REMAINS OF PREDATED ROCK LOBSTERS	12
4.	CARAPACE LENGTHS OF ROCK LOBSTERS IN COMMERCIAL POTS WHERE PREDATION HAS OCCURRED	23
5.	GUT CONTENTS OF OCTOPUSES CAUGHT IN ROCK LOBSTER POTS	29
6.	EXPERIMENTAL AQUARIUM FOR TESTING DISTANCE CHEMORECEPTION	31
7.	EXPERIMENTAL ARRANGEMENT FOR SENSITIVITY TESTS	33
8.	GUT CONTENT OF POT-CAUGHT OCTOPUSES WITH RESPECT TO THE SIZE OF THE OCTOPUS	40
9.	AQUARIUM ARRANGEMENT FOR ROCK LOBSTER POT ENTRY TRIALS BY OCTOPUSES	41
10.	CARAPACE LENGTHS OF ROCK LOBSTERS PRESENTED TO OCTOPUSES IN AQUARIUM POT ENTRY TRIALS	45

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THE PREDATION OF POT-CAUGHT WESTERN ROCK LOBSTER (PANULIRUS LONGIPES CYGNUS) BY OCTOPUS.

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SUMMARY

The losses to the western rock lobster fishery through the predation of pot-caught rock lobsters by octopus were estimated from samples taken on commercial boats in the four seasons 1972/73 - 1975/76. In most seasons approximately 200 000 legal-sized rock lobsters were lost. In the 1975/76 season the estimated financial loss from octopus predation was $392 000. The estimated losses probably represent minimum values. Studies of the biology and behaviour of octopus were carried out to examine the methods of detection, location and entry into rock lobster pots by octopus. The use of octopus traps in rock lobster pots significantly increased the catch of octopus from rock lobster pots without any significant effect on rock lobster catches.

I INTRODUCTION

The octopus (*Octopus tetricus* Gould, 1852) has been recognized as an important predator of pot-caught western rock lobsters (*Panulirus longipes cygnus* George) for many years. However the magnitude of predation was not generally appreciated until Morgan (unpub.), in an investigation at the Abrolhos Is. in 1972, found a 43% reduction in the average number of live rock lobsters taken in pots which had been entered by an octopus. When combined with the observed number of octopus entries per pot lift the data indicated that a decrease of 23% in the total take of rock lobster due to octopus may be expected. Extrapolation to the whole fishery, assuming all rock lobsters lost to be of legal size, suggested that approximately 400 000 lb of rock lobster, worth in excess of $500 000 at 1972 prices, was lost annually through octopus predation.

Octopuses have previously been recorded as predators in other fisheries. Garstang (1900) reported that a plague of *O. vulgaris* caused havoc in the crab and lobster fisheries in the English Channel in 1899 while a similar situation occurred again in 1950 (Rees and Lumby, 1954). Several instances of the predation of trap-caught Dungeness crabs by octopuses were recorded by High (1976). The predation of pot-caught *Jasus edwardsii* and *J. verreauxi* by *O. maorum* in the New Zealand rock lobster fishery was discussed by Ritchie (1972). In the Hokianga area of New Zealand in 1970 the loss per boat through octopus predation was estimated at NZ$29/day (Ritchie, 1972). McPherson and Gabriel (1962) and Burdon (1972) have reported the predation of pot-caught rock lobsters by octopus in S.E. Australia.

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In an attempt to quantify more exactly the loss of western rock lobsters due to octopus predation, a programme of research funded by the Fishing Industry Research Trust Account, was commenced in December 1973. Consideration was also to be given to possible ways of reducing the losses caused by predation of pot-caught rock lobsters by octopus. This report describes the outcome of the research.

II THE WESTERN ROCK LOBSTER FISHERY

The fishery for the western rock lobster is the most important single species fishery in Australia with a value of approximately $32 000 000 in the 1975/76 season. It is governed by a complex set of regulations which have been reviewed by Bowen (1971). The fishery is located along the western coast of the southern half of Western Australia (Figure 1) and takes place from November 15 to August 14, except at the Abrolhos Is. where fishing is only permitted from March 15 to August 14.

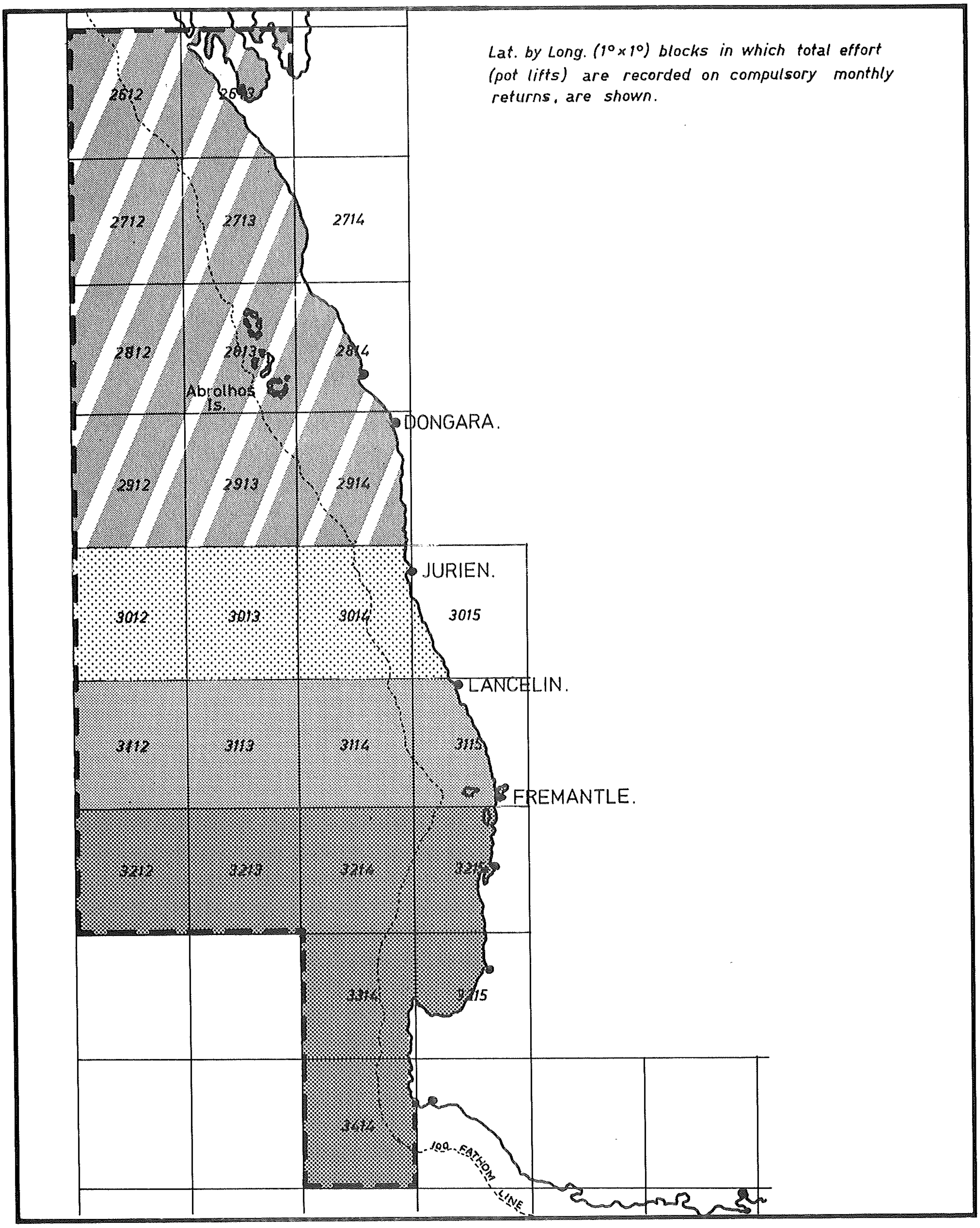
Rock lobsters are caught in baited pots (traps) set amongst reef areas which are the habitat of rock lobsters. The pots are usually constructed either of wooden battens fixed to a rectangular wooden frame or lengths of cane or wire mesh on a steel, beehive-shaped frame (Figure 2). Old cane pots are sometimes covered with wire mesh to reinforce them and prolong their useful life. The usage of the three pot types varies in different areas of the fishery. In the 1973/74 season Morgan and Barker (1975) recorded that the percentages of the various pot types used by fishermen completing voluntary log sheets were:

	Cane Beehive	Batten	Wire Beehive
North of latitude 30°S	10.4%	83.0%	6.6%
South of latitude 30°S	67.6%	27.5%	5.0%

Pots have a single entrance (neck), usually on the upper surface of the pot, and are required by law to have an escape gap with minimum dimensions 54mm x 305mm, to allow the escape of small rock lobsters. The minimum legal size of rock lobsters is 76mm, measured from the base of the rostral horns to the posterior edge of the carapace. Undersized rock lobsters captured in pots must be returned to the sea.

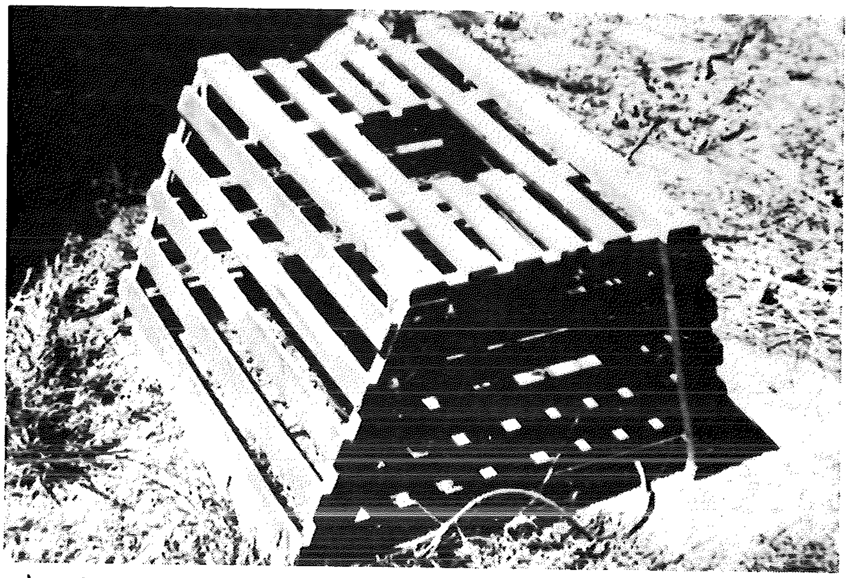
Pots are baited with a variety of baits, the most popular bait being a combination of either cattle hocks or pieces of cattle hide and fish, which may be either whole fish, fish heads or fish pieces (Morgan and Barker, 1975). Pots are usually checked and reset every morning, unless bad weather or other factors intervene.

Figure 1. Rock lobster fishing areas.



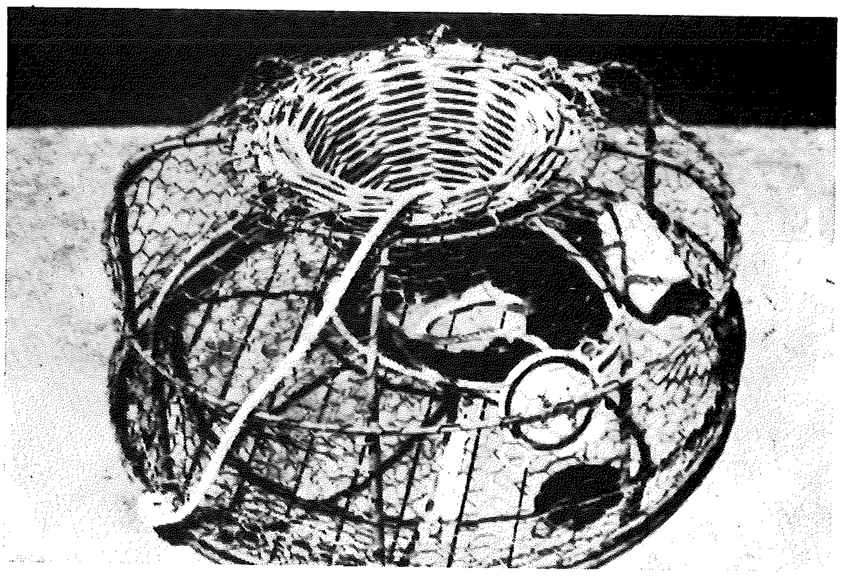
The shading indicates the block groupings used in the estimation of total predation and number of octopus caught.

Figure 2. Principal pot types used in the rock lobster fishery



a) Batten pot

b) Cane pots



c) Wire pot

III PREDATORS OF POT-CAUGHT WESTERN ROCK LOBSTERS

Several species of octopus are found within the range of the fishery but only one, *O. tetricus*, is a predator of pot-caught rock lobsters. Another species, probably *O. flindersi*, occasionally enters pots and eats the bait but has not been known to predate rock lobsters. The small blue-ringed octopus *Hapalochlaena maculosa* is sometimes caught in pots but does not predate rock lobsters. The giant cuttlefish, *Sepia apama*, occasionally enters pots and predates rock lobsters. Several species of fish, including baldchin groper (*Choerodon paynei*), snapper (*Chrysophrys unicolor*), parrotfishes (Family Labridae), leather jackets (Family Aluteridae) and wobbegong or carpet sharks (*Orectolobus ornatus*) have been reported as predators of pot-caught rock lobsters.

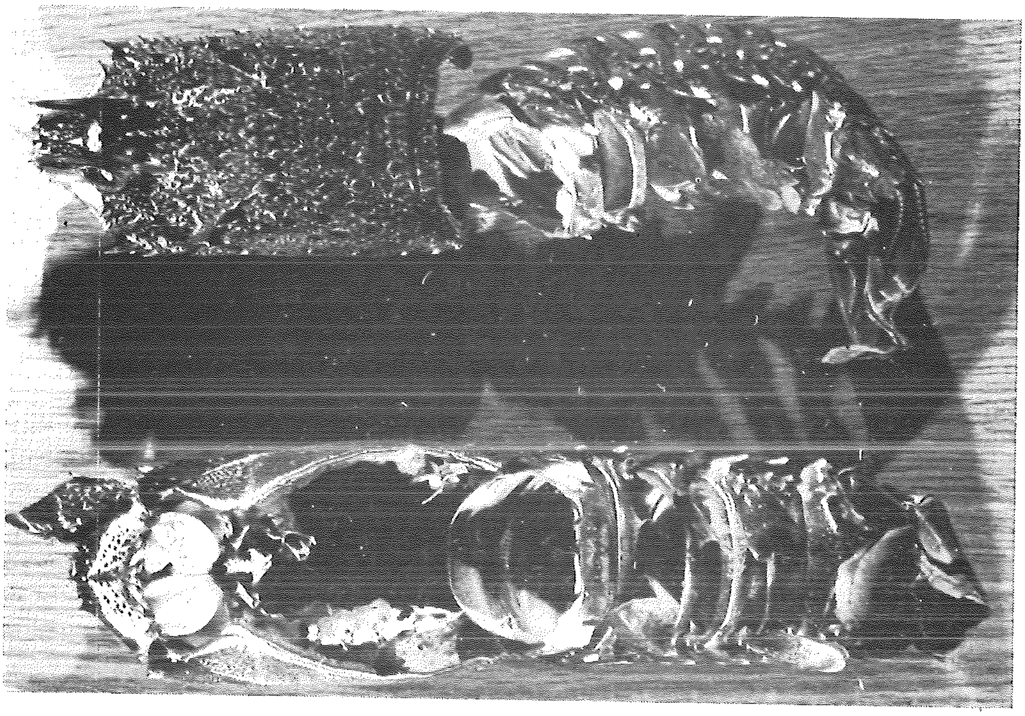
Octopuses and cuttlefishes have characteristic methods of predation which allow the predator to be identified even when it has subsequently escaped from the pot. Rock lobsters predated by octopus are partly or fully separated at the junction of the cephalothorax and abdomen, and the tissues of the cephalothorax and sometimes the abdomen consumed (Figure 3). In addition the cephalothorax may also be wholly or partly opened along the branchio-stegal line. In contrast to the careful dismembering of the exoskeleton by octopuses, cuttlefishes simply bite large pieces of exoskeleton and tissue from the rock lobster with their powerful beaks. The remains of rock lobsters predated by cuttlefish often consist only of the anterior portion of the cephalothorax (Figure 3). Fish usually predate rock lobsters by biting holes in the flesh on the underside of the abdomen at the junction of the cephalothorax and abdomen, with the exception of wobbegong sharks which usually take the whole animal in one mouthful.

IV ESTIMATION OF THE LOSS OF POT-CAUGHT ROCK LOBSTERS BY PREDATION

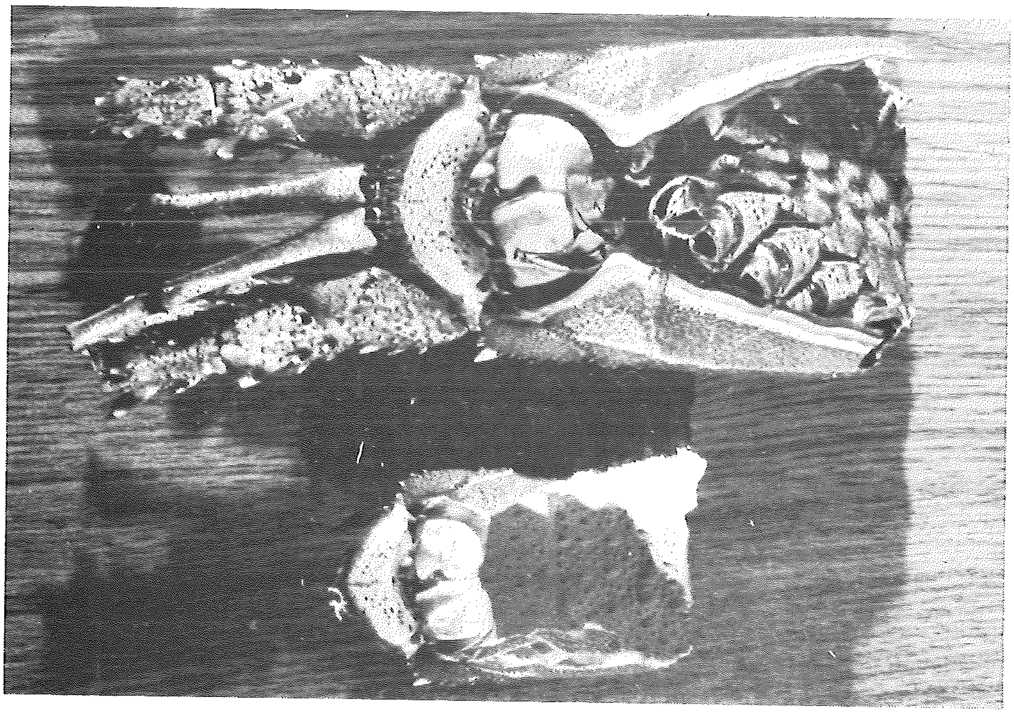
METHODS

Sampling of commercial catches as part of a programme to monitor changes in the rock lobster stock has been carried out by the rock lobster research group since the 1971/72 season. Since 1972/73 these samples have included records of the number of dead rock lobsters in the catch resulting from all forms of predation, and the number of octopus caught. In the 1974/75 and 1975/76 seasons records of the identity of the predator and the size (carapace length) and sex of the predated rock lobster were also made, except where the bodies were too severely damaged to determine these parameters. The number of pots containing octopus and the number showing detectable signs of former occupation by octopus (i.e. typical octopus-predated rock lobster, severe damage to bait holders) were also recorded. On occasions, when time permitted, measurements of all the rock lobsters in a single pot showing octopus predation were taken as a group to determine the size relationship between the predated rock lobster and other rock lobsters in the pot.

Figure 3. Typical remains of predated rock lobsters.



a) Two octopus predated rock lobsters.



b) Two cuttlefish predated rock lobsters.

The commercial catch sampling programme sampled boats operating from or near to four ports (Fremantle, Lancelin, Jurien, Dongara - Figure 1). The sampling programme aimed to sample catches from four depth ranges (0-10Fm, 10-20Fm, 20-30Fm, and over 30Fm), with a target of 400 rock lobsters from each depth range for each month at eact port. The target was not always fulfilled, either because certain depth ranges were not fished at some times of the season or because of low catch rates or bad weather. Because the target was in terms of the number of rock lobsters sampled, the number of pots sampled varied inversely with the catch rate.

Compulsory monthly returns completed by all fishermen and compiled by the Australian Bureau of Statistics recorded the total effort of the fishery in 1^{o} latitude x 1^{o} longitude grid blocks (Figure 1). So that the sample results could be weighted to reflect the variations in effort in different areas, the samples were allocated to the 1^{o} x 1^{o} block in which they were taken.

RESULTS

The numbers of pots sampled, the number of predated rock lobsters and the number of octopus caught are shown by depth range in Table 1 (a - d) for the ten months of fishing during the seasons 1972/73, 1973/74, 1974/75, and 1975/76. For the latter two seasons the predated rock lobsters are divided into octopus-predated, cuttle-fish-predated, and fish-predated. Samples were recorded from the five 1^{o} x 1^{o} blocks - 2914, 3014, 3015, 3115, 3215. These blocks account for approximately 65% of the effort of the fishery in any one season. The total number of pot lifts for each month for every block for the 1972/73, 1973/74, and 1974/75 seasons are shown in Table 2 (a - c). The effort figures for the 1975/76 season were not available at the time of preparation of this report.

The samples for 1972/73, 1973/74, and 1975/76 showed significant differences ($P < 0.001$, Chi-square test) in the total number of predated rock lobsters/pot lift from the various depth ranges, while the 1974/75 sample showed no significant differences between depths. This pattern also occurred with the octopus-predated rock lobsters in the 1974/75 and 1975/76 seasons. The number of octopus caught/pot lift showed significant differences ($P < 0.001$) between the various depth ranges in all the four seasons. In the seasons in which there were significant differences, the rate of predation and the octopus catch rate in the 0-10Fm range were consistently higher than expected. The rate of predation and the octopus catch rate in the 10-20Fm range fluctuated, being high in some seasons and low in others while in the 20-30Fm and over 30Fm depth ranges the rate of predation and the octopus catch rate were usually lower than inshore. Since the distribution by depth range fished of the effort in the fishery is not recorded, the differences in the number of predated rock lobsters/pot lift and the octopus catch rate between the various depth ranges cannot be directly accounted for in the estimates of predation. However the influence of the variations with depth must be recognized in interpreting the results.

(i) TOTAL PREDATION

For the seasons 1972/73 - 1974/75 estimates of the total number of predated rock lobsters in any block in any month in which a sample was taken were obtained by multiplying the mean number of predated

TABLE 1. Commercial catch samples 1972/73 to 1975/76.

TABLE 1a. 1972/73 Season.

BLOCK		2914				3014				3015				3115				3215			
DEPTH CAT. (FM)		0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+
NOV.	POT LIFTS	199	60			320	24							116				35			
	PRED. R/L	3	0			15	0							15				0			
	No. OCTOPUS	6	11			7	0							3				0			
DEC.	POT LIFTS	99	136	89				191	28					192	168	136	120			147	21
	PRED. R/L	3	13	3				5	4					17	4	5	0			3	3
	No. OCTOPUS	5	11	3				4	2					8	1	0	0			7	0
JAN.	POT LIFTS	176	84	78	148			50		168				236						49	
	PRED. R/L	15	13	1	0			0		3				5						2	
	No. OCTOPUS	20	7	0	0			0		3				2						0	
FEB.	POT LIFTS	110			120	255		135		166				440			117			172	
	PRED. R/L	4			0	9		0		8				29			0			8	
	No. OCTOPUS	2			0	4		0		11				17			0			7	
MAR.	POT LIFTS	233	165	75		50	138			87		192		618	357	90				174	
	PRED. R/L	6	7	3		3	4			9		0		28	6	0				0	
	No. OCTOPUS	2	7	1		2	1			3		0		9	1	0				0	
APR.	POT LIFTS	88	178	75		128	140	167	84	245				192						254	
	PRED. R/L	0	0	0		2	0	0	0	5				7						7	
	No. OCTOPUS	0	0	0		1	1	0	0	2				2						2	
MAY	POT LIFTS	172		512	75					75		93		114		186		208			
	PRED. R/L	6		13	10					0		1		0		1		0			
	No. OCTOPUS	4		8	0					0		0		0		0		0			
JUNE	POT LIFTS	66	75	107										537							
	PRED. R/L	2	11	6										8							
	No. OCTOPUS	3	6	1										6							
JULY	POT LIFTS	176	26			59								150							
	PRED. R/L	19	0			3								5							
	No. OCTOPUS	6	1			1								3							
AUG.	POT LIFTS	75				156				154											
	PRED. R/L	4				0				6											
	No. OCTOPUS	2				0				3											

TABLE 1b. 1973/74 Season.

BLOCK		2914				3014				3015				3115				3215			
DEPTH CAT. (FM)		0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+
NOV.	POT LIFTS					172				78				96							
	PRED. R/L					1				1				0							
	No. OCTOPUS					3				3				5							
DEC.	POT LIFTS	185	86				124	232		78	272			96	96						
	PRED. R/L	0	5				0	0		0	1			0	0						
	No. OCTOPUS	0	3				0	5		1	7			0	0						
JAN.	POT LIFTS	90	90			78		135	100	75	75			96	96	108					84
	PRED. R/L	0	0			3		2	0	2	3			6	0	0					0
	No. OCTOPUS	0	0			0		6	0	3	5			0	0	0					0
FEB.	POT LIFTS	78	84	84		78	78		135	147				190		393				272	
	PRED. R/L	6	6	0		0	1		1	10				21		1				0	
	No. OCTOPUS	4	11	0		0	1		0	7				17		4				5	
MAR.	POT LIFTS	150	235		288	183			405	142								168		202	
	PRED. R/L	12	7		5	13			7	0								11		2	
	No. OCTOPUS	3	12		0	5			2	9								12		3	
APR.	POT LIFTS	75		236	313	156	93	270								107					
	PRED. R/L	5		0	12	4	3	3								0					
	No. OCTOPUS	3		0	1	0	0	3								1					
MAY	POT LIFTS	120			298	181				220											
	PRED. R/L	4			19	7				8											
	No. OCTOPUS	4			6	1				2											
JUNE	POT LIFTS	75		231	178	111				242											
	PRED. R/L	4		12	1	2				7											
	No. OCTOPUS	1		3	2	0				3											
JULY	POT LIFTS	119		120	222	235				266					160						
	PRED. R/L	8		0	3	13				2					0						
	No. OCTOPUS	3		0	0	13				1					1						
AUG.	POT LIFTS	133		234		224															
	PRED. R/L	1		3		13															
	No. OCTOPUS	3		0		5															

TABLE 1c. 1974/75 Season.

BLOCK		2914				3014				3015				3115				3215			
DEPTH CAT. (FM)		0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+
NOV.	POT LIFTS	233				348	134			74				181					96		
	OCTOPUS PRED.	11				10	4			0				9					1		
	C/FISH PRED.	0				3	0			0				0					2		
	FISH PRED.	0				0	0			0				0					0		
	No. OCTOPUS	6				8	4			0				9					4		
DEC.	POT LIFTS	134	61			126	66			150	75			233	240	63	88			156	
	OCTOPUS PRED.	4	2			7	1			1	0			4	5	2	9			3	
	C/FISH PRED.	0	0			0	0			0	0			0	0	0	1			0	
	FISH PRED.	0	0			0	0			0	0			0	0	0	0			0	
	No. OCTOPUS	2	1			3	3			2	2			10	4	0	0			4	
JAN.	POT LIFTS	258	45	45	180	79		79	106	131				156		108			138	18	
	OCTOPUS PRED.	15	3	9	4	4		0	0	4				10		0			0	0	
	C/FISH PRED.	2	0	0	0	0		0	0	0				0		0			1	0	
	FISH PRED.	0	0	0	0	1		0	0	0				1		0			0	0	
	No. OCTOPUS	10	1	3	0	3		0	2	3				3		0			1	0	
FEB.	POT LIFTS	127	334			569	21	89		75				365	347	194		103			
	OCTOPUS PRED.	6	8			23	6	0		2				13	6	1		8			
	C/FISH PRED.	0	0			0	0	0		0				0	0	0		0			
	FISH PRED.	1	0			1	0	0		0				0	0	0		0			
	No. OCTOPUS	0	12			9	1	2		4				11	3	0		14			
MAR.	POT LIFTS	249	196		119	85	127			207				96	118			72			
	OCTOPUS PRED.	1	11		1	6	2			4				0	9			13			
	C/FISH PRED.	0	0		0	0	0			0				0	0			0			
	FISH PRED.	0	0		0	0	0			0				0	0			0			
	No. OCTOPUS	5	5		0	4	2			3				0	2			3			
APR.	POT LIFTS	103	101		107	191	82	108		75		123		92	176					36	
	OCTOPUS PRED.	6	2		1	2	0	3		3		4		2	3					0	
	C/FISH PRED.	0	3		0	0	0	0		0		3		0	1					0	
	FISH PRED.	0	0		0	0	0	0		0		0		0	0					0	
	No. OCTOPUS	1	1		0	4	0	1		2		0		1	0					0	
MAY	POT LIFTS	256	100		106	290	166			231										156	
	OCTOPUS PRED.	8	6		5	6	5			5										1	
	C/FISH PRED.	0	7		2	0	2			0										1	
	FISH PRED.	0	0		0	0	0			0										0	
	No. OCTOPUS	5	0		2	6	6			3										2	
JUNE	POT LIFTS					381	31			265				168				182			
	OCTOPUS PRED.					10	0			5				5				4			
	C/FISH PRED.					0	0			0				0				3			
	FISH PRED.					1	0			0				0				0			
	No. OCTOPUS					1	0			4				2				3			
JULY	POT LIFTS	211	63	120		84	68	72	86	87									140		
	OCTOPUS PRED.	2	5	0		5	5	3	0	1									0		
	C/FISH PRED.	2	1	0		1	5	0	1	0									1		
	FISH PRED.	0	0	0		0	0	0	0	0									0		
	No. OCTOPUS	0	0	0		0	0	0	0	0									0		
AUG.	POT LIFTS	111		67		110				217				79	194						
	OCTOPUS PRED.	2		8		4				4				2	1						
	C/FISH PRED.	0		1		0				0				0	0						
	FISH PRED.	0		0		0				0				0	0						
	No. OCTOPUS	2		0		0				0				1	0						

TABLE 1d. 1975/76 Season.

BLOCK		2914				3014				3015				3115				3215			
DEPTH CAT. (FM)		0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+	0-10	10-20	20-30	30+
NOV.	POT LIFTS	252				287				150				389	38			281			
	OCTOPUS PRED.	1				15				1				11	3			5			
	C/FISH PRED.	0				0				0				0	0			0			
	FISH PRED.	0				5				0				0	0			0			
	NO. OCTOPUS	3				11				0				14	0			5			
DEC.	POT LIFTS	67	41	239	30				135	50				96			85		72		
	OCTOPUS PRED.	4	2	9	0				2	1				9			2		0		
	C/FISH PRED.	0	0	0	0				0	0				0			0		0		
	FISH PRED.	0	0	0	0				0	0				0			0		0		
	NO. OCTOPUS	1	0	0	0				1	1				2			1		0		
JAN.	POT LIFTS		114			203	13			134	125			97		312				98	118
	OCTOPUS PRED.		13			10	0			13	11			10		4				2	0
	C/FISH PRED.		0			0	0			0	0			0		0				0	0
	FISH PRED.		0			1	0			0	0			0		0				0	0
	NO. OCOTOPUS		2			2	0			9	1			6		2				3	1
FEB.	POT LIFTS	265	74	271		91				139	108			144	204				72		
	OCTOPUS PRED.	27	12	5		10				10	5			5	9				1		
	C/FISH PRED.	0	0	0		0				0	0			0	0				0		
	FISH PRED.	0	0	0		0				0	0			0	0				0		
	NO. OCTOPUS	18	5	5		3				5	0			1	1				2		
MAR.	POT LIFTS	186	113		256		228	67	17	74				177	213	483	66	103		250	
	OCTOPUS PRED.	13	7		0		21	1	2	4				5	14	6	1	8		5	
	C/FISH PRED.	0	0		0		0	0	0	0				0	0	0	0	0		0	
	FISH PRED.	0	0		0		2	0	0	0				0	0	1	0	0		0	
	NO. OCTOPUS	4	4		0		2	1	1	2				6	2	0	2	7		3	
APR.	POT LIFTS	175			227	96	132		129	83				339	117	433	32			168	
	OCTOPUS PRED.	7			10	0	0		3	0				2	0	8	0			3	
	C/FISH PRED.	0			0	0	0		0	0				1	0	0	0			0	
	FISH PRED.	0			0	0	7		0	1				0	0	0	0			0	
	NO. OCTOPUS	6			2	3	0		4	0				5	0	0	0			0	
MAY	POT LIFTS	75				162				222				311	332						
	OCTOPUS PRED.	2				2				3				3	7						
	C/FISH PRED.	0				2				2				0	0						
	FISH PRED.	0				0				0				0	0						
	NO. OCTOPUS	2				1				3				6	2						
JUNE	POT LIFTS	148		117		144				12	115			130							
	OCTOPUS PRED.	6		0		2				0	2			6							
	C/FISH PRED.	0		0		0				0	1			0							
	FISH PRED.	0		0		0				0	0			0							
	NO. OCTOPUS	5		0		1				0	0			1							
JULY	POT LIFTS	145		95		202				30		63		279		206					
	OCTOPUS PRED.	14		0		12				0		0		13		1					
	C/FISH PRED.	0		0		0				0		0		0		1					
	FISH PRED.	0		0		0				0		0		0		0					
	NO. OCTOPUS	3		0		3				0		0		2		0					
AUG.	POT LIFTS	88	72	53						82				88		134					
	OCTOPUS PRED.	4	1	4						1				6		0					
	C/FISH PRED.	0	0	0						0				0		0					
	FISH PRED.	0	0	0						1				0		0					
	NO. OCTOPUS	2	0	0						0				0		0					

TABLE 2A - EFFORT (POT LIFTS) BY BLOCK AND MONTH 1972/73 SEASON.

BLOCK	NOV	DEC	JANUARY	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
2612										
2613								2 352		
2712					1 586					
2713	8 997	20 612	28 840	27 384	26 610	20 379	21 688	20 895	23 714	9 561
2714	6 067	13 159	16 247	10 867	12 884	15 726	11 337	11 721	14 500	9 282
2812					1 589	2 786	2 300	642	1 861	255
2813	3 858	1 741	576	2 270	260 976	432 771	305 327	128 166	161 651	65 342
2814	148 347	269 886	123 244	99 064	93 209	82 433	87 462	67 592	64 655	21 520
2912										
2913		10 290	2 775	980	11 561	15 220	11 674	2 733	4 634	1 544
2914	260 326	510 267	242 852	227 110	225 969	152 529	149 472	135 669	135 195	43 249
3012	702	2 807	1 755	1 404	2 456	1 052	1 169			
3013	1 641	13 655	7 008	4 078	2 879	5 342		840		
3014	120 220	302 869	184 047	163 221	202 186	168 483	79 171	60 621	60 446	20 731
3015	30 441	84 304	72 246	51 298	53 876	42 691	9 744	8 690	7 057	3 050
3112	3 102	3 807	2 820	2 115	2 679	2 679				
3113	976		5 265	4 455	3 134		240			
3114	14 358	46 911	46 774	36 975	39 452	29 079	7 235	4 561	724	900
3115	167 779	372 386	238 036	236 621	275 668	196 719	88 557	69 088	55 185	18 566
3212										
3213										
3214	1 394		1 190	1 020	2 400		1 232	1 002	95	52
3215	9 735	79 655	60 072	43 421	47 219	50 136	28 372	24 740	11 989	5 376
3314	91		1 500	1 260	1 260	1 300				
3315	741	5 560	6 268	7 683	8 369	5 380	3 523	4 409	3 312	2 390
3414		1 260	3 600	3 840	2 434	359				

TABLE 2B - EFFORT (POT LIFTS) BY BLOCK AND MONTH 1973/74 SEASON.

BLOCK	NOV	DEC	JANUARY	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
2612										
2613		1 800	840		3 795	1 148	3 749		2 560	840
2712										
2713	6 131	16 390	34 417	21 669	27 217	19 764	19 331	20 238	20 723	4 912
2714	7 721	12 283	24 736	14 056	18 353	18 895	16 465	14 608	8 923	558
2812		1 350	836	968	5 100	5 430	4 026	1 260	855	
2813	4 368	11 404	2 754	3 108	252 303	430 173	286 275	110 252	156 999	43 866
2814	128 540	277 555	112 174	96 715	96 238	91 601	75 368	66 099	70 309	22 953
2912					3 640	2 400				
2913	2 712	13 747	5 574	3 585	19 467	22 812	10 222	2 622	5 460	1 740
2914	242 518	503 001	277 244	221 712	233 336	184 873	134 444	116 411	132 781	37 058
3012	3 462	8 079	1 989	2 674	1 879	2 223				
3013	810	5 778	7 392	6 966	9 888	4 962	135	1 683	560	
3014	125 731	305 305	223 471	189 217	255 396	198 234	99 590	88 369	84 394	25 236
3015	26 657	81 041	49 134	38 808	64 289	34 967	18 124	20 135	15 883	4 273
3112	987	5 666	3 102	2 874	3 384					420
3113	3 184	4 392	1 386	4 732	1 950	1 200	3 150	2 850	2 410	794
3114	18 966	44 164	55 790	43 046	52 993	34 181	8 655	3 035	2 120	600
3115	158 313	374 687	285 330	301 537	379 095	240 525	129 708	124 162	89 158	28 730
3212										
3213										
3214		4 050				1 184				
3215	14 007	90 140	77 082	79 032	100 118	52 524	34 945	33 508	23 038	8 040
3314			2 535							450
3315	2 498	5 637	4 022	6 838	3 000	2 570	1 204	4 663	2 850	2 036
3414			690	2 221	1 760	240				

TABLE 2c - EFFORT (POT LIFTS) BY BLOCK AND MONTH 1974/75 SEASON.

BLOCK	NOV	DEC	JANUARY	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
2612										
2613				3 260	1 980		2 880	2 325	1 480	
2712										
2713	7 988	22 610	44 997	27 619	25 791	28 839	24 470	23 275	23 033	15 284
2714	10 185	20 112	21 559	15 014	15 084	18 303	15 530	16 714	15 072	5 549
2812					2 410	2 320	2 512	3 787	1 551	1 068
2813	1 911		6 885	2 985	268 826	457 198	320 765	110 517	121 633	49 926
2814	131 272	261 903	112 954	97 407	96 368	91 294	70 703	50 124	55 328	35 397
2912	310	1 701	972							
2913	1 512	7 620	5 472	3 402	5 112	13 708	8 487	420	1 562	2 134
2914	249 265	470 355	223 155	235 210	233 602	199 576	172 919	131 433	128 683	56 713
3012					1 624	1 395				
3013	1 296	5 260	4 435	2 235	4 385	2 178				
3014	138 417	313 410	191 829	182 658	228 534	200 629	111 803	85 135	81 865	41 707
3015	26 731	65 376	56 562	56 547	61 429	55 685	29 621	21 872	16 811	10 317
3112	1 410	7 020	2 961	2 961	2 961	2 820				
3113	1 200	2 175		1 950	1 950	3 180	1 725	1 275		
3114	20 691	57 708	51 688	54 741	55 175	38 520	6 782	12 296	8 591	5 039
3115	199 503	416 994	322 008	365 229	383 243	287 065	176 654	153 940	105 017	42 243
3212										
3213										
3214										
3215	25 602	86 017	64 433	74 884	72 427	55 384	45 801	38 789	27 812	14 399
3314					360	1 410				
3315	1 320	4 488	3 402	2 772	2 736	2 296	1 440	2 550	792	854
3414			1 000							

rock lobsters per pot lift in the sample by the total fishing effort for that block in that month. The sum of the monthly predation predation estimates provided an estimate of the predation occurring in the months in which the various blocks were sampled.

To estimate the total predation in the fishery it was necessary to obtain an estimate of the predation in the months in which the usual blocks were not sampled as well as in the unsampled blocks. In some seasons there were significant differences ($P < 0.05$) between the sampled blocks in the number of predated rock lobsters per pot lift, the northernmost block (2914) being consistently above average while the other blocks were usually average or below average. The estimated catch rate of predated rock lobsters per pot lift calculated from the sampled months of a block, was therefore applied only to the recorded effort in blocks of the same latitudinal position, as well as the effort in the unsampled months of that block, e.g. the mean annual rate for 3115 was applied to blocks 3112, 3113, and 3114 as well as to the unsampled months of 3115 (Figure 1). For the more northerly and southerly blocks of the fishery, which were not sampled, the mean rate of the closest sampled block was used, i.e. the rate for 2914 was applied to the effort of blocks 2612/13, 2712-2714, 2812-2814, and 2912/13 while the rate for 3115 was applied to blocks 3414, 3314/13, 3212-3215, and 3112-3114. The estimates for 3014 and 3015 were pooled and the mean rate applied to the effort in the unsampled months of those blocks and the other blocks on the same latitudinal level. The predation estimates for the sampled block/months and for the latitudinally grouped unsampled blocks and block/months were summed to give an estimate of the total predation (Table 3). For the 1975/76 season, for which effort figures were not available, the mean number of predated rock lobsters per pot lift in the samples was simply multiplied by the estimated total effort for the season (approximately 9.5 million pot lifts - G.R. Morgan, pers. comm.) to obtain a total estimate.

TABLE 3 - Estimated total number of predated rock lobsters in the seasons 1972/73 - 1975/76.

Season	Est. No. Predated Rock Lobsters
1972/73	353 000
1973/74	203 000
1974/75	377 000
1975/76	340 000

(ii) PREDATION BY VARIOUS SPECIES

The records for the 1974/75 and 1975/76 seasons (Table 1, c and d) show that octopuses are the principal predators of pot-caught rock lobsters. The contribution of the various predators to the total predation in 1974/75 and 1975/76 (Table 4) was estimated by multiplying the total number of predated rock lobsters by the overall percentage of rock lobsters in the samples which were predated by each predator.

TABLE 4 - Estimated number of rock lobsters predated by octopus, cuttlefish and fish in the 1974/75 and 1975/76 seasons.

Season	Octopus Predated	Cuttlefish Predated	Fish Predated
1974/75	334 000	39 000	4 000
1975/76	321 000	5 000	14 000

(iii) SIZE AND SEX OF PREDATED ROCK LOBSTERS

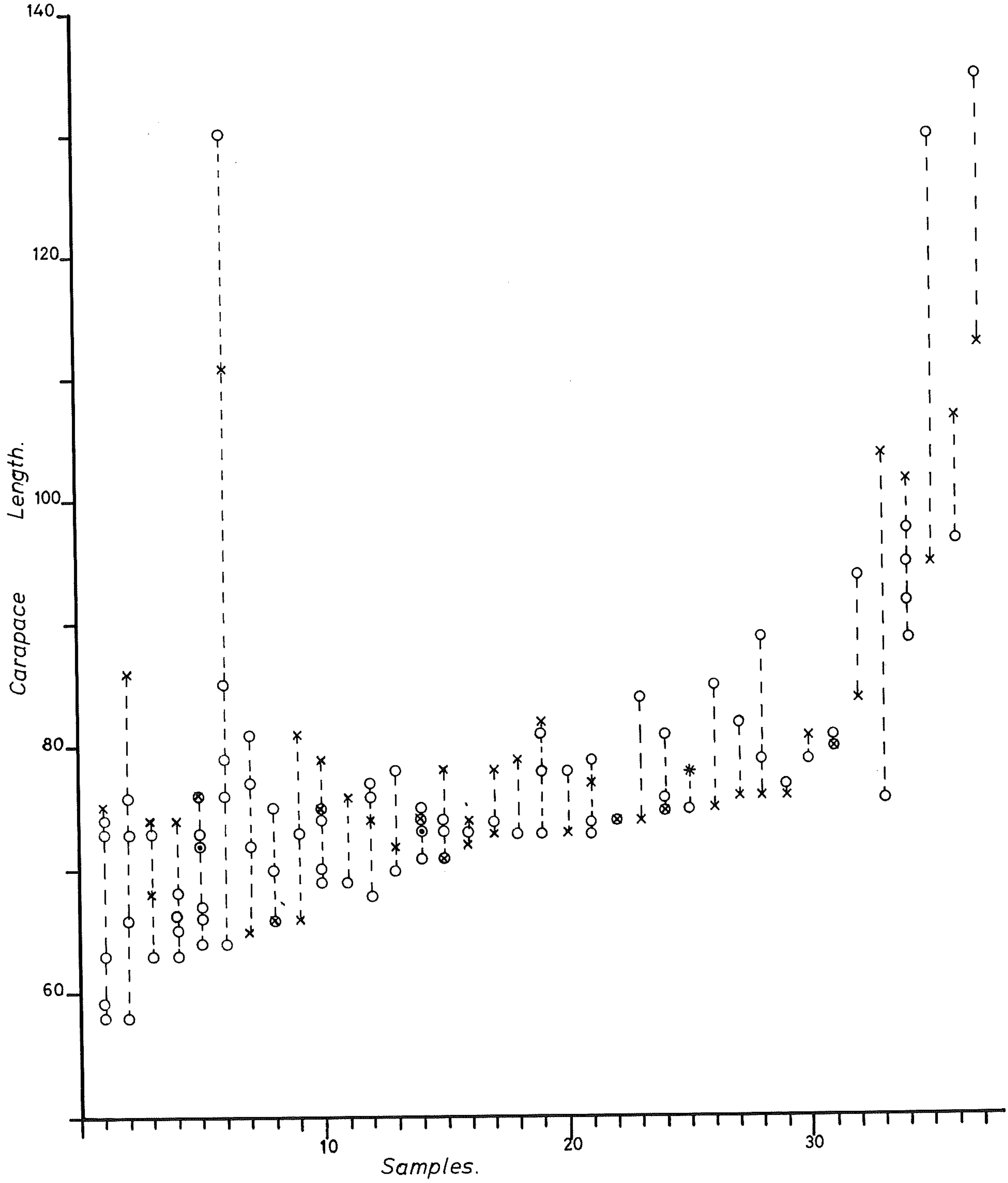
Not all predated rock lobsters in the samples from the 1974/75 and 1975/76 seasons were of legal commercial size (⩾ 76mm carapace length (Table 5). In the two seasons respectively only 55.4% and 60.0% of the measurable octopus-predated rock lobsters in the samples were of legal size.

TABLE 5 - Size (carapace length) of predated rock lobsters in commercial catch samples.

	⩾ 76mm		< 76mm		Unmeasurable	
	74/75	75/76	74/75	75/76	74/75	75/76
Octopus Predated	200	240	161	156	9	25
Cuttlefish Predated	27	4	12	2	4	1
Fish Predated	3	6	1	11	1	1

Many fishermen claim that octopuses always attack the largest rock lobster in a pot. To examine this, records were made during the 1975/76 season, when time permitted, of the sizes of rock lobsters in a pot where octopus predation had occurred. Many pots contained only one dead rock lobster, either because the pot only contained one rock lobster when the octopus entered or because other rock lobsters present in the pot had escaped from the pot following the entry of the octopus. In some pots two dead rock lobsters were found but no live animals, while other pots showed both live and dead rock lobsters. Pots in which both live and dead rock lobsters occurred provided an opportunity to examine whether any selection for size occurred (Figure 4). The data show no obvious selection for rock lobsters of any particular size or relative size. There was no significant difference between the mean carapace length of the predated rock lobsters and that of all the rock lobsters in the pots where predation occurred.

Figure 4. Carapace lengths of rock lobsters in commercial pots where octopus predation occurred.



= octopus predated rock lobster

= live rock lobster

2 predated rock lobster

2 live rock lobster

1 live and 1 predated rock lobster

Vertical broken lines join carapace lengths of rock lobsters together in one pot.

69943-5

Both male and female rock lobsters were predated by the various predators (Table 6). In the 1975/76 sample there were no significant differences between the numbers of each sex predated, assuming equal numbers of males and females available in the pot, while in the 1974/75 sample, there were significantly more ($P < 0.05$) females than males predated by octopus. However the ratio of males to females in pots is not constant but varies with depth and time of season (Morgan and Barker, 1974, 1975), so that it is possible that the greater number of females predated in the 1974/75 sample simply reflects a higher proportion of females in pots where octopus predation occurred.

TABLE 6 - Sexes of predated rock lobsters in commercial catch samples.

	Male		Female		Unsexable	
	74/75	75/76	74/75	75/76	74/75	75/76
Octopus Predated	148	165	187	196	35	60
Cuttlefish Predated	15	1	23	3	5	3
Fish Predated	3	6	1	11	1	1

(iv) LOSS OF COMMERCIALLY-SIZED ROCK LOBSTERS

As not all the rock lobsters predated by the various predators were legal-sized, saleable individuals, the immediate losses were less than the total losses, as the undersized individuals would have been thrown overboard anyway. The loss of legal-sized rock lobsters (Table 7) was estimated by multiplying the total estimated loss from the various predators by the percentage of predated legal-sized individuals in the samples. For 1972/73 and 1973/74 seasons a mean percentage from the 1974/75 and 1975/76 samples for all predators was used.

TABLE 7 - Estimated number of legal-sized rock lobsters predated.

Season	1972/73	1973/74	1974/75	1975/76
All predated	206 000	118 000	215 000	203 000
Octopus Predated	-	-	185 000	195 000
Cuttlefish Predated	-	-	27 000	3 000
Fish Predated	-	-	3 000	5 000

FINANCIAL LOSS TO THE FISHERY

To estimate the loss in financial terms it is necessary to know the loss in terms of weight, as the price paid is on a weight basis. The weight of rock lobsters can be estimated from the carapace length using the formula

$$W = 0.002831 L^{2.744} \text{ (g)}$$ (G.R. Morgan, unpub.)

The mean weights of legal-sized, predated rock lobsters (Table 8) were determined for the 1974/75 and 1975/76 samples by grouping the measurable, legal-sized predated rock lobsters into 10mm size groups. The mean length for each size grouping was determined and a mean weight value calculated for each size group, using the mean length. The weight value determined from the mean length of each size group will be a slight underestimate of the actual mean weight as the relationship between length and weight is not linear. However grouping the data into 10mm size groups reduces this error to a negligible level. An overall mean weight was calculated, weighted for the number of individuals in each size category.

To estimate the mean weight of predated rock lobsters in the 1972/73 and 1973/74 seasons, a weighted mean of the mean weights of all the predated, legal-sized rock lobsters from the 1974/75 and 1975/76 samples was used (553 g).

TABLE 8 - Mean weights (g) of predated, legal-sized rock lobsters.

	1974/75	1975/76
Octopus predated	562 g	542 g
Cuttlefish predated	618 g	542 g
Fish predated	456 g	444 g

The estimated weight loss for the various seasons (Table 9) must then be multiplied by the average price/kg paid in the four seasons. The price paid for rock lobsters varies depending on the nature of the sale (cash or pool price) as well as varying from port to port and during the season. Average values used were - 1972/73 - $2.40/Kg; 1973/74 - $2.70/Kg; 1974/75 - $2.70/Kg; 1975/76 - $3.70/Kg. Table 10 shows the estimated financial loss.

TABLE 9 - Estimated weight loss (Kg) through predation.

	1972/73	1973/74	1974/75	1975/76
All Predators	112 000	64 000	122 000	110 000
Octopus Predated	-	-	104 000	106 000
Cuttlefish Predated	-	-	17 000	2 000
Fish Predated	-	-	1 000	2 000

TABLE 10 - Estimated financial loss through predation.

	1972/73	1973/74	1974/75	1975/76
All Predated	$269 000	$173 000	$330 000	$406 000
Octopus Predated	-	-	$281 000	$392 000
Cuttlefish Predated	-	-	$46 000	$7 000
Fish Predated	-	-	$3 000	$7 000

(vi) ESTIMATE OF THE NUMBER OF OCTOPUS CAUGHT

Using the same methods as were used to estimate total predation, the total number of octopus caught was estimated from the sample data (Table 11).

TABLE 11 - Estimated number and weight of octopus caught.

Season	No. of Octopus	Weight of Octopus (Kg)*
1972/73	263 000	247 000
1973/74	167 000	160 000
1974/75	191 000	180 000
1975/76	147 000	138 000

* beheaded

The weight of individual octopuses caught in pots may vary between 100g and several kilos, but the average size caught is usually between 500g and 2Kg. Fishermen usually behead octopus before either discarding them or delivering them to the processing factory. The mean weight of a sample of 429 beheaded octopuses delivered to processors at Fremantle, Two Rocks and Dongara was 0.94Kg. Using this mean weight an estimate of the total weight of octopus caught was made (Table 11).

DISCUSSION

As the specific aim of the rock lobster monitoring programme was to sample a particular target number of rock lobsters from the four depth ranges, the sampling effort was almost certainly not distributed over the depth ranges in the same proportion as the total fishing effort. However this could not be corrected because details of fishing effort by depth categories were not available. It is most likely that the deeper areas, where predation and octopus catch rates were generally low, were oversampled while the shallow areas, where predation and octopus catch rates were high, were undersampled. Extrapolating the sample data to the total fishery therefore probably underestimates predation in the coastal blocks and overestimates predation in the offshore blocks. However the offshore blocks, excluding the Abrolhos Is. region (block 2813) which has a similar incidence of predation to the adjacent coastal blocks, only account for 5% of the total fishing effort. The overestimation of the predation in the offshore blocks probably does not fully counterbalance the underestimate of predation in the coastal blocks, so that the predation losses and octopus catches calculated probably represent minimum values. The value calculated for fish predation may also be a minimum value. R.G. Chittleborough (pers. comm.) has indicated that the incidence of predation by fish is considerably higher in the Abrolhos Is. area than in the coastal areas.

The data shows clearly that octopuses are the principal predators of pot-caught rock lobsters. In 1975/76 octopuses predated an estimated 195 000 legal-sized, pot-caught rock lobsters causing a loss of $392 000. In the same season the estimated losses from cuttlefish ($7 000) and fish ($7 000) predation were relatively minor. In the 1974/75 season an estimated 185 000 legal-sized rock lobsters were predated by octopuses, causing a loss of $281 000. Cuttlefish figured more prominently in the 1974/75 season as predators of pot-caught rock lobsters, causing an estimated loss of $46 000, while the estimated loss from fish predation was only $3 000. The loss of undersized rock lobsters may have an effect in subsequent seasons when the survivors of these animals would otherwise have been available for capture. However the reduction in the available stock due to predatory losses in earlier seasons is probably relatively small and has not been considered in calculating the losses in any one season.

As a percentage loss, the losses to the rock lobster fishery from octopus predation are only approximately 1% of the annual value of the fishery, but in absolute terms the loss is highly significant when rated against the total value of some fisheries for other species.

V ASPECTS OF OCTOPUS PREDATION

An integral part of the research programme was the consideration of possible ways of reducing either the degree of octopus predation or the cost of octopus predation to the fishery. With this objective in mind a number of aspects of octopus predation were examined in both the field and the laboratory.

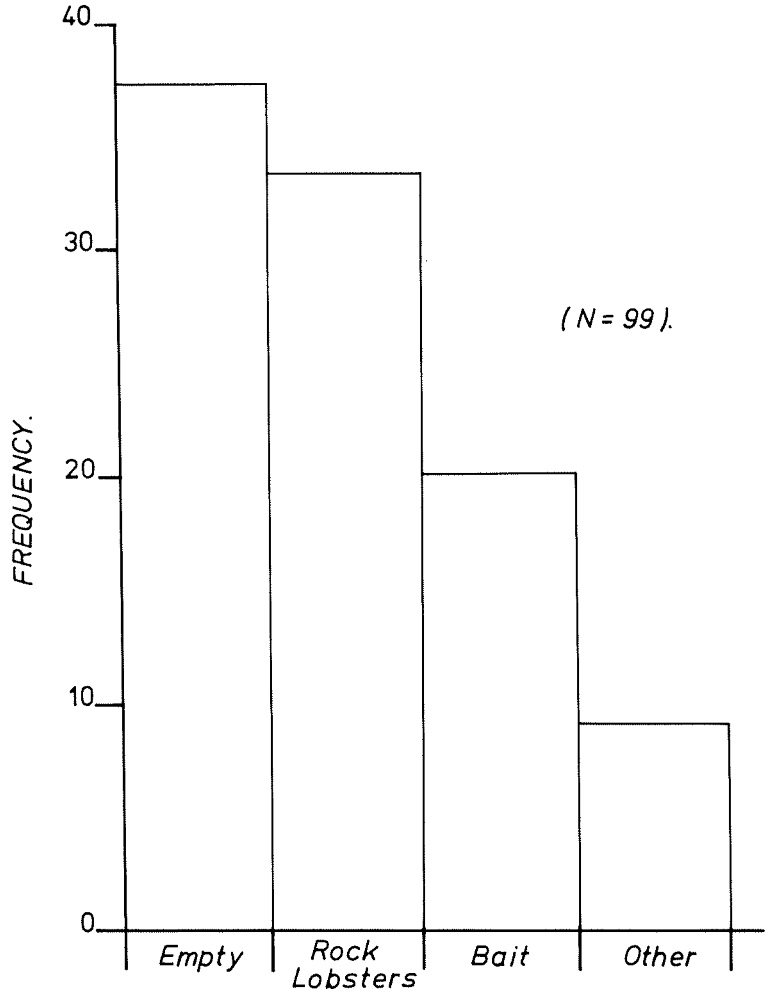
A. THE ATTRACTION OF OCTOPUSES TO ROCK LOBSTER TRAPS

The cephalopod eye is a highly developed sensory organ and appears to be the major sensory organ used by squid, cuttlefish, and octopus in locating and successfully attacking prey at close range (Wells, 1966). The anatomy of the eye and conditions of visibility underwater suggest that the eye is not used for distance vision (Wells, 1966) and is unlikely to be used to locate prey at a distance. The eye is also useless if the prey is obscured by the terrain. Kayes (1974) showed that *O. vulgaris* is basically a nocturnal species, making long hunting trips at night, while during the day individuals generally remain in, or within close proximity to, their lair. Yarnall (1969) found *O. cyanea* to be crepuscular, feeding in the morning and evening while remaining in its hole during the middle of the day and night. Little is known of the daily hunting pattern of *O. tetricus* but octopuses have been found in rock lobster pots set amongst reef during the day and checked shortly afterwards (D. Wright, pers. comm.). In *O. vulgaris*, at least, the light levels prevailing during the hunting period are likely to limit the usefulness of the eye as a prey-detector.

Yarnall (1969) found that *Octopus cyanea* in a natural situation either waited in their lair for prey to pass by or undertook short hunting trips from their lairs and made apparently speculative attacks on likely places where crabs may be found. Little attention has been given to distance chemoreception as a sense used in locating live or dead prey, although Wells (1963) noted that sardine blood in the water excited *O. vulgaris* in aquaria to move around their tanks. Wells (pers. comm.) considered that *O. vulgaris* are scavengers as well as predators.

Octopuses, like other coleoid cephalopods, have a small group of sensory cells located between the hind border of the eye and the edge of the mantle (Watkinson, 1909), the so-called "olfactory organ". Laboratory testing of the "olfactory organ" in various cephalopods has, however, produced inconclusive results. Polimanti (1913) showed that *Sepia*, clamped by means of the cuttlebone, made violent escape movements when a variety of substances (acetic acid, clove oil, bergamot oil and others) were released into the water near the "olfactory organ" but he did not repeat these experiments with the organ denervated or removed. Giersberg (1926), Wells (1963), and Messenger (1967) showed that extirpation of the "olfactory organ" produced no visible changes in the response of octopuses to fish juices. Woodhams and Messenger (1974) examined the ultrastructure of the "olfactory organ" and concluded that the anatomical evidence indicated that the organ had a chemosensory function. However the neural connections of the organ led them to surmise that it may possibly be involved in the detection of sexual pheromones.

Figure 5. Gut contents of octopuses caught in rock lobster pots.



Messenger (1967) observed that in blinded octopuses sardine juices pipetted at the "olfactory organ" produced no immediate response. After several seconds octopuses showed some response and the arms began to writhe. The response was similar to that elicited by holding a sardine about 2cm from the arms of a blinded octopus or pipetting sardine juice onto the arms. Messenger (1967) felt that the delayed response when sardine juice was pipetted onto the "olfactory organ" reflected the time required for diffusion of the juice to the arms where it was detected by the chemosensitive cells in the sucker rim (Wells, 1963).

The gut content of octopuses caught in rock lobster pots often contain bait (Figure 5). Octopuses with bait as gut contents are also often the only inhabitant of a lifted pot. This suggests that octopuses may also be attracted to pots by the bait rather than by trapped rock lobsters. Investigations of the ability of octopuses to detect "odours" and to successfully locate baits without visual assistance were therefore considered desirable. Observations on the behaviour of octopuses attempting to locate baits were also made in the hope that they might indicate the receptors involved.

METHODS

(i) Aquarium Experiments

Octopuses (200 - 1 000g) were collected from terracotta octopus traps set in depths of 5 to 8m in the vicinity of the W.A. Marine Laboratories. They were transported to the laboratory in wet calico bags and isolated, each in a covered asbestos cement aquarium measuring 63 x 50cm x 48cm high, with a flow of clean seawater (2 litres/min) at ambient temperature (17-22°C). Each octopus was provided with a terracotta pot as a refuge.

Octopuses were fed a diet of mussels *(Mytilus edulis)* and abalone *(Haliotis roei)*, each animal being fed enough food to approximately maintain its weight at capture. (An average food intake of 1 to 2% of the octopus body weight per day is sufficient to maintain body weight (Joll, 1977). Octopuses were fed three times per week and kept for a period of approximately two weeks to allow them to adjust to the aquarium situation before use in trials.

(a) Bait Location Trials

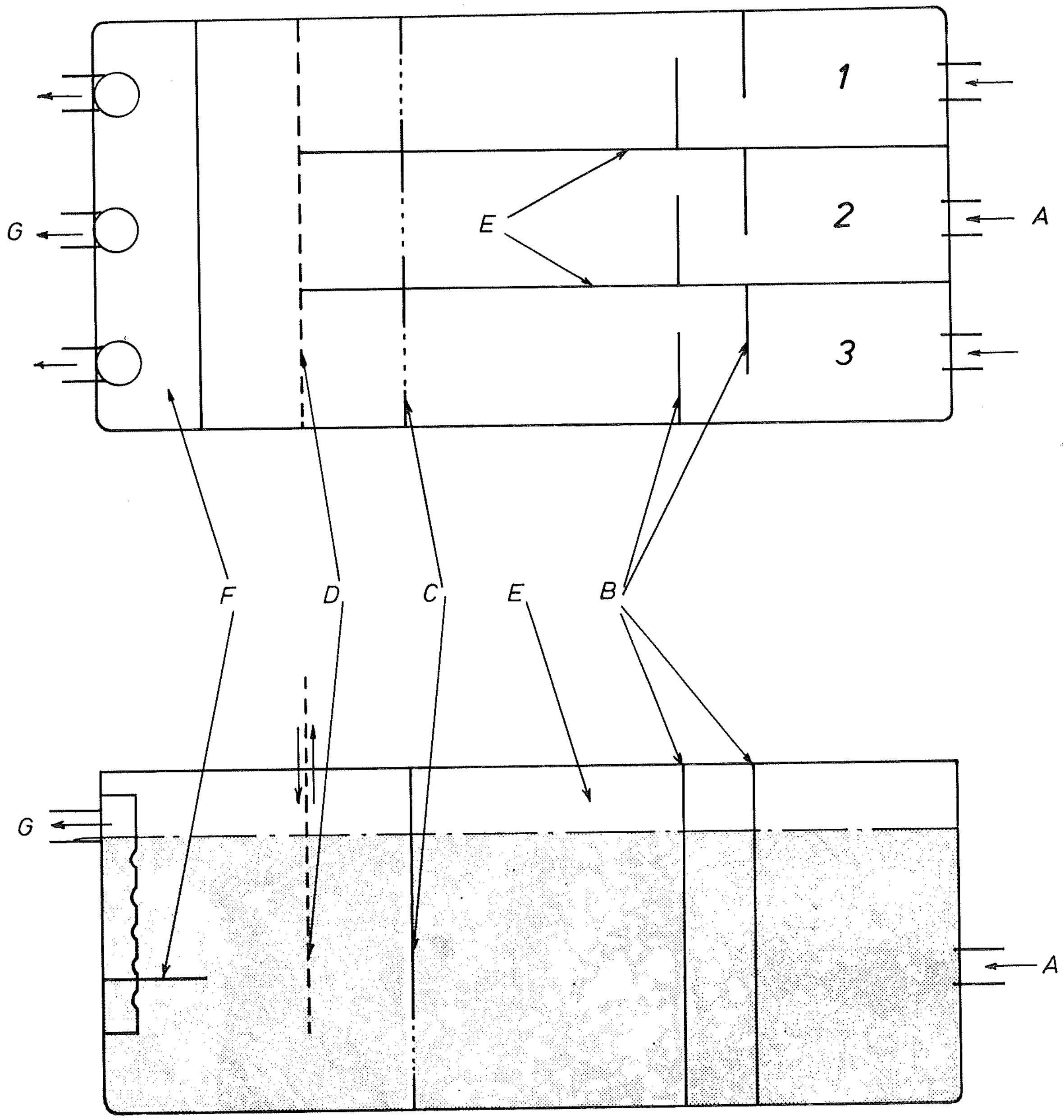
The bait location trials were conducted in a rectangular asbestos cement tank (Figure 6) 150 x 60cm x 38cm high with a water depth of 29cm (total volume 261 litres). The tank was divided for approximately 75% of its length into three equal width (20cm) channels and at the head of each channel a sub-surface jet provided a flow of clean seawater at 2 litres/min. Three overflow pipes were provided at the undivided end of the tank and these were mounted into a plastic roofed refuge area so that water was drawn from under, as well as above, the refuge. The undivided area of the tank could be separated from the divided area by sliding down a perforated partition.

Each channel contained a pair of offset sheets of PVC, to act as sight baffles. These were set approximately 40cm from the inlet jet, while at the far end of the channel, 20cm back from the end of the divider, another PVC baffle (C in Figure 6) with a 10cm diameter hole in the middle served to control the flow patterns in the tank. Preliminary dye tests with flouroscein showed that there was no leakage from one channel to the next and no backflow or eddies carrying water from one channel into any of the others. Apart from a small opening at the undivided end to allow a low level of illumination, the aquarium was screened with black plastic sheeting to prevent octopuses from seeing the observer. Observations were made through small peepholes in the sight-screening.

Octopuses were fasted for 3 days prior to a trial to ensure that they were hungry. They were introduced into the test aquarium approximately four hours before a trial and were allowed access to all parts of the tank during this period to familiarise themselves with its arrangement. At the end of the familiarisation period octopuses were usually located in the refuge in the undivided area of the tank, but if not they were moved into this area. The perforated partition was then lowered to separate the octopus from the divided section of the tank. Bait material, either freshly opened mussel, the visceral mass and shell of an abalone *(H. roei)* after removal of the foot or crushed crab *(Leptograpsus variegatus)*, was placed in one of the channels immediately below the inlet jet and behind the sight baffle.

Figure 6. Experimental aquarium for testing distance chemoreception.

A. Plan view



B. Side view

A. Inlet jets (2 l/min each).
B. Sight baffles.
C. Flow control baffle.
D. Perforated partition.
E. Dividing wall.
F. Refuge area.
G. Water outlets.

A period of approximately 20 minutes was allowed to elapse to allow the juices from the bait material to flow down the channel and establish a reasonable concentration gradient, as dye trials had indicated that 20 minutes was sufficient time to establish a satisfactory concentration gradient.

After the 20 minute period the perforated partition was raised and the octopus allowed free access to the divided portion of the tank. The octopus was allowed a further 20 minutes in which to locate the bait. An octopus was scored as having successfully located the bait if it moved into the channel where the bait was located and took the bait within the 20 minute period. Movement into another channel (past baffle c) prior to movement into the correct channel and taking the bait was scored as a failure as this may have only represented random searching. Movement into the incorrect channel, movement into the correct channel but failure to take the bait, or no movement at all were also scored as failures (i.e. animals either failing to locate the bait successfully or apparently failing to detect the "odour" at all). Each octopus was given three trials in the experimental aquarium, the bait being placed nonsequentially once in each of the three channels.

(b) Sensitivity Trials

A stock solution of 10g (wet weight) of abalone *(H. roei)* foot muscle homogenized in 10ml of filtered seawater, made up freshly each day, was used to examine the sensitivity of octopuses to dissolved chemical "odours". Diluted test solutions were made up from 1 ml of the stock solution by progressive 10x dilutions.

Hungry octopuses were transferred to the test aquarium (Figure 7) in their refuges and left for a minimum of 1 hr to acclimatize. The refuge was placed approximately 30 cm away from, and facing, the inlet jet which was fed from a constant head supply. 1 ml of the test solution was rapidly injected into the outlet from the constant head apparatus and the responses of octopuses observed through a one-way window. Positive responses to the test solution (movement out of the refuge towards the jet) were rewarded with small pieces of abalone flesh. Seawater blanks were injected prior to each test solution. For comparison, tests were also made of the sensitivity of a rock lobster.

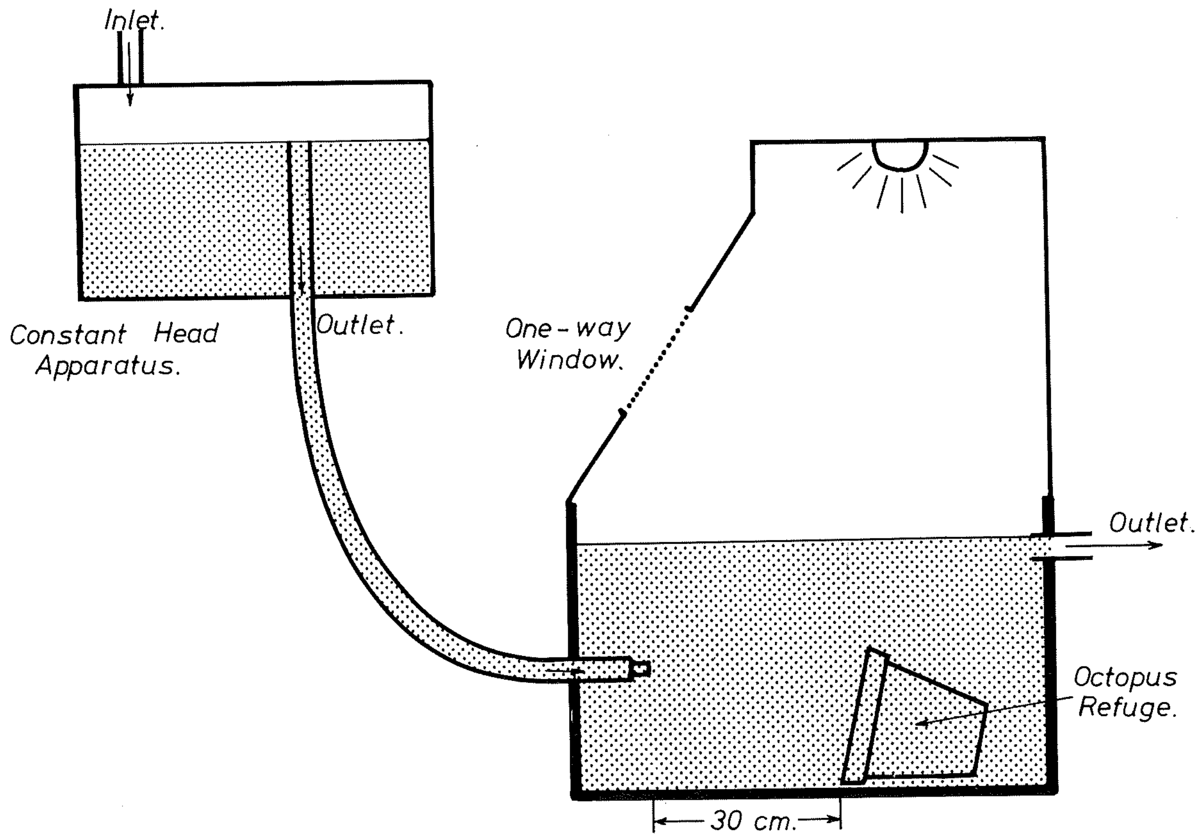
The dilution of the test sample after injection into the test aquarium was measured by injecting 1 ml of flouroscein dye solution and sampling from the dye cloud at the entrance to the octopus refuge. Optical densities of the samples were measured at 493 nanometres. The dye took approximately 3 sec. to reach the refuge, the maximum concentration being 4×10^{-2} of the applied concentration.

(ii) <u>Field Experiments</u>

Pot Location Trials

To examine the importance of bait in attracting octopuses to pot-caught rock lobsters a field trial was conducted in an area west of Garden Is. Twenty-four wire research pots (without escape gaps) were divided into four categories and set and pulled daily over a four-day period. The four categories were:

Figure 7. Experimental arrangement for sensitivity tests.



(a) empty

(b) bait (cattle hock and fish head) only

(c) four rock lobsters only

(d) bait and four rock lobsters

The entrances to all pots were partially wired over to prevent the entry of rock lobsters into pots in the "bait only" category and to prevent the escape of rock lobsters from the pots containing rock lobsters.

Pots were set at least 70 feet apart to reduce the possibility of interaction of areas of attraction.

RESULTS

(a) <u>Bait Location Trials</u>

In the thirty-six trials which were run, octopuses generally showed a movement response to the presence of "odours" in the water, only two of them not moving out of the undivided area of the tank within the 20 minutes allowed (Table 12). Of those that did respond, twenty-five octopuses moved directly into the correct channel and took the bait. Of the other nine animals which showed movement responses, six moved into an incorrect channel before moving into the correct channel and taking the bait while three moved into the correct lane initially but did not take the bait, either remaining stationary for the remainder of the 20 minute period or moving off to another channel.

If the movement response was not related to any positive chemoreception by octopuses then initial penetration of any one of the three channels would be expected to be equally distributed. The results show that significantly more ($P < 0.001$) of the initial movement responses were into the channel containing the bait indicating an ability to detect the presence of the bait by distance chemoreception, while the high percentage of octopuses which took the bait indicated an ability to locate its source with accuracy.

<u>TABLE 12</u> - Location of hidden baits by octopus.

OCTOPUS	CHANNEL CONTAINING BAIT								
	1			2			3		
	Result	Bait	Time	Result	Bait	Time	Result	Bait	Time
78	+	A	<1	+	A	3	+	M	3.5
79	+	M	6	+	A	6	+	A	8
81	0	A		+	A	8	0	A	
82	-	A		+	M	*	+	A	*
83	+	A	<1	+	A	5	-×	A	
87	+	A	5	+	A	<1	+	A	*
88	+	A	<1	+	A	<1	-	A	
89	-	A		+	A	8	+	A	2
90	-×	C		-	A		-×	A	
93	+	A	*	+	A	*	-	A	
94	+	C	<1	+	A	2	+	A	<1
95	+	A	4	-	A		+	C	<1

Key:- + = successfully located bait, entered correct channel only.
- = failed to locate bait or entered incorrect channel first.
0 = failed to locate bait; did not move into any of the channels.
A = Abalone
M = Mussel
C = Crab
Times are in minutes; * = climbed or squeezed under the perforated barrier before it was raised.
× = moved into correct lane first but did not take bait.

(b) Sensitivity Trials

Both octopuses tested were unable to detect test solutions with concentrations weaker than 10^{-9} of the stock solution, although octopus No. 95 showed variable results at 10^{-8} (Table 13). Considering the further dilution of the test solution after injection (approximately 400 x) the weakest detectable concentration was approximately 4×10^{-11} that of the stock sollution. The rock lobster showed positive responses to test solutions with concentrations 10^{-13} that of the stock solution (4×10^{-15} after injection). At weaker concentrations the rock lobster began showing positive responses to the blanks as well.

TABLE 13 - Sensitivity of octopus and rock lobster to dilutions of abalone foot muscle homogenate.

Concentration of test solution	Octopus		Rock Lobster
	No. 93	No. 95	
10^{-2}	++		
10^{-3}	?++		
10^{-4}	++		
10^{-5}	+		
10^{-6}	+		
10^{-7}	+++	++	+
10^{-8}	++++	--+-+	+
10^{-9}	-++++	-+	+
10^{-10}	----	-	+
10^{-11}			++
10^{-12}			+
10^{-13}			+?
10^{-14}			??

+ Positive

- No response

? Positive response to blank

(c) Pot Location Trials

The number of pots in each category entered by octopuses are shown in Table 14.

TABLE 14 - Number of pots entered by octopuses in pot location trials.

Pot category	Empty	Bait only	Rock lobsters only	Bait and lobsters
No entries	0	0	3	3

Entries include both pots capturing octopuses as well as pots where octopuses have escaped prior to lifting the pot. In pots containing rock lobsters evidence of escaped octopus is usually provided in the form of a typical octopus-predated rock lobster, but unless there was severe damage to the bait it is possible that the entry and escape of an octopus from the "bait only" pots would go undetected. However the results serve to illustrate that bait is not the only factor involved in the location of pot-caught rock lobsters by octopus.

DISCUSSION

In responding to "odours" in the water octopuses often extended the arms greatly and were seen to move their suckers, somewhat in the manner of an octopus which has just received a piece of food at the end of one arm and passes it from sucker to sucker towards the mouth. In determining in which channel to move first in the food location trials, octopuses often approached the lower baffle at the entrance to the channel and extended one or several arms through the hole, apparently to sense the "flavour" of the water passing out that channel. This behaviour was similar to the arm writhing reported by Messenger (1967) when a sardine was placed in close proximity to the arms of *O. vulgaris* or sardine juice pipetted onto the arms.

The results of the bait location trials showed that octopuses can successfully find baits without visual assistance while the behaviour observed in both the food location and the sensitivity trials suggests that the chemoreceptors involved are probably located on the suckers. It may be argued that the concentration of attractant chemicals in the water in the food location trials was unrealistically high and that the suckers would not normally be involved in detecting concentrations of chemicals at the levels likely to come from rock lobster baits in the sea. However Wells (1963), in examining the ability of *O. vulgaris* to distinguish between hydrochloric acid, quinine sulphate or sucrose and sea water by contact of the chemosensory suckers with absorbent material soaked in solutions of various strengths, found octopuses to be sensitive to concentrations as low as 2×10^{-5}M (7.3×10^{-4}g/l) {HCl}, 2×10^{-4}M (6.8×10^{-2} g/l) {Sucrose}, and 4×10^{-9}M (3.1×10^{-6}g/l) {quinine sulphate}. At these levels the octopuses were still responding very consistently and Wells considered that there was no reason to believe that the threshold for the chemotactile sense of the octopuses had been approached. Wells *et al* (1965) showed octopuses could discriminate with their suckers between KCl solutions and seawater with concentrations of Kcl as low as 10^{-5}M (7.5×10^{-4}g/l) while some individuals were able to detect concentrations as low as 10^{-10}M (7.5×10^{-9}g/l). The behaviour of *O. tetricus* in the sensitivity trials suggests that the distance chemoreceptors of octopuses are also located on the suckers.

The sensitivity of octopuses to the various dilutions of dissolved food "odours" are not directly comparable to those of Wells (1963) where the dilutions of pure chemicals were expressed in molar form. The particular chemicals in the complex mixture derived from abalone foot muscle responsible for stimulating food seeking behaviour are unknown. As with the lobster *Homarus gammarus* (Mackie 1973), the attraction of a mixture is probably greater than that of individual components. The results of the sensitivity trials do however indicate a fairly well developed olfactory capability, although not as sensitive as that of rock lobsters.

The concentration of attractant "odours" emanating from rock lobster baits in the sea is unknown but it appears likely that the octopus olfactory system would be sufficiently sensitive to detect and locate them from moderate distances. Undue weight should not be given to olfaction alone as a sense by which octopuses locate rock lobster pots. The field trials showed that rock lobster pots set with only rock lobsters in them but no bait also catch octopuses. Both vision and olfaction would appear to be responsible for the detection and location of rock lobster pots.

B. REPULSION OF OCTOPUSES FROM ROCK LOBSTER POTS

Hancock (1974) showed that rock lobster pots containing dead rock lobsters in addition to bait caught significantly less rock lobsters than normally baited pots. He also described several other examples from U.K. fisheries where dead crustaceans of particular pest species were included in the bait to repel that species from traps. This suggested the possibility of deterring octopuses from rock lobster pots by including dead octopus in the bait.

Field trials to examine the effect of including dead octopus in the bait were conducted in March and May 1974. The results (Table 15) showed no significant difference in the catch rate of octopus by the various baits. In the third trial the two octopuses caught in the pots with octopus bait were feeding on the octopus bait when the pots were landed. Octopuses in the wild and in the aquarium have been observed to eat their own species, so that attraction by, and feeding on, the octopus baits would not be unexpected.

In the first trial four wobbegong sharks (*Orectolobus* sp.) were caught in the sixty-five pots baited only with octopus. As wobbegong sharks are a predator of octopus (Chittleborough, 1975 and pers. obs.) baiting pots with octopus may attract these animals into pots. Wobbegong sharks caught in pots are often killed for sale or domestic consumption by fishermen. Baiting of pots with octopus may therefore lead to an increased mortality of one of the predators of octopus. Such a result would not be compatible with attempts to reduce predation by octopus.

In the first trial only one basket of octopus was used and the low catch rate of rock lobsters may have been the result of inadequate amounts of bait. In the second and third trials the quantity of bait was increased to two and three baskets of octopus bait respectively, but the catch rates of rock lobsters still remained significantly lower than with ordinary baits.

TABLE 15 - Effect of using octopus as a component of rock lobster bait.

Bait	Trial 1+			Trial 2++			Trial 3+++		
	Pot Lifts	Rock Lobster	Octopus	Pot Lifts	Rock Lobster	Octopus	Pot Lifts	Rock Lobster	Octopus
Hock & Fish	83	181 (2.18)	19 (0.23)	75	331 (4.41)	1 (0.01)	19	57 (3.00)	0 (0.0)
Octopus Only	65	83 (1.28)	8 (0.12)	75	191 (2.55)	3 (0.04)	15	10 (0.67)	2 (0.13)
Hock, Fish & Octopus	68	249 (3.66)	14 (0.21)	-	- (-)	- (-)	-	- (-)	- (-)

\+ 1 bait basket frozen octopus
++ 2 bait baskets frozen octopus
+++ 3 bait baskets fresh octopus
Figures in brackets are the catch/pot lift

Fresh octopus was used in the third trial to examine the possibility that any repellant activity of the dead octopuses used in the first and second trials may have been degraded by freezing the octopus. Although the data is limited the results do not suggest that there is any benefit to be gained by using fresh rather than frozen octopuses as bait.

The results of the field trials using octopus as a component of the bait did not indicate any repellant activity to octopuses by dead octopus. Consideration was also given to the potential repellant action of other organisms, such as moray eels and starfish. Moray eels have been reported as predators of octopus by a number of authors (e.g. Lane 1957, Voss 1971, Berry 1971, Ritchie 1972) while contact with starfish tube feet or exposure to aqueous extracts of starfish tube feet has been shown to elicit escape responses in a number of gastropod and bivalve molluscs (Feder 1963, Feder and Lasker 1964, Feder and Christensen 1966). However octopuses presented with food (abalone foot muscle) in association with aqueous extracts of starfish (*Coscinasterias calamaria* (Gray)) or scrapings of epidermal slime from moray eels (*Gymnothorax* sp.) did not show any escape responses or inhibition of feeding. Exposure of octopuses to ink ejected by other octopuses did not elicit any behavioural responses indicative of "alarm substances" of potential value as repellants.

The possibility of repulsion of octopus from rock lobster pots by a substance which would act selectively for octopus and not simultaneously depress rock lobster catches seems remote. However the visual acuity of octopuses suggested that a visual repellant may be a possibility. An experiment to examine the potential for visual repellants was conducted in the laboratory using a model of a moray eel, made from a piece of car inner tube, suspended

...side a steel rock lobster pot containing two rock lobsters. An octopus placed in the aquarium approached the pot and appeared to examine the model visually. After about 1 min. the octopus stretched an arm through the sides of the pot and began a tactile examination of the model. After a short tactile examination the octopus retracted its arm, moved up the pot and entered through the neck. The octopus subsequently captured a rock lobster and paid no more attention to the model. While the octopus apparently recognized the form of the model the visual appearance was not in itself sufficient to repel the octopus.

C. ENTRY INTO AND ESCAPE FROM ROCK LOBSTER POTS BY OCTOPUS

The rock lobster pot provides a physical barrier between trapped rock lobsters and approaching predators. A knowledge of the methods used by octopuses to penetrate this barrier and enter pots was considered useful in that it might highlight aspects of pot design which could be changed to make pots "octopus-proof".

METHODS

Octopuses (> 500 g) were captured and maintained as described in section V A (Methods). A minimum size of 500 g was selected because field observations indicated that octopuses weighing less than this do not predate rock lobsters in pots (Figure 8). Acclimatized octopuses were individually transported in their refuges from the small aquaria to a large (5m diam., 1m deep, water flow 12 litres/ min.) outdoor aquarium for pot entry trials. After several hours acclimatization to the large aquarium a rock lobster pot containing two or three legal-sized rock lobsters was introduced into the pool. The pot was placed approximately 1m from the octopus refuge with the escape gap offset 90° from the octopus refuge (Figure 9). The behaviour of the octopus and the rock lobsters was observed through a one-way window in a "hide" at the side of the aquarium.

Three pot entry trials were conducted with each octopus, one trial on each of the three different pot types used in the fishery (Figure 2). The trials were arranged so that each pot type was presented an equal number of times as first, second or third in the series. The time taken for an octopus to enter a pot (from first contact to completely inside the pot) was noted. The areas of entry were categorized and recorded as one of three groups.

(i) Neck - the opening in the top of the pot by which rock lobsters enter the pot;

(ii) Escape gap - the 305 x 54mm gap in the fabric of the pot designed to allow the escapement of small rock lobsters;

(iii) Side - the fabric of the walls of the pot.

RESULTS

A total of ninety pot entry trials were carried out using thirty different octopuses (Table 16). The pot entry trials were conducted during the day and octopuses usually left the pot unobserved during the night or early morning. However fifteen exits from pots were observed (Table 17).

Figure 8. Gut content of pot-caught octopuses with respect to the size of the octopus.

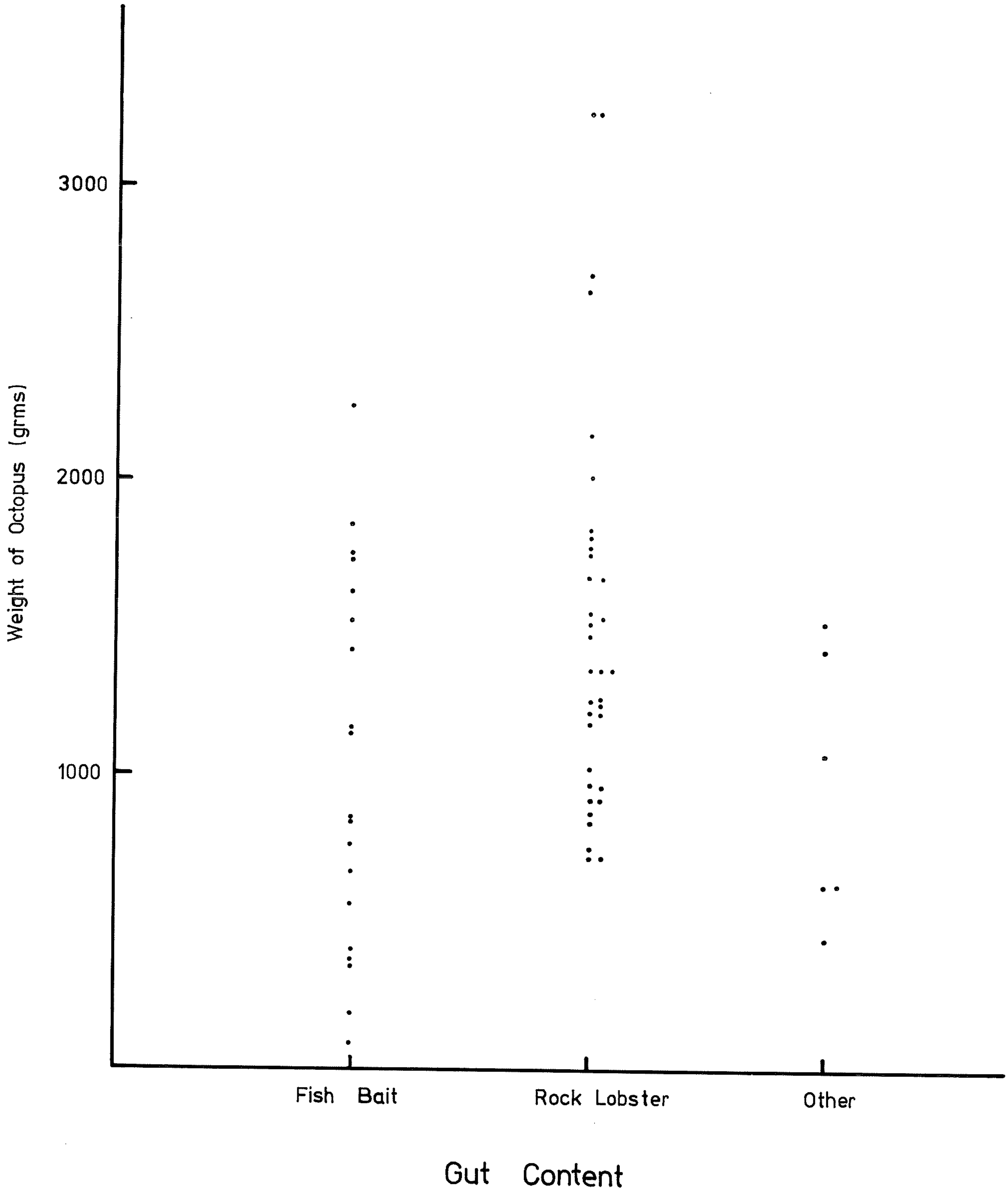


Figure 9. Aquarium arrangement for rock lobster pot entry trials by octopuses.

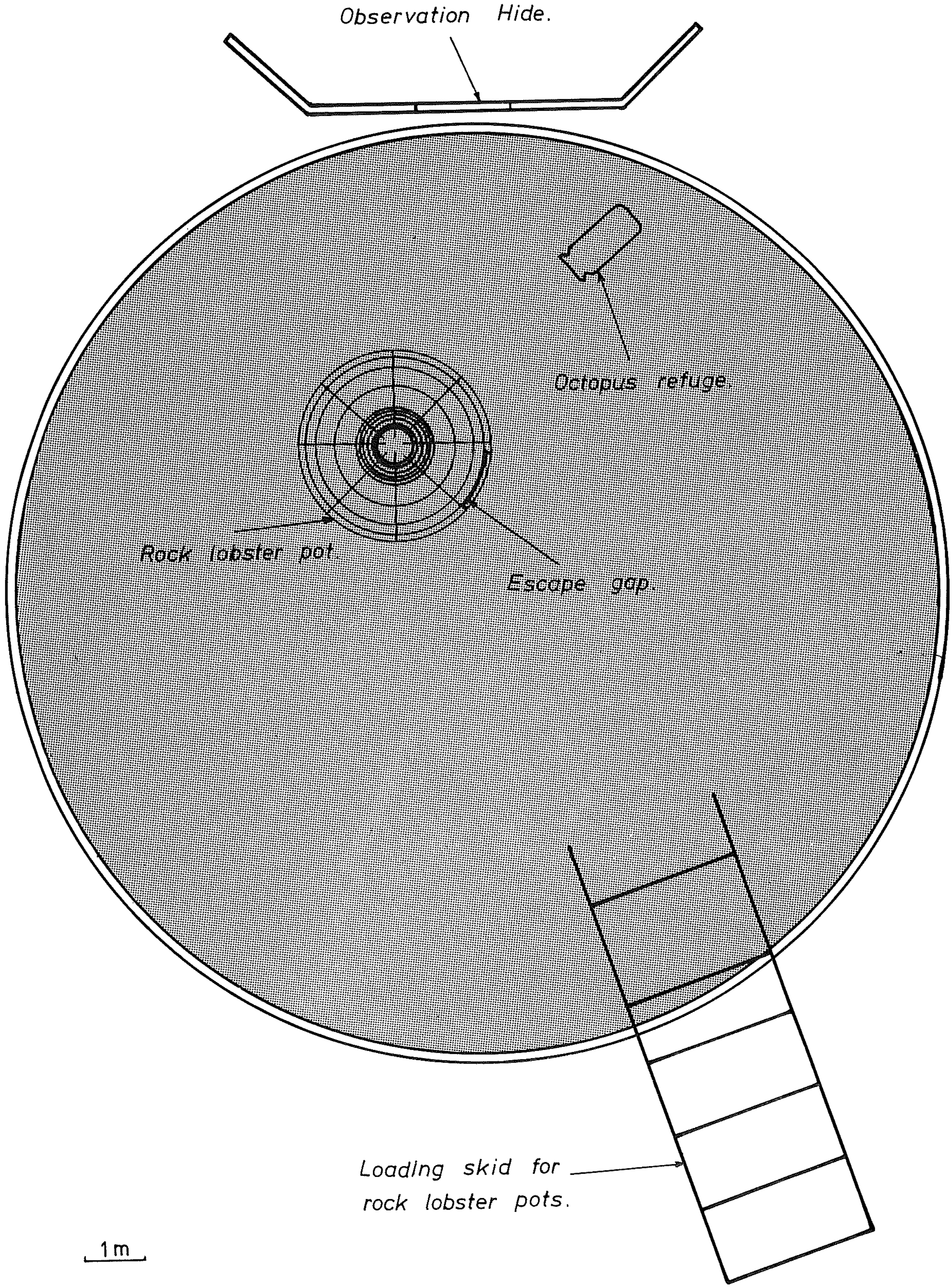


TABLE 16 - Areas of entry into rock lobster pots by octopuses.

Pot Type	Area of Entry			Mean time to Enter (Mins)
	Neck	Escape Gap	Side	
Cane	2	11	17	1.48
Batten	3	7	20	1.85
Wire	18	3	9	3.16

TABLE 17 - Areas of exit of octopuses from rock lobster pots.

Pot Type	Area of Exit		
	Neck	Escape Gap	Side
Cane	0	2	4
Batten	0	1	3
Wire	0	1	4

DISCUSSION

The results show clearly that in cane and batten pots, the most common types of pots, the major area of entry is through the fabric of the sides of the pot, the escape gap and the neck being used less commonly. The dimensions of the spaces between the sticks of cane and the wooden slats varied between 20 and 40mm (3/4" - 1½") and between 20 and 35 cm (8" - 14") long and did not seriously hamper the passage of octopuses through the spaces - octopuses simply flattened their bodies and passed through. The 55mm (2") hexagonal wire mesh covering the wire pot did, however, seriously obstruct the passage of octopuses into pots. Old cane pots covered with wire mesh probably present a similar difficulty to octopuses.

Despite the small dimensions of the wire mesh some octopuses still managed to squeeze through, but most octopuses entered wire pots via the neck. Entry of octopuses through the neck of wire pots appeared to be largely fortuitous rather than by "recognition" on the part of the octopus that this provided an alternative site of entry. With all types of pot octopuses usually made their first contact on the side of the pot and began reaching through the sides and attacking rock lobsters. With cane and batten pots octopuses often eventually just "slipped through" the sides into the pot, but the dimensions of the mesh prevented this happening in wire pots. With wire pots octopuses still attacked from outside initially, but when they were unable to grasp the rock lobsters properly they usually began moving back and forth over the top and sides of the pot, pursuing the rock lobsters. In the course of pursuing the rock lobsters, octopuses often passed over the neck of the pot and eventually usually entered via the neck. Octopuses moving around the sides of steel pots often passed over the escape gap. While some entered through the escape gap most failed to "recognize" it as a site of easier entry and continued attacking until they entered at some other point.

The greater difficulty experienced by octopuses in passing through the wire mesh on wire pots or the extra time spent locating alternate entry sites is reflected in the longer mean time taken to enter wire pots - 3.16 min. as against 1.48 min. and 1.85 min. for cane and batten pots respectively. While wire pots were the most difficult for octopuses to enter they did not prevent octopuses from ultimately gaining entry to the pot but merely slowed them down. There would appear to be little value in recommending that the spacing of the materials of cane and batten pots be reduced to make entry through the sides more difficult as the results with steel pots indicate that alternate entry sites would soon be located. The presence of large openings in rock lobster pots to allow for the entry of rock lobsters and the escapement of small rock lobsters will always allow the entry of octopuses, no matter how impenetrable the sides of the pot may be.

Of the fifteen observed exits from pots, only four were via the escape gap, the remainder being through the sides of the pots. Escape gaps have received critical comment from some fishermen who consider that they are a major cause of the escape of octopuses from pots. The low frequency of observed exits through the escape gap does not support that view, while the ability of octopuses to enter and leave pots through the sides indicates that closure of the escape gap would not prevent the escape of octopuses from pots.

Despite these laboratory observations G.R. Morgan (unpub.) found that, in the field, wire pots with escape gaps retained a significantly smaller proportion of the octopuses which entered the pots than pots without escape gaps. Ritchie (1972) reported a similar finding with *O. maorum* in the New Zealand rock lobster fishery. Ritchie (1972) noted that the positioning of the escape gap at the bottom edge of the New Zealand rock lobster pots allowed octopuses to escape easily during hauling of the pot. In the trials conducted by Morgan, the hauling lines were attached on the same side of the pot as the escape gap, making escape during hauling more difficult. While the laboratory observations indicate that the escape gap is not critical in facilitating the exit of octopuses from rock lobster pots while on the bottom, the field tests of Morgan and Ritchie nevertheless indicate that escape gaps do reduce the proportion of octopuses caught. Some escapement of octopuses during pot hauling may be avoided by attaching the hauling rope on the same side as the escape gap or by not having the escape gap at the bottom edge of the pot.

D. THE BEHAVIOUR OF OCTOPUSES AND ROCK LOBSTERS IN POTS

The experimental apparatus used to examine the methods of pot entry by octopuses also provided an opportunity to examine in detail the behaviour of octopuses and trapped rock lobsters. The following is a general description summarizing the observations which were made.

On contacting a rock lobster pot octopuses usually attempted to attack the trapped rock lobsters through spaces in the fabric of the pot before eventually entering the pot. This external attack phase varied in duration from about 10 secs. to 10 mins. With cane and batten pots the external attack phase was usually fairly short and ended with the octopus entering the pot. Because of the greater difficulty in entering wire pots, the external attack phase was usually somewhat longer. During the period of external attack the rock lobsters showed some "agitation" and usually moved to a point in the pot as far away from the octopus as they could get. Sometimes an octopus managed to capture a rock lobster from outside the pot but, in all cases, was unable to secure an adequate grasp on the rock lobster, which eventually escaped from its hold.

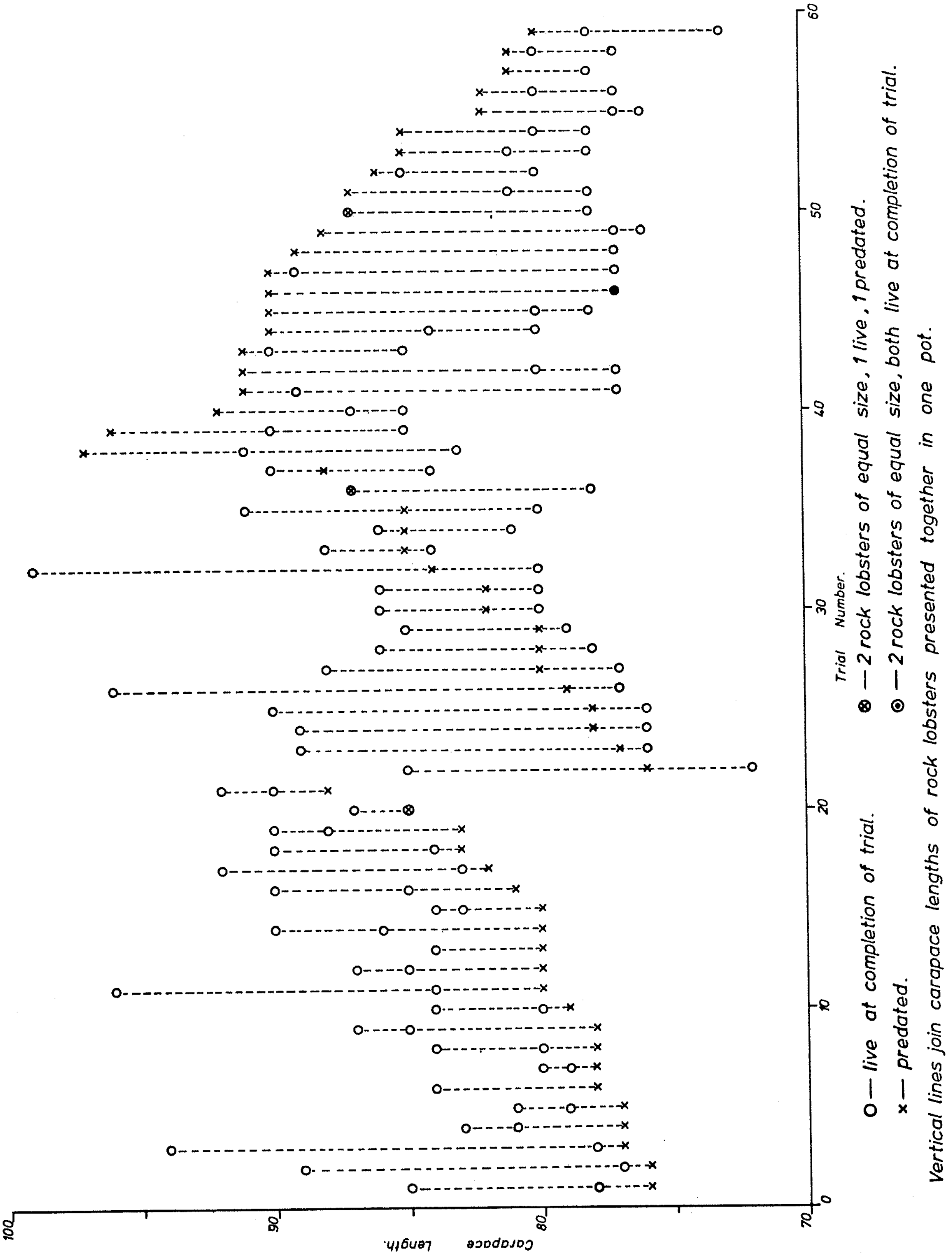
When an octopus finally entered a pot, the rock lobsters showed considerable "agitation" and moved quickly away when contacted by an octopus arm. Octopuses showed no selection of rock lobsters by size (Figure 10) or sex (Table 17) and usually attacked the nearest rock lobster. Rock lobsters sometimes lowered their antennae toward the octopus in an apparently defensive gesture. Octopuses often grasped and pulled the antennae, at which point they were usually autotomized by the rock lobster. Rock lobsters attacked by octopuses also commonly autotomized legs to escape the grasp of the octopus.

TABLE 18 - Sexes of rock lobsters predated in pot entry trials.

	♂	♀
Total No. presented in pots	89	81
No. predated	25	33

In some cases rock lobsters which were the subject of an attack by an octopus showed a swimming escape reaction. This swimming reaction, in which rock lobsters swim backwards propelled by their tails, is a normal reaction by rock lobsters to octopuses in the wild (Berry 1971 and pers. obs.). Observations in the aquarium indicated that rock lobsters can swim considerably faster than octopuses. Unhindered rock lobsters placed in the large (5m diam.) outdoor aquarium with hungry octopuses began the swimming escape reaction when approached by the octopus. Octopuses usually began swimming in pursuit but were easily outdistanced by the rock lobster. In the field such a reaction is probably an effective escape measure but, within the confines of a pot, rock lobsters are unable to escape farther than the length or diameter of the pot. In the circular cane and steel pots, rock lobsters sometimes swam in circles around the perimeter of the pots. In one instance, a rock lobster began a swimming escape reaction upwards while standing beneath the neck of the pot and actually swam out of the pot.

Figure 10. Carapace lengths of rock lobsters presented to octopuses in aquarium pot entry trials.



After an octopus had entered a pot, rock lobsters sometimes attempted to escape through the escape gap. Because (except in one instance) only legal-sized rock lobsters were used in the trials, the escape gap was usually too small to allow them to pass, although one rock lobster (77mm carapace length) managed to pass through the escape gap. Octopuses sometimes attempted to pull captured rock lobsters out of the pot through the escape gap but they were usually too large to pass through. In one case an octopus pulled a 77mm carapace-length rock lobster through the escape gap, but on other occasions octopuses were forced to abandon this course of action and return inside the pot to feed.

Once an octopus succeeded in securing a rock lobster, it was held firmly by all the arms, effectively restraining movement. The web of the octopus was usually spread to its maximum size to form an "umbrella" over the rock lobster. Rock lobsters were usually held from the dorsal surface but were sometimes held side-on or on the ventral surface. Death of the rock lobster occurred 20-30 min. after capture. In a separate series of experiments, rock lobsters fed to octopuses and then pulled away again after 5-15min., showed no signs of mechanical injury or puncture marks. The rock lobsters were sometimes completely rigid with "fear" or from the toxic action of the saliva, but recovered within 10 min.. As with the prey of other species of *Octopus* and *Eledone* (Bidder 1966), the rock lobsters showed no puncture marks or other forms of mechanical injury. The lack of puncture marks suggests that the toxic saliva was secreted into the chamber formed by the web of the octopus and absorbed by the rock lobster through the gills and other permeable surfaces.

The nature of the venom in the saliva of *O. tetricus* was not examined, but it is probably similar to that of *O. vulgairs* (Ghiretti 1960), since the time taken for the death of the prey is similar in *O. vulgaris* and *O. tetricus*. The venom was certainly not as virulent as that of the small blue-ringed octopus *Hapalochlaena maculosa*, where the death of crabs occurred within 2 to 3 mins of attack (Tranter and Augustine, 1973). Humans bitten by *O. tetricus* do not show any of the usually fatal symptoms associated with bites from *H. maculosa* (Sutherland and Lane 1969, McMichael 1971), although some local discomfort and swelling may occur.

As with other octopods (Bidder 1966, Morishita *et al* 1974, Morishita 1974 a, b, c), the salivary secretions of *O. tetricus* have a digestive action on the tissues of the prey. This digestive action breaks down the attachment of tissues to the exo-skeleton, allowing the prey to be easily dismembered and allowing the octopus to consume tissues from otherwise inaccessible areas of the body. *O. tetricus* usually severs the cephalothorax (head) from the abdomen (tail) and feeds first on the organs and muscle tissue in the head. Octopuses usually only commence on the muscular tail region after consuming the contents of the head.

The attachment of the muscle tissue in the tail is often completely severed by the digestive action of the octopus' saliva, so that, on hauling the pot to the surface, the muscle tissue may fall out of the severed tail section, giving the impression that the tissues of the tail have also been eaten. However, data on octopus gut contents indicate that an octopus would not be capable of eating the amount of tissue in a legal-sized rock lobster. The maximum weight recorded during this programme for the gut contents of an individual octopus caught in a rock lobster pot was 89g, while the largest daily food intake recorded in an aquarium experiment of growth and feeding (Joll, 1977) was 214g. In the latter case the food consumed was from two separate feedings over a 24-hr period. These data indicate that the maximum meal size of *O. tetricus* is probably 100 to 150g of tissue. This is only approximately half or less than half of the tissue weight of a legal-sized rock lobster.

In cases where completely clean exoskeletons of predated rock lobsters occur in pots, it is likely that tissue has been lost during hauling of the pot, or scavenged by other animals. Where more than one legal-sized predated rock lobster occurs in a pot, it probably indicates the entry into the pot at various times of more than one octopus. The time taken to kill and eat one legal-sized rock lobster was noted to vary between approximately four and eight hours. In the twelve to sixteen hours for which rock lobsters may be held in pots (on 24-hr. settings) prior to hauling, two or more octopuses would have time to enter a pot, feed, and perhaps leave again before the pot is hauled. In the pot-entry trials, it was noted that octopuses usually did not remain in rock-lobster pots for long after the meal was finished and rarely stayed longer than 24 hrs.

E. REDUCTION OF THE ESCAPE OF OCTOPUSES FROM ROCK LOBSTER POTS

Samples taken in the 1974/75 and 1975/76 seasons from commercial pots set for 24-hour periods indicated that only approximately 47% of pots which were entered by octopuses retained and caught the octopuses. Pots set for longer periods (two days and over) caught only approximately 16% of the octopuses known to have entered them. Aquarium observations have indicated that octopuses spend only four to eight hours in a pot, so that an octopus which entered a pot during the day or evening, could be expected to have left the pot by the time it was hauled.

The failure to retain an octopus presents the likelihood that it may enter another pot at some later date and predate more rock lobsters. Capture of an octopus would prevent further losses from that individual and provide some financial recompense for any loss of rock lobsters by sale of the octopus.

Octopuses readily occupy holes in reefs, empty shells and similar recesses as shelters and as lairs for egg-laying. This behaviour has been used by fishermen of many nations to catch octopus. Terracotta and other earthenware pots are used by fishermen in the Mediterranean and by Japanese fishermen to catch octopus, while fishermen in the Indo-Malay region use large *Lambis* shells (Voss 1973, 1974, von Brandt 1974). Terracotta pots were used in this research programme as a means of obtaining octopuses for aquarium study.

The readiness with which octopuses occupy traps suggested that instead of leaving the pot after feeding, an octopus might occupy such a trap if it were placed in a rock lobster pot. Preliminary experiments with wire research pots (without escape gaps) pulled on a daily basis, indicated that octopuses would occupy octopus traps placed in rock lobster pots, significiantly increasing the retention of octopuses while not adversely affecting the rock lobster catch. In order to verify whether this result was applicable to standard commercial rock lobster pots, extended field trials were conducted with commercial operators.

The field trials were based on pots set and pulled on a daily basis. Fishermen operating in deeper water or in the latter part of the season often have pot settings of 2-4 days, while inclement weather may sometimes cause other fishermen to leave their pots set for several days. In order to have a basis for predicting what may occur in pots set for periods longer than one day, aquarium trials were undertaken to examine the result of protracted occupation of traps by octopuses.

METHODS

(i) Field Trials

Two approximately 3-week trials were conducted from commercial boats, one operating out of Fremantle using cane beehive pots, the other operating out of Dongara using batten pots. Terracotta octopus traps were secured with tie-wires into half the pots, the entrances of the traps being placed so that they faced upwards when the pot was hauled. Pots with octopus traps and ordinary pots were mixed together so that any line of pots contained approximately equal numbers of each pot type. The pots were pulled on a daily basis.

Records were kept for each pot of the number of rock lobsters and octopus caught. The number of octopus-predated rock lobsters was noted as well as whether or not octopuses were occupying the traps at the time of capture. Pots not catching octopus but showing octopus-predated rock lobsters or other signs of former octopus occupation were noted. The number of live, legal-sized rock lobsters caught by the two pot types was recorded for the whole fishing period at Dongara. At Fremantle the number of live, legal-sized rock lobsters caught by the two pot types was only recorded after the first nine days of fishing, and it was necessary to make a change to the normal handling practice in order to record these data.

(ii) Aquarium Trials

Trials were conducted in the large outdoor aquarium (cf. V c, Fig. 9). Hungry, aquarium-acclimatized octopuses were placed in the large aquarium with a terracotta pot as a refuge. A rock lobster pot containing three legal-sized rock lobsters was introduced into the aquarium, and the time of entry by the octopus into the pot noted. The pot was checked regularly and the time of exit and the fate of the trapped rock lobsters recorded.

RESULTS

Table 18 (a and b) shows the results from the two ports on a daily basis, while Table 19 shows the combined results. The results of the aquarium trials are shown in Table 20.

For 1-day settings, the catch rate of octopus in pots with octopus traps (0.187 octopus/pot lift) was significantly higher ($p < 0.001$) than in pots without octopus traps (0.059 octopus/pot lift), while there was no significant difference at the 5% level in the catch

TABLE 19 - Catches of normal commercial rock lobster pots and pots fitted with octopus traps.

(a) Cane beehive pots (Fremantle)

One-day settings	POTS WITHOUT OCTOPUS TRAP					POTS WITH OCTOPUS TRAP				
DATE	No. of Pot Lifts	No. of Octopus Caught	No. Rock Lobster Caught	No. Live, Legal-sized Rock Lobster	No. Octopus-Predated Rock Lobster	No. of Pot Lifts	No. of Octopus Caught	No. of Rock Lobster Caught	No. Live, Legal-sized Rock Lobster	No. Octopus-Predated Rock Lobster
25.2.76	44	2	109		2	40	15	83		10
26.2.76	43	7	89		5	40	12	86		5
27.2.76	43	7	85		10	39	18	84		9
28.2.76	44	4	76		6	38	9	59		8
29.2.76	43	5	62		6	39	15	39		8
1.3.76	42	3	119		8	39	9	131		8
2.3.76	43	10	74		16	40	11	66		12
3.3.76	42	4	77		8	39	13	49		8
4.3.76	43	6	66		6	39	7	74		5
5.3.76	43	4	57	46	4	39	12	29	22	4
6.3.76	43	3	57	37	8	39	11	43	27	5
7.3.76	43	5	75	51	10	39	10	80	57	7
8.3.76	42	2	78	56	4	39	5	68	50	1
9.3.76	41	3	43	25	2	39	10	39	29	4
10.3.76	42	1	46	45	0	38	7	54	52	1
11.3.76	41	0	32	30	0	39	2	23	23	1
12.3.76	41	1	15	12	0	39	1	11	11	0
13.3.76	41	0	57	49	1	39	7	55	42	3
14.3.76	41	0	45	43	1	39	3	57	43	2
TOTAL	805	67	1262	394 (418 Pot Lifts)	97	742	177	1130	356 (389 Pot Lifts)	101

TABLE 19 - Catches of normal commercial rock lobster pots and pots fitted with octopus traps.
(b) Batten pots (Dongara)

One-day Settings	POTS WITHOUT OCTOPUS TRAP					POTS WITH OCTOPUS TRAP				
DATE	No. of Pot Lifts	No. of Octopus Caught	No. Rock Lobster Caught	No. Live, Legal-sized Rock Lobster	No. Octopus-Predated Rock Lobster	No. of Pot Lifts	No. of Octopus Caught	No. Rock Lobster Caught	No. Live, Legal-sized Rock Lobster	No. Octopus-Predated Rock Lobster
12.3.76	35	3	69	44	3	39	7	68	41	3
13.3.76	36	1	121	59	2	39	7	147	62	3
14.3.76	37	3	140	59	4	38	3	116	48	3
15.3.76	37	0	135	49	2	38	3	162	61	4
16.3.76	37	0	157	42	7	38	8	172	52	4
17.3.76	37	1	154	57	4	38	9	122	41	6
18.3.76	37	1	112	40	3	38	2	111	35	4
19.3.76	37	2	120	27	5	38	5	91	37	4
20.3.76	37	0	95	35	1	38	3	86	19	3
21.3.76	37	0	98	30	5	38	8	95	32	3
22.3.76	37	2	168	60	4	38	4	153	48	2
23.3.76	37	0	226	59	2	38	6	220	55	10
24.3.76	37	1	249	63	1	38	6	207	52	6
25.3.76	37	1	277	75	2	38	3	290	61	3
26.3.76	37	2	250	59	7	38	5	262	62	4
27.3.76	37	2	230	50	0	38	12	205	44	9
28.3.76	37	1	130	30	3	38	6	169	34	5
29.3.76	37	1	163	59	1	38	4	189	78	3
30.3.76	36	1	208	82	1	38	5	204	67	1
31.3.76	36	0	135	55	3	36	1	143	71	0
1.4.76	37	4	169	71	1	37	4	130	73	3
TOTAL	773	26	3406	1105	61	797	111	3342	1073	83

TABLE 20 - Combined results of commercial fishing trials at Dongara and Fremantle using normal rock lobster pots and pots fitted with octopus traps.*

	No. of Pot Lifts	No. of Octopus Caught	No. of Rock Lobsters Caught	No. of Live, Legal-Sized Rock Lobsters	No. of Octopus Predated Rock Lobsters
Pots with Octopus Trap	1539	288	4472	1429 1186 pot lifts	184
Pots without Octopus Trap	1578	93	4668	1499 1191 pot lifts	158

* One-Day Pulls

TABLE 21 - Period of residency by octopus in rock lobster pots containing octopus traps (aquarium trials).

Octopus No.	Pot Type	No. days resident in R.L. pot	No. R.L. predated*
76	Batten	3	1
76	Cane	2	1
80	Wire	5	2
85	Batten	10	3
89	Batten	4	1
89	Wire	13	3
86	Batten	<1	1
89	Cane	15	3
86	Cane	9	2
76	Wire	4	0
85	Wire	16	3
84	Wire	3	1
85	Cane	12	3

* R.L. pot always contained three rock lobsters.

rates of rock lobsters (2.958 rock lobsters/pot lift for standard pots as against 2.906 rock lobsters/pot lift for pots with octopus traps . There was no significant difference, at the 5% level, in the catch rates of live, legal-sized rock lobster by the two pot types (1.259 rock lobsters/pot lift for standard pots, as against 1.205 rock lobsters/pot lift for pots with octopus traps).

DISCUSSION

Although the difference in catch rate of live, legal-sized rock lobsters between pots with and without octopus traps was not statistically significant, general observations suggest that the small reduction in catch rate recorded (4.3%) cannot be ignored and might well become statistically significant in a larger sample. Quite a few pots with octopus traps which caught octopus in the traps, did not contain any predated rock lobsters, the octopuses presumably having entered the pot to feed on the bait. In pots where rock lobsters have been predated, the remains would probably act as such a strong repellant to other rock lobsters (Hancock, 1974) that the deterrent effect of octopuses retained in pots where predation has occurred is unlikely to be of much consequence. Octopuses remaining in pots where no predation has occurred probably also act as repellants to rock lobsters and prevent such pots from functioning as normal catching units. Catching and culling such octopuses does have the advantage that it prevents the octopus from re-entering a pot at some time in the future and perhaps predating a rock lobster.

For one-day settings, the mean percentage retention of octopuses which entered pots with octopus traps was 80.1%, compared with 43.9% for ordinary pots. No field data were available on the ability of the octopus traps to retain octopuses over the periods longer than one-day settings, but the results of the aquarium trials (Table 20) indicated that octopuses would take up residence in traps in the rock-lobster pots for prolonged periods, despite the availability of other refuges. Only one octopus did not take up residence in the trap in the thirteen trials conducted. The mean time spent in the pot in trials in which octopuses took up residence in the trap was 7.5 days, with a range from two to sixteen days. These observations indicate that octopus traps could be expected to retain octopuses in the pots for longer than one day. A problem associated with the prlonged retention of octopuses in pots is that two to three days after the initial predation, octopuses usually regain their appetite sufficiently to attack and kill another rock lobster, if one is available in the pot. Where an octopus stayed in a pot for longer than four days, two rock lobsters were always predated and, in five cases where octopuses stayed for periods of longer than nine days, all three rock lobsters were predated.

Of the 288 octopuses caught in pots with octopus traps, 154 were occupying the octopus traps at the time of capture. This behaviour indicates that the traps do provide an acceptable refuge which octopuses will occupy in a field situation, instead of leaving the pot. Terracotta traps, such as were used in the experiment, would not be suitable for general use in commercial rock lobster pots, as they are expensive, heavy, and prone to fracture. A light, cheap and durable plastic trap would probably function as well, in terms of providing a suitable refuge for octopuses. In the aquarium octopuses have shown that they will occupy refuges made of a variety of materials, e.g. metal, plastic, asbestos cement. Of the materials readily available, plastic is probably the cheapest and most durable under field conditions. However, any traps used should be of dark-coloured materials, as light-coloured or shiny materials are likely to cause the attraction of more octopuses to pots.

While octopus traps in rock-lobster pots provide an efficient means of retaining octopuses in pots, they do not prevent predation. However, fishermen using octopus traps in rock lobster pots could benefit in several ways, depending upon the acceptability of the octopus traps to the industry and the prices paid for octopus and rock lobster. Small numbers of fishermen using the traps could probably expect an increased catch rate of octopus to around three times their present rate. If a small reduction in the catch of rock lobsters did eventuate, the present price differential between the two species, plus the cost of purchasing traps, may mean that fishermen at ports where low prices are paid for octopus (e.g. 20-30¢/kg) would probably lose financially. Fishermen at ports where higher prices are paid for octopus (e.g. $1/kg) would probably make a profit. The fishing mortality generated by small numbers of fishermen would probably not be sufficient to have any great impact on octopus numbers.

Widespread use of traps could be expected initially to produce an increase of approximately three times in the octopus catch, but probably a small decrease in the catch of rock lobsters. Sustained fishing could be expected to generate sufficient fishing mortality to lead to some reduction in octopus numbers and the octopus catch rate, although the extent of the reduction is difficult to predict. Benefits may then accrue by a reduction in the level of predation by octopus. Acceptability of octopus traps would be dependent upon price differentials between rock lobster and octopus being such that fishermen did not lose money at any stage. Considering the increased supply of octopus which the use of traps would bring about, steps may have to be taken to explore new market outlets to ensure that octopus prices did not fall to uneconomic levels through over-supply.

VI GENERAL DISCUSSION

The predation of legal-sized, pot-caught rock lobsters by octopus is the most significant cause of direct loss to the rock lobster fishery. Legal-sized rock lobsters predated by octopus could otherwise be landed and sold, and the catch of the fishery increased without increasing pressure on the stocks. Under-sized rock lobsters are also predated by octopus but the extent to which this represents a loss to the fishable stock is difficult to compute, since their numbers will be reduced by natural mortality or death as a result of handling at capture. Examination of the mounds of old food items at the entrances to octopus lairs suggests that octopuses are not major predators of rock lobsters in their natural habitat. The greater swimming speed of rock lobsters also indicates that rock lobsters would have little difficulty escaping from approaching octopuses, although by leaving their shelters to do so may expose them to other predators. The predation of rock lobsters by octopus must therefore be considered to result primarily from the trapping of rock lobsters in pots.

Both the "odour" of the bait and the presence of trapped rock lobsters appear to be responsible for attracting octopuses to rock-lobster pots. The particular chemicals in baits responsible for the attraction of octopuses are not known, but it would seem likely that octopuses respond to a spectrum of chemicals similar to that which attracts rock lobsters. There would appear to be little prospect of developing baits which are simultaneously attractive to rock lobsters an non-attractive to octopuses. As the presence of trapped rock lobsters is also attractive to octopuses, the use of baits which are merely non-attractive to octopus would not prevent the attraction of octopuses to pots containing rock lobsters.

The observations of Hancock (1975) on the repulsion of crustacean species by the dead of the same species raised the possibility of active repulsion of octopuses by the incorporation of dead *Octopus* as a component of the bait. Field trials with *Octopus* baits, however, showed no repellant activity to octopuses of *Octopus* bait. Indeed, there were even indications that *Octopus* bait may be attractive to octopuses. *Octopus* bait alone was a poor bait for rock lobster. Limited laboratory testing of moray eel and starfish extracts, for which there was some basis for considering as potential repellants, did not reveal any repellant activity. A trial with a model moray eel suggested that octopuses would not be repelled by visual deterrants, such as models of their predators, unless the models were extremely realistic in both visual and tactile aspects.

Octopuses proved capable of penetrating pots made of a variety of materials. Wire-covered pots proved the most difficult for octopuses to enter, but the wire covering only delayed their ultimate entry, and did not prevent it. With the necessity for pots to have an entry port for rock lobsters, and the legal requirement for pots to have an escape gap, it is difficult to conceive of any changes in pot design which could make pots octopus-proof. Even if the fabric of the pot was impenetrable, octopuses would still eventually gain entry to the pot through either the neck or the escape gap.

Laboratory observations did not indicate that the escape gap was of significance in allowing the escape of octopuses while pots were still on the bottom, although observation of commercial pots showed that octopuses sometimes escape through the escape gap when pots were hauled. In many of these commercial pots, the escape gaps were situated opposite the hauling rope, and on the lower edge of the pot, so that octopuses were pushed up against the escape gap and almost forced out of the pot by the thrust of water when the pots were hauled to the surface. Many fishermen were under the misapprehension that it was a legal requirement for the escape gap to be so positioned. Placing escape gaps in the upper surfaces of pots, or nearer the attachment of the hauling rope, would probably reduce these last minute escapes.

The use of octopus traps in rock lobser pots significantly reduced the escape of octopuses from pots, by providing a refuge which octopuses occupied instead of leaving the pot. Use of octopus traps does not prevent predation occurring, but has the benefit that octopuses caught may be sold, thus partially compensating for the loss by predation. Culling of an octopus prevents further predation by that individual. However, the overall effect of the use of octopus traps on octopus population numbers depends on the extent of their use in the fishery and the ability of octopus populations to cope with the increased fishing mortality. While the reduced catch rate of rock lobsters by pots with octopus traps observed in the field trials was not significant statistically (at the 5% level), it seems likely that the prolonged retention by the octopus traps of octopuses which might otherwise leave the pot could be expected to cause a significant decrease in rock lobster catch rates in long term trials.

If a small reduction in the rock lobster catch rate, due to the use of octopus traps, is in fact to be expected, then price differentials between octopus and rock lobster and variations in the price paid for octopus make the economic acceptability of octopus traps marginal. Fishermen at ports where low prices are paid for octopus would be better off to simply maintain their present practice of culling any octopuses caught, but without attempting to catch more of them by using octopus traps in their pots. Fishermen at ports where high prices are paid for octopus could probably use octopus traps in their pots and show a profit, even if there was a small reduction in their rock lobster catch. Adequate market outlets would need to be available to absorb the increased supply of octopus to avoid prices falling to uneconomic levels through over-supply. Depending upon the extent of usage of octopus traps, some benefits may also accrue through a reduction in octopus numbers and a decrease in the level of predation.

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