Trap behaviour of the western rock lobster, *Panulirus cygnus*: *in situ* comparisons of the ‘white’ migratory phase and the ‘red’ residential phase and the influence of conspecifics in the laboratory.

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Declaration

I solemnly declare that this thesis is my own account of my research and contains work which has not been previously submitted for any degree at any tertiary institution.

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November 2009
Abstract

The fishery for the western rock lobster (*Panulirus cygnus*) is one of the largest and most valuable single species fishery in Australia. However, few studies have examined the behaviour of this species and its interaction with traps (known as ‘pots’) in either the field or laboratory. The life cycle of the lobster incorporates a migratory phase (known as the ‘whites’), in which sub-adult (4 – 5 year old) *P. cygnus* moult into a creamy pale pink exoskeleton in November and migrate offshore to breed and return to the more sedentary ‘red’ phase. In this study I used direct *in situ* video observations of *P. cygnus* to investigate the effect of the migratory phase on trap behaviour. I also used video observations in the laboratory to investigate whether the presence of a large lobster in the trap affected the behaviour of smaller individuals outside the trap.

Proportionally, the behaviour of the white migratory lobsters around a trap did not differ significantly from that of lobsters in the more sedentary red phase. However, there were a significantly higher number of observations during the whites phase (*n* = 224) than during the reds (*n* = 39). The difference is likely to be a reflection on the performance of the camera trap in the reds phase as there was a significant disparity between the catch rate of the camera trap and three standard control traps and as such, further replicates in a reds phase are required to increase the robustness of this study. On a few occasions, lobsters were observed to exit the trap through the neck entrance, however, a much higher proportion of lobsters in both phases escaped through the escape gap.
Laboratory experiments were performed to observe the behaviour of small legal-sized *P. cygnus* (76 > 85 mm carapace length [CL]) when approaching a trap containing a large lobster (> 98 mm CL). The laboratory observations found that small lobsters of both sexes spent significantly more time on and around a trap containing a large female than one containing a large male. However, the number of entries and the catch rate did not differ significantly among treatments (trap with large male; trap with large female; and empty trap) and thus, a large trapped conspecific was not found to have any effect on the catchability of small approaching lobsters.

Agonistic interactions resulting in the retreat of an individual were observed around the trap in both the field and laboratory studies. Species other than *P. cygnus*, most notably octopus (*Octopus tetricus*), were observed interacting with the trap *in situ* and may affect the catchability of lobsters. Population estimates of the western rock lobster fishery rely, in part, on trapping surveys to provide stock assessment data. The modelling used to predict abundance involves the catchability parameter (*q*) which can be affected by lobster behaviour. Direct observations of trap behaviour are useful for understanding how catchability is influenced by this factor and may lead to improvements in stock assessment and gear efficiency.
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Chapter 1

General introduction

Background

The western rock lobster, *Panulirus cygnus* George, (known locally as ‘crayfish’) is a spiny (rock) lobster (Family: Palinuridae) endemic to the west coast of Australia and is the target species of the largest and most valuable single species fishery within Australia (Phillips *et al*., 2007). *Panulirus cygnus* are predominantly nocturnal, sheltering in ledges and caves during the day and foraging at night for food items such as molluscs, worms, small crustaceans, coralline algae and seagrass (George *et al*., 1979; Chittleborough, 1970). The lifecycle of *P. cygnus* is characterised by a mass migration of pre-adult individuals that have undergone a colour change from a deep red to a creamy or pale pink colour; a feature unique amongst spiny lobsters (Wade *et al*., 2008). The fishery for *P. cygnus* is sustainably managed by controlling the fishing effort based on the analysis of a comprehensive fisheries database (Phillips and Melville-Smith, 2005). This sustainable management was recognised when the fishery was the first to be certified by the Marine Stewardship Council in March, 2000 (Phillips and Melville-Smith, 2005).

Lifecycle and biology

The larval cycle of *P. cygnus* has 11 complex stages and lasts 9 to 11 months (George *et al*., 1979). During these stages, the transparent larvae (phyllosoma) are carried up to 1,500 km offshore before metamorphosing into the puerulus stage,
which is the first stage with a morphology similar to adults, and actively swimming towards the coast to settle on shallow limestone reefs (1 – 20 m depth) (George et al., 1979; Phillips, 1981). After settling, the puerulus moult and are typically 8 mm in length and pigmented (Phillips, 1972; George et al., 1979). These juveniles concentrate on the shallow inshore reefs, sheltering in caves and ledges during the day and foraging at night (Chittleborough, 1970). When these lobsters are pre-adult (4 – 5 years old), they migrate to deeper offshore spawning grounds on the outer part of the continental shelf that are more suited to the release of planktonic larvae (Chittleborough, 1974; George et al., 1979; Phillips, 1983). Prior to this migration offshore, these pre-adult lobsters will moult from the existing red exoskeleton to become pale pink in colour, colloquially referred to as the ‘whites’ (George et al., 1979). The pale coloured exoskeleton is thought to provide camouflage for the migration over sand (Melville-Smith, 2003) and it gradually returns to the red colour over a two month period (George, 1958).

Like all crustacea, the growth of *P. cygnus* occurs at each moult (George et al., 1979). The five distinct stages of the moult cycle can be described in three categories as post-moult (stages A and B), inter-moult (stage C), and pre-moult (stages D and E) (Drach, 1939; George et al., 1979). The behaviour and feeding of *P. cygnus* is affected greatly by moult stage: animals in a pre-moult stage are less active than those in other stages (Morgan, 1978) and feeding rates are highest for lobsters in post-moult stages (Chittleborough, 1975). Ovigerous setae (fine hairs) appear on the endopodites (abdominal swimmerets) of mature females following a moult in June or July and indicate that a female is in a setose (breeding) phase (de Lestang and Melville-Smith, 2006). During mating, the male
attaches a spermatophore (known as a ‘tar spot’) to the sternal plate of the female (Chittleborough, 1976). After the female exudes the eggs they are attached to the ovigerous setae and can be fertilised by scratching the tar spot and releasing sperm (Chittleborough, 1976). The fertilised eggs will incubate for between 19 to 68 days until they hatch and are released into the water column (Chittleborough, 1976). Large females may breed again in the same season without moulting (known as double-breeders) (de Lestang and Melville-Smith, 2006). By March most setose females will have moulted into a non-setose phase which can be retained by fishers, provided they are within the size limits (de Lestang and Melville-Smith, 2006).

The fishery

The limited entry trap fishery for *P. cygnus* is one of the largest spiny lobster fisheries in the world and, with a long term annual catch averaging approximately 11,000 t (valued at A$300 million), it provides employment for about 10,000 people (Caputi *et al*., 2003; Western Rock Lobster Council, 2006). The western rock lobster occurs in commercial quantities along approximately 1,000 km of the Western Australian coast, from Cape Leeuwin (34° 22’ S, 115° 8’ E) to the North West Cape (21°48’ S, 114°9’ E) (Phillips *et al*., 2007; Waddington and Meeuwig, 2009). The fishing season for *P. cygnus* typically consists of two phases, the first period from November to January targets the whites as they migrate offshore, and the second period from February to June targets the more sedentary reds phase (Hall, 1997). The whites are thought to have higher catchability than the residential red lobsters (Melville-Smith *et al*., 2003) which has been attributed to
the recent moulting event that elicited the colour change and the subsequent increase in food requirements that occurs after moulting (Morgan, 1974; Chittleborough, 1975, George et al., 1979). In the short period that the whites are available to the fishery, approximately 40% of the annual catch is taken (Morgan, 1980). The catch of $P. \text{cygnus}$ from recreational fishers (estimated at 206 t in 2007/08) is small in comparison to the commercial fishery and these fishers generally use traps from a vessel or hand loops while diving (Department of Fisheries WA [DFWA], 2009). The commercial fishery predominantly uses wooden batten traps (known as pots) made from jarrah or pine, but dome shaped cane ‘beehive’ traps are also used; both types must be fitted with three escape gaps to assist the escape of undersized animals (DFWA, 2009). There were 386 licensed commercial fishing vessels in the 2008/09 season, which is a reduction from 780 vessels in the 1982/83 season (Brown and Caputi, 1985; DFWA, 2009).

Management

The fishery for $P. \text{cygnus}$ that began in the early 1900’s became limited entry in 1963 and is currently input controlled (George et al., 1979; Caputi et al., 2003). Management is divided into three zones: the Abrolhos Islands region (Zone A); the North Coastal region (Zone B); and the South Coastal region (Zone C) (Hall, 1997). The length of the season differs between zones (Zone A: 15th November to the 30th June; Zone B: 25th November to the 30th June; Zone C: March 15th to the 30th of June) as do the size restrictions. Currently, the minimum legal size for $P. \text{cygnus}$ is 77 mm carapace length (CL). Females above 105 mm CL in zone C, and above 95 mm CL in zones A and B, are also protected, as are females in a
reproductive state (setose, tar spot or berried). In the past, lobster traps have
caused the death of Australian sea-lion (*Neophoca cinerea*) pups by drowning. To
address this, traps that are fished in shallow water (0 – 20 m depth) between
Wedge Island and Freshwater Point are required to fit a Sea Lion Exclusion
Device (SLED). The SLED may be internal in the form of a rod protruding
towards the neck entrance from the trap bottom or external in the form of a rigid
piece of material bisecting the trap entrance (DFWA, 2006).

*Catchability*

One variable of stock assessment methods is the catchability parameter (*q*), which
has been described as the probability of an individual being caught by the random
application of a standard unit of fishing effort (Morgan, 1974). The catchability
parameter links the observed catch rate from trapping surveys to the abundance of
a lobster population (Green, 2002), but the catchability of an individual may be
influenced by its behavioural response (Penn, 1984). Many factors can affect the
catchability of *P. cygnus* by influencing behaviour including physical factors such
as light intensity, temperature and swell (Chittleborough, 1970; Morgan, 1974;
Jernakoff, 1987; Srisurichan *et al.*, 2005), and biological factors including size,

*Comparisons of migratory phase*

One biological factor that has not been investigated for *P. cygnus* is the influence
of the migratory phase on behaviour. Studies have investigated the movement
patterns of lobsters in the whites phase (Phillips, 1983; MacArthur et al., 2008b), but none have attempted to quantify behaviour. Lobsters in the whites phase are thought to have higher catchability (Melville-Smith et al., 2003) than those in the reds, which is attributed to the higher food requirements of post-moult individuals (Morgan, 1974).

One of the aims of this thesis was to investigate the hypothesis that the behaviour of lobsters in the white phase differs from that in the reds and if the behavioural difference contributes to the higher catchability of the whites (Chapter 2). Behaviour was investigated by directly observing the lobsters in situ using a trap mounted multi-camera video system. These direct video observations can potentially explain differences in behaviour which would lead to a more robust estimation of the catchability co-efficient (\(q\)) and thus more accurate population estimates from trapping surveys.

**Investigation of the influence of conspecifics**

Another factor that has not been studied for *P. cygnus* is the possible influence of conspecific competition and aggressive interactions on the behaviour and catchability of individuals. Miller (1990) provides a review of lobster species in which larger conspecifics are dominant in aggressive encounters and suggests that these interactions may prevent some smaller individuals from entering traps. In contrast to these lobster species, in the laboratory, small *P. cygnus* individuals are more catchable than larger individuals (Morgan, 1979 cited in Miller, 1990). The
second part of this study aimed to investigate the influence of a large trapped *P. cygnus* individual on the behaviour and catchability of smaller lobsters approaching the trap (Chapter 3). This component of the thesis aimed to elucidate the effect that aggressive interactions and competition for food has on the behaviour of smaller *P. cygnus* and to relate this to possible influences in catchability which, as explained earlier, may have implications for stock assessment methods.

Chapter 4 provides an overview of the conclusions and recommendations from all components of this thesis and discusses the implications of the results for current stock assessment methods and future research.
Chapter 2

A comparison of the trap behaviour of western rock lobster (*Panulirus cygnus*) during the migratory ‘white’ phase and the residential ‘red’ phase.

Summary

Approximately forty percent of the total annual catch of western rock lobsters, *Panulirus cygnus*, is comprised of pale-coloured migratory pre-adult ‘white’ lobsters (Morgan, 1980); the remainder of the catch being comprised of the more sedentary red phase. The whites are thought to be more catchable than the reds, which has been attributed to their recently-moulted state, and as a consequence, their greater requirement for food (Melville-Smith *et al.*, 2003; Morgan, 1974). The current study used a trap mounted multi-camera video system to film the trap behaviour of *P. cygnus* in the field during both the whites (November - December) and the reds phase (March). The behaviour of the lobsters around the neck of the trap and at the side of the trap were observed and separated into seven behavioural categories. The overall pattern of behaviour displayed by the lobsters did not differ significantly between the whites and reds phase. Observations of lobsters entering the trap accounted for approximately 60% of the neck camera observations for both phases. Lobsters were observed to exit the trap through the neck entrance on seven occasions in the whites phase but not at all in the reds. The use of the escape gap by lobsters was proportionally high in both phases: approximately 70% and 94% of lobsters that entered escaped through the escape gap in the whites and reds respectively. However, there was a markedly larger number of observations for the whites (*n* = 224) than the reds phase (*n* = 39).
indicating that lobsters were either much more active during the whites phase or more abundant. The very low number of behavioural observations in the reds phase may indicate that further investigations are required during the reds phase of the fishing season. Agonistic behaviour between conspecifics and interactions of other species with the trap were observed; particularly with octopus (*Octopus tetricus*) which appeared to have an inhibitory affect on the entry of lobsters to the traps.

### 2.1 Introduction

The annual migration of pale-pink coloured immature western rock lobsters, *Panulirus cygnus*, occurs from November to January and coincides with the beginning of the commercial and recreational fishing season (George, 1958; George *et al*., 1979). The migration takes these pre-adult (4 – 5 year old) lobsters from shallow nearshore reefs to deeper offshore spawning grounds (Phillips, 1983). These migratory lobsters were initially thought to be a separate species due to the difference in colour from the normal dark red hue (George, 1958). The colour change occurs in the moult prior to migration and is thought to provide added camouflage to the lobsters when migrating over sand (Melville-Smith *et al*., 2003). Although the whites are not as popular on the international market as those of a deep red colour (Melville-Smith *et al*., 2003), they are a valuable resource and compose approximately 40 % of the total annual catch, which has a long term average of approximately 11 000 t (Morgan, 1980; Caputi *et al*., 2003). The newly moulted white lobsters are thought to have a higher catchability than the more sedentary ‘red’ individuals (Melville-Smith *et al*., 2003), which has been
attributed to the higher food requirements associated with recently moulted individuals (Morgan, 1974). However, catchability is also influenced by the behavioural responses of the target species (Penn, 1984); therefore, it is possible that the behaviour of these migrating individuals may also contribute to their high catchability and anecdotal evidence from fishermen suggests that these animals often enter unbaited traps, possibly using them as a source of shelter.

There are no known in situ studies that observe the trap behaviour of P. cygnus, or any in situ or laboratory studies that observe the behaviour of the whites phase of this species. Only one study is known in which the behaviour of P. cygnus was observed in situ; Cobb (1981) utilised divers to observe the behaviour and den residency of P. cygnus on two small patch reefs at Seven Mile Beach. However, these observations were made without artificial light and consequently were restricted to a short period either side of sunset or sunrise. Several studies have used tracking devices to observe the movements of P. cygnus at night (Jernakoff, 1987; MacArthur et al., 2008a & 2008b) and around a trap (Jernakoff and Phillips, 1988). However, none of these studies provide direct observations of the trap behaviour of P. cygnus.

A number of recent studies have demonstrated how video systems can be used to observe lobster behaviour in situ (Jury et al., 2001; Green, 2002; Weiss et al., 2006 & 2008). These studies demonstrate how observations may be able to quantify the influence that behaviour can have on the catchability of a lobster. Observations from in situ video systems are preferable to diver observations
because they minimise disturbance to behaviour while providing access to a greater range of habitats (Jury et al., 2001; Mills et al., 2005). The current study used a relatively inexpensive trap-mounted video system, illuminated with red light, to observe and compare the trap behaviour of *P. cygnus* over two periods of the annual rock lobster fishing season. The first period of sampling was during the whites migration in November and December, and the second was during March, when the more sedentary post-moult red lobsters are caught (Brown and Caputi, 1985). The study tested whether the behaviour varies between the whites and reds phase in the life cycle of *P. cygnus*, particularly the hypothesis that proportionally more lobsters enter the trap during the whites phase than in the reds. Agonistic interactions between conspecifics and inter-specific interactions with the trap were also noted. This study provides information on the behaviour of *P. cygnus* that can be used to understand catchability and may be a reference for further studies of the species behaviour using *in situ* video observations.

### 2.2 Materials and Methods

*Experimental area*

*In situ* video observations of lobster behaviour were made in shallow inshore waters (6 - 10 m depth) near Cervantes (30°30′0″ S, 115°3′57.6″E), a small coastal community 231 km north of Perth in the south coastal management zone (Zone C) of the western rock lobster fishery (Figure 2.1). Cervantes lies near the northern boundary with Zone B which is at the centre of the range of *Panulirus cygnus* and the western rock lobster fishery (Macarthur et al., 2008a). The temporal restrictions placed on the fishers of Zones A and B do not apply to Zone
C and the town supports a relatively large fleet. Field work was undertaken to observe lobsters during both the whites and reds phases of the lobster season using the same commercial fisher and vessel during both seasons.

Figure 2.1. Bathymetry map with the locations of the camera trap during the whites (filled circle) and the reds (filled triangle).
The whites phase was surveyed between 25th November and 8th December 2008 and the reds phase between 16th and 31st of March 2009. Both these periods were around the new moon as it has been found that comparably less *P. cygnus* are caught in the period around the full moon (Srisurichan et al., 2005).

The surveying sites were selected by the skipper of the vessel after he had taken the environmental conditions into consideration and were intended to maximise the chance of lobsters interacting with the traps (Figure 2.1). The experimental site was within the Sea Lion Exclusion Device (SLED) zone, as designated by the DFWA (DFWA, 2006). However, an exemption was obtained from the DFWA to allow the traps to be fished in this area without a SLED attached so that the results from this study could be comparable to fisheries outside the SLED zone, as it has been shown that certain versions of the SLED may affect the catch rate of the traps (DFWA, 2006).

*Video System*

All observations were recorded by a self contained video system designed by Natalie Toon of Murdoch University for use in her PhD thesis. The video system (Figure 2.2) consisted of a commercial jarrah batten trap with a stick neck entrance and three escape gaps. The trap was modified to incorporate three cameras mounted on steel brackets at one end: one raised camera with a view of the dorsal entrance and a camera on each side of the trap with a view of the sides. Three red lights were fitted inside the trap directed outwards to illuminate the area
outside the trap. Red light (wavelength: 660 nm) was used as spiny lobsters are known to have low sensitivity to light of this wavelength, it penetrates water further than infrared and many video cameras are highly sensitive to red light (Kennedy and Bruno, 1961; Cummins et al., 1984; Weiss et al., 2006). Underwater cables connected the lights and cameras to an underwater housing that was deployed alongside the trap. The underwater housing contained two gel cell 72 amp hour 12 V batteries and three Digital Video Recorder (DVR) devices to receive and record the video feed from cables attached to each camera. The underwater housing was constructed from stainless steel pipe (length: 800 mm, diameter: 315 mm, wall thickness: 9.5 mm) that had removable 40 mm thick acetate end bells secured to each end by stainless steel screws and made watertight by a large ‘O’ ring (Figure 2.2). The underwater housing was fitted within a rectangular shaped stainless steel frame and secured with rope and a removable crossbar at one end; this setup allowed the system to function in any position. Connection was made between the interior and exterior of the underwater housing via waterproof ‘Impulse’ connectors fitted through one of the acetate end bells which also had a vacuum port. Any spaces in the interior of the housing were packed with fire retardant foam sheets to prevent movement. When fully charged, the power from the batteries maintained the system for more than 24 h. The housing system weighed approximately 120 kg and was able to be retrieved easily by two people with the use of a standard trap winch. The batteries and DVR devices were recharged and data retrieved on land. For this reason, the camera system was only able to be deployed on every second day of the sampling periods. Between filming days the camera and control traps were removed from the water.
Figure 2.2. Photograph of the underwater housing and trap with mounted cameras on the ‘pot tipper’ after retrieval.

**Deployment and retrieval**

The video system and three standard traps as controls were deployed from the vessel within the commercial fishing period, from approximately 6 am to 2 pm each day. Every effort was made to retrieve the system at a similar time to deployment to allow 24 h of filming. However, the daily operation of the commercial vessel dictated the time of retrieval and it was not possible to achieve this on three occasions.
The system was rigged similar to that used when fishermen run ‘double gear’: the underwater housing was tethered to the float line by a short rope (< 2 m length) at a point approximately eight metres before the trap to prevent collision between the two units during deployment and retrieval. Two people were required to safely deploy and retrieve the system. During deployment, the power unit was released over the side of the boat a few seconds before the camera trap to prevent entanglement and the system was marked by two surface floats. Blue mackerel (*Scomber australasicus*) was used as bait during the whites and heads of orange roughy (*Hoplostethus atlanticus*) were used during the reds due to the unavailability of blue mackerel. To retrieve the video system, the float line was grappled and then winched around the winch capstan to maximise control. The power unit was brought onboard first with the use of the ‘pot tipper’ and detached from the float line before the camera trap was then winched onboard. The size, sex, reproductive state (setose, tar spot or berried) and distinctive features (missing appendages or carapace damage) were recorded for any lobsters caught in the camera trap or in the control traps.

The system was deployed successfully on five occasions for each season (Table 2.1). Due to the malfunction of one of the DVR devices, no footage was obtained from the left side camera during the reds and the observations from this camera have not been analysed. On three separate occasions, one of the two other cameras either did not function or the view was obstructed by weed. Observations from the neck camera were gathered for four nights in both phases (Table 2.1). Observations from the right camera (referred to as ‘side camera’) were completed for five nights in the whites phase and for four nights in the reds (Table 2.1).
Table 2.1. Table displaying the nights that each camera was successful (√) or unsuccessful (X) in gathering footage including the total number of successful nights of camera observations.

<table>
<thead>
<tr>
<th>Night</th>
<th>‘Whites’</th>
<th></th>
<th>‘Reds’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Neck</td>
<td>Side</td>
</tr>
<tr>
<td>1</td>
<td>26-Nov</td>
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<tr>
<td>4</td>
<td>5-Dec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>5</td>
<td>8-Dec</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Environmental data**

Qualitative measurements of wind speed and direction, swell, seas, air temperature and cloud cover were recorded for each day of filming. Water temperature was recorded accurately every hour when the trap was deployed by a temperature logger that was provided by the DFWA and fixed to the camera trap. Water movement was measured qualitatively as low, medium or high from observations of the trap and the benthic environment during analysis of the video.

**Data retrieval and analyses**

The field footage was transferred to external hard drive between filming nights to be analysed at a later date. Five categories of observed behaviours were recorded from the footage obtained by the camera positioned over the neck and two categories from the cameras on the side of the trap (Table 2.2). The time each observed behaviour occurred was also recorded.
Table 2.2. Description of the categories of behaviour recorded from cameras at the neck and on the side of the lobster trap. FOV = field of view.

<table>
<thead>
<tr>
<th>Camera position and category of behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neck</strong></td>
<td></td>
</tr>
<tr>
<td>Investigation</td>
<td>A lobster enters the FOV and then leaves the FOV without entering the neck of the trap</td>
</tr>
<tr>
<td>Entry</td>
<td>A lobster enters the FOV and then completely enters the trap</td>
</tr>
<tr>
<td>Exit</td>
<td>A lobster climbs out from within the trap to the top of the trap via the neck</td>
</tr>
<tr>
<td>Entry attempt</td>
<td>A lobster enters the neck from the top of the trap and then exits the neck onto the top of the trap</td>
</tr>
<tr>
<td>Exit attempt</td>
<td>A lobster climbs out from within the trap into the neck and then re-enters the trap</td>
</tr>
<tr>
<td><strong>Side</strong></td>
<td></td>
</tr>
<tr>
<td>Approach</td>
<td>Lobster enters the FOV and then leaves FOV to continue investigating the trap</td>
</tr>
<tr>
<td>Retreat</td>
<td>Lobster leaves the FOV to retreat away from the trap</td>
</tr>
</tbody>
</table>

It was not possible to follow individual lobsters when they moved outside the field of view and lobsters that re-entered the field of view could have been counted more than once. Therefore, the actual number of individual lobsters observed was not able to be determined. To compare behaviours between phases the number of observations in each category was expressed as a proportion of the total number of observations for the night and the mean proportion of observations in each category was calculated for the whites and reds period of filming. The mean number of observations recorded per hour for each night was calculated separately for the neck and side camera, and the reds and the whites phases. When a filming period was less than 24 h, the hours in which no footage was obtained were omitted from these calculations.
It was not possible to view every escape gap but the number of lobsters that entered through the neck and escaped via the escape gaps could be gathered through the following equation:

\[ n_{\text{gap escapes}} = n_{\text{neck entries}} - (n_{\text{neck exits}} + n_{\text{lobsters retained in trap}}) \]

Any lobsters that entered through an escape gap and exited via the neck of the trap would confound the above equation. However, these lobsters would be small and they could therefore easily exit via the escape gaps. The above equation therefore provides a close representation of the number of lobsters entering via the neck and exiting via escape gaps. The number of escapes via the escape gaps was expressed as a proportion of the number of entries for each night and the mean number of escapes was calculated for each season.

Preliminary observations of the footage highlighted a behaviour in which lobsters fed on the bait through the neck without actually entering the trap. To compare this behaviour between phases, the amount of time each lobster spent in the neck was recorded. The proportion of lobsters that entered the trap and were retained was calculated for each night and this allowed a mean proportion to be calculated for each season. The mean daily catch rates of the camera and control traps were also calculated and prior to analysis, the control traps were grouped to allow comparisons with the camera trap within each season.

Observations of agonistic interactions between conspecifics were noted and the participants were labelled either aggressive or submissive based on the
descriptions of behaviour in Cobb (1981). Inter-specific interactions with the lobster trap (excluding fish) were also noted in detail.

Students T-tests were used for comparisons of the behavioural categories between the two phases. Proportional data were arcsine transformed before analysis and the duration in neck data was log transformed prior to analysis. The hourly temperature readings provided by the temperature logger were used to calculate a daily mean temperature for each survey day.

2.3 Results

Environmental data

The mean water temperature was significantly higher \((t_{229} = -40.24, P < 0.001)\) in the reds \((23.30 \pm 0.04 \, ^\circ C)\) than in the whites phase \((21.33 \pm 0.03 \, ^\circ C)\) by about 2 \(^\circ C\) (Figure 2.3). The mean estimated swell height and wind speed during daylight hours in the whites phase \((swell: 1.5 \pm 0.1 \, m; \ wind: 10.1 \pm 0.6 \, kts)\) were similar to those during the reds \((swell: 1.4 \pm 0.2 \, m; \ wind: 11.6 \pm 1.3 \, kts)\). Average water movement was assessed as medium in the whites and high in the reds phase. The high amount of water movement in the reds often resulted in the trap ‘walking’ (shuffling along the bottom) or rolling from side to side. There were also a number of observations in the reds phase of lobsters getting swept outside the field of view by water movement as they were approaching or entering the trap.
Figure 2.3. The mean temperature (± 1SE) for each survey day in the whites (solid) and reds (dashed) phases as recorded by a temperature logger.

_Catch rates, size and sex_

The mean daily catch rate did not differ significantly between the camera trap (2.60 ± 1.69) and the three control traps (2.73 ± 0.76) (t₈ = 0.440, P = 0.671) in the whites phase (Figure 2.4). In contrast, in the reds phase the mean daily catch rate was significantly lower in the camera trap (0.60 ± 0.40) than in the three control traps (5.87 ± 0.95; t₈ = -2.31, P = 0.05) (Figure 2.4). The mean carapace length (CL) of lobsters retained in the trap was significantly longer in the whites (77.05 ± 0.39 mm [CL]) than in the reds phase (74.44 ± 0.55 mm [CL]) (t₁₄₅ = 3.34, P = 0.001) and the percentage of retained lobsters that were male was higher for the whites phase (59.3%) than the reds (47.2%).
Observations of behaviour

The mean number of observations per night for the neck camera was considerably higher in the whites period of filming in November and December (27.0 ± 10.8; \( n = 108 \)) than in the reds phase in March (3.8 ± 1.3; \( n = 15 \)) (\( t_6 = 2.15, P = 0.075 \)). The mean number of observations per night from the side camera was also higher during the whites phase (23.20 ± 7.00; \( n = 116 \)) than the reds (6.00 ± 1.68; \( n = 24 \)). The majority of observations in the whites phase occurred on two nights (Figure 2.5). Lobsters were directly observed to exit the trap via the escape gap on five occasions in the whites phase and on one occasion in the whites a lobster was observed entering via the escape gap. No direct observations of escape gap exit or entry were recorded in the reds phase. No observations of ‘exit attempt’ behaviour were recorded for either season and ‘exit’ behaviour was observed only in the whites (\( n = 7 \)). The mean proportion of behaviour observed by the neck camera was similar between phases for each behavioural category and analysis found
there to be no significant differences (Figure 2.6; Table 2.3). Similarly, the mean proportion of approaches and retreats of the total observations from the side camera did not differ significantly between phases (Figure 2.6; Table 2.3).

Although lobsters spent more than twice the amount of time in the neck feeding on the bait through the bait basket in the reds phase (587.50 s ± 330.57, n = 14) than in the whites phase (277.02 s ± 45.97; n = 90), this difference was not significant because of the variability during the reds (Table 2.3). The mean proportion of entries that resulted in exits via the escape gaps tended to be higher for lobsters in the reds phase (0.94 ± 0.06) than for those in the whites (0.69 ± 0.16; P = 0.10) (Table 2.3). The proportion of lobsters retained in the trap from those that entered did not differ significantly between phases (whites: 0.16 ± 0.15; reds: 0.06 ± 0.06) (Table 2.3). The remaining proportion of lobsters that entered the trap in the whites exited via the neck (0.15 ± 0.03).

Figure 2.5. A comparison of the number of observations from the neck camera per night between the whites (white) and the reds (shaded) phases (whites: n = 108; reds: n = 15).
Figure 2.6. The mean proportion of observations (± 1 SE) in each behaviour category in the whites (white) and the reds (shaded). The total number of observations for each camera were whites: neck = 108, side = 116; reds: neck = 15, side = 24.

Table 2.3. Summary of behavioural comparisons between the whites and reds phases by independent sample t-tests (d.f. = degrees of freedom; sig = significance).

<table>
<thead>
<tr>
<th>Variable and camera</th>
<th>t-value</th>
<th>d.f.</th>
<th>Sig (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigation proportion</td>
<td>0.658</td>
<td>6</td>
<td>0.54</td>
</tr>
<tr>
<td>Entry proportion</td>
<td>-0.451</td>
<td>6</td>
<td>0.67</td>
</tr>
<tr>
<td>Exit proportion</td>
<td>8.161</td>
<td>6</td>
<td>0.00</td>
</tr>
<tr>
<td>Entry attempt proportion</td>
<td>-0.292</td>
<td>6</td>
<td>0.78</td>
</tr>
<tr>
<td>Duration in neck (log transformed)</td>
<td>0.068</td>
<td>102</td>
<td>0.95</td>
</tr>
<tr>
<td>Exits via escape gap as a proportion of entries</td>
<td>-1.946</td>
<td>6</td>
<td>0.10</td>
</tr>
<tr>
<td>Retained lobsters as a proportion of entries</td>
<td>0.569</td>
<td>6</td>
<td>0.59</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side camera approach proportion</td>
<td>0.105</td>
<td>7</td>
<td>0.92</td>
</tr>
<tr>
<td>Side camera retreat proportion</td>
<td>-0.105</td>
<td>7</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Activity

The activity pattern of lobsters was similar across both cameras and phases; typically activity peaked in the hours after sunset and then declined throughout the night with a small peak again before sunrise (Figure 2.7). No lobsters were observed outside the trap between sunrise and sunset in either phase. The number of entries had a sharp peak around 22:00 h but was reasonably consistent for the remainder of the night in the whites phase. In comparison, the exits from the trap appear to concentrate at the beginning and end of the night (Figure 2.8).

Agonistic intra-specific interaction

Agonistic interactions between conspecifics outside the trap were observed on one occasion for the neck camera and on six occasions for the side camera. The majority of observations of agonistic interactions occurred during the whites phase ($n = 6$). In 85.7% of these interactions, the submissive lobster retreated away from the trap outside the field of view of the camera.
Figure 2.7. The mean number of observations for each hour of filming (± 1 SE) for: a) the neck camera during the whites phase ($n = 108$); b) the neck camera during the reds phase ($n = 15$); c) the side camera during the whites phase ($n = 116$); and d) the side camera during the reds phase ($n = 24$) (Shaded bar indicates period between sunset and sunrise: no observations were made outside this time; note difference in y-axis scales).
Inter-specific interaction

Several interactions of other species with the trap were observed (Table 2.4.). During daylight, numerous species of fish, predominantly wrasse (Labridae), sheltered inside and near the trap and a number of species fed on the bait through the bait basket. Eels frequented the trap in both seasons, usually remaining around or inside the bait basket. Australian pied cormorants (*Phalacrocorax varius*) entered the neck of the trap and examined the interior and these occasions were preceded by the rapid exit of all fish from the trap. Rays were often seen swimming near the trap and on two occasions were observed lying on the dorsal side of the trap, possibly attempting to feed on the bait (Table 2.4). Octopus (*Octopus tetricus*) were usually observed feeding on the bait through the bait basket from inside the trap or sheltering in a corner of the trap. Octopus were observed eight times over six days and, on a number of these occasions, lobsters were present in the trap with an octopus. Yet, no interactions were observed
between an octopus and a lobster. No lobsters were observed to enter the trap while an octopus was present; however, six of the eight octopus observations were made in daylight. On one occasion during the whites, an adult Australian sea-lion (*Neophoca cinerea*) approached the trap several times in pursuit of an octopus that was sheltering in the corner of the trap (Table 2.4). The sea-lion was able to feed on the octopus by lifting the side of the trap with its nose and then letting it drop down. These actions were repeated several times until the octopus moved close to the neck of the trap, after which the seal thrust its head into the entrance of the trap and retrieved the octopus.

Table 2.4. The number of observations of inter-specific interactions with the trap in each season.

<table>
<thead>
<tr>
<th>Species</th>
<th>n observations</th>
<th>'Whites'</th>
<th>'Reds'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian pied cormorant (<em>Phalacrocorax varius</em>)</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Octopus (<em>Octopus tetricus</em>)</td>
<td>7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Southern Eagle Ray (<em>Myliobatis australis</em>)</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Stingray (<em>Dasyatis spp.</em>)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Australian sea-lion (<em>Neophoca cinerea</em>)</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Crab <em>spp.</em></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Panulirus cygnus* individuals interacted with another species on one occasion; during the whites phase a large decorator crab entered the trap and interacted with two individual lobsters that were outside the trap. One lobster continued to approach the entrance of the trap, while the second lobster retreated hastily, by tail flicking, after contact with the crab. The decorator crab was retained in the trap.
2.4 Discussion

The whites phase consists of individuals migrating into deeper waters to breed and this phase is thought to be one where animals are moving greater distances each night and have higher energetic requirements than the reds (Phillips, 1983). These migratory energy requirements, in addition to the higher feeding requirements related to the recent moult event, do not appear to alter the trap behaviour of the whites as it was proportionally similar to the more sedentary reds. As such, these animals do not appear to be more catchable than the reds when interacting with the trap. The high catchability of the whites may therefore be due to these animals being more active and less reluctant to approach a trap which also explains the higher mean number of observations in the whites phase when compared to the reds. However, the high catch rate of the control traps compared to the camera trap in the reds suggests that the lobsters in this phase were abundant and active but may have been more reluctant to approach the camera trap than the control traps. Therefore, the low number of observations in the reds phase may have been due to the performance of the camera trap.

There was no difference in the setup of the camera or control traps between phases with the only differences being the deployment locations and the type of bait. The location of each trap was changed for each day of filming within a phase and thus it is unlikely that the camera trap was placed in an unproductive area on each of the five occasions. A pilot study with the same camera trap in the Abrolhos Islands during a reds phase found no difference between the camera trap catch rates and that of standard traps. However, the habitat sampled in that study
was considerably more protected than that in the current study (N. Toon, Murdoch University, *pers. comm.*). A greater amount of water movement was seen on the video footage during the reds compared to the whites and this may have had a more pronounced effect on the camera trap than the control traps. The extra equipment, cables and ropes associated with the camera trap could have potentially caused increased noise or movement that may have deterred the lobsters during the reds phase. The increased water movement may have also worked to increase the catch rates of the control traps during the reds as it has been suggested that water movement disturbs the benthic environment, possibly increasing food availability while offering greater protection and thus resulting in more foraging activity (Srisurichan *et al.*, 2005). It is also possible that heavy fishing during the season may have removed more catchable lobsters from the experimental area, leaving a greater proportion of ‘trap-shy’ individuals that were more easily deterred by the equipment associated with the camera trap. Further sampling in the reds phase may determine whether the low number of observations was due to the performance of the camera trap or the catchability of the red lobsters, and additional laboratory testing of the camera trap may identify the deterring factor if it exists.

The number of observations, and hence activity, varied greatly among days in the whites phase. The majority of observations in the whites phase were made on two consecutive deployment nights, with few observations recorded on the first and last night of deploying the traps (Figure 2.5). From a qualitative analysis of the video, there were not obvious differences that would account for the variability between nights (such as the presence of predators or difference in substrate
between nights). This difference between nights might be due to setting the trap in different locations each night and the position of the trap in relationship to the bottom currents and odour plumes from the bait in the trap. From studies of tagged lobsters, Jernakoff and Phillips (1988) found that *P. cygnus* down current from a trap travelled distances of up to 120 m to enter the trap, whereas lobsters up current from the trap often travelled within 20 m and did not visit the trap. This finding highlights the importance of the direction of water movement on the attraction of lobsters to the trap and may explain the variability in the number of observations between nights. All survey sites were located adjacent to reef but the direction of the water movement would have determined how the bait odour was dispersed and whether it reached the foraging range of a lobster.

Although not significant, the longer mean time spent in the neck appears to indicate that the red individuals may be less willing to enter the trap than the whites. However, it is more likely that this reflects the higher number of observations for whites and as a consequence higher levels of intra-specific competition: often a lobster in the neck of the trap would be displaced into the trap by another individual entering the neck thus shortening the time in the neck. The absence of exit behaviour in the reds phase may have been the result of a combination of a low number of entries (*n* = 8) and a smaller mean carapace length than in the whites phase which meant that the escape gaps were able to be utilised more often.
A large proportion of lobsters that entered the trap were able to escape through the escape gap in both seasons and a small proportion escaped through the neck in the whites. These results indicate that a large proportion of the lobsters that entered the trap would most likely be considered undersized (< 77 mm CL), particularly in the reds phase (94%). Undersize lobsters are common on shallow reefs such as those within the sampling area (Phillips, 1983) and the removal of legal-sized lobsters will increase the proportion of undersize lobsters throughout the season. Observations of *P. cygnus* escaping through the neck were also documented in an electromagnetic tagging study by Jernakoff and Phillips (1988) and Green (2002) observed a higher rate of escape through the neck for southern rock lobster, *Jasus edwardsii* (24%) after entering a trap (see also Chapter 3.4). The low number of exits through the neck observed in this study is more likely to be a reflection of the size structure of the population in the shallow sampling area rather than the ability of *P. cygnus* to escape the trap. One would expect that an increase in the mean carapace length of a population would result in a smaller proportion of lobsters that are able to escape through the escape gaps and a higher proportion relying on the neck entrance to escape.

The observed size difference of lobsters that were retained in the trap between the whites and reds may be due to the proximity of the sampling area to the Cervantes harbour. This area is heavily fished and the impact of the fishing season results in the removal of legal-size lobsters (≥77 mm CL) as the season progresses leaving a higher proportion of undersize individuals. This difference is similar to that observed by Chubb and Barker (2005) from the FDWA commercial monitoring data; they recorded an average carapace length decrease of 2 mm in males and 3
mm in females in the catch between November and March in 2001/2002. The decrease in average carapace length is probably also responsible for the higher rate of escapes from the escape gap observed in the reds compared to the whites. The smaller proportion of males caught in the camera and control traps in the reds phase when compared to the whites may be due to the restrictions placed on females of a certain reproductive stage (setose, tar spot and berried) which will result in a higher proportion of females being returned to the water. The proportional decline of males between November and March in the current study (approximately 12%) was more marked than that observed from commercial monitoring by the FDWA (approximately 2-4%) for Jurien between 2001 and 2003, although the sample size of the current study (n = 145) was much smaller than that from the monitoring data (n > 600) (Chubb and Barker, 2005)

*Panulirus cygnus*, and spiny lobsters in general, are regarded as nocturnal foragers (George et al., 1979). On shallow nearshore limestone reefs, such as those in the sampling area for this study, *P. cygnus* have been found in caves and ledges throughout the day and foraging in the surrounding habitat during darkness (Cobb, 1981; Jernakoff, 1987). Like previous studies, the current study found that *P. cygnus* was active at night, as all observations of lobsters occurred between sunset and sunrise. This pattern of nocturnal activity is similar to that observed in the laboratory (Chapter 3) and by Morgan (1978). The initial attraction to the baited trap by lobsters in the surrounding area may account for the peak in activity shortly after sunset that was observed in this study, and also that observed in the laboratory in Chapter 3. The time of day that entries and exits occurred during the whites phase suggests that entry behaviour is responsible for this early
peak in activity. In a study on the foraging movements of individual lobsters using electromagnetic tags, Jernakoff (1987) found that *P. cygnus* was active throughout the night, which is probably more representative of natural foraging activity. The current study only indicates trap activity and it is likely that when the lobsters were not interacting with the trap they may have been foraging elsewhere.

Trap inhibition from agonistic interactions (see Chapter 3.1) has not been documented for *P. cygnus*, as this species is generally thought to be gregarious (Chittleborough, 1975). The low number of aggressive interactions (*n* = 7) in comparison to the number of observations (*n* = 263) suggest that agonistic behaviour is not as common for *P. cygnus* as it is for other species of lobster (see Chapter 3.1 for review). Individual lobsters could not be identified once they had left the field of view in this study and it was therefore not possible to determine whether retreating submissive lobsters re-approached the trap. However, the occurrence of agonistic interactions near the trap and the subsequent retreat of the submissive lobster, suggest that trap inhibition may occur for *P. cygnus*, although possibly at a level that is not likely to have a large impact on catchability.

The difference in the number of inter-specific observations between the whites phase (*n* = 18) and the reds (*n* = 4) is largely due to the higher number of octopus and cormorant observations during the whites phase. The lower number of octopus observations in the reds could be a result of the impact of the *P. cygnus* fishery, which retains octopus as a by-catch (Joll, 1977; Fletcher *et al.*, 2005). The
interaction of the sea-lion with the trap demonstrated the ingenuity associated with this species and was further support for the inclusion of SLED’s in the traps in this area of the fishery.

Octopus were observed to be active during the day and night in this study which supports observations from other recent studies (Brock et al., 2006; Weiss et al., 2008). There have been no known studies on the influence of red light on the behaviour of Octopus tetricus. However, Weiss et al. (2006) found that the predation rate of Caribbean spiny lobster, Panulirus argus, by the common octopus, Octopus vulgaris, was not affected by the use of red light. Octopus were observed interacting with the trap on 6 of the 10 days surveyed in this study, yet none of these observations would have been documented without video observation as no octopus were retained when the trap was pulled. No lobsters were observed to enter a trap when an octopus was present at the neck. Recent estimates propose that 220,000 to 300,000 octopus are caught by lobster fishermen each year and in the 1970’s, octopus were estimated to predate on up to 377, 000 trapped P. cygnus a year (Joll, 1977; Fletcher et al., 2005). However, the actual effect on the catch rate of P. cygnus may be much higher; the results from this study suggest that octopus frequent a much higher proportion of traps than is evident after the trap is pulled, and that the presence of an octopus may inhibit the entry of P. cygnus. The results also show that octopus do not enter the trap solely to predate on P. cygnus; they appear to be attracted by the bait as suggested by Joll (1977) and were not observed to interact with lobsters when they shared the trap.
The presence of a ray lying over the dorsal entrance to the trap will inhibit the entry of lobsters through the neck, however, both observations of this behaviour occurred over a short period (< 10 minutes) and this behaviour by rays is unlikely to have a large affect on trap entries. The influence of a large decorator crab that resulted in the retreat of one *P. cygnus* individual but not another demonstrates how individual behaviour influences catchability and underlines the difficulty associated with estimating this factor. Decorator crabs are not a major by-catch of the *P. cygnus* fishery (Fletcher *et al.*, 2005) and any impact of this species on the catchability of lobsters is likely to be minimal.

The design of the experiment could have been improved as problems were encountered during the course of the survey. Any improvement that would increase the catch rate of the camera trap in the reds phase would make the study more robust. Possible solutions include selecting a more sheltered site as an experimental area to lessen the effect of water movement on the trap. Adding extra ballast to the trap would also have prevented movement; however, the extra weight may have made the system unmanageable. Soaking the camera and control traps prior to surveying and between filming would possibly prevent movement of the traps and the observations would also be more representative of a commercial trap. Soaking could have been accomplished in the current study but it would have added an extra cost associated with a longer fieldtrip and also would have consumed considerably more of the commercial fishers time. The use of a volunteering commercial fisher and their crew enabled this study to be performed at a relatively low expense by a single researcher but it also restricted the amount of time available to the researcher each day. Access to a research vessel would
have offered more time which could have allowed for filming on consecutive
nights and diver visual census surveys to be conducted simultaneously. In
addition, a longer surveying period for each season may have reduced the
variability of the data between nights, especially in the reds phase.

Conclusion

The video observations gathered from this study provide an insight into the
behaviour of *P. cygnus* and associated species around a baited trap, and have
drawn attention to influences that may affect the catchability of lobsters. The trap
behaviour of *P. cygnus* did not differ significantly between phases; indicating that
white and red lobsters behave similarly around a trap. Further observations would
increase confidence in the similarity of behaviour as there were a low number of
observations and high variability in the observations of the reds phase. Most
observations of agonistic interactions resulted in the retreat of one lobster from
the trap indicating that competition for food exists amongst *P. cygnus* individuals
and that this could result in the trap inhibition of submissive individuals.
Although aggressive trap behaviour between lobsters was displayed infrequently
in this study, it has the potential to have a marked impact on catchability in other
environments or at other times of the fishing season if competition was fierce.
The prevalence of octopus interactions with the trap, and the inhibition of octopus
on lobster entries, highlights the significance of the octopus/lobster interaction to
the rock lobster fishery. Joll (1977) investigated the predation rate of octopus on
trapped *P. cygnus* and Cobb (1981) studied the behavioural reaction of *P. cygnus*
to octopus near their den. However, neither of these studies investigated the effect
that an octopus interacting with the trap has on lobster catchability. On several occasions, octopus were observed feeding on the bait at the neck of the trap for an extended period of time. The presence of a known predator of *P. cygnus* at the entrance to a trap is likely to have a substantial impact on catch rate and requires additional study.

Understanding how the behaviour of the target species, and also that of other species that interact with the fishing gear, affects catchability is important for improving gear efficiency and stock assessment estimates and also for managing the sustainable harvest of fished populations. The current study demonstrates how a relatively inexpensive video set up can deliver *in situ* observations of the trap behaviour of lobsters. Observations of this nature are central to understanding how lobsters interact with a trap and to improving estimates of the catchability coefficient (*q*).
Chapter 3

Does the presence of a large western rock lobster (*Panulirus cygnus*) within a trap affect the behaviour of approaching smaller conspecifics?

**Summary**

Size and agonistic behaviour influences the catchability of many species of lobster; often larger individuals are more catchable (Smith, 1944; Miller, 1990; Frusher and Hoenig, 2001). In contrast, smaller individuals of the western rock lobster, *Panulirus cygnus*, have been found to be more catchable than large animals (Morgan, 1979). Although, agonistic displays towards conspecifics and aggressive competition for resources have also been documented (Cobb, 1981). The present study focuses on how the presence of a large *P. cygnus* in the trap influences the behaviour of smaller individuals with respect to approaching and entering the trap. It was completed by recording video observations in the laboratory and comparing the behaviour of small lobsters (76 to 85 mm carapace length [CL]) between three treatments: a baited trap seeded with a large male lobster (> 98 mm CL), a baited trap seeded with a large female lobster (> 98 mm CL), and a baited empty trap as a control. The activity of the small *P. cygnus* individuals peaked after the onset of darkness. The duration of approaches (time spent near the trap) and the duration of contact (time spent on the trap) were significantly longer for the small lobsters in the large female treatment than those in the large male treatment. However, the entry and approach rates did not differ significantly between treatments, which suggest that the influence of a trapped
large lobster on the behaviour of smaller individuals in this study may not have been large enough to affect their catchability. Catchability is a variable in calculations of population estimates of lobsters from trap surveys and as such, any unaccounted influence on catchability may have an effect on the accuracy of these estimates.

3.1 Introduction

Estimates of lobster abundance from fisheries data and fishery-independent surveys are affected by the influence of environmental and biological factors on behaviour (see Chapter 1). For many lobster species, the size of individuals affects their catchability, and in general, larger lobsters are more catchable than smaller individuals (Smith, 1944; see Miller, 1990 for review; Frusher and Hoenig, 2001; Tremblay and Smith, 2001). The higher catchability of large individuals can be attributed to larger foraging ranges, greater food requirements and faster walking speeds than smaller conspecifics (Morrissy, 1973). On the other hand, the trap design used in some fisheries can increase the escape rate of large animals thus reducing their catchability (Green, 2002). Lobster size may also affect the catchability of some species that have a size-related dominance hierarchy, for example, smaller lobsters may be deterred from entering traps when a larger individual is present in the trap (Miller, 1990). Ihde et al. (2006) outlined the implications of not taking the effect of size-related hierarchies into account for interpreting the results from lobster population surveys: size compositions may be biased towards larger individuals and thus smaller individuals will be underrepresented in trap samples.
Miller (1990) reviewed the effectiveness of lobster traps and documented a number of studies where the catchability of larger animals was higher than small individuals and hence smaller individuals of these species were underrepresented in traps. Recently, Tremblay et al. (2006) hypothesised that the agonistic behaviour at high densities of large American lobsters, *Homarus americanus*, made smaller individuals less catchable. This effect has also been documented for spiny lobsters (Family: Palinuridae). In a study based on video observations of the southern rock lobster, *Jasus edwardsii*, Green (2002) found that the entry of smaller individuals into traps was inhibited by the presence of larger individuals within the traps. Size-related hierarchies and agonistic behaviour have also been recorded for the spotted spiny lobster, *Panulirus guttatus*, (Segura-Garcia et al., 2004) and also for post-puerulus *P. cygnus* (Berrill, 1976). Cobb (1981) observed *P. cygnus* individuals displaying agonistic behaviour towards conspecifics in competition for shelter space, which would often result in the smallest lobster leaving to find new shelter. However, a tank experiment by Morgan (1979, cited in Miller, 1990) found that large *P. cygnus* (> 85 mm in carapace length [CL]) were less catchable than smaller individuals (76 to 85 mm CL); smaller males were twice as likely, and females of the same size three times more likely, to be caught than larger individuals.

The addition of a seeded conspecific to traps reduced the catch of *H. americanus* (Miller & Addison, 1995) and the addition of female *J. edwardsii* seeds to traps in summer inhibited the entry of smaller individuals (Ihde et al., 2006). In contrast to these observations, fishermen in the Florida fishery for the Caribbean spiny lobster, *Panulirus argus*, have reported that seeding traps with undersize
conspecifics can improve catch rates by more than three times due to the gregarious nature of this species (Lyons & Kennedy, 1982, cited in Miller, 1990).

This study used a laboratory study to investigate the behaviour of small legal-sized *P. cygnus* individuals (76 to 85 mm in CL) when approaching a trap seeded with a large lobster (> 98 mm CL) and to consider whether catchability was likely to be affected by the presence of a large individual in the trap. Investigations were also made into whether the sex of both the large and small lobsters influenced behaviour.

### 3.2 Materials and Methods

*Gathering and holding of lobsters*

Lobsters were provided for use in the tank experiments by the Geraldton Fishermen’s Co-operative and were caught by commercial fishermen using baited traps. The lobsters were held in a communal tank (length: 2.00 m; width: 2.00 m; depth: 1.20 m; approximate volume: 4,800 L) at Challenger TAFE in Fremantle, Western Australia. Concrete blocks were provided for shelter and the lobsters were regularly fed mussels (*Mytilus edulis*). In the holding tank, the lobsters were exposed to the same water conditions as the treatment tanks (see below) and natural lighting conditions provided by the facility.

*Experimental design*

Moon phase affects the catchability of western rock lobsters (Section 2.2). To negate the influence of the full moon all three tests were run in the two week period over the new moon between 26th August and 10th September 2008. Three
rectangular treatment tanks were used: two of the tanks had black walls and were similar in size (length: 3.00 m; width: 1.30 m; depth: 0.64 m; approximate volume: 2,500 L), while one tank had white walls and was slightly larger than the others (length: 3.12 m; width: 1.40 m; depth: 0.67 m; approximate volume: 3,000 L).

Each tank contained a single commercial batten lobster trap (jarrah stick-neck with three escape gaps) at one end and a shelter constructed from concrete blocks at the other end. A shallow layer of sand was used as substrate in each tank and seawater flowed continuously into the tanks at an approximate rate of 10 L/min and at a temperature of 19˚C. A light:dark cycle was simulated using artificial lighting; 12 h with a daylight fluorescent tube (06:00 – 18:00 h) and 12 h with a red light tube (18:00 – 06:00 h). This cycle closely corresponded to the natural light cycle in August and September. Red light was used as illumination for the video recordings during the dark cycle as it is outside the spectral range of spiny lobsters (Cummins et al., 1984; Chapter 2.1).

A camera was positioned above the trap in each tank that provided a complete view of the trap and surrounding area. The field of view extended to approximately 1.5 m in each direction from the trap entrance. Another camera was positioned above the shelter in each tank to provide a complete view of the tank and to assist with identifying individual lobsters.

The moult stage of each lobster was assessed following Morgan (1974) and the sex and size of each lobster were also recorded (Table 3.1). Twelve of the lobsters were classed as small (i.e. 76 to 85 mm in CL) and of these, nine were at the inter-
moult stage (stage C) of ecdysis and three were at the pre-moult stage (stage D). Three groups of four small lobsters were used for each trial as *P. cygnus* has been shown to display greater movement and food consumption at this density (Waddington *et al.*, 2005). Moult stage is also known to affect food consumption in *P. cygnus* (Morgan, 1974) and accordingly the lobsters were divided so each group contained three inter-moult lobsters and one pre-moult lobster. All three pre-moult lobsters moulted after the second test; as a result the exoskeletons of these lobsters were assessed before using them in the third test and all exoskeletons were considered to be sufficiently hard for use in this test. None of the small females used in the treatments were setose.

A total of three large lobsters were used in these experiments (Table 3.1). The large non-setose female lobster (98.5 mm CL) moulted after the first test and was replaced by another large non-setose female of similar size (98.7 mm CL) for the remaining two tests. The same large male lobster (104.9 mm CL) was used for each of the male tests. Small lobsters were identified by reflective numbers glued to the carapace and each group was acclimatised for 24 h in their respective treatment tank prior to each test. Any small lobsters that had entered the trap during acclimation were released and the trap was baited with one frozen mullet (*Mugil spp.*) at 12:00 h. A large female lobster was placed in a trap in one of the tanks, a large male in the trap in another tank and the trap in the remaining treatment tank was left empty as a control. Observations were recorded in real time onto a hard drive for a 24 h period. The tests were replicated three times maintaining the same small lobster groups and rotating them between treatments.
Table 3.1. The sex, size (carapace length, CL) and moult stage of lobsters used in the experiments on the effect of a large trapped lobster on the behaviour of small lobsters (Moult stage: C = inter-moult; D = pre-moult).

<table>
<thead>
<tr>
<th>Group</th>
<th>Sex</th>
<th>CL (mm)</th>
<th>Moult stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small 1</td>
<td>Female</td>
<td>76.8</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>77.6</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>79.5</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>79.7</td>
<td>C</td>
</tr>
<tr>
<td>Small 2</td>
<td>Female</td>
<td>77</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>77.3</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>82.3</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>83.2</td>
<td>C</td>
</tr>
<tr>
<td>Small 3</td>
<td>Female</td>
<td>76.9</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>80.1</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>81.2</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>82.7</td>
<td>D</td>
</tr>
<tr>
<td>Large</td>
<td>Male</td>
<td>104.9</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Female(1)</td>
<td>98.5</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Female(2)</td>
<td>98.7</td>
<td>C</td>
</tr>
</tbody>
</table>

Video Observations

Observations of lobsters were watched on digital video playback at normal speed (x 1). Between observations the footage was fast forwarded (x 8), stopped when a lobster entered the field of view and cued back to the beginning of the observation. The behaviour of lobsters was recorded in seven main categories of behaviour (Table 3.2) similar to those used by Smith and Sumpton (1989) for describing the behaviour of the blue swimmer crab, *Portunus pelagicus*. The categories for behaviour were approach; retreat; contact; point of contact; position of large lobster during contact; entry; and escape. The time of each behavioural event was also recorded. Any agonistic interactions between the large and small lobsters, as well as between small lobsters, were also noted and the participants
were labelled either aggressive or submissive based on the descriptions of behaviour in Cobb (1981).

Table 3.2. The seven behavioural categories used to classify the behaviour of lobsters (following Smith and Sumpton, 1989) in experiments on the affect of a large trapped lobster on the behaviour of small lobsters.

<table>
<thead>
<tr>
<th>Behaviour category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Lobster completely enters the field of view</td>
</tr>
<tr>
<td>Retreat</td>
<td>Lobster completely leaves the field of view</td>
</tr>
<tr>
<td>Contact</td>
<td>An approaching lobster climbs up onto the side of the trap (incidental contact not included)</td>
</tr>
<tr>
<td>Point of contact</td>
<td>The 90° quadrant of the trap perimeter that houses the approaching lobster when contact is recorded</td>
</tr>
<tr>
<td>Large lobster position</td>
<td>The 90° quadrant of the trap that houses the majority of the large lobster when contact is recorded</td>
</tr>
<tr>
<td>Entry</td>
<td>Lobster releases grip on the neck and is inside the trap</td>
</tr>
<tr>
<td>Escape</td>
<td>Lobster that had previously entered the trap exits via neck or escape gap</td>
</tr>
</tbody>
</table>

Data Analyses

In addition to analysing the categories of behaviour observed, a number of variables were calculated using the observed behaviours in order to investigate the affect of the large lobster inside the trap on the small lobsters approaching the trap. These were: a) the mean proportion of approaches that resulted in entries; b) the mean duration of each approach; c) the mean duration of contact with the trap; and d) the quadrant that the small lobster initially made contact in with relation to the position of the large lobster (see below, Figure 3.1).

The duration of an approach was measured as the time that elapsed between when a lobster approached the trap and when the lobster either retreated from the trap or
entered the trap. The duration of each contact with the trap was measured as the
time that elapsed between the initial contact with the trap and the time the lobster
climbed off the trap or entered the trap. When each contact with the trap by a
small lobster occurred, the position of the large lobster was noted and the
quadrant in which contact occurred was recorded as: A: the same quadrant as the
large lobster; B: the clockwise quadrant to the large lobster; C: the quadrant
opposite the large lobster; and D: the anti-clockwise quadrant to the large lobster
(Figure 3.1). Data were only obtained for the large male and female treatments as
there was no large lobster seeded in the control trap and the null hypothesis was
that there would be no difference in number of contacts between quadrants.

One-way ANOVA tests were used to test for significant differences between
treatments and Tukey HSD tests were performed post-hoc to determine which
groups differed significantly. Prior to ANOVA, the contact duration and approach
duration data were log transformed to correct right skewness and the percentage
of approaches that resulted in entries data was arcsine transformed. Paired T-tests
were used to test for significant differences between sexes within treatments. A
chi-squared test was used to determine whether the proportion of small lobster
contacts differed amongst quadrants in relationship to the position of the large
lobster, assuming an expected value of 25 % of observations in each quadrant i.e.
the contact quadrant was independent of the presence of the large lobster.
Figure 3.1. The definitions of quadrants used to record the position that a small lobster made contact with the trap in relation to the position of the large lobster. Quadrant of contact: A - same quadrant; B - clockwise quadrant; C - opposite quadrant; and D - anti-clockwise quadrant.

3.3 Results

During the three trials, a total of 97 approaches were made towards the trap in the control treatment, resulting in seven small lobsters entering the trap and four lobsters being retained (Figure 3.2). This compares with a total of 117 approaches in the large male treatment, resulting in three lobsters entering the trap, all of which were retained (Figure 3.2). The large female treatment had a total of 76 approaches and seven of the eight small lobsters that entered the trap were caught (Figure 3.2). Thus, lobsters escaped from the traps four times in total: three in the control treatment and once in the large female treatment (Figure 3.2) and this represented 22.2 % of all lobsters that entered the traps. A total of 24, 29 and 32 contacts with the trap were made by small lobsters in the control, large male and large female treatments respectively (Figure 3.2). There was no significant difference between treatments for the number of approaches ($F_{2,33} = 0.79, P = 0.464$), the number of entries ($F_{2,33} = 2.46, P = 0.101$), the number of escapes
(F$_{2,33} = 2.03$, $P = 0.148$) or the number of contacts with the trap (F$_{2,33} = 0.23$, $P = 0.794$).

The number of approaches to the trap peaked sharply after the onset of darkness at 18:00 h in all three treatments (Figure 3.3a), after which, the number of approaches decreased throughout the night with a small peak again after midnight for the control and large male treatments (Figure 3.3b, c). In the large female treatment, the number of approaches continued to decrease throughout the night (Figure 3.3d). A total of 20.4 % of all approaches ($n = 290$) and 38.9 % of all the entries ($n = 18$) occurred during periods of simulated daylight (06:00 – 18:00 h). Almost all diurnal activity during the daylight period occurred shortly after the addition of bait, between 12:00 and 18:00 h ($n = 57$), with nearly no observed activity between 06:00 and 12:00 h ($n = 2$). The high proportion of entries during
Figure 3.3. The total number of approaches (solid line) and entries (x 10) (dashed line) for each hour, pooled over three experiments, for a) all three treatments, b) the control, c) the large male and d) the large female treatment (shaded area indicates period of darkness).
periods of light were mainly due to two lobsters which both entered the trap before 17:00 h in all three tests and contributed almost a quarter (23.7%) of all diurnal approaches.

The mean proportion of approaches that resulted in entries was higher in the large female treatment (0.114 ± 0.030 [1SE]) than in the control (0.072 ± 0.038) and large male treatments (0.025 ± 0.013), however these differences were not significant ($F_{2,6} = 1.71, P = 0.259$) (Figure 3.4). The mean proportion of approaches that resulted in retained lobsters differed from the proportion that entered in the control (0.041 ± 0.020) and large female (0.102 ± 0.033) treatments but not in the large male as there was no escapes in this treatment and all lobsters that entered the trap were retained (Figure 3.4).

![Figure 3.4. The mean proportion of approaches (± 1SE) that resulted in: entries (white) and retained lobsters (shaded) for each treatment.](image-url)
The mean approach duration was significantly longer for lobsters in the large female treatment (340.0 ± 53.1 s) than individuals in the control (232.4 ± 33.6 s) or large male (192.0 ± 23.0 s) treatments ($F_{2, 270} = 3.84, P = 0.023$) (Figure 3.5). Post-hoc analysis revealed that the mean duration of approach was significantly shorter for the large male than the large female treatment ($P = 0.020$). The mean approach duration for small females was longer than that for small males in all three treatments and was significantly longer in the large male ($t_{110} = -2.819, P = 0.006$) and female treatments ($t_{66} = -2.474, P = 0.016$) but not in the control ($t_{91} = -1.133, P = 0.260$).

The mean duration of contact with the trap for the control treatment (106.4 ± 18.6 s) and large male treatment (103.6 ± 19.4 s) were similar and significantly shorter than that for the large female treatment (230.0 ± 33.8 s; $F_{2, 82} = 4.46, P = 0.015$) (Figure 3.5). Tukey’s test found that the mean duration of contact for the large male treatment was significantly shorter than the large female treatment ($P = 0.018$). The mean contact duration in each treatment did not differ significantly between the sexes (control: $t_{22} = 1.661, P = 0.111$; large male: $t_{27} = -0.524, P = 0.605$; and large female: $t_{30} = -1.032, P = 0.310$).
Figure 3.5. The mean duration (± 1SE) in seconds of each approach (white) and contact with the trap (shaded) for each treatment.

The proportion of lobsters making contact with the trap did not differ significantly among quadrants in relationship to the position of the large lobster for either the large male ($X^2_3 = 2.00, P = 0.57$) or large female treatments ($X^2_3 = 2.03, P = 0.57$). Within treatments, the mean number of approaches per individual by small female lobsters were almost double that of males in the control (small male: $5.6 ± 2.7$; small female: $9.9 ± 2.7$) and large female treatments (small male: $4.2 ± 1.5$; small female: $7.9 ± 2.6$). In the large male treatment however, male and female lobsters made a similar number of approaches (small male: $10.6 ± 4.3$; small female: $9.1 ± 2.3$) (Fig 3.6.) but these differences were not significant in any of the three treatments (control: $t_{10} = -1.074, P = 0.308$; large male: $t_{10} = 0.326, P = 0.751$; and large female: $t_{10} = -1.085, P = 0.304$). The number of entries into the trap also did not differ significantly between sexes for any of the three treatments (control: $t_{10} = 0.090, P = 0.930$; large male: $t_{10} = 0.968, P = 0.356$; and large female: $t_{10} = -0.381, P = 0.502$).
No agonistic interactions were observed between the large trapped lobster and small approaching lobsters. However, a total of 23 agonistic interactions between small lobsters outside the trap were observed that usually resulted in the submissive lobster retreating out of the trap camera view (Table 3.3). The proportion of interactions shows that in the majority (69 %) of agonistic interactions, the aggressive lobster was male and the submissive was female.

Table 3.3. Proportion of agonistic interactions between small lobsters divided into sex and dominance (aggressive or submissive).

<table>
<thead>
<tr>
<th>Submissive lobster</th>
<th>Aggressive lobster</th>
<th>Total (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Male</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>Female</td>
<td>0.69</td>
<td>0.17</td>
</tr>
<tr>
<td>Total</td>
<td>0.78</td>
<td>0.21</td>
</tr>
</tbody>
</table>
The total number of approaches differed significantly between the small individuals ($F_{11, 24} = 3.05, P = 0.011$; Figure 3.7) and post-hoc analysis found that only two lobsters (1F and 4F) differed significantly at an individual level ($P = 0.040$).

Figure 3.7. The number of approaches for each individual small lobster in the control (black), large male (white), and large female (shaded) treatments ($M = \text{male}; F = \text{female}$).

3.4 Discussion

*In situ* observations of *P. cygnus* (Jernakoff, 1987) and other palinurid lobsters, such as *P. argus* (Bertelsen and Hornbeck, 2009) and *J. edwardsii* (MacDiarmid *et al.*, 1991), as well as non-palinurid species of lobster including the European lobster, *Homarus gammarus*, (Smith *et al.*, 1998), support the suggestion that lobsters typically forage at night (Herrnkind, 1980). The activity of the small *P. cygnus* in the laboratory experiments in this study was observed to be predominantly nocturnal ($n = 231$) with a large peak in activity immediately after dark. These observations of peak activity are similar to those by Morgan (1978) in
a laboratory study of juvenile *P. cygnus*. In his study, Morgan placed a single lobster in a tank without shelter and measured the activity rate using an actograph that recorded the number of contacts a lobster made with an open circuit wire.

Peak activity after dusk has also been observed in the laboratory for the cape rock lobster, *Jasus lalandii*, (Fielder, 1965) and *P. argus* (Lipcius and Herrnkind, 1982), and also in field observations of adult *P. argus* (Weiss et al., 2008). In contrast, *in situ* electromagnetic tagging observations of juvenile *P. cygnus* by Jernakoff (1987) found nocturnal activity to be constant throughout the night. The observations by Jernakoff are likely to be more representative of the activity pattern of *P. cygnus*, as activity may decline earlier in the night in a laboratory setting due to the spatial constraints associated with aquaria. In the current study, the adding of fresh bait to the trap may account for the initial peak in activity. The decline in activity throughout the night is likely due to captured lobsters being removed from observation.

*Panulirus cygnus* does not typically display diurnal activity *in situ* (Cobb, 1981; Jernakoff, 1987; Chapter 2.3). However, spiny lobsters kept in a predator free environment show an increase in diurnal activity (Lozano-Álvarez, 1996). This factor, and the possibility that lobsters learned to become active in the laboratory when fed during the day for an extended period, may account for the observed activity during the simulated daylight hours in the current study. Waddington *et al.*, (2005) also observed that *P. cygnus* in the laboratory were active during the day, although in that study the amount of activity during periods of light was much more marked than the current study.
Morgan (1978) found that activity did not differ significantly between sexes in laboratory studies. However, the reproductive state of the females in that experiment was not noted. Reproductive state was shown to affect the activity of *P. cygnus* by Waddington *et al.* (2005), who used video observations of tank experiments. They showed that unmated mature females (with ovigerous setae) and those with early stage eggs moved significantly more than males and females with late stage eggs. *In situ* observations of juveniles found that males were more active than females (Jernakoff, 1987). The current study found no significant difference in activity between the sexes; however, it is interesting to note that, although not significant, females appeared to display more movement than males for all treatments except the large male.

Lobster traps do not retain every lobster that enters; Jury *et al.* (2001) observed that 94% of *H. americanus* which entered a trap subsequently escaped before the trap was hauled. In contrast to the traps used in the *P. cygnus* and *J. edwardsii* fisheries which have dorsal entrances, the traps used in the *H. americanus* fishery have side entrances which may offer more chance of escape. Green (2002) used remote video to observe the behaviour of *J. edwardsii* around a trap and found that 24% of lobsters were able to escape through the entrance. The current study found the escape rate of *P. cygnus* (22%) to closely match that of *J. edwardsii*, although it must be noted that the trap used in Green (2002) was fitted with a plastic collar neck which is designed to prevent escape.

The significantly shorter periods of approach and contact with the trap in the large male than the large female treatment could potentially indicate an agonistic
mechanism of the large male around the trap particularly when the low proportion of approaches resulting in entries for this treatment is also considered. Conversely, these results could also indicate an attractive quality in the large female treatment, as the proportion of approaches that resulted in entries for this treatment was higher than that of the control and male treatments.

Studies of other decapod species have observed a decline in approaches to the trap as catch increases (known as trap saturation) and suggest that it may be due to intimidating occurring at a distance from the trap due to chemical signals (Miller, 1978a; 1978b, cited in Miller, 1990). Ammonium, an excretory product of decapods, has been shown to decrease the feeding response of the Californian spiny lobster, *Panulirus interruptus*, and may be responsible for the inhibition (Zimmer-Faust et al., 1984). If the large *P. cygnus* individuals inhibited smaller individuals at a distance through chemosignals, it would be manifest in these observations as a smaller number of approaches from small lobsters in the large lobster treatments. However this did not occur and as such, the current study found no inhibition effect occurring at a distance from a trap containing a single large *P. cygnus*.

Miller (1990) suggests that agonistic encounters occurring outside the trap are probably more influential on catch rates than those between animals inside and animals outside the trap. In the current study, agonistic interactions between the small lobsters outside the trap were dominated by males, usually over females. However, this did not lead to significantly higher entries or approaches by males and did not cause significant trap inhibition. *In situ* observations from Chapter 2
of this study also suggest that some inhibition may occur outside the trap in *P. cygnus*; it would be interesting to observe such interactions in an environment in which food resources were scarce and/or lobster densities were high. Thomas *et al.* (2003) reported that agonistic behaviour and size dominance in *J. edwardsii* increased as feed availability decreased. Thus, this experiment could be replicated using underfed large and small lobsters as subjects in order to amplify any affect on behaviour and more closely depict *in situ* circumstances where food availability is usually limited (Chittleborough, 1975).

A number of improvements could have been made to increase the robustness of this study. These include ensuring that all three treatment tanks were identical in dimension and also using a preliminary dye dispersion assessment to determine difference in odour plumes. However, these improvements to the differences between experimental tanks may not have been necessary if the treatments were also rotated between the tanks in the opposite direction to the groups of small lobsters. A larger pool of lobsters would have enabled only lobsters in the intermoult stage to have been used and new animals for each replicate of the experiment. With a larger set of lobsters it may have allowed for the sex of the lobsters to be better tested as a factor in the design. As stated earlier, underfeeding the experimental lobsters prior to testing may have amplified the results, possibly producing greater disparity in the results between treatments.

The results from the current study did not show any significant attraction or inhibition effect from large lobsters but they appear to indicate that the behaviour of small lobsters is somewhat influenced by the presence of a large lobster inside
a trap. However, because of some of the issues about the experimental design as outlined above, particularly the low number of replicates, and the use of experienced animals, the results cannot be regarded as being definitive. A more robust laboratory study, with an increased replication and using naive animals for each test, coupled with catch rate data gathered from in situ trapping with large lobsters seeds, similar to Ihde et al. (2006), would presumably provide a much clearer indication of the effect of trapped large lobsters and trap saturation on the catch rates of smaller P. cygnus. Any influence on the trap behaviour of smaller lobsters is likely to affect their catchability and ultimately the catch rates of these animals. With catchability commonly used in surveys to ascertain estimates of population size and structure (Waddington et al., 2005), alterations to trap behaviour may result in inaccurate estimates and give a false indication of the population structure. Thus, for confident predictions of population structures through trapping surveys a complete understanding of the trap dynamics of P. cygnus is required, including the effects of con specifics on behaviour.
Chapter 4

General Conclusions

This study outlined the advantages and shortcomings of both the *in situ* and laboratory observations of behaviour. *In situ* observations provided direct observations of lobsters interacting with a baited trap but many variables were not able to be controlled, such as water movement and lobster density, and these limited the conclusions that could be drawn from the results. These variables were able to be controlled in the laboratory but the results gathered may not be indicative of *in situ* behaviour and density would be higher than in a field environment (Miller and Addison, 1995). An example of lobster behaviour in the laboratory not representing *in situ* behaviour is demonstrated when comparing the activity pattern of the lobsters between the two sections of this study. During the laboratory experiments lobsters were active during periods of daylight; this was not observed in the *in situ* study. For this reason, it is best that results from laboratory experiments should be confirmed in the field (Miller and Addison, 1995).

The *in situ* observations in this study found no difference in the trap behaviour of migratory white *P. cygnus* in comparison to that of the more sedentary red phase and identified possible influences on catchability that would be useful to investigate, such as the prevalence of octopus in and around the trap. Large amounts of water movement appeared to deter lobsters from approaching the camera trap during the reds phase through an unknown mechanism which would need to be addressed in order for robust observations to be gathered. The
laboratory observations found that the small approaching lobsters spent a significantly longer time on and around a trap containing a large female than a trap containing a large male. However, this did not affect the number of entries by the small lobsters or the catch rates, which did not differ significantly between the control trap (no large lobster), the large male and large female traps. As such, a large trapped lobster does not appear to influence the catchability of the approaching small lobsters.

The higher number of agonistic interactions observed over a much shorter period in the laboratory \((n = 23)\) than from \(in\ situ\) observations \((n = 7)\) is likely attributable to the greater field of view afforded by the cameras in the laboratory and possibly the higher density of animals. These interactions were shown to be dominated by males in the laboratory and often resulted in the retreat of the submissive lobster in both studies, although it could not be determined whether this affected catchability. Further study of these interactions would be useful in elucidating the influence that aggressive behaviour around a baited trap may have on the catchability of certain lobsters.

A number of problems were encountered in this study that lead to a low number of observations and high variability within some of the data. Improvements would include deploying the \(in\ situ\) video system in a more sheltered sampling area or determining the mechanism that appeared to deter lobsters in high water movement. With additional funding and time, a more robust laboratory study to test the influence of conspecifics on the catchability of \(P.\ cygnus\) could be
performed. This would involve testing the behaviour and catchability of individuals across a range of sizes when interacting with conspecifics around the trap and also testing the influence of trap saturation by measuring the approach and entry rates of lobsters to a trap containing a range of lobster biomass.

Ultimately, this study has demonstrated how a relatively inexpensive video system can be used to deliver direct observations of lobsters in situ. The study has also identified the potential limitations of the current system with regards to water movement and catch rate and may provide a reference for future studies using similar systems. Direct observations of lobster behaviour are useful for understanding the catchability co-efficient ($q$) and may lead to improvements in stock assessment and gear efficiency.
References


