FRDC FINAL REPORT

ROCK LOBSTER ENHANCEMENT AND AQUACULTURE SUBPROGRAM: EVALUATING THE RELEASE AND SURVIVAL OF JUVENILE ROCK LOBSTERS RELEASED FOR ENHANCEMENT PURPOSES

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November 2004

FRDC 2000/185

Australian Government
Fisheries Research and Development Corporation

ROCK LOBSTER ENHANCEMENT & AQUACULTURE SUBPROGRAM

NIWA
Taihoro Nukurangi

Gardner, Caleb.
Rock lobster enhancement and aquaculture subprogram : evaluating the release and survival of juvenile rock lobsters released for enhancement purposes.

Bibliography.
Includes index.
ISBN 1 86295 189 6.

1. Spiny lobsters - Tasmania. 2. Mariculture - Tasmania. 3. Aquaculture - Tasmania. I. Tasmanian Aquaculture and Fisheries Institute. II. Fisheries Research and Development Corporation (Australia). III. Title. (Series : FRDC Project ; no. 2000/185).

639.5409946

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2000/185 Rock lobster enhancement and aquaculture subprogram: evaluating the release and survival of juvenile rock lobsters released for enhancement purposes

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1. Objectives

1. To develop release protocols to minimise mortality based on the anti-predator behaviour of wild and cultured juvenile *J. edwardsii*.
2. To provide recommendations on release (micro) habitats for optimising the benefit of enhancement operations.
3. To evaluate the conclusions of objectives 1 and 2 in pilot scale enhancement experiments.

2. Non-Technical Summary

OUTCOMES ACHIEVED

This project developed methods to optimise the survival of juvenile rock lobsters released for enhancement purposes. An immediate application is for the release of juveniles in Tasmania as part of puerulus harvest operations. These operations collect settling puerulus for aquaculture and are obliged to return a portion of the juveniles after 12 months (35 g) to compensate for those that would have naturally survived.

Although juvenile rock lobsters in culture tend to forage in open areas during daylight hours, feeding at dusk can induce more normal foraging patterns. Initial concerns that juveniles reared in tanks would fail to recognise predators were unfounded. We found that the juveniles avoided predators in the same manner as wild controls immediately after release onto coastal reef. Unlike overseas enhancement operations with clawed lobsters, predation around the time of release was not significant and release in to cages did not appear to be necessary to exclude predators. Survival was highest when releases were conducted at night and in winter.

Suitable release habitats can be adequately selected by divers on the basis of qualitative factors such as presence of other juveniles, abundance of shelter, and good algal cover. There did not appear to be justification for expensive surveys of potential predation rates when selecting sites for release.

An initial period of movement following release, particularly in the first 24 hours, was

detected in all pilot-scale releases. This movement was occasionally over 1 km and had the potential to reduce survival as juveniles were not constrained by reef boundaries and walked into exposed sandy areas, sometimes failing to find shelter by morning. Release into cages for 48 hours in areas of complex reef structure, or release onto large areas of reef overcame this problem.

Survival of cultured juveniles was compared to that of wild controls in pilot scale releases at 4 sites with over 2200 juveniles. Estimates of the survival of cultured juveniles were equivalent to wild controls after 48 hours. At one site, survival of cultured juveniles appeared to be lower than that of controls in the first 48 h post release, although this appeared to be due to movement. That is, released juveniles appear to have disappeared from surveys by walking rather than from predation. Tethering results provided an upper estimate of predation during the first 48 hours of 5%.

Survival of southern rock lobsters in enhancement operations appears to be high and can be optimised by simple protocols during release. These results have application in addition to the release of juveniles and have recently been applied in pilot-scale translocation of larger mature lobsters in Tasmania.

The release of juvenile lobsters for enhancement purposes was initiated in Tasmania on a pilot scale as part of puerulus harvest operations. The puerulus stage of southern rock lobsters is reached after an 18-24 month larval life following which puerulus can be captured on collectors that mimic natural reef. After a further 12 months in culture, juvenile southern rock lobsters grow to around 35 g, which is the size of animals released in this study. This around the size at which southern rock lobsters begin to become sociable and cohabit in dens. It is believed that the release of juveniles at this size allows them to avoid the period of high mortality that occurs during the first 12 months with natural survival during this period estimated at less than 10%.

This study aimed to develop release protocols for rock lobster enhancement operations that optimised survival. Part of this research involved large-scale releases that simulated release operations conducted for enhancement purposes. Research was conducted in both Tasmania and New Zealand to utilise expertise across the broad range of behavioural and ecological processes that affect survival of juvenile lobsters.

Release protocols to minimise mortality

An initial concern was that the altered behaviour of juvenile lobsters reared in tanks would affect their survival after release. In particular, juveniles cultured in tanks tend to emerge from shelter during the day and forage in open areas. This behaviour does not occur in the field and was considered to represent a probable risk of increased predation. This issue was addressed in two ways. First, we examined methods for initiating more natural behavioural patterns of lobsters in tanks during the grow-out phase. Secondly, we examined the behaviour of "naïve" lobsters following release onto natural reef: did they respond normally to predators?

We found that the foraging and emergence patterns of juvenile lobsters in captivity could be made equivalent to natural patterns by the controlled addition of a predator, such as a fish. This acclimatisation to a predator is used widely in enhancement operations for finfish where survival after release is subsequently improved. Although

the addition of a predator produced normal foraging behaviour, it also reduced growth and condition as juveniles spent more time sheltering rather than feeding. A more appropriate solution for culture situations was to supply feed to lobsters at dusk. This simple change in husbandry could be achieved using automatic feeders that dispensed food at dusk and was highly effective for inducing normal foraging behaviour.

Although it was possible to modify the behaviour of juveniles, subsequent experiments demonstrated that these steps are not necessary for enhancement operations. Key findings from video observations of released juveniles were that juveniles grown in captivity appear to retain an innate ability to recognise and respond appropriately to predators. This is an encouraging result for enhancement operations and also suggests that juvenile lobsters do not need to be habituated to predators prior to release. The risk of cannibalism in culture may help in maintaining appropriate predator avoidance behaviour.

The timing of predation was examined in both Tasmania and New Zealand to identify the times of day that should be avoided during release operations. This issue was examined in two ways. Lobsters were tethered to stop watches so that the timing of predation was recorded automatically. In addition, released juveniles were monitored by remote video with infra-red illumination that was invisible to both juvenile lobsters and potential predators. Both methods confirmed that mortality of released juveniles was highest in the first two hours after release and around dawn. Best survival was between midnight and dawn. Consequently, it is recommended that release operations aim to release animals around midnight.

Releases of juvenile lobsters in enhancement operations in Europe have been impacted by high predation during the release of juveniles. We examined this issue using diver and camera observations of pilot-scale releases. In Tasmania, these showed that while predation occasionally occurred immediately following release, the process of releasing lobsters did not attract large numbers of predators. This was caused by behaviour of the dominant daytime predator in Tasmania: male blue-throated wrasse (*Notolabrus tetricus*). As these species are fiercely territorial, pilot scale releases generally occurred within the range of only 1 or 2 fish, resulting in low predation pressure from these species at the time of release. These fish often actively excluded other predators from the release site to maintain their territory. Predation during daylight releases in New Zealand had the potential to be higher than in Tasmania because of the presence of a small diver-positive wrasse (spotties; *Notolabrus celiodotus*) that schooled when they attacked juvenile lobsters.

One method for improving survival of lobsters at release, if this was of concern, is to place the animals inside cages that exclude predators so that they can find shelters without risk of mortality. We released lobsters into mesh cages of 3m x 3m placed on reef for 48 h. These increased the number of lobsters resighted in later dive surveys, although acoustic tracking suggested that this was largely due to suppression of a 'flight' response rather than a decrease in mortality. Lobsters that had been caged for 48 h were less likely to move beyond the area searched by divers than uncaged lobsters. The usefulness of cages is dependent on habitat complexity. Where there are insufficient hides for all lobsters within the caged area (likely in commercial-scale releases), the effectiveness of cages is diminished. This is because those lobsters without suitable shelters tend to disperse widely as soon as the cage is removed. Given the apparently high survival of lobsters released directly by divers, the prescription that

cages be used for commercial release would be an extremely conservative move likely to incur considerable costs to operators.

During the planning of commercial releases of juveniles in Tasmania there was concern that survival may be lower in some seasons than others. We compared survival of juveniles released in winter and summer at sites in 2 bioregions in Tasmania. Sites in different bioregions were selected to provide diversity of potential predators. At the southern site (Adventure Bay) there was no seasonal difference in predation rate. At the northern site (Rheban Beach) predation pressure was significantly higher in summer. The conclusion for these experiments is that winter releases are preferred.

In summary, optimal release protocols can be based on a few simple elements. Optimal timing for releases appeared to be late in the night during winter months. Juveniles reared in captivity appeared to respond appropriately to predators after release. A highly conservative release strategy would include conditioning of juveniles to nocturnal foraging prior to release and caging of animals on complex reef for a period of 48 h before release.

Selecting release (micro)habitats for optimising the benefit of enhancement operations

Another objective of the project was to provide recommendations on release habitats. This involved comparing the survival of juveniles released onto a range of habitats. Note that we only selected healthy rocky reef ecosystems for release sites, as this was a more realistic scenario for future commercial-scale releases. A large amount of preliminary research was involved in the development and testing of methods to determine differences in survival between habitats.

We examined several methods to compare survival between habitats. Each had varying levels of complexity, expense and power. These techniques were: (1) Baited video drops; (2) Tethering trials; and (3) Pilot-scale releases. For methods 1 and 2 it was necessary to know the identity of predators, which we established using a remote video system with infrared illumination.

The baited underwater video technique was a possible method for testing sites prior to large scale releases. It is a quick and simple method involving dropping a frame with a video and bait from a vessel, and recording the number of fish predators attracted within a period of time, say 15 minutes. Although this proved to be effective for assessing the abundance of finfish predators, it failed to measure the total abundance of predators. This was because a high proportion of predation events were by octopus. Consequently, we failed to detect any correlations between predation of juvenile lobsters and fish abundance measured by baited video.

Another method to compare between sites was the measurement of survival of juvenile lobsters that were tethered so that they couldn't roam large distances away from the site of release. Video observations of these lobsters suggested caution in the interpretation of tethering results. Tethered lobsters were monitored by video at 4 sites in Tasmania. Surprisingly, large lobsters and a crab species (*Nectocarcinus tuberculosis*) were found to be significant predators of tethered juvenile lobsters. Validation trials in a mesocosm or 'artificial reef' showed that this was largely an artefact of tethering – large lobsters and crabs were generally unable to capture untethered lobsters. This implies that for

tethering results to be used to compare habitat types, there must also be video observations to identify the predator.

In selecting sites for tethering and pilot-scale release trials we targeted only sites that we believed appropriate for releases. Sites were selected on the basis of the presence of wild juvenile lobsters, an obvious abundance of appropriate sized shelters for the size of lobster being released and a moderate to high algal density to provide cover when lobsters were first released. At each site, microhabitat data including rugosity, algal density and species abundance, den size and distance from the reef edge were collected. Variability in predation pressure between sites as measured by tethering was low, and few correlations were found with microhabitat variables. These results, combined with high apparent survival of lobsters, suggest that our selection criteria for sites were appropriate and that there is little to be gained from the added expense of microhabitat surveys when selecting sites for commercial release.

One aspect that appears to provide guidance in the selection of habitat for releases is the effect of reef size. Acoustic tracking and modelling of movement from pilot-scale releases revealed that lobsters exhibit a 'flight' response when first released. During this period they do not respond to habitat boundaries, and are likely to move onto sand. Apparently reduced survival at one pilot-scale release site (Adventure Bay), where the reef was small and isolated from other areas of reef, appeared to be due to lobsters leaving the reef during this 'flight' response period. Diver observations at that site confirmed this with some juveniles found exposed in areas of open sand on the day after the release. We propose that lobsters should be released on large areas of reef rather than isolated or patch reef. If the area of reef available for releases is limited, seafloor cages could be employed to suppress the 'flight' response.

In summary, suitable release habitats can be adequately selected by divers on the basis of presence of other juveniles, abundance of shelter, and good algal cover without the need for expensive surveys of potential predation rates. Large-scale releases should be conducted on large areas of contiguous reef, as sand boundaries do not constrain movement in the initial 48 h after release.

Evaluating survival of juveniles in pilot-scale releases

All pilot scale releases of cultured lobsters were combined with tagging of control, wild juveniles and survival was measured relative to those wild juveniles. This was because the object of releasing juveniles was not to eliminate predation, only to reduce it to the same level as experienced by wild juveniles. Pilot scale releases were conducted at 4 sites that spanned 2 bioregions.

A total of 2244 lobsters were released and all were individually marked with antennal tags. These tags allowed divers to identify the juveniles without capturing them. The survival of juveniles after release was monitored by a series of intensive diver surveys on the release reef and also neighbouring areas. Survival was estimated from this resighting data using modern survival estimation models (Cormack-Jolly-Seber and multistate derivatives). We used these models in an attempt to separate movement from survival, although it is clear that our estimates of survival remained biased lower by movement. That is, our estimates of "mortality" include some individuals that left the site by walking, rather than dying.

Initial releases took place on isolated patch reefs with the aim of retaining lobsters within an area that could be readily searched by divers. This approach was later changed to release on contiguous reef when it was apparent that a sand edge was not a barrier to lobsters movement during their initial 'flight' response. Models that included movement parameters (multistate models) and acoustic tracking revealed that on-grown lobsters tend to move further than wild-caught lobsters during the initial 'flight' response.

At 3 of the 4 sites, there was no detectable difference between survival of cultured and wild-caught lobsters, suggesting that any artefacts of the ongrowing and release processes had no effect at these sites. This result was encouraging for enhancement operations as it implied that the risk of mortality for released juveniles rapidly became equivalent to that of a wild juvenile.

At the 4th site (Adventure Bay), apparent survival was lower for on-grown lobsters in the first 24 h post release. Video-referenced tethering trials showed that predation pressure at that site was no higher than at other sites. However, this site differed from the others in that it was the smallest area of reef, with proportionally more 'edge' due to it's long and narrow shape. The reef was surrounded by large expanses of sand with little neighbouring reef. The observed difference in apparent survival was likely to be caused by these site differences. As naïve lobsters move further than wild-caught lobsters on release, a larger number will move off the reef and onto sand. As there was little other reef surrounding the release reef, mortality amongst lobsters that leave this reef was apparently high.

At 3 of the 4 sites, apparent survival was lower for the first 24 h post release than for the remainder of the trials. Evidence from diver and camera observations following release, maximum likely predation estimates from camera-referenced tethering trials, and an experiment using seafloor cages in combination with acoustic tags suggest that this lower "survival" was due to movement away from the survey site rather than high predation when released.

In summary, survival of released juveniles appears equivalent to that of wild lobsters of an equivalent size after 48 h post release. Estimates of survival of cultured juveniles were sometimes lower than that of wild controls in the first 48 h post release, although these occasions appeared to be biased to some extent by movement. That is, released juveniles appear to have disappeared from surveys by walking rather than from predation.

KEYWORDS: rock lobster enhancement, *Jasus edwardsii*, survival estimation, mark-recapture.

3. Acknowledgments

This research was completed with financial support from FRDC through the Rock Lobster Enhancement and Aquaculture Subprogram (RLEAS) and the two collaborating research organisations where the research was based: The Tasmanian

Aquaculture and Fisheries Institute (TAFI; Hobart, Australia) and the National Institute for Water and Atmospheric Research (NIWA; Wellington, New Zealand).

Additional financial support was provided by the Foundation for Research Science and Technology (FoRST; contract number CO1X0209), the Ian Potter Foundation, and the TAFI Scholarship Scheme.

Numerous people made substantial contributions to the project including:

John Hunt, Sam Ibbott, Shane Fava, Pip Cohen, Rob Kilpatrick, Andrew Cawthorn, Dr Bradley Crear, Brett Hislop, Craig MacKinnon, Carl Waterworth and Simon Wilcox assisted with field operations.

Natalie Rathke, Mark Grubert, Justin Ho and Ed Smith in maintaining tank based experiments.

Miles Lawler, Vanessa Haley and Dr Alan Jordan of SeaMap Tasmania for mapping of sites (http://www.utas.edu.au/docs/tafi/seamap/).

Dr Alistair Dunn and Prof. Craig Johnson provided statistical advice.

Dr Roger Pradel provided advice and software for GOF testing of multistate data.

Improvements to draft manuscripts were made with the assistance of several reviewers including Dr Hilary Oliver and Prof. Craig Johnson.

Brian Eldridge and Margaret and Tony Ibbott provided field stations at Opossum bay and Orford.

Ken Downing assisted through the design and construction of the chronographic tethering devices.

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4. Background

The high market value of lobsters around the world over has driven interest in increasing production. Options to increase production include improved fisheries management (eg quota increases in South Australia and Tasmania), aquaculture (Kittaka and Booth, 1994; Phillips and Evans, 1997), and fishery enhancement (Conan, 1986; Addison and Bannister, 1994).

Examples of proposed or current enhancement activities include:

- Direct enhancement of local reefs with juveniles collected and ongrown as puerulus. In New Zealand this is of special interest for local indigenous fishing zones (taiapure and maitaitai).

- Shifting of animals between areas in the fishery to achieve benefits such as growth, market quality or regional egg production. In Tasmania there is considerable industry support for shifting animals from low growth areas in the SW to high growth areas in the NW of the State.

- Release of juveniles collected as puerulus and ongrown for 12 months. This is currently a requirement of the pilot-scale puerulus ongrowing industry in Tasmania where release of ongrown juveniles is intended to compensate for puerulus harvest.

Regardless of the source of animals, these enhancement operations have a common need: that survival of released animals be optimal.

The need to optimise survival of released juveniles is already current in Tasmania where licences for the collection of wild pueruli were issued. Only one operator has attempted pilot-scale collection to date with impressive catches of several thousand puerulus from a deployment of 200 collectors serviced only twice. While large-scale collection of puerulus and ongrowing in culture appears viable, there is concern amongst fishers and managers on impacts of collection on wild stocks. This concern is based in part on evidence of a close relationship between puerulus settlement and fishery catch in subsequent years (Phillips, 1986; Gardner *et al*., 2001). Impacts on the wild resource are addressed through "reseeding" or the release of a proportion of the juveniles ongrown in culture.

Reseeding provides a mechanism whereby the wild stock can be maintained or enhanced in parallel with the development of an ongrowing industry. Reseeding involves the release of a proportion of collected pueruli after a period of ongrowing. When this proportion equals natural survival over the same period, and reseeded animals survive and assimilate fully into wild populations, the direct effects of puerulus removal are neutralised. If the number of reseeded animals exceeds natural survival to the same stage, stock enhancement is achieved.

There is little published data on the mortality of spiny lobster pueruli settling onto reef. Natural mortality of *Panulirus argus* for the year following settlement is estimated at about 97% (Herrnkind and Butler, 1994). Small-scale experiments yielded highly variable but similar results for *Jasus edwardsii* (Edmunds, 1995). In contrast, mortality

rates of less than 5% for the same period have been achieved with pueruli ongrown in tanks (Crear *et al*., 1998; Kingston, 1999). This large difference between captive and wild survival underpins the potential of reseeding to compensate for puerulus harvest.

The research conducted here involved collaboration between Tasmanian and New Zealand research teams. Both had conducted previous research on enhancement of rock lobsters although with different emphasis. Previous research in New Zealand evaluated the feasibility of enhancement by tracking the fate of small numbers of individuals released under varying conditions, while Tasmanian research had resulted in the development of methods for the estimating survival in large batch releases. The research conducted here extended previous work by investigating factors influencing survival of released juveniles, and attempting to optimise these in pilot-scale releases.

Fundamental to the research conducted in this project was the observation that predation of hatchery-reared fish and invertebrates released into the wild tends to be substantial (Olla *et al*., 1998; Nodtvedt *et al*., 1999). Not only does the act of release disturb and agitate the individuals, which may make them more susceptible to predation, but they may not recognise predators or take evasive action (Olla *et al*., 1998). An additional problem in nocturnally active species such as rock lobsters is that tank-reared individuals may emerge from shelters at inappropriate times thereby exposing themselves to a higher risk of predation.

5. Need

Enhancement offers a mechanism to increase production of rock lobsters, both by increasing production from coastal reef and also by providing a mechanism for biological neutrality in the harvest of puerulus (thus overcoming a barrier to ongrowing). Additional benefits include the ability to increase biomass and egg production in regions considered depleted, which enhances resource sustainability.

Although the potential benefits of enhancement are broad, the value of the concept is critically affected by the survival of juveniles after release. Low survival reduces the economic benefit and also nullifies assumptions on the biological neutrality of the harvest of puerulus.

This project addressed the need for information on how to release juveniles so that survival is optimised. Future release efforts will be assisted by information on habitat choice, so that return from enhancement is maximised, in terms of animals surviving through to harvest size.

6. Overview of experiments

Seven separate experiments were designed to meet the objectives of the project. These experiments were:

Experiment 1. Anti-predator behaviour of "wild" and "naïve" juvenile lobsters. The behavioural response of juveniles when confronted by a predator was remotely via IR video. Responses were categorised and quantified to assess if naïve lobsters were able to respond appropriately. This experiment used 2% of project resources.

Experiment 2. Timing of predation on naïve juvenile *Jasus edwardsii*. The diel timing of predation was assessed in two ways. First, timing of predation in field trials was established by IR video observation. Secondly, juveniles were tethered to a automatic timers that were triggered by predators. This experiment used 3% of project resources.

Experiment 3. Emergence behaviour of "wild" and "naïve" juvenile lobsters. We investigated the effect of presence of predators (blue cod) and timing of feeding on the emergence behaviour of juvenile lobsters. Experiments were tank-based and emergence was quantified by video. This experiment used 12% of project resources.

Experiment 4. Effect of exposure to predators on anti-predator behaviour and survival of juvenile lobsters. The behaviour and survival of lobsters reared with and without predators for 12 months was contrasted with wild juveniles, when exposed to a new predator. Animals surviving 24 hours were subsequently re-tested with another predator to determine if there was any change in their response after repeated exposure. This experiment used 10% of project resources.

Experiment 5. Relative survival of juveniles out planted at replicate sites within the same habitat. Survival was measured for juveniles released in different habitats and different seasons. Animals were tethered so this experiment only provided a relative measure of survival, not an absolute measure. Additional research on the assumptions associated with tethering was undertaken to validate this research. This experiment used 10% of project resources.

Experiment 6. Comparison of moulting mortality between wild and naïve lobsters in field trials. Divers undertook pilot-scale releases of juveniles with subsequent resighting surveys. Animals that had moulted between surveys could be established because each juvenile was measured at release and tagged with both an antennal tag, which is shed at the moult, and a microwire tag, which is retained through the moult. Resighting data was then used to test if survival for the naïve group was lower through the moult than for the wild group. This experiment used 3% of project resources.

Experiment 7. Survival of released juveniles in pilot scale releases. Three large pilot-scale releases were undertaken to measure survival of juveniles in different bioregions. Juveniles were tagged and resighting surveys undertaken by teams of divers. This experiment used 60% of project resources.

7. A remote multi-camera system for *in situ* observations of lobster behaviour and ecosystem interaction

This chapter describes the video system used for field based experiments on lobster behaviour and survival described in several of the following chapters. The construction and design of the system was largely undertaken by David Mills, Stewart Frusher (TAFI) and Gerald Verdouw (Kingston Electronics). Funding was supplied by the Ian Potter Foundation.

7.1 Abstract

There are few options for obtaining information on intra and inter-species behavioural interactions between marine animals other than direct observation. Underwater video and infrared lighting can be used to overcome some of the biases and limitations associated with diver observations. We outline the assembly and application of a multi-camera underwater video system consisting largely of moderately priced components produced for the security surveillance industry. Signals from up to 8 cameras on the seafloor are processed on a floating pontoon into a single video stream and transmitted to a remote monitoring station for viewing or recording. High-red and infrared lights are used for night viewing to minimise disturbance. Experiments incorporating this system have provided high-quality data on predation and behaviour of lobsters.

7.2 Introduction

Mark/recapture tagging programs have traditionally provided data on animal movement and growth necessary for building single species population models for stock assessment and management purposes (Pollock 1991; Williams *et al*. 2002). As the resolution and complexity of models has increased, and issues related to spatial management have come to the fore, higher resolution data from acoustic telemetry tags have been incorporated into models and management regimes (Pine *et al*. 2003; Lindholm and Auster 2003). With the building emphasis on multi-species and ecosystem-based management (Constable 2001), scientists must respond by broadening further the scope of information collected. Tagging methods are limited to varying degrees in spatial resolution, and are generally incapable of resolving intra and inter-species behavioural interactions at the level of individual animals (but see Sauer *et al*. 1997). The role of these interactions in structuring ecosystems is indisputable (Piraino *et al*. 2002), but the study of such interactions in the marine environment presents considerable technical difficulties. There are few alternatives to visual observation for obtaining this information.

Direct observations of marine animal behaviour are restricted to varying degrees by the harsh operating environment. Physiological limits to dive duration and physical limits to range of visibility complicate such studies underwater. Behaviour of animals being observed is likely to be altered by the close proximity of divers (eg Rutecki *et al*. 1983). These difficulties are compounded when observing animals such as lobsters that are most active at night. Not only does diving become more hazardous, animals are also likely to respond to the presence of visible light required for observation.

Underwater video, time-lapse recording technology and lighting at wavelengths invisible to animals have been adopted to overcome these problems. The use of single camera, fixed video systems has enabled constant monitoring of a limited area for periods of hours to days (Chapman and Howard 1979; Burrows *et al*. 1999; Jury *et al*. 2001). While the use of video overcomes many of the problems and biases associated with diver observations, a single, fixed camera has a limited field of view. This problem is compounded at night when field of view is further limited by lighting. Possibilities to overcome this limitation include the use of remotely controlled cameras with zoom, pan and tilt functions, or the use of multiple cameras. We chose to adopt the latter as we believe it offers a simple, robust system with greater versatility. This paper provides details of a multi-camera system constructed predominantly using off-the-shelf items designed for the security surveillance industry.

7.3 System assembly

The camera system has 3 main component types: An underwater system consisting of cameras and lights, a surface pontoon system including power supply, video processor and transmitter and a remote monitoring system including video receiver, decoder and a recording device (Figure 1).

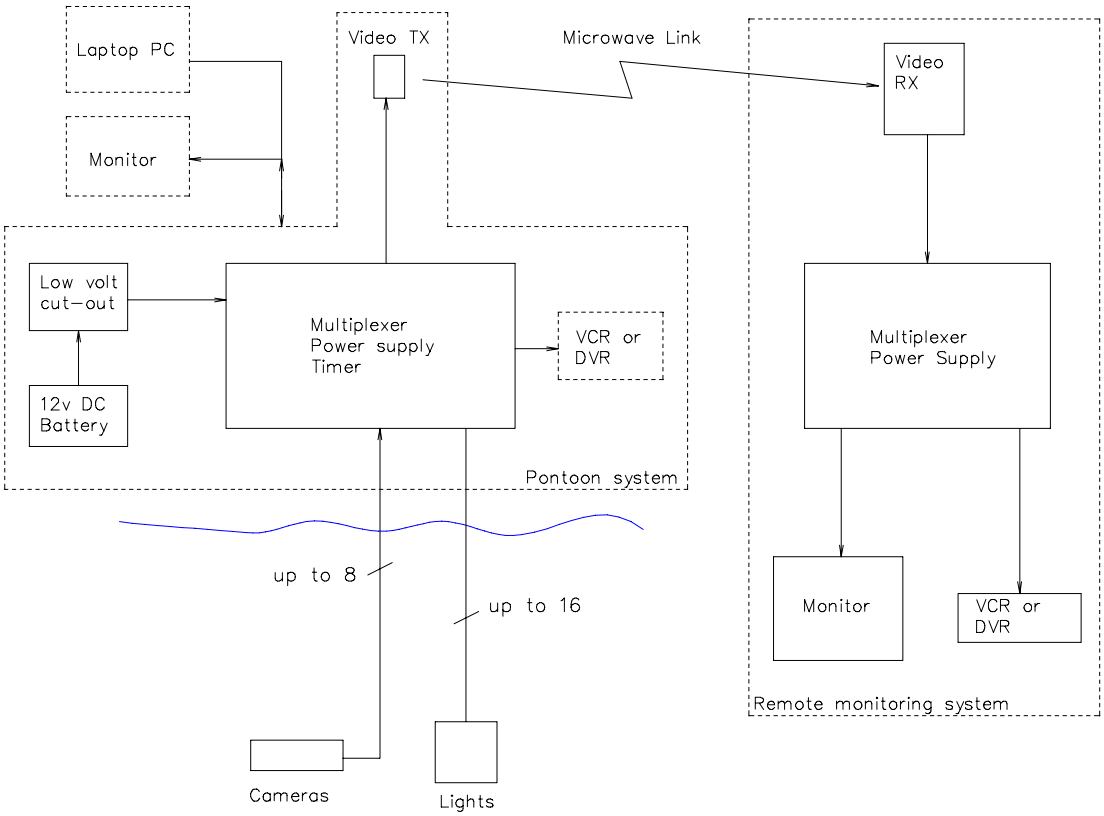

Figure 1. Schematic representation of camera system. The pontoon system provides power to lights and cameras, and receives the signals from up to 8 cameras. These are processed into a single data stream, and transmitted (TX) to the remote video receiver (RX). Camera settings and frame rates can be altered using a computer via a physical connection to the multiplexer unit. The multiplexed video signal can be recorded to a single storage medium (eg video cassette) at a remote station or on the pontoon.

Camera modules were low light (0.05 lux) black and white 1/3" CCD (Charge Couple Device) image sensors with a 3.6mm lens providing a 92° viewing angle in air (reduced in water). Black and white CCDs were used as they have a far broader wavelength detection capability than colour modules, enabling viewing with infrared light. Camera modules were protected in waterproof housings, and linked to the surface system by 30 m polyurethane-sheathed copper cable. To guarantee a clean power supply for the cameras, a switch-mode DC-DC converter was fitted providing regulated 12vDC.

We constructed high-red lights emitting a wavelength of 680 nm and infrared lights with wavelength of 845 nm for use in different circumstances. Choice of wavelength of lighting sources is critical. Absorption of light in water increases dramatically as wavelength increases into the red region of the visible spectrum, and then increases exponentially at infrared wavelengths. Increases are particularly marked at about 700nm for red light and 850nm for infrared light (Kirk 1994). Applying formulae presented in Kirk (1994) we find that in water only 14% of 830 nm infrared light is transmitted at a distance of 1m and this reduces to 2% when at a wavelength of 880 nm.

All lights consisted of an array of 40 high intensity light emitting diodes (LEDs) encapsulated in resin for protection and waterproofing, and connected to the pontoon system via 30m polyurethane-sheathed cable. Two of these lights were deployed with each camera.

Camera and light cables are connected on the surface pontoon to a weatherproof housing (Figure 2) containing the camera power supply, a timer to allow lights to be switched on and off when appropriate, and a multiplexer. A duplex time-division multiplexer is central to the functioning of this system. The multiplexer receives the signals from up to 8 cameras simultaneously, samples the video inputs from each camera sequentially, and interleaves sampled frames into one composite video signal. This coded signal from all cameras can then be recorded directly on a single recording medium, or transmitted to a remote monitoring station. To view the signal, whether live or from videotape, a decoding multiplexer reassembles the frames into single camera video streams. Images can be viewed with several cameras displayed on a split screen, or a single camera can be viewed in full-screen resolution. The penalty for using a multiplexed signal is that the frame rate from each camera is reduced to a degree defined by the number of cameras being monitored. For example, when recording 24 hrs of footage to a 3 hr videotape with 8 cameras connected, a frame is captured from each camera at approximately 1 second intervals. Multiplexer setting including individual camera brightness and contrast, frame capture rate and on-screen displays can be adjusted using a laptop computer interfaced to the multiplexer via a weatherproof connector on the housing.

Power is provided to the system by 2 x 165 amp-hour deep-cycle lead acid batteries housed in waterproof boxes on the pontoon (Figure 2) that were connected in series. Batteries must be exchanged at intervals of 24-48 hrs, depending on light usage. Solar panels could be used to extend time between battery changes although they would be susceptible to damage during system deployment. A low-voltage cutout unit is connected in series after the batteries. If circumstances such as poor weather do not allow for battery changes, this prevents over-discharge and subsequent damage to the batteries.

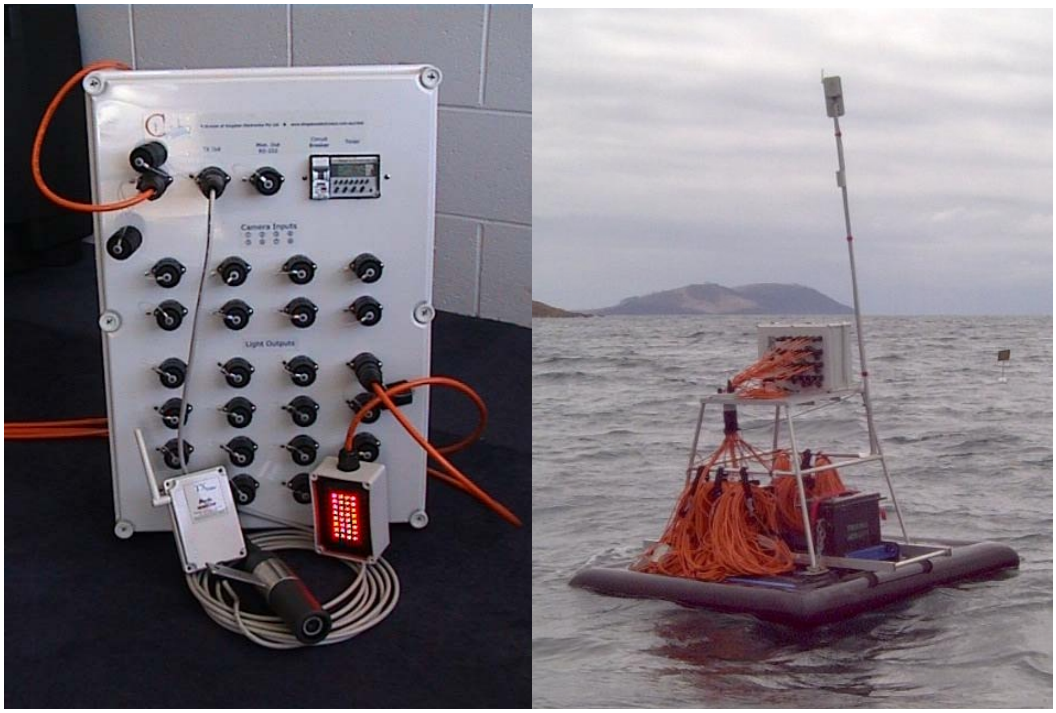

Figure 2. Left - Main multiplexer, power supply and timer unit with weatherproof connectors for camera inputs (8 connectors) power supply to lights (16 connectors) and multiplexer control, transmitter out and power in from batteries (1 connector each). Also shown are a camera (lower centre) transmitter (lower left) and high-red light (lower right). **Right** - Pontoon with light and camera cables coiled on frame ready for deployment. A moulded plastic hood covers the top of the system once deployment is complete.

The camera signals are transmitted to a remote monitoring station using a microwave video link operating in the 2.4GHz license-free band. Output power is low (10mW) and transmission range varies greatly depending on weather, location and antenna type. With a directional parabolic antenna on the receiver, range may be up to 1.6km. The remote monitoring station may be set up on a boat or on land, and consists of a video receiver, multiplexer to decode video signals, a monitor and a recording device. Camera signals can be recorded using a 12 v time-lapse VCR or similar digital device. Where there is no convenient site to establish a remote station, the signal can be recorded on the pontoon. This system has the disadvantage that access to the pontoon is required to change recording media.

The pontoon base was constructed from 3 squares, one inside another, of welded polyethylene tubing (250 mm diameter, 12 mm wall thickness). The outer square has sides of 1.7 m. This provides sufficient buoyancy and stability to support the camera system and up to 2 people during battery changes and deployment. Cameras and lights are deployed by lowering them to the seafloor through a 0.3 x 0.3 m hole in the centre of the pontoon. An aluminium frame supports the weatherproof housing (and recording device if used) approximately 1 m above the water surface. A plastic hood (not shown in Figure 2) is placed over the housing once the system is deployed. The pontoon is held in place and stabilised by 3 anchors connected by chain and rope to the sides of the pontoon. This prevents the pontoon from turning and tangling camera and light cables. The system can be deployed by 3 operators in a vessel as small as 7 m.

This system has the capacity to generate immense quantities of video data. For review purposes, a video signal splitter was built that enabled the signal to be fed to 2 multiplexers, and thus up to 8 cameras could be viewed simultaneously on 2 split screens. When an event of interest occurred, single cameras were brought up in full screen view for detailed observation. Signals recorded in 24 hr time-lapse were reviewed at standard video speed, thus taking a minimum of 3 hours to review 24 hours of footage from up to 8 cameras.

7.4 System Applications

This system has been used successfully for monitoring the behaviour of lobsters and observing interactions between lobsters and predators. Examples include using cameras to positively identifying predators responsible for kills in tethering trials (Chapters 9, 10 and 15) and observing lobster behaviour and interactions around traps. These experiments illustrate the versatility of the system. In lobster reseeding trials we used individual cameras to observe simultaneous replicates in a tethering trial (Figure 3), while multiple cameras were used to observe different perspectives of lobster behaviour around a single lobster trap in catchability experiments.

Different lighting can be used depending on subjects being observed. The anatomy of *Jasus edwardsii* eyes is such that they are incapable of perceiving red light of wavelength greater than 600 nm (Meyer-Rochow and Tiang 1984). Accordingly high-red lights could be used without concerns about influencing behaviour if observing behaviour of lobsters is the objective of experiments. As the extinction of high-red light in water is substantially lower than that of infrared light (Kirk 1994), high-red lights provide brighter illumination than infrared lights for the same power consumption. In reseeding trials we were interested in the behaviour of lobster predators including fish and octopus. The complex eyes of these predators can likely perceive high-red light, so infrared lights were used. The dual infrared lights are capable of effectively illuminating an area of seafloor not greater than 0.8 x 0.8 m from a distance of approximately 0.8 m.

The system has also been used to observe the behaviour and fate of lobsters released to a reef after being grown in captivity for a year from the puerulus stage, observe octopus behaviour in and around lobster pots, and asses abundance of reef fish. Among projects planned are identifying predators of sea urchins, comparing behaviour of lobsters on artificial and natural reefs, observing behaviour of settling lobster post-larvae and monitoring spawning behaviour of reef fish.

The camera system has provided valuable insights into the identity of predators and predation patterns and also the behaviour of target species to fishing gear. We believe that the use of video systems as described in this paper will become an integral component of research to address questions relating to ecosystem-based management including the effects of fishing on the marine environment.

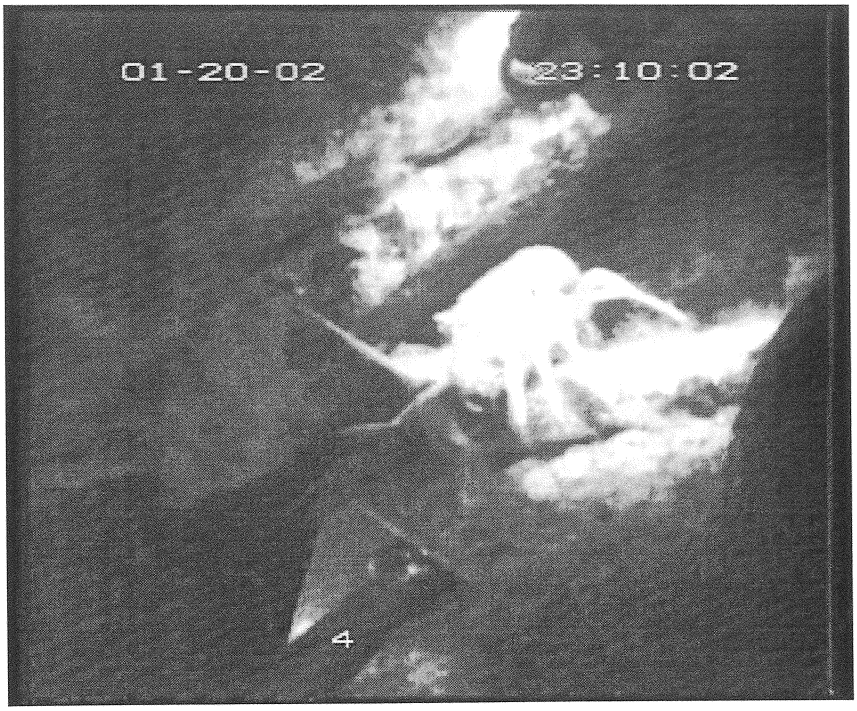

Figure 3. Adult wild lobster observed at night under infrared light just after capturing a small tethered lobster.

8. Comparative anti-predator behaviour of juvenile lobsters (*Jasus edwardsii)* reared under differing levels of predation risk versus wild lobsters

This chapter addresses Objective 1: to develop release protocols to minimise mortality based on the anti-predator behaviour of wild and cultured juveniles. Results are presented from experiment 1, which utilised 2% of project resources. Key findings were that juveniles grown in captivity appear to retain an innate ability to recognise and respond appropriately to predators. This is an encouraging result for enhancement operations and also suggests that juvenile lobsters do not need to be habituated to predators prior to release.

8.1 Abstract

Global interest in aquaculture and stock enhancement as a means of increasing fishery productivity has prompted research on the viability of releasing hatchery reared fish and invertebrates into the wild. Predation of hatchery-reared animals soon after their release into the wild can be a significant source of mortality due, not only to the stress induced by the release itself, but also to the failure to recognise potential predators or to take appropriate evasive action. We conducted a series of experiments to investigate the anti-predator responses of 1-year post-settlement juvenile spiny lobsters (*Jasus edwardsii*) caught as recently settled puerulus and on-grown in captivity under differing levels of predation risk. We also documented the anti-predator behaviour of lobsters released into the wild after 1 year in captivity. We found that lobsters raised without predators for 8 months significantly reduced their levels of activity outside shelters when subsequently introduced to a predator compared with juveniles raised with predators (ANOVA: $F_{1,15094} = 1146.95$, $p<0.001$). This apparent over-reaction may be necessary for lobsters to learn the appropriate anti-predator response. Lobsters raised without predators and released into the wild displayed the same suite of behaviours as wild lobsters. Released lobsters spent more time defending and fighting amongst themselves than the wild lobsters, but they displayed the appropriate anti-predator responses when approached or attacked by a predator. Our results show that juvenile spiny lobsters habituate to the absence of a predator when reared in captivity for long periods but display an innate ability to recognise and respond to predators when encountered in a hatchery environment or in the wild.

8.2 Introduction

Increasing human population and demand for fishery product is placing mounting pressure on the coastal marine environment. While Australian and New Zealand wild lobster fisheries have considerable potential for expansion through optimising harvest strategies, there is also increasing interest in aquaculture and enhancement as a means of increasing production. Although not a replacement for good management of existing stocks, one approach to spiny lobster enhancement is reseeding through the transfer of juveniles from one area of coast to another.

In Europe and North America, enhancement efforts date back to the 1850's with the development of aquaculture facilities for the American clawed lobster, *Homarus*

americanus and the European clawed lobster, *H. gammarus* (Bannister and Addison, 1998). Since the 1970's there has been renewed interest in enhancing wild stocks due to the commercial realisation that the rearing of lobsters to adult size was financially unviable (Bannister and Addison, 1998). Juvenile clawed lobsters reared from egg in captivity and implanted with tiny coded magnetic tags have been released as part of collaborative research programmes in the United Kingdom, Norway, France and Ireland (Latrouite and Lorec, 1991; Mercer and Browne, 1994; Dannevig, 1928; Tveite and Grimsen, 1995; Bannister and Addison, 1998; van der Meeren and Naess, 1993). Of the almost 400,000 lobsters released in northern Europe between 1983 and 1994, approximately 32% were recaptured in the fishery, 26% of those in Norway (Bannister and Addison, 1998). The data indicates that survival after release was reasonably good, but with room for improvement.

Spiny lobster enhancement practices are a little different to those for clawed lobsters owing to the lengthy larval life and the corresponding difficulty in culturing larvae. In order to release juvenile spiny lobsters they must first be caught in the wild using artificial surfaces or collectors (Booth and Tarring, 1986). In Tasmania, one of the fisheries management strategies agreed on in recent years has been the limited and controlled harvest of *J. edwardsii* puerulus (first settling stage of juvenile spiny lobsters) from the wild for commercial aquaculture operations (Gardner *et al*., 2000). A concern with the harvest of puerulus is that it effectively increases the fishing mortality on wild stocks, so returning a proportion of the juveniles after one year of on-growing provides a mechanism for biological neutrality. When the percentage of juveniles returned to the wild and surviving is greater than natural survival over the same period, enhancement is achieved (Gardner *et al*., 2002).

The rational for on-growing the recently settled juveniles is so they may reach a size at which they are less vulnerable to predation and this can take up to a year (McKoy and Esterman, 1981; Rayns, 1991). During this time in captivity behavioural changes can occur which may compromise their survival in the wild.

Predation of captive reared, or naïve, individuals soon after their release into the wild environment can be a significant source of mortality in a range of fish and invertebrates (Nodtvedt *et al*., 1999; Olla *et al*., 1998). Not only does the act of release disturb and agitate the individuals, which may make them more susceptible to predation, but also they may fail to recognise potential predators or to take appropriate evasive action (Olla *et al*., 1994; Olla *et al*., 1998; Nodtvedt *et al*., 1999; Jachner, 2001; van der Meeren, 2000).

Our concerns that juvenile lobsters may fail to recognise and avoid predators when release is a common issue in enhancement operations. In similar research on hatchery-reared coho salmon smolt, the behavioural deficits and vulnerability to predators were investigated by Olla and Davis (1989) with the aim of optimising enhancement operations. They found that, despite an innate ability to recognise and avoid predators, these skills were not fully developed. Salmon smolt that had survived a recent physical encounter with a predator had improved survival relative to naïve counterparts (Olla and Davis, 1989). The authors also found that mortality after release could be halved simply by exposing smolt to a predator behind a Plexiglass shield. The rapid improvement in predator avoidance that was observed in this study demonstrated that although salmon possess an innate ability to respond to predation, the skills associated

with anti-predator behaviour need to be sharpened or honed to be effective (Olla and Davis, 1989). An important practical finding in relation to enhancement of lobsters is that benefits from exposure to predators prior to release can be gained even over short durations.

Small-scale experiments on the survival of released juvenile *J. edwardsii* have been conducted in Tasmania (Mills *et al*., 2004). Survival was 100% for wild and naive lobsters but due to the small sample size (n=9) does not negate the potential for high mortality among released lobsters when reseeded at higher densities. Furthermore, the habitat where trials were conducted was in a sheltered estuary and not typical of coastal reef in the region (Mills *et al*., 2004). Thus there is a need for additional research of naïve lobsters to understand how their altered behaviour may influence their survival on coastal reefs.

The anti-predator behaviour of juvenile lobsters largely extends to nocturnal foraging, defensive postures with the antennae or chelae oriented toward the predator and tail flipping backwards as an escape response (Lawton, 1987; Oliver *et al*., submitted). However, unlike the solitary and aggressive clawed lobsters, spiny lobsters form social aggregations at about 1 year of age (Butler *et al*., 1999) and this confers a protective advantage on individuals. In an artificial hatchery environment, when feed during the day and reared without predators, lobsters may fail to identify potential predators and a breakdown of the daytime defensive aggregations may occur.

Although *J. edwardsii* juveniles intended for release are initially collected from the wild and are, therefore, not strictly hatchery-reared, it is possible their anti-predator behaviour may not develop fully in psychosensory-deprived conditions such as at a captive facility (Olla *et al*., 1998; Kellison *et al*., 2000). In this paper we present the results of tank- and field-based experiments designed to compare the anti-predator behaviour of lobsters reared under differing levels of predation risk and to assess the anti-predator responses of the naive lobsters versus wild lobsters after their release into the wild.

8.3 Methods

8.3.1 Laboratory-based rearing trials and predator exposure experiment

Seven hundred and twenty lobsters (mean carapace length = 20mm) were collected from several sites along the east coast of the north island of New Zealand using puerulus collectors (Booth and Tarring, 1986) and randomly assigned to one of twelve circular tanks (1.8m diameter x 0.5m deep) at densities of sixty animals per tank. At the start of the experiment all animals were blotted dry, weighed and measured. Weight was measured to the nearest 0.1g on an analytical balance and carapace length (CL) was measured to the nearest 0.1mm with vernier callipers from the base of the antennal platform to the posterior dorsal margin of the carapace, along the midline. Tanks were randomly assigned to one of four treatments with a feeding regime of either daytime or night-time feeding and with or without a predator, in an orthogonal design. Lobsters were placed in the tanks 2 weeks prior to the introduction of the predators to allow them to acclimatise to the shelter arrangement provided. The shelters were

constructed using concrete building blocks with holes too small for the cod to enter but large enough to offer the lobsters protection and shelter from predators and light.

Lobsters were fed to excess with opened green mussels (*Perna canaliculus*) at either midday, by staff, or midnight with automatic feeders. The automatic feeders were inexpensively made using a solenoid actuator that triggered a tray to drop at midnight programmed by an automatic timer.

Medium sized blue cod (*Parapercis colias*), a common endemic inshore species, (size range = 20-30 cm) were selected as predators and were collected locally using baited pots and fishing rods with barbless hooks. Blue cod are persistent diurnal predators of juvenile lobsters on New Zealand's temperate reefs and the medium sized cod used in this study were collected from habitat with juvenile reef-dwelling lobsters. Larger blue cod primarily inhabit reef edge and sand flat areas (R.Cole, NIWA, unpub.data) and are not often encountered by juvenile lobsters. One cod was added to each of the six tanks (from a total of 12) randomly selected as a predator treatment. Blue cod in the day-fed treatment could feed on the mussels supplied to the tank for the lobsters at midday, so the cod in the night fed experimental tanks were also directly fed a sufficient amount of mussel during the day to maintain condition. Blue cod become quite tame when kept and fed in captivity so, at monthly intervals, the cod were released at the collection sites and replaced with freshly caught animals.

After eight months in this experimental arrangement, twenty animals were randomly selected from each of the twelve rearing tanks and their anti-predator responses were tested remotely. Each of the experimental tanks was tested twice, ten individuals on each occasion, in a random order over twelve successive nights. Each replicate utilised different individual animals to maintain independence.

Response to predators was examined in two test tanks, identical in size to the rearing tanks, with shelters and three medium sized blue cod. Lobsters were released into the shelter in the afternoon where activity and behaviour were monitored remotely using infra-red sensitive video cameras linked to a video recorder. The first three hours were recorded in real time, because it was expected that most of the predator/prey interactions would occur soon after release of the lobsters, and the following 24 hours of activity were recorded onto a single three hour tape using time lapse recording facilities. Sony CC-23 IR cameras were housed in off-the-shelf underwater flashlight housings. Ritelite RL-1050 underwater lamps fitted with filters to allow transmission of light between 650ηm and 850ηm provided illumination at night. *Jasus edwardsii* are insensitive to wavelengths beyond 650ηm (Myer-Rochow and Tiang, 1984).

Video analyses rated the behaviour of the cod when they interacted with the lobsters and the corresponding response of the lobsters. Behaviours recorded were attack or approach by the cod towards the lobsters, and defence, retreat, or no response by the lobsters. In addition, we recorded the number of lobsters in and out of the shelter throughout the experiment as a proxy for foraging activity. The following day, lobsters were removed from the test tanks, counted, injuries noted, and antennal tagged, before being returned to the original rearing tanks so as to maintain constant density. The cod were released at the end of the experiment near to the site from which they were collected and the lobsters were kept for further experiments on behaviour and movement.

8.3.2 Field-based predator exposure experiment

Several hundred post-puerulus lobsters were collected over a period of months from Gisborne, New Zealand, using puerulus collectors (Booth and Tarring, 1986), and on-grown in captivity in a laboratory in Wellington for one to two years, yielding a variety of different sized captive-reared lobsters. The animals were kept communally in 300 litre tanks with fresh seawater flow in excess of 1 litre per hour per 100g of body weight, and provided with aeration. Freshly opened mussels (*Perna canniculus)* were fed daily during daylight hours and the empty shells removed 24 hours later. Predators were absent.

Field observations were conducted at 2 sites over 2 nights in Wellington Harbour during November 2000. On separate nights, a 10m research vessel was anchored over reef with wild lobsters and suitable but empty dens into which the captive lobsters could be released. Three infra-red cameras were positioned facing into three separate dens. One den contained wild lobsters and captive lobsters were released by hand into the two remaining dens. The 10 captive lobsters released into each den ranged in size between 30-35mm CL while the wild lobsters ranged between 40-80 mm CL.

Captive lobsters were released at 2 separate times during the same day in order to test the effect of timing of release on response to predators. The first release took place during daylight hours, between 1200 and 1330 hrs. Lobsters were observed in real time via camera from onboard the boat and after all captive lobsters had emerged from the dens the second release took place at approximately 0000 – 0130 hrs, around 4-4.5 hours after sunset. Observations of lobsters in this second release were maintained until these captive lobsters also emerged from the dens.

In the absence of split-screen capability, the video cycled around the 3 dens twice a minute pausing to record activity in each den for 10 seconds. Every time the camera paused on a den, records were made of the number of lobsters in that den, their activity (Table 1), the presence and type of predator and the response of the lobsters to any external stimulation (predators, wave action, other benign den-sharing species). The frequency of activities such as fighting, defending, grooming and walking (Table 1) were calculated for both wild and captive lobsters, as was their response to the presence of predators. Anti-predator responses were recorded as antennal waving and pointing, retreating, tail flipping backwards, or lunging at the predator and snapping of the antennae (Table 1).

Table 1. The behaviour of both wild and released juvenile lobsters was described by these activity patterns and behavioural units.

Behavioural Unit	Activity	Description
Alert	Alert	Antennae pointing towards den entrance, first pair of legs pumping to enhance water movement across sensory organs and gills
Grooming	Grooming	Cleaning of carapace and abdomen using periopods
Walking	Walk forward	Motion towards den entrance
	Rocking	Forward and backward rocking motion
	Emerging	Movement towards den entrance and departure from den
Fighting	Intraspecific fighting	Aggressive contact between like-sized lobsters
	Jostling	Push at another lobster resulting in its displacement
Defence/Anti-predator behaviour	Antennae pointing	Pointing both second antennae toward another animal or object
	Tail flip	Fast backwards escape movement using the abdomen flex response
	Aggressive lunge and snap	Forward lunge in the direction of another animal and snap of second antennae together
	Retreat	Movement away from perceived threat
	Tail Erect	Rising up to maximum height on all periopods with tail horizontally erect ready for attack or tail flip

8.4 Results

8.4.1 Laboratory-based rearing trials and predator exposure experiment

One data set was removed from the statistical analyses at the outset after video tape analysis revealed that a cod had moved into the shelter after the lobsters had all departed from the den at 1711hrs. The data from this test is misleading because it was visually obvious the lobsters were trying to return to the den but were prevented from doing so. The data from this test was a daytime feeding – predator present treatment.

No predation of juveniles by blue cod was recorded in any of the trials although behaviour of the juvenile lobsters appears modified by the presence of these fish. Significant differences in the levels of activity outside the den were apparent between all treatments (Figure 4;ANOVA: $F_{3,15094} = 477.57$, $p<0.001$). The lobsters raised in treatments containing predators exhibited significantly higher levels of apparent foraging activity, measured as the number of animals that had emerged from the den, when exposed to a predator than those in treatments raised without predators (ANOVA: $F_{1,15094} = 1146.95$, $p<0.001$). Furthermore, apparent foraging activity levels were significantly higher in lobsters that had been reared with night time feeding than those reared with daytime feeding (ANOVA: $F_{,1.15094} = 11.88$, $p<0.001$). The interaction of these two variables was also significant. Lobsters reared with a predator and under a night time feeding regime spent a significantly greater amount of time away from the central den when exposed to a predator, than those lobsters fed during the day and

encountering a predator for the first time (Figure 4; ANOVA: $F_{1,15094} = 228.28$, $p<0.001$). Not surprisingly, we found that lobsters in all treatments generally remained under the cover provided by the den during daylight hours (Figure 4; ANOVA: $F_{7,15094} = 637.22$, $p<0.001$),.

The anti-predator behaviour of lobsters from the 4 treatments was not significantly different (Figure 5). Across all of the trials lobsters spent between 0.5 and 8% of the total test time defending themselves from the blue cod (Figure 5). There were only a few occasions, less than 1% of the total encounters, when the approach of a cod did not elicit a detectable response from the lobsters. Intraspecific fighting occurred less than 1% of the total test time (Figure 5). Often, 1 lobster would bully or push the other lobsters out of the den and then prevent them from entering the shelter again; expelled lobsters would occasionally force their way back into the den.

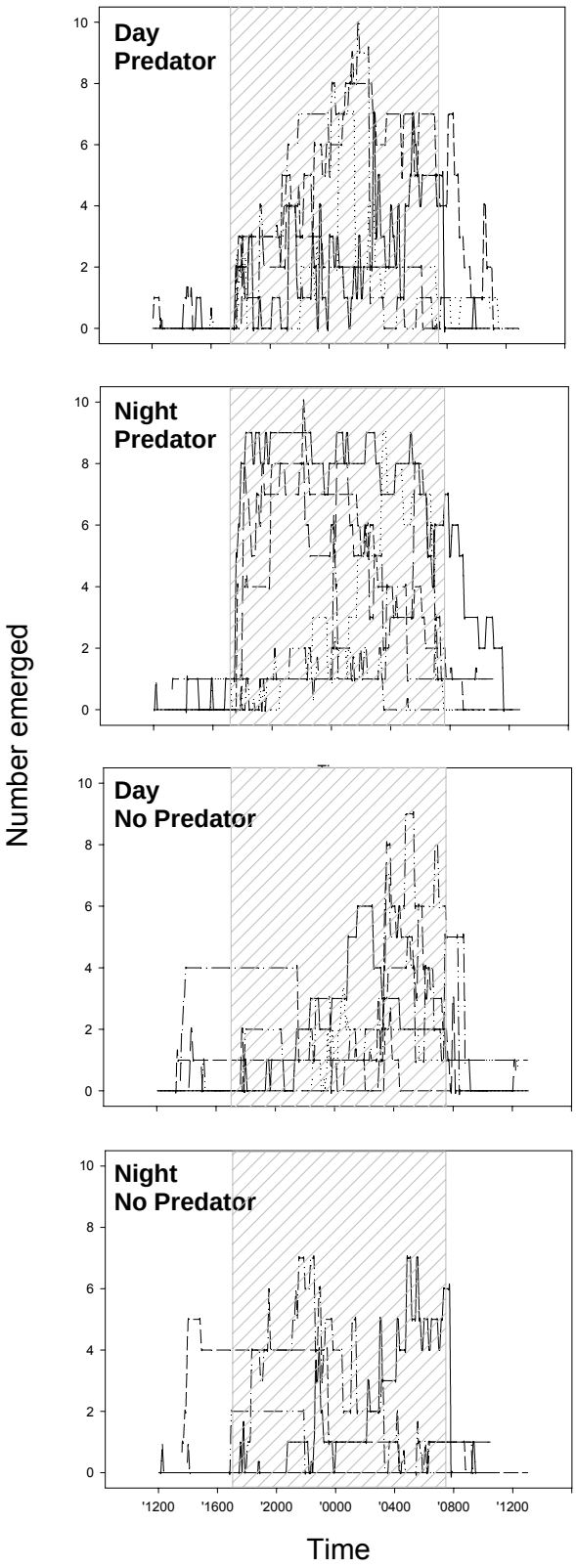

Figure 4. Emergence activity of lobsters from the four rearing treatments when exposed to predators. The shaded area represents the hours of darkness. Each line represents a replicate 24hr test.

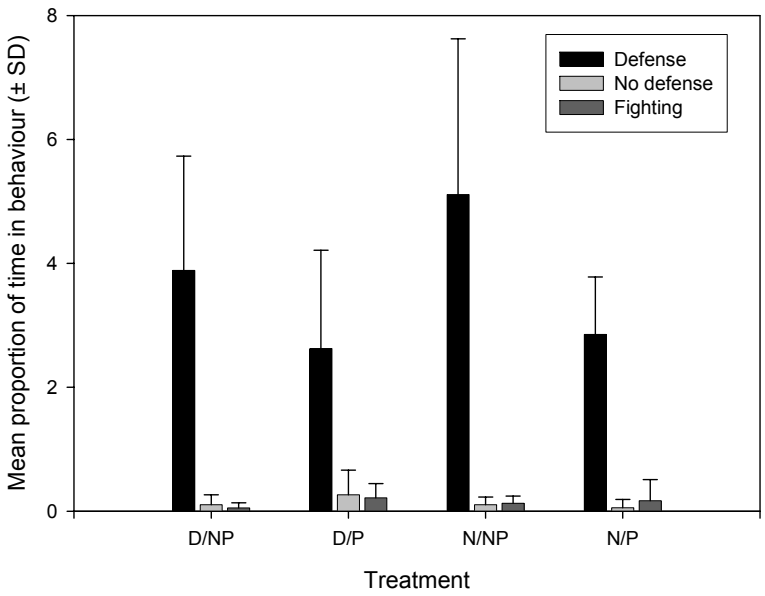

Figure 5. The mean proportion of time spent responding or not responding to predators or intraspecific fighting for the 4 rearing treatments when exposed to a predator.

8.4.2 Field-based predator exposure experiment

Lobsters released into the wild spent the first 2-3 minutes jostling for position in the dens. Several lobsters moved out of the camera field of view and their fate is unknown. Of those remaining lobsters at all four releases, one mortality from predation by a group of spotties (*Notolabrus celiodotus*) was observed 8 minutes after release.

Predation pressure, measured as the total time in minutes when predators were recorded in the field of view, varied widely within and between night and day and the two trials (
Figure 6). However, there was no significant difference in predation pressure between wild and captive lobster den sites, night and day, or trials (ANOVA: $F_{1,11}$= 0.58, p = 0.487).

The anti-predator responses of lobsters were recorded and calculated as a proportion of time in which predators were present. There were no significant differences between wild and captive-reared juvenile lobsters in the amount of time spent exhibiting anti-predator responses (ANOVA: $F_{1,5}$= 0.2, p = 0.898) (Figure 7).

The activity budgets of wild and released lobsters were analysed using the G test of goodness of fit. This analysis revealed that there was a significant difference in the types of activity between wild and released juveniles ($G = 13.006 > \chi^2_{0.05(4)} = 9.488$) (Figure 8). Naïve lobsters spent more time exhibiting defensive behaviour than wild lobsters, contributing to 85% of the G statistic. The amount of time spent fighting amongst themselves was also higher in naïve lobsters, contributing to 15% of the G statistic.

When the lobsters were not moving around the den they always appeared alert, based on movement of antennae and 1st periopods, and this behaviour occupied the greatest

proportion of time over the duration of the experiment for both wild and captive-reared lobsters (95% and 88% respectively) (Figure 8).

The proportion of time spent grooming prior to emergence and walking around within the den was similar between captive-reared and wild juveniles (Figure 8).

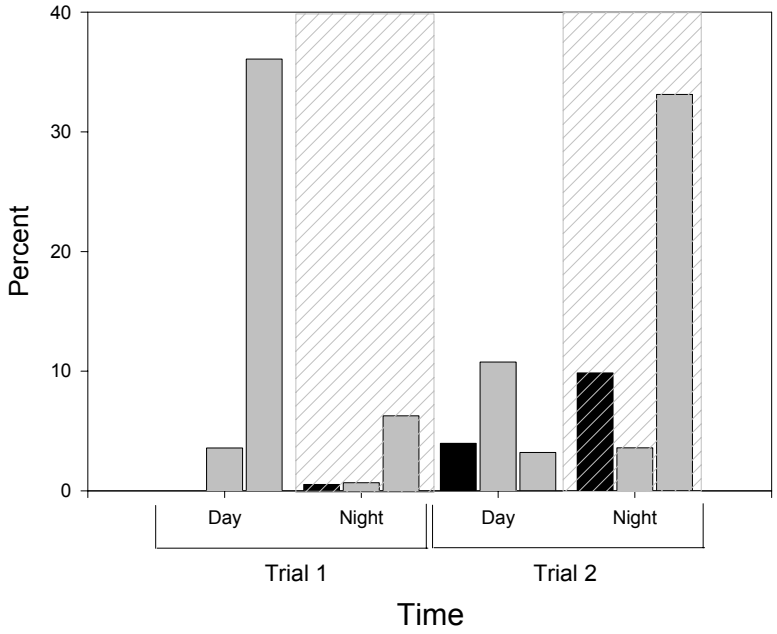

Figure 6. Proportion of time in which predators were present during the field-based emergence experiments. Light bars represent the two captive-reared treatments and the solid bars represent the wild treatment. The shaded area represents the hours of darkness.

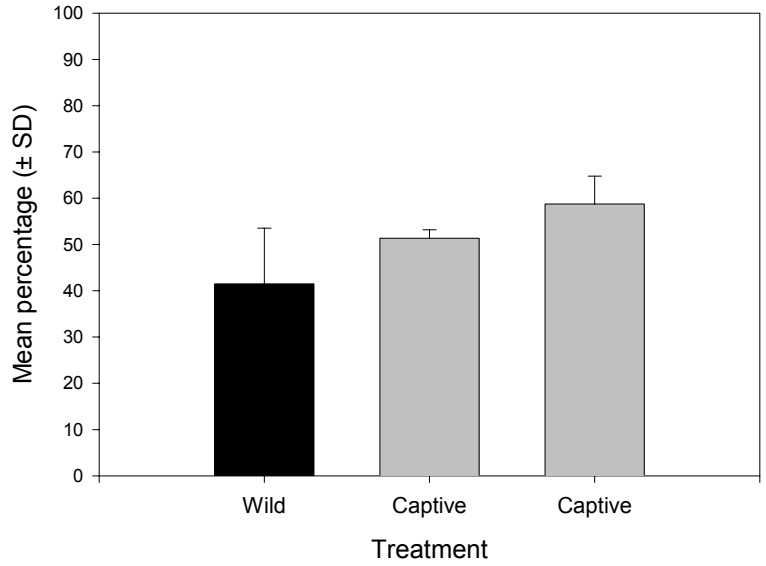

Figure 7. Mean percentage of time when predators were present in which captive-reared (light bars) and wild (solid bar) lobsters spent displaying anti-predator behaviour.

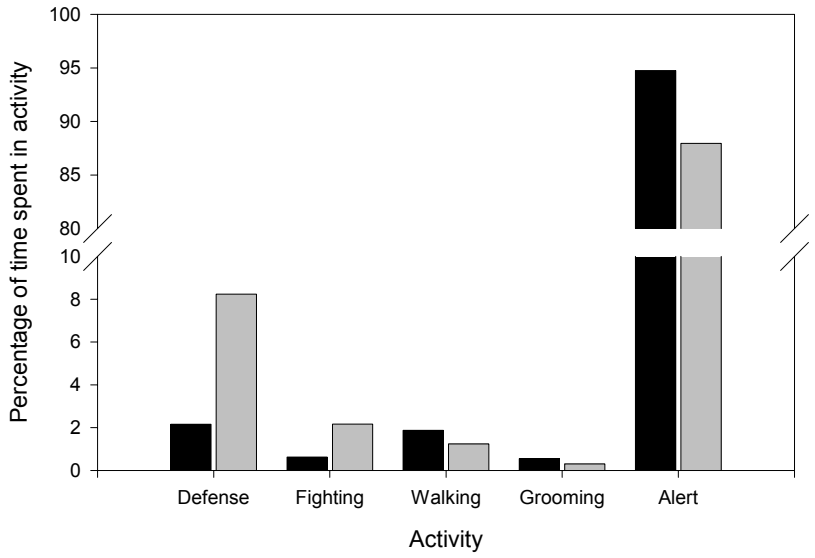

Figure 8. Activity budget for the wild (solid bar) and captive -reared (light bars) lobsters released into the field .

8.5 Discussion

Several previous studies have investigated whether fish and invertebrates reared in captivity for the purposes of stock enhancement fully develop the suite of anti-predator responses required for survival in the wild. It has been proposed that hatchery reared individuals, although hard-wired to respond to predation, may fail to recognise potential predators and fail to take appropriate evasive action having been reared in a pyschosensory-deprived environment (Jachner, 2001; Kellison *et al*., 2000; Nodtvedt *et al*., 1999; Olla *et al*., 1998)

Our results show that for juvenile spiny lobsters reared in captivity for 1 year this is not the case. Juvenile lobsters displayed appropriate anti-predator responses when first encountering a predator, both in an artificial experimental environment and in natural coastal reef. The juveniles appeared restless and disorientated immediately after release into the wild, but when released slowly and provided with a suitable shelter they were able to defend themselves and their den successfully.

These findings are consistent with our previous study of emergence patterns of wild and naïve lobsters (Oliver *et al*., submitted), where we demonstrated that naïve lobsters resumed normal nocturnal activity patterns when released into the wild despite an apparent breakdown of circadian rhythms in captivity.

Previous research with fish has shown that predator training prior to release significantly reduces mortality (Olla *et al*., 1998). This training may take the form of introducing a predator to the tank either directly or indirectly using odour or visual cues, or, in the case of social species, by being in the presence of survivors and interpreting their behaviour. Our results from the experiment in which lobsters were exposed to a predator, some for the first time, revealed that they did not require training but instinctively recognised and responded appropriately to the presence of predators.

There were significant differences in the apparent foraging activity levels of lobsters raised in the different treatments and subsequently exposed to a predator. Lobsters that had been reared with a predator spent more time out of shelters at night than lobsters reared without a predator. This is consistent with studies of cultured scallops (Lafrance *et al*., 2003) and hatchery-reared roach (Jachner, 2001). Lafrance *et al*. (2003) demonstrated that cultured scallops clapped for a longer time but with less intensity, measured as claps per minute, than wild scallops, in response to a starfish predator. They proposed that the cultured scallops were over-reacting by clapping for a significantly longer period, even though they did not achieve the distance from the predator that the wild scallops obtained with a more efficient clapping rate. As with scallops, it appears that the naïve juvenile lobsters in our study, over-responded to predators in terms of the duration of their response.

Studies with juvenile roach showed that hatchery-reared individuals spent virtually all of their time in the refuge or close by, when exposed to alarm substance obtained from dead roach, such that foraging efficiency was severely compromised (Jachner, 2001). In contrast, the experienced fish did not alter their foraging behaviour or swimming speed when presented with the same alarm substance cue. Jachner (2001) proposed that this strong initial response by the naïve roach may be necessary for the fish to learn how to respond to a predator, and it is only through repeated survival and subsequent weakening of the reaction that naïve animals arrive at the most appropriate response. After 3 encounters with the alarm cue, the response of the naïve roach began to weaken (Jachner, 2001). The lobsters exposed to a predator for the first time in our study may be displaying the same initial over-reaction, which would lessen with time and with further exposure to predators.

Furthermore, in a study of movement by released juvenile *J. edwardsii* Mills *et al*. (2004) found differences in the stomach contents of wild and released lobsters, which may support the idea that because of this initial over-reaction, released lobsters do not forage over the same range immediately after release as wild lobsters.

Olla *et al*. (1998) suggested that for species that normally display aggressive behaviour, artificial propagation might increase aggressiveness, which could result in reduced predator awareness. While spiny lobsters are not as aggressive as clawed lobster species, the activity budget we presented for juveniles released into the wild (Figure 3) showed that the amount of time spent fighting amongst themselves was 3 times greater in captive lobsters than in wild lobsters. The fighting was largely for better positions within the den, but also included fighting without any apparent goal of improved shelter or other resource. Intraspecific interaction was much less in the wild lobsters, which remained largely motionless during the day, hugging the den surfaces with antennae lying flat. The increased levels of aggressive behaviours seen here in naïve lobsters may increase vulnerability to predation as predators often concentrate their efforts on conspicuous individuals or those that have become separated from the group (Olla *et al*., 1998). Furthermore, mass release of hyper aggressive lobsters may have a negative impact on the resident wild lobsters. Olla *et al*. (1998) found that hatchery reared fish, more accustomed to high densities, may linger in the release area rather than dispersing and aggressively exclude wild fish from the habitat. Work currently underway will elucidate the effects of releasing large numbers of lobsters on wild populations.

Dominance hierarchies are well documented in clawed lobsters reared in captivity (Cobb *et al*., 1982; Cobb and Tamm, 1975) and 'bullying' behaviour has frequently been observed in our experiments, where the same lobsters will emerge more quickly than others and defend food when it is provided, even when fed to excess. These same dominant animals may expose themselves to a higher risk of predation when released into the wild by making themselves more conspicuous. However, by virtue of their aggression they are also often the largest lobsters and this may improve their survival.

It is possible that in all our experimentation to measure anti-predator behaviour we have overlooked one of the most frequently encountered predators - other lobsters. Cannibalism is common in lobsters (Rayns, 1991) and this alone may be enough to maintain a sufficient repertoire of anti-predator behaviours in culture tanks in the absence of fish predators. It is difficult to measure the level of cannibalism in the wild but in captivity it is frequently observed even when food is plentiful.

In conclusion, juvenile spiny lobsters reared in captivity for 1 year habituated to the absence of predators, but displayed appropriate anti-predator responses immediately upon encountering a fish predator. These lobsters are not strictly hatchery reared due to the inability to raise spiny lobsters from egg, so it is possible that they have had exposure to predators in the brief period between settlement and capture on artificial puerulus collectors. Additional development of anti-predator responses may have come through exposure to conspecifics as cannibalism is frequently observed in captivity. While naïve lobsters were able to avoid predators, other aspects of the behaviour of naïve lobsters on release may influence longer-term survival and the impact of enhancement operations on wild populations. Naïve lobsters appeared to "overcompensate" following interaction with a predator by reducing apparent foraging behaviour for a longer period than wild controls. Naïve lobsters also engaged in more aggressive behaviour to conspecifics, which could influence population dynamics and suggests potential for displacement of wild juveniles.

9. Behaviour of naïve juvenile spiny lobsters (*Jasus edwardsii*) following release

This chapter addresses aspects of Objective 1: to develop release protocols to minimise mortality based on the anti-predator behaviour of wild and cultured juveniles. It is based on experiments 1, 3 and 4, which utilised 24% of project resources.

The principle conclusions in relation to Objective 1 were that: (1) the behaviour of juvenile lobsters reared in tanks is modified with increased activity out of shelters during the day; (2) this behaviour can be readily modified by feeding lobsters at night or by placing a finfish predator in the tank; and (3) juvenile lobsters appear to recognise predators and respond appropriately when released into the wild, even when reared with daylight feeding cycles in the absence of predators. The implications of these findings for enhancement are that cultured juvenile lobsters appear to adequate behavioural responses to avoid predators when released and there is no indication of reduced behavioural competency relative to wild juveniles.

9.1 Abstract

Circadian rhythms are ubiquitous to organisms, arising in response to both environmental and physiological stimuli. Spiny lobsters (*Jasus edwardsii*) are no exception, maintaining strict nocturnal patterns of foraging activity in the wild, presumably to avoid predation. These nocturnal activity patterns have been shown to continue, in the short term, in the captive environment. In the long term, however, when raised in the absence of predators and fed during the day, daytime activity increases. In a series of lab and field based experiments we tested: (1) how the emergence patterns of wild and captive-reared juvenile lobsters differed; (2) if predation risk and timing of food availability affect the emergence activity of captive-reared lobsters; and (3) whether the behavioural changes observed in captivity persist after release into the wild.

We found that lobsters reared in captivity for 1 year exhibit significantly higher levels of daytime activity than their like-sized wild counterparts (ANOVA: $F_{1,1583}=79.16$, $P<0.001$) and that this daytime activity could be reduced by 50% by either rearing the lobsters with a predator (ANOVA: $F_{1,251}=80.93$, $P<0.001$) or by feeding them at night (ANOVA: $F_{1,251}=87.61$, $P<0.001$). In combination, predator presence and night-time feeding further reduced emergence to low levels (ANOVA: $F_{1,251}=7.81$, $P<0.05$). However, a field experiment in which we observed the behaviour and emergence times of captive-reared lobsters immediately after release on reefs where predators were abundant revealed that regardless of rearing conditions and associated changes in behaviour, lobsters assess the risk of predation and revert to nocturnal emergence patterns. Spiny lobsters are, therefore, capable of assessing predation risk and modifying their emergence patterns accordingly, thus removing any need to train lobsters, as is the case with some fish, prior to release back into the wild.

9.2 Introduction

Circadian rhythms are ubiquitous to organisms, arising in response to one or more environmental variables. The New Zealand rock or spiny lobster, *Jasus edwardsii*, is no exception, restricting its activities to the hours of darkness and typically exhibiting a discrete unimodal activity pattern (Williams and Dean, 1989). This timing of emergence is assumed to be associated with predator avoidance as lobsters spend the daylight hours sheltering in dens and crevices, emerging during the night to forage on sedentary prey in the rocky habitat. Nocturnal activity is particularly important for the survival of juvenile lobsters that are more vulnerable to predation, by virtue of their size, from the suite of daytime visual predators (Lawton, 1987).

The role of predation as a selective force in the evolution of reproductive strategies, cryptic colouring, and activity patterns, has long been recognised (Lima and Dill, 1990). The strict diurnal activity patterns of juvenile lobsters have been well described by Williams and Dean (1989) who found a weak endogenous timing system but strong dependence on exogenous stimuli, especially light levels. These responses may be the result of predator and prey interactions over evolutionary time but do not rule out the potential for modifications of behaviour in response to varying levels of predation risk (Lima and Dill, 1990). The risk of predation may change with increasing prey size, season, or time of day, and behavioural plasticity permits animals to maximise their foraging and social activities thereby increasing their potential for growth and/or reproduction (Morse, 1980).

The release of captive-reared juvenile fish and invertebrates to enhance wild stocks has been practiced for many decades and is undergoing a recent surge of interest. Lobster stock enhancement efforts date back to the early 1800's and have generally met with limited success. Return rates of the mostly clawed lobster species have typically been low and teasing apart the relative contributions of predation and emigration to these low return rates has been virtually impossible. One factor that has been proposed to explain the apparent low rates of survival is inappropriate behaviour, particularly response to predators (Olla *et al*., 1994; Olla *et al*., 1998).

The rearing of animals in captivity has the potential to weaken behavioural adaptations or strategies that would normally develop in the wild in response to encounters with conspecifics and predators. Numerous studies have shown that hatchery-reared fish do not develop the full suite of anti-predator behaviours required for survival in the wild (Olla *et al*., 1998; Nodtvedt *et al*., 1999; Jachner, 2001; Kellison *et al*., 2000). For example, Kellison *et al* (2000) found that hatchery-reared flounder took longer to become cryptic in the presence of predators than wild flounder thus increasing their susceptibility to predation. Similarly, Nodvedt *et al* (1999) found that hatchery-reared juvenile cod were more active and maintained a shorter distance from a larger cod predator than their wild counterparts. Lastly, schooling behaviour in fish, a strategy used to reduce the probability of predation in facultative schoolers, may not develop fully in hatchery-reared walleye pollack (Olla *et al*., 1998).

Due to the difficulty of rearing spiny lobsters through the lengthy larval stages, they are captured in the wild as recently settled puerulus using artificial surfaces or collectors (Booth and Tarring, 1986). These very small juveniles are, therefore, not strictly hatchery-reared and initially display typical predator avoidance behaviour and

nocturnal activity patterns. In many fish and invertebrates these nocturnal activity patterns have been shown to continue, in the short term, in the captive environment (Williams and Dean, 1989). In the long term, however, when raised or on-grown in the absence of predators and fed during the day, anecdotal reports suggest daytime activity increases.

We undertook a study to document the influence of the captive environment on the activity patterns of wild and like-sized captive-reared juvenile *Jasus edwardsii*. In a series of tank-based experiments we tested (1) how the emergence patterns of wild and captive-reared juvenile lobsters differed: (2) if predation risk and timing of food availability affect the emergence activity of captive-reared lobsters; and (3) whether the behavioural changes observed in captivity persist after release into the wild.

9.3 Methods

9.3.1 Emergence experiment

Several hundred post-puerulus lobsters were collected over a period of months from Gisborne, New Zealand, using puerulus collectors (Booth and Tarring, 1986), and on-grown in captivity in a laboratory in Wellington for one to two years, yielding a variety of different sized naïve lobsters. The animals were kept communally in 300 litre tanks with fresh seawater flow in excess of 1 litre per hour per 100g of body weight, and provided with aeration. Freshly opened mussels (*Perna canniculus)* were fed daily during daylight hours and the empty shells removed 24 hours later. Predators were absent.

In January 2001 two replicate concrete tanks (1.8m diameter x 0.5m deep) were set-up with infra-red sensitive video cameras linked to a time-lapse video recorder. Flow-through seawater was delivered to the tanks as described above and a single large shelter of conditioned concrete building blocks was constructed. Food was not provided.

Over 11 successive nights, either ten captive-reared or ten wild lobsters sized between 30-70mm carapace length were released into the shelter in each of the two replicate tanks. Wild lobsters were collected by hand from shallow reefs at the entrance to Wellington Harbour immediately prior to the experiment. Activity and emergence times were monitored remotely using infra-red sensitive video cameras linked to a video recorder. Twenty-four hours of activity was recorded onto a single three hour tape using time lapse recording facilities. Sony CC-23 IR cameras were housed in off-the-shelf underwater flashlight housings. Ritelite RL-1050 underwater lamps, fitted with filters to allow transmission of light between 650ηm and 850ηm, provided illumination at night. *Jasus edwardsii* are insensitive to wavelengths beyond 650ηm (Myer-Rochow and Tiang, 1984).

Videotapes were analysed and the hours of emergence documented. Analysis of the tapes consisted of recording the position of all lobsters in the tank every 20 seconds and this yielded over 2700 data points. Lobster positions were demarcated using lines painted on the tank floor designating areas that were ‘shelter’, ‘home’, ‘near home’ or ‘emerged’. ‘Shelter’ was recorded if any part of the animal was in the shelter. ‘Home’

was noted if an animal was one body length from the shelter. "Near home' was noted if an animal was between two and four body lengths from home. Finally, "emerged' was noted if an animal had crossed the line most distant from the shelter (more than four body lengths), or had disappeared out of the field of view of the camera. Using these labels, the position of each lobster could be recorded over 24 hours starting with all ten at home and usually zero at home during some hour of the night when all the lobsters had emerged.

For each designated position in the tank a value from 0 – 4 was assigned, the lowest value given to 'shelter' and the highest value being assigned to 'emerged'. Thus when all lobsters were in the shelter their locomotor activity would be calculated as 0 (10 x 0) and when they were all emerged, locomotor activity was recorded as 40 (10 x 4), for instance. Using the resulting data, plots of locomotor activity were made.

9.3.2 Activity habituation experiment

Seven hundred and twenty lobsters (mean carapace length = 20mm) were collected from the east coast of the north island using puerulus collectors (Booth and Tarring, 1986) and randomly assigned to one of twelve circular tanks (1.8m diameter x 0.5m deep) at densities of sixty animals per tank. At the experiment start all animals were blotted dry, weighed and measured. Weight was measured to the nearest 0.1g on an analytical balance and carapace length was measured to the nearest 0.1mm with vernier callipers from the base of the antennal platform to the posterior dorsal margin of the carapace, along the midline. Tanks were randomly assigned to one of four predation risk and timing of feeding treatments, in an orthogonal design. Lobsters were placed in the tanks 2 weeks prior to the introduction of the predators to allow them to acclimatise to the shelter arrangement provided.

Lobsters were fed to excess with opened green mussels (*Perna canaliculus*) at either midday, by staff, or midnight with automatic feeders. The automatic feeders were inexpensively made using a solenoid actuator that triggered a tray to drop at midnight programmed by an automatic timer.

Medium sized blue cod (*Parapercis colias*) (mean length = 20-30 cm) were selected as predators and were collected from the south coast of Wellington using baited pots and fishing rods. Blue cod are persistent diurnal predators of juvenile lobsters on New Zealand's temperate reefs and the medium sized cod occur in the same habitat as the juvenile reef-dwelling lobsters. Larger blue cod primarily live on sand flats and are not often encountered by juvenile lobsters. One cod was added to each of the six tanks randomly selected to house a predator. Blue cod in the day fed treatment could feed on the mussels supplied to the tank for the lobsters at midday, so the cod in the night fed experimental tanks were also directly fed a small amount of mussel during the day so that they did not starve.

Blue cod have a tendency to jump out of uncovered tanks if startled, so we had to occasionally replace cod within the experimental tanks during the experiment. Spare blue cod were held in a communal tank with the identical shelter arrangement as experimental tanks and fed green mussels.

At fortnightly intervals, half an hour after the midday feeding, a census was taken of all the tanks to record the number of lobsters that had emerged from the shelters and were associated with the food provided in the tank. These data was then used to calculate the effect of predator presence or absence and feeding time on the daytime emergence times of juvenile lobsters.

Overall, the lobsters were on-grown for eight months until August, 2001. At the experiment end all surviving animals were blotted dry, weighed and measured as at the experiment start. Notes were also taken of any missing appendages or broken antennae.

9.3.3 Field-based emergence experiment

Field observations were conducted at two sites on the Miramar Peninsula near the entrance to Wellington Harbour during November 2000. The lobsters used in the field experiment had been collected from Gisborne using puerulus collectors (Booth and Tarring, 1986) 1-2 years previously and on-grown in captivity. Animals were maintained communally as in previous experiments, in a flow-through seawater system and fed mussels *ad libitum*.

On two separate nights the boat was anchored over a carefully selected site at which wild lobsters could be found and included some suitable but empty dens into which the captive lobsters could be released. Three infra-red cameras were positioned facing into three separate dens. One den contained wild lobsters (35-45mmCL), and captive lobsters (30-35mm CL) were released into the two remaining dens.

Groups of 10 captive lobsters were released into each "release" den at 2 separate times during the same day. The first release took place during daylight hours, between 1200 and 1330 hrs. Lobsters were observed in real time via camera from onboard the boat and after all lobsters had emerged from the dens the second release took place between 0000 – 0130 hrs. Observations of lobsters in this second release were continued until these lobsters also emerged from the dens.

Video analyses were undertaken in the laboratory. In the absence of split-screen capability the video cycled around the 3 dens twice a minute pausing to record activity in each den for 10 seconds. Every time the camera paused on a den records were made of the number of lobsters in the den, their activity, the presence and type of predator and the response of the lobsters to any external stimulation (predators, wave action, other benign den-sharing species). The emergence times of lobsters were plotted by applying a moving average function to the percentage of animals remaining in the den during the experiment.

9.4 Results

9.4.1 Tank-based emergence experiments

Lobsters reared in captivity spent more time out of their shelter during the day than wild lobsters (ANOVA: $F_{1,1583}=79.16$, $P<0.001$) (Figure 9). However, no significant difference in nighttime locomotor activity or shelter occupation was detected (ANOVA: $F_{1,1139}=3.81$, $P=0.0513$). Not surprisingly, both captive-reared and wild

lobsters exhibited significantly higher levels of activity at night than the day (ANOVA: $F_{1,2723}$=2177.13 , P<0.001).

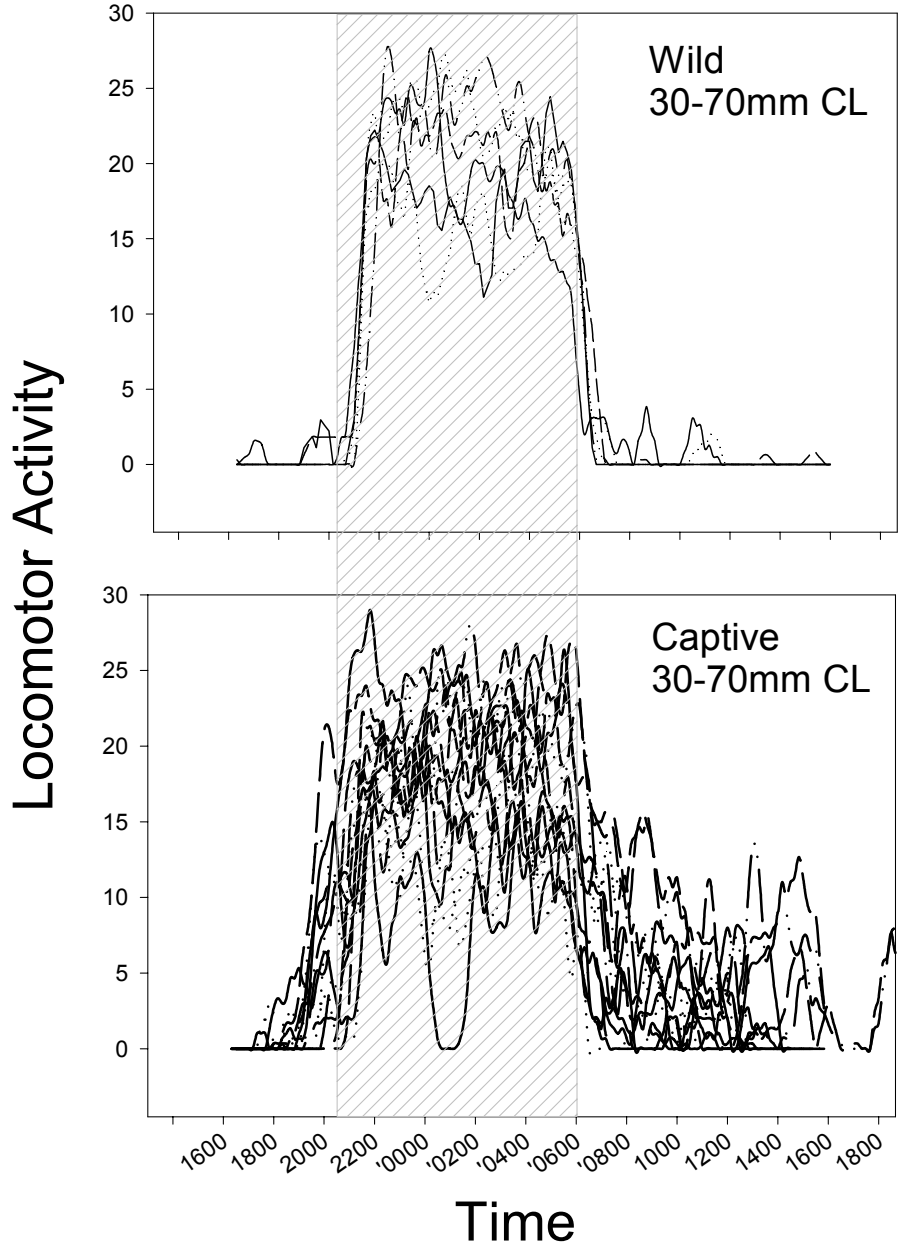

Figure 9. Locomotor activity in captivity of wild lobsters and like-sized captive-reared lobsters. Shaded area represents the hours of darkness. Each line represents a replicate trial.

9.4.2 Activity Habituation Experiment

Activity

Emergence times of lobsters were significantly different between treatments. The mean number of lobsters that emerged during the noon census was greatest for the treatment in which lobsters were raised without predators and fed during the day (Table 2).

Nocturnal feeding and predator presence independently and significantly reduced the daytime emergence activity of the lobsters (ANOVA: $F_{1,251}$=87.61, P<0.001; $F_{1,251}$=80.93, P<0.001 respectively). The interaction of these two components was significant but small (ANOVA: $F_{1,251}$=7.81, P<0.05) and could be considered largely additive, in combination reducing noon activities to very low levels (Table 2).

Table 2. The mean number of lobsters recorded out of the shelters in each treatment during the live-rearing trials, noon census ± SE.

Treatment	Mean number emerged at census	Standard error
No predator/daytime feeding	22.32	1.44
No predator/night-time feeding	9.06	0.94
Predator present/daytime feeding	9.46	1.27
Predator present/night-time feeding	2.96	0.37

Condition (weight/CL ratio)

There was no significant difference in weight/carapace length ratio between treatments at the beginning of the experiment (ANOVA: $F_{1,719}$=0.88, P=0.556). At the end of the experiment the weight/carapace length ratio, a measure of nutritional condition and thus a proxy for the potential for growth (Oliver and MacDiarmid, 2001), was significantly depressed in treatments containing predators regardless of whether the treatment was fed during the day or night (ANOVA: $F_{1,533}$=133.21, P<0.001; Figure 10). For a given carapace length, animals in treatments without a predator had a larger weight/carapace length ratio than those reared with a predator. Fifty percent of lobsters in the treatment without a predator had a weight/carapace length ratio over 0.686, compared to the 50th percentile for the treatment with a predator of 0.594. Feeding times did not significantly influence growth rate (ANOVA: $F_{1,533}$=3.59, P=0.059).

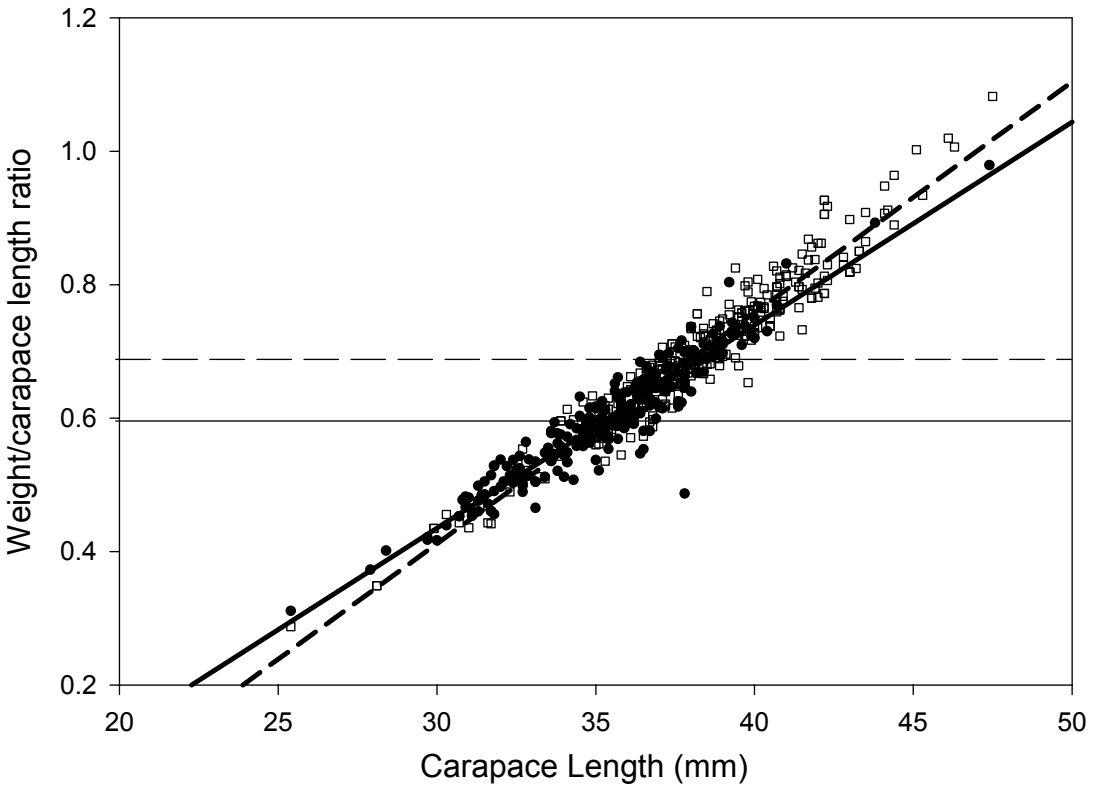

Figure 10. Weight/carapace length ratio for lobsters reared with and without a predator. Open squares and a dashed line represent lobsters reared without a predator and solid squares and a solid line represent lobsters reared with a predator. Horizontal lines represent the 50th percentile of the treatment without a predator (dashed line) and the treatment with a predator (solid line).

Injury and survival

There was a significant difference between treatments in the amount of physical injury sustained to animals (ANOVA: $F_{1,11}$=83.61, P<0.001). Lobsters reared with predators sustained significantly more limb and antennal damage (36%) than lobsters reared without predators (6%). Among those treatments reared with a predator, animals fed at night suffered more than twice the damage than those fed during the day (ANOVA: $F_{1,11}$=24.14, P<0.05).

Survival of juveniles raised with predators was significantly lower than lobsters raised without predators ($F_{1,11}$=28.05, P<0.001). Survival of juveniles raised without predators was 83% compared to 65% for juveniles raised with predators. There was no significant effect of feeding regime on survival (ANOVA: $F_{1,11}$=0, P=1).

9.4.3 Field-based emergence experiments

Field-based video footage was used to obtain emergence times of each wild and released lobster. A Total Time on Test analysis was used to calculate the time between release and emergence and a mean estimate of time to emergence for each treatment (Figure 11). There was large variation in the time to emerge, although generally lobsters released at night departed more quickly than those released during the day. The confidence intervals around emergence times of wild lobsters released at night are

large because there were few lobsters left in the den to observe (n = 6,2). Overall there were no significant differences in emergence times between wild and released lobsters. Lobsters released at night generally emerged from the den within a shorter time frame than those released during the day (5.2 hours compared with 1.4 hours), however, this was not significant.

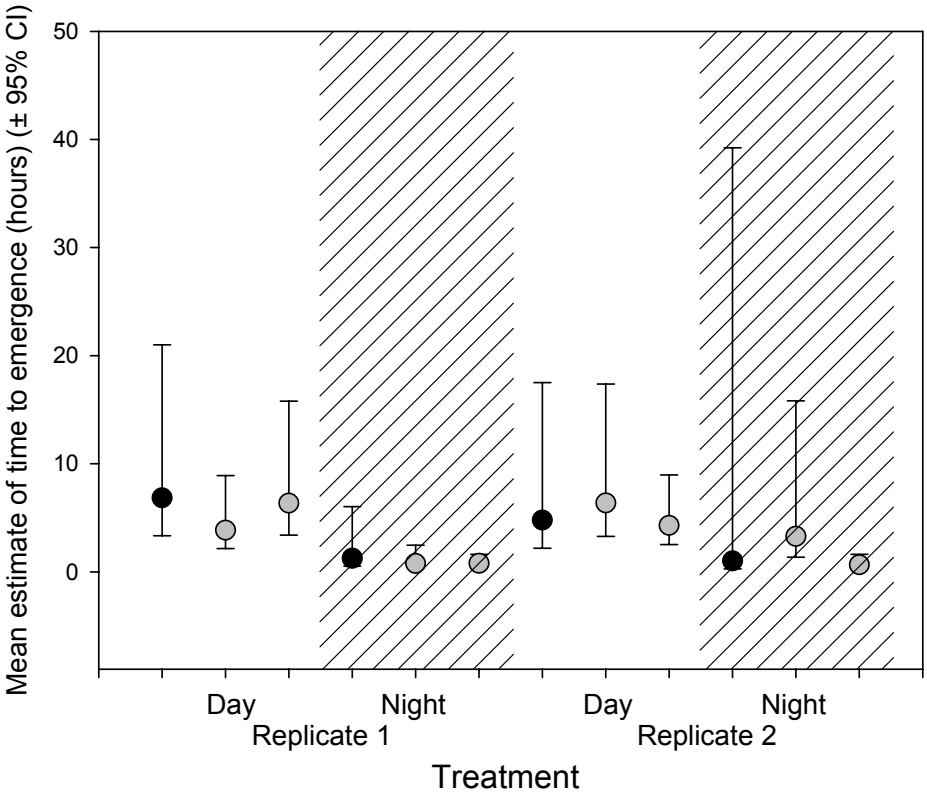

Figure 11. Mean estimate of time to emergence since release as calculated using a Total Time on Test analysis. Black circles denote the den of wild lobsters and grey circles denote the replicate dens into which captive-reared lobsters were released. The shaded areas represent the second release of lobsters at night.

9.5 Discussion

With rare exceptions, all organisms have circadian rhythms that arise in response to exogenous and endogenous stimuli (Williams and Dean, 1989; Lewis, 1994). In juvenile spiny lobsters these rhythms are important for foraging, finding shelter and avoiding predation. In the wild, juvenile spiny lobsters maintain strict nocturnal patterns of emergence and foraging activity (Jernakoff, 1987; MacDiarmid *et al*., 1991). In contrast, juvenile lobsters reared in captivity for extended periods (>6 months) exhibit significantly higher activity levels during daylight hours. Our experiments demonstrated that when maintained in typical hatchery conditions, that is, fed during the day when it is most convenient for staff to feed them, and raised without predators, juvenile spiny lobsters emerge more frequently during the day to forage and spend less daylight time sheltering in the den. This behaviour, if exhibited in the wild, would be potentially fatal because it would expose the juveniles to a suite of predators they have never before encountered (Lawton, 1987; Spanier *et al*., 1998). From the

experiments conducted here we were able to draw several important conclusions in relation to the potential fate of captive reared lobsters released into the wild for the purposes of enhancement.

Firstly, the emergence patterns of captive reared lobsters could be manipulated by the presence or absence of predators and by the time of feeding. Both of these factors independently altered emergence patterns, with the presence of a predator or night-time feeding maintaining normal nocturnal emergence patterns. Conversely, as frequently observed in aquaria, lobsters fed during the day and raised without a predator spent more time out of the shelter and foraging during the day. Lobsters thus display high plasticity in their foraging behaviour and this may prove to be a useful strategy in a changing environment (Morse, 1980; Lima and Dill, 1990). Stein and Magnuson (1976) reported similar findings from their laboratory studies in which crayfish (*Orconectes propinquus*) modified their activity patterns in the presence of predators. The crayfish spent more time seeking protective shelter and less time foraging than when predators were absent (Stein and Magnuson, 1976).

However, reducing exposure to predators by restricting activity carries a cost, which was slower growth. Lobsters reared with predators in our experiments had significantly reduced growth rates, compared to lobsters raised without predators. The presence of predators directly prevented lobsters from leaving the shelter during the day through perceived predation risk. This significantly reduced the amount of time lobsters spent foraging and the foraging range, resulting in a trade-off between energetic considerations and predation risk (Spanier *et al*., 1998). Conversely, lobsters reared without predators, having assessed the predation risk, modified their activity patterns to increase the time spent foraging and eating and thus maximising growth.

Injury and mortality were higher when a predator was present, further highlighting the disadvantages of rearing juveniles with predators. The lobsters were probably able to avoid predation, as they grew larger toward the experiment end and may have suffered higher levels of predation at the experiment start when they were around 20mm CL. Considerable evidence also exists for hungry individuals foraging despite an elevated risk of predation (Morse, 1980) and in the hierarchical system that frequently operates amongst captive lobsters whereby dominant animals eat first and hoard food (Cobb and Tamm, 1975; Thomas *et al*., 2003). This may have forced some individuals to forage in the open in the presence of predators.

An increase in size dramatically reduces the predation risk for lobsters and there is some evidence that releasing well fed animals improves initial survival rates because they are less stressed and do no take risks to obtain food (Hossain *et al*., 2002). In experiments with Japanese flounder and a crab predator Hossain *et al*. (2002) found that not only was post-release stress exacerbated by starvation, but depriving the flounder of food during pre-release predator training hindered their ability to learn appropriate predator avoidance behaviours.

Having established that emergence behaviour could be manipulated, we needed to determine if lobsters released back into the wild required this training or maintenance of behaviour. Our field release analyses revealed that juvenile lobsters raised in the absence of predators and fed during the day resume normal nocturnal emergence patterns when released into the wild. Lobsters released during the day generally

remained in the den until after nightfall when like-sized wild lobsters emerged. Lobsters released at night left the den in a shorter space of time than those released during the day indicating that time to departure was not related to time since release but to darkness. Therefore there appears to be no requirement to on-grow juvenile lobsters in the presence of predators. In a hatchery situation, nocturnal feeding times would be sufficient to maintain nocturnal emergence patterns. However, this practice may be unnecessary if when disturbed or displaced into a new environment, juvenile lobsters revert to instinctive nocturnal foraging behaviour.

The extensive literature discussing behavioural deficits and the merits of predator training for fish prior to their release into the wild concludes that generally, hatchery-reared fish have higher rates of survival if they are exposed to predators prior to release. Lobsters do not appear to suffer from these same deficits and this may be because they are originally collected from the wild after a lengthy larval period (~18 months) in the open ocean (Bruce *et al*., 2000). It is possible that lobsters reared from egg in a captive environment could suffer more severe behavioural deficits.

In conclusion, juvenile lobsters raised in captivity and fed during the day in the absence of predators modify their emergence patterns and are more active during the day than their wild counterparts. This would suggest that lobsters are capable of making decisions based on their assessment of predation risk versus energy acquisition. This plasticity in behaviour may be strategically important for maximising foraging range and duration in the absence of predation pressure. The ability to habituate to a predator-free environment with plentiful food rapidly improves growth rate such that lobsters can reach a body size at which they are less vulnerable to predation.

The implications for on-growing juveniles in captivity for later release back into the wild are two-fold. Firstly there is no need to alter existing rearing practices as the lobsters resume normal “wild” behaviour and secondly, the lobsters can be released during the day or night without fear of emergence at inappropriate times.

A greater consideration may be the exact timing and site of release to reduce encounter rates with predators. It may be more important to assess predator type and abundance and shelter suitability and availability at sites intended for enhancement. These factors may prove to be more important for the survival of reseeded juvenile lobsters. Recently completed research will elucidate the relative effects of site suitability and predation intensity relative to timing of release.

10. Timing of predation on naïve lobsters released for enhancement purposes

This chapter reports on research directed to objective 1: to develop release protocols to minimise mortality of released juveniles. Key findings in relation to this objective were that mortality of released juveniles was highest in the first two hours after release and around dawn. Best survival was between midnight and dawn. Consequently, it is recommended that release operations aim to release animals around midnight.

The research presented in this chapter was based on experiment 2 (timing of predation on naïve juvenile *Jasus edwardsii*) which was allocated 3% of project resources.

10.1 Introduction

Tethering has been used successfully in several predator-prey systems to assess predation on temporal and spatial scales. Tethering results represent the predation potential, defined as the rate at which prey would be consumed if they were readily available to predators (Aronson and Heck, 1995; Peterson *et al*., 2001) and despite its limitations, is useful for measuring relative predation rates.

In a series of field based experiments we used tethering to measure the relative timing and intensity of predation associated with the release of juvenile lobsters for enhancement purposes. A significant issue limiting the success of stock enhancement efforts is the high mortality of released individuals. Not only does the act of release disturb and agitate the individuals, which may make them more vulnerable to predation, but the disturbance created by divers, boats or simply the sudden appearance of prey animals where before there were none may invite the unwanted attention of predatory species. Furthermore, the timing of predation may vary across the day and between seasons according to the activity and abundance of predators.

In this paper we present the results of experiments conducted in New Zealand and Australia to determine when predation upon released lobsters was most likely to occur. Using chronographic tethering devices and video surveillance equipment at 10 sites we could assess the best time of the day to release lobsters to mitigate high mortality due to predation.

10.2 Methods

10.2.1 New Zealand experiment

Several hundred post-puerulus lobsters were collected over a period of 6 months from Gisborne, New Zealand, using crevice-type puerulus collectors (Booth and Tarring, 1986), and on-grown in captivity in a laboratory in Wellington for one to two years, yielding a variety of different sized captive-reared lobsters. The animals were kept communally in 300 l tanks with fresh seawater flow in excess of 1 l/h per 100 g of body weight, and provided with aeration. Freshly opened mussels (*Perna canniculus)* were

fed daily during daylight hours and the empty shells removed 24 h later. Predators were absent.

Twenty chronographic tethering devices were designed and built using cheap stopwatches with implanted reed switches. Lobsters were tethered to a magnet which, when turned during a predation event, passed over the reed switch and stopped the clock. Using this method we could calculate the time of predation. The tension of the magnet was adjusted to ensure that the strength of a lobster tail flipping would not trigger the timer. These devices were fastened to lead anchors (approximately 100 g) with steel grapple-hooks so that neither lobsters or predators could remove them.

Fifty-eight intermoult juvenile lobsters ranging in size from 37 to 41mm carapace length were tethered to these chronographic tethering devices (CTD) at 6 sites in Wellington Harbour (Figure 12) over a period of 8 months. Lobsters were attached to the CTD using a monofilament nylon line tied around the thorax between the 3rd and 4th legs. A swivel was mounted on the dorsal surface of the carapace to reduce tangling. The tether was approximately 30 cm long. Lobsters were placed in hides into which they could fully withdraw to avoid predators, and the anchor placed adjacent to the hide. Tethered lobsters were placed out at each of the 6 sites for 48 h. They were monitored at 24 h and 48 h intervals, after which they were removed.

The sites chosen comprised shallow Mesozoic greywacke reef areas covered with slightly varying degrees of the giant kelp, *Macrocystis pyrifera*, fucoidal macroalgae and beds of laminarian algae. All sites were approximately 5 m in depth and bordered by sand on the seaward sides.

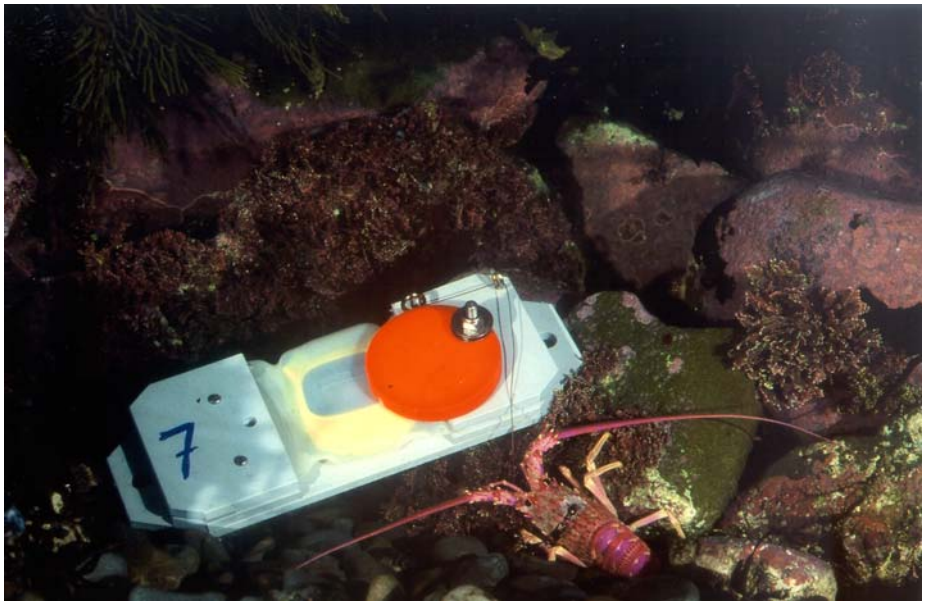

Figure 12. Juvenile lobster tethered to a chronographic tethering device (CTD). Lobsters were placed near suitable dens into which they could withdraw for protection.

10.2.2 Tasmanian experiment

Lobster pueruli were collected from Bicheno on the east coast of Tasmania. Rearing conditions were similar to those in New Zealand, although lobsters were fed a mixed diet of opened fresh blue mussels (*Mytlius edulis planulatus*) and commercial prawn pellets. Lobsters were grown in tanks for 12 to 15 months, attaining a carapace length of 30 to 52 mm. Water temperature over this period ranged from 11 to 19°C. As with New Zealand trials, animals were reared without predators and in tanks with flow through water supply with exchange rates in excess of 1 l/h per 100 g body weight, plus aeration.

Tethering trials were conducted at 4 sites in southern and south-eastern Tasmania of varying exposure and habitat complexity. Winter (June-August) trials were conducted at all sites and were replicated in summer (December-February) at 2 sites (Adventure Bay and Rheban Beach).

On each occasion, 3 replicate tethering trials were conducted over consecutive 48 h periods. For each replicate, 20 lobsters were tethered to 20 numbered 100 g lead anchors with steel grapple hooks using a 25-30 cm length of nylon monofilament line. The attachment of lines to lobsters and placement of lobsters within hides was the same as per the New Zealand trials. Where necessary, macroalgal stipes were removed from the tethered range of the lobster to avoid entanglement. Positions of tethered lobsters were recorded relative to a 50 m transect line deployed across the site. For replicate trials the transect line was moved to ensure that individual hides were used only once. This was done to minimise any consistent bias due to hide selection.

During each replicate, 6 or more lobsters were monitored using a remote infrared capable camera system. The system consisted of 6 low light (0.05 lux) monochrome CCD cameras with accompanying twin infrared light sources, linked by 30 m cables to a surface pontoon. The pontoon housed an 8 channel multiplexer to allow the signal from all cameras to be recorded on a single videotape, a timelapse video cassette recorder (VCR), video transmitter and batteries to power the system. Infrared lights were set by timer to come on at dusk, and turn off at dawn. Tape speed on the VCR was set to record 24hrs of footage on a 3hr tape, and multiplexer frame rate was set at 80 ms, providing an image from each camera every 480 ms. Camera signals could be recorded using the VCR on the pontoon, or a transmitted signal could be recorded at a remote base station.

Divers noted the presence or absence of each tethered lobster after 24 h, and again at 48 h, when all lobsters were removed. If lobsters being observed by cameras were missing after 24 h, the camera was moved to another lobster to maximise the number of predation events observed.

Video footage was later reviewed in the laboratory, when time of predation and identity of predators was established.

10.2.3 Data analyses

We recorded when the tethered lobsters were deployed and recovered, whether the lobsters had been predated upon and if so, the time displayed on the watches or the

video. We could then calculate the survival time and use survival analysis techniques to determine if there were any differences in survival between sites in both New Zealand and Tasmania. We used the statistical package NCSS to run the analyses, including log-rank tests to compare survival curves.

The timing of predation was analysed using Chi square tests. The 48h experiment was divided into post-release, day and night categories to determine the frequency of predation events within these time periods and assist analyses.

10.3 Results

Survival analyses revealed that there was no significant difference in the distribution of survival rates between sites in New Zealand or Australia (Log-rank test $\chi^2 = 10.66$, df = 8, p = 0.222). The data were then analysed without site as a factor to yield a plot of survival over time (Figure 13). Fifty percent of all lobsters survived the 48h experiment.

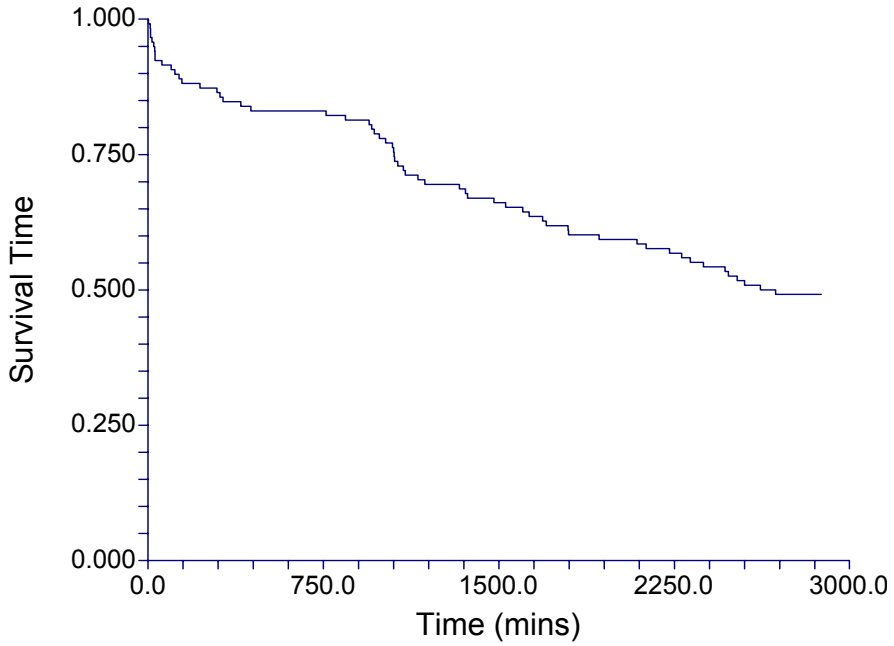

Figure 13. Cumulative survival rates of tethered juvenile lobsters from both New Zealand and Australian trials combined.

Frequency distribution and chi square analyses revealed a significantly greater chance of predation within the first 2 hours after release ($\chi^2 = 71.1044$, df = 7, $p<0.001$). Lobsters were 5 times more likely to be predated upon immediately following release than expected by chance alone, the significance of this time period contributing to 75% of the chi-square statistic. A smaller 11% of the chi-square statistic was explained by predation at dawn.

Remote camera observations made in the Tasmanian experiments revealed that of the recorded events, lobsters were predated upon by fish 46% of the time. Octopus and

crabs were also key predators representing 19% of the predation events each. And somewhat surprisingly, cannibalism was very high with 6 out of 37 (16%) recorded events being attack of the tethered lobster by another free-roaming lobster.

Diver observations in Wellington also reported high predation rates by octopus and fish immediately after the tethered lobsters were placed out. Small schools of a diver-positive wrasse species (*Notolabrus cheliodotus*) were observed to attack and kill experimental lobsters during release, despite the ability of the lobster to withdraw on the long tether into a den.

10.4 Discussion

There were no detectable differences in relative predation rates across sites in New Zealand and Tasmania probably due to the suitability of sites chosen for study. All sites provided suitable shelter in the form of dens and macro-algae cover and although predator density and composition was expected to vary across sites this did not induce significant differences in timing and intensity of predation.

The digital timing device used in this study is a simple and inexpensive method of measuring survival time of tethered prey. Despite problems with some of the mechanisms not working, we were able to record 29 predation events across 5 sites.

The high mortality rates within the first 2 hours of release suggest that predators are attracted by the activity of divers and release protocols may need to provide for greater protection of the lobsters in the first 24h, such as traps or cages that open at a set time after placement to release the lobsters. Further, placing lobsters outside of areas or dens not occupied by wild residents may make them more vulnerable to predation due to our anthropomorphic interpretation of den suitability.

The apparent higher rate of predation at dawn was a surprising observation and suggests that this time of day would be particularly poor for release operations. In contrast, lowest rates of mortality were observed between midnight and dawn which suggests that the most optimal time for release is during that period.

We wish to emphasize that the predation rates we report here are relative measures recorded in representative benthic habitats and do not reflect absolute predation rates. Tethering estimates are likely to be biased due to the inability of the prey to escape. With this in mind, 50% of lobsters survived beyond the first 48h and thus survival rates of free roaming lobsters can be expected to be substantially higher. This suggests favourable survival rates for lobsters reared in captivity for one year and released for enhancement purposes.

11. Comparison of moulting mortality between control (wild) and released lobsters in field trials.

This chapter addresses aspects of Objective 1: to develop release protocols to minimise mortality based on the anti-predator behaviour of wild and cultured juveniles. It is based on experiment 6, which utilised 3% of project resources.

Results from this section were not robust due to low sample sizes. However, it was clear that some released juveniles moulted successfully and grew with moult increments equal or even greater to those of wild controls. There was no indication of increased mortality at moult in released juvenile lobsters relative to wild controls. This implies equal levels of fitness and ability to find suitable shelter at the time of moulting in both groups. Our results do not support the extra effort of grading juveniles before release to exclude pre-moult animals.

11.1 Introduction

After surviving initial predation threats and finding shelter following release, the next major test of survival for naïve lobsters is likely to be associated with moulting. The ability to moult successfully will be influenced by appropriate feeding, and thus adequate nutrition, prior to the moult. Behavioural responses to predators and choice of shelter location will also be critical around the moult as animals are soft-shelled and thus less mobile at moulting and more vulnerable to predation.

The potential for moulting to of juveniles to influence predation risk is especially pronounced when releases are made in spring when temperature is increasing and moulting of juveniles is frequent (Edmunds, 1995). Releases at this time of year occurred in all trials in this project because most juveniles reached 12 months post-settlement in spring, which is the time of peak puerulus catches. Similar releases in spring would be expected where the released juveniles are sourced from ongrown juveniles collected as puerulus for aquaculture.

11.2 Methods

Moult mortality trials were conducted at Adventure Bay on the eastern side of Bruny Island, southeastern Tasmania (147°21’28"S, 43°21’254"E). The release site in the southern corner of Adventure bay consisted of an isolated area (approx. 80 m x 40 m) of high profile reef in 7 – 9 m depth. Patchy low profile reef continued for another 50-80 m to the north to a depth of 13-14 m.

Naïve lobsters for this trial were provided to TAFI at puerulus stage by a commercial licence holder (Tassal LTD.) and were obtained from predator exclusion cages around salmon culture pens when biofouling was cleared from the cages. Lobsters were then ongrown in tanks for 12 to 15 months, attaining a size of 30-52 mm CL.

SCUBA divers captured wild lobsters by hand within a week of the release. Although divers targeted lobsters in the same size range as naïve lobsters, such animals were rare

and wild lobsters up to 75 mm were collected to increase numbers available for release. We anticipated that larger lobsters could later be excluded from analyses if survival or resighting probability proved to be size-dependant.

Wild and naïve juvenile lobsters were tagged with visible antennal tags and internal microwire tags (Figure 14 and Figure 15). Visible tags were lost with the lobster's carapace during moulting, however microwire tags were retained through moulting. This allowed recaptured animals to be classified as either "moulted", where only the microwire tag was retained, or "unmoulted", where the antennal tag was retained. This system introduced some risk of false classification of juveniles as "moulted" where the antennal tag was lost. We checked for this possibility by comparing size of juveniles at release and recapture, which was possible as both antennal and microwire tags were individually coded.

We released 800 tagged lobsters (601 naïve, 199 wild) simultaneously at dusk. A diver released lobsters in the centre of the reef from a large mesh bag, and no assistance was given in finding shelter.

Surveys to assess survival through moult were conducted at longer intervals than those used to measure survival or movement (Chapter 15), to increase the opportunity for juveniles to moult before recapture. Resampling surveys were conducted 17, 51 and 136 days after release.

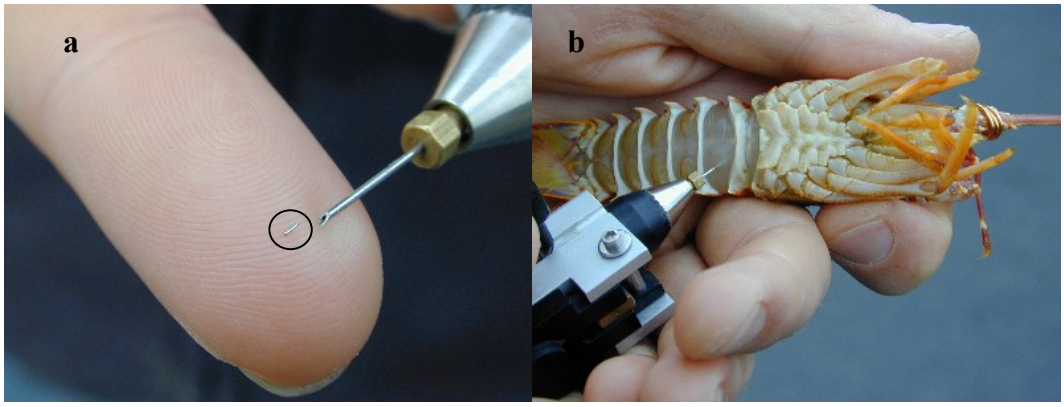

Figure 14. a) Coded microwire tag (on finger) and applicator needle b) Injecting coded microwire tag into juvenile lobster.

Figure 15. Antennal tag with individually coded sequence of coloured beads.

11.3 Results and discussion

Due to high wild juvenile lobster abundance at the release site, and high rates of dispersal of lobsters, fewer lobsters were recaptured than anticipated. Table 3 shows the details of 23 microwire tagged lobsters captured in 3 dive surveys (approximately 24 diver hours). On each occasion, microwire tagged juveniles represented 5-10% of the total juveniles captured.

Only 5 of these lobsters were from the naïve group, giving a ratio of about 4.6 wild lobsters to every naïve lobster recaptured. This does not compare favourably with a ratio of 2.4 to 1 from the final pre-moult sample, and superficially could be taken to indicate high moult mortality amongst naïve juveniles

However, it is apparent that there is a consistent size-related resighting/recapture bias that is largely independent of group. This bias is apparent in both resighting probability of antennal tags and recapture of microwire tags (Figure 16). Note that while the patterns of bias are very similar, the magnitude is far greater for microwire recaptures. This suggests divers were less able to resight smaller juveniles than larger juveniles, and that divers had reduced success in recapturing smaller juveniles relative to larger juveniles. Reduced success in recapturing smaller lobsters is presumably due to greater difficulty in extracting small juveniles from smaller crevices.

The difficulties associated with capturing small juveniles from the wild resulted in only 17% of wild-caught lobsters being under 40 mm CL, compared with 99% of naïve lobsters. However, low resighting of small juveniles is not a result of poor survival amongst naïve juveniles, as the effect can still be clearly seen when data for naïve juveniles is excluded (Figure 17). Lobsters over 60 mm CL are also under-represented in samples of wild-caught lobsters, while lobsters of 44-60 mm CL are clearly over represented. No large ongrown juveniles over 60 mm were released at the Bruny Is. site so the apparent reduced catchability of this group could only be seen in wild controls. We suspect that this observation was due to increased movement of larger control juveniles away from the release site after undergoing the disturbance of tagging.

Table 3. Details of recaptured microwire tagged lobsters. Group (N=naïve, W=wild). Δ CL = change in carapace length between release and recapture. Days = number of days between release and recapture. *= Female 'in berry'.

Capture date	Group	Release CL(mm)	Recapture CL(mm)	Δ CL (mm)	Days	Sex
10/10/2002	N	35	38	3	17	F
10/10/2002	W	54	61	7	17	F
10/10/2002	W	47	52	5	17	M
10/10/2002	N	36	37	1	17	M
10/10/2002	W	56	60	4	17	F
10/10/2002	W	69	72	3	17	M
13/12/2002	W	60	65	5	51	M
13/12/2002	W	41	44	3	51	M
13/12/2002	N	33	38	5	51	M
13/12/2002	W	73	77	4	51	M
8/3/2003	W	56	80	24	136	F
8/3/2003	W	56	71	15	136	F*
8/3/2003	W	67	79	22	136	M
8/3/2003	N	36	60	24	136	F
8/3/2003	N	31	52	21	136	M
8/3/2003	W	57	66	9	136	M
8/3/2003	W	64	74	10	136	F*
8/3/2003	W	38	64	26	136	M
8/3/2003	W	52	69	17	136	F
8/3/2003	W	55	74	19	136	M
8/3/2003	W	53	70	17	136	M
8/3/2003	W	62	74	12	136	F
8/3/2003	W	65	83	18	136	F

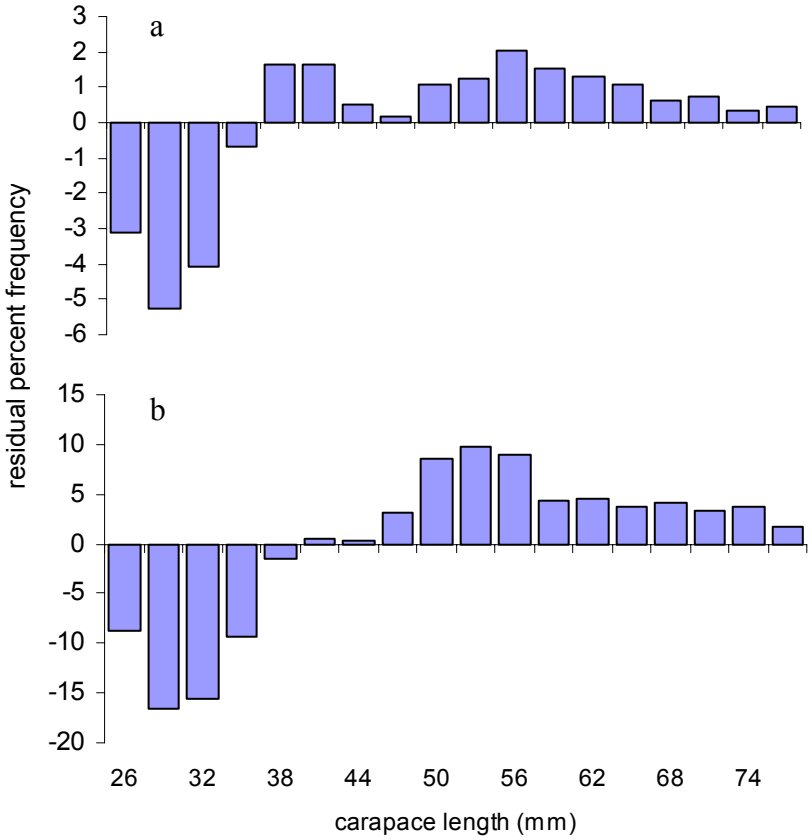

Figure 16. Consistent size-based bias in a) resighting of antennal tags by divers and b) recapture of microwire tagged juveniles, showing that juveniles below about 40mm CL are consistently under-represented in samples, while larger animals are over represented. Data are smoothed (3 point moving average) residuals from comparing length frequencies of all lobsters released with CL at time release or resighted/recaptured lobsters.

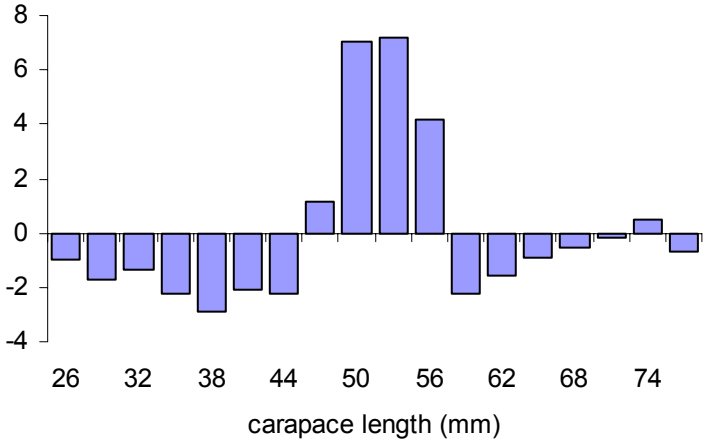

Figure 17. Bias in recapture probability of wild caught microwire tagged juveniles. The Y-axis denotes residual percent frequency so that negative scores indicate a reduced probability of recapture and positive scores indicate increased bias towards recapture.

Results on differential rates of recapture indicate that longer-term survival of naïve juveniles should only be compared with controls of the same size. For lobsters less than 40 mm CL, the final resighting survey yielded a ratio of naïve lobsters to wild-caught of 6:1 for pre-moult juveniles. This is roughly equivalent to the ratio of 5:1 for juveniles that had moulted and only retained their microwire tags. While it is unwise to draw firm conclusions from such a small number of recaptures, it is clear that some naïve juveniles are able to moult successfully and avoid predators during this period. We also note that there was no indication from our limited results that naïve lobsters were less able to survive moulting than wild controls.

Information on moult increment was also obtained where juveniles had moulted and shed their antennal tags. Moult increments of recaptured naïve lobsters were generally equivalent to that of wild-caught lobsters at liberty for the same period. It appears that in the high growth summer period between the 51 day sample and the 136 day sample some lobsters have moulted once (with growth as low as 9mm over this period) while others have moulted twice (growth of up to 26 mm). Both naïve lobsters captured in the 136 day sample appear to have moulted twice, and have grown more than many of the wild-caught juveniles, suggesting that they have adapted to gathering food in the wild.

12. Behaviour of ongrown juvenile spiny lobsters, *Jasus edwardsii* after reseeding to a coastal reef in Tasmania, Australia.

This chapter contributes to objectives 1, 2 and 3. Information on behaviour after release was used to gain an improved understanding of the method of release. In particular, there was concern that released animals may spend a considerable amount of time moving and searching for habitat in the first few hours after release, which would increase predation risk. Patterns of movement in relation to habitat features such as boundaries of reef with sand were also investigated to provide recommendations on the most suitable release habitats. Lastly, the distance that juveniles dispersed after release was measured to design sampling protocols in large scale releases of juveniles where survival was measured – that is, how large an area should resighting surveys cover?

Key findings were that lobsters regained normal nocturnal behaviour after release and only moved at night, this reiterates other results that confirm that juveniles revert to normal behavioural patterns at release (Chapter 9). Juveniles invariably sought shelter immediately after release and remained in shelters until night-time. Released juveniles displayed no tendency to move toward their site of origin; this observation was also true for translocated wild juveniles. This implies that enhancement operations would be successful at raising density in release sites. Movement was quantified and tended to be greatest in the first 48 hours after release. These results contributed to sample design for objective 3 – measuring survival in large scale releases.

Results presented here also utilised data collected for project FRDC 1999/314. Those data were reanalysed here, primarily to contribute to planing of large-scale releases of juvenile lobsters.

12.1 Abstract

Detailed information on movement, behaviour and habitat use is required to assess survival of juvenile lobsters released from tanks back to natural reef. To this end, acoustic tags were used to track 9 juvenile lobsters from 3 treatment groups: lobsters ongrown for 1 year from wild-caught pueruli, locally caught wild lobsters and translocated wild lobsters. All lobsters were tracked for 11 days and recaptured. Lobsters only moved at night; during the day they sheltered in dens within the reef. All lobsters selected dens providing apparently good shelter, and ongrown lobsters were as likely as wild-caught lobsters to co-habit with other wild juveniles and adults. Highest levels of activity occurred in the initial 12 h after release. Distances moved each night declined throughout the study, whereas the likelihood of lobsters occupying the same den on consecutive days increased. Translocated lobsters showed no homing tendencies. Ongrown lobsters showed evidence of adapting to wild food sources, although their diet differed from that of wild lobsters. Similarities in behaviour of wild and ongrown lobsters are encouraging for future reseeding efforts.

12.2 Introduction

Programs to protect, enhance or rebuild marine stocks through reseeding must be conducted with a good understanding of post-release survival (Blankenship and Leber, 1996). This is because captive rearing of marine organisms may lead to inappropriate responses to predators (Tsukamoto, 1993), inability to gather adequate food (Olla *et al*., 1994) or modified diel activity rhythms (Nagata and Koike, 1997), any of which may reduce survival following release. This study represents preliminary work towards quantifying post-release survival of 1-year-old reseeded juvenile southern rock lobsters, *Jasus edwardsii*. Acoustic tracking was used to obtain information on post-release movement and behaviour, which assists in the development of robust field and analytical protocols for assessing survival.

12.3 Methods

12.3.1 Site selection

Tracking was conducted on an area of patch reef adjacent to Glenvar Point in the Derwent River, southern Tasmania (43°00’11"S, 147°23'49"E; Figure 18). The site is a discrete area of low-relief reef (maximum rise 2 m) in 5-7 m of water, with numerous resident juvenile lobsters. The low relief of this site minimizes reflection of acoustic pulses, which can cause erroneous position readings (Van der Meeren, 1997). The reef covers an area of approximately 2500 m^2 and supports a dispersed macro-algal cover of predominantly *Ecklonia radiata*, which occurs at greatest density towards the centre of the reef. The reef is isolated from other lobster habitat by sand on its western boundary, and unstructured flat sandstone platforms on other sides. Patchy areas of platform reef extend offshore on the western boundary, the closest being approximately 100 m from the boundary of the study reef.

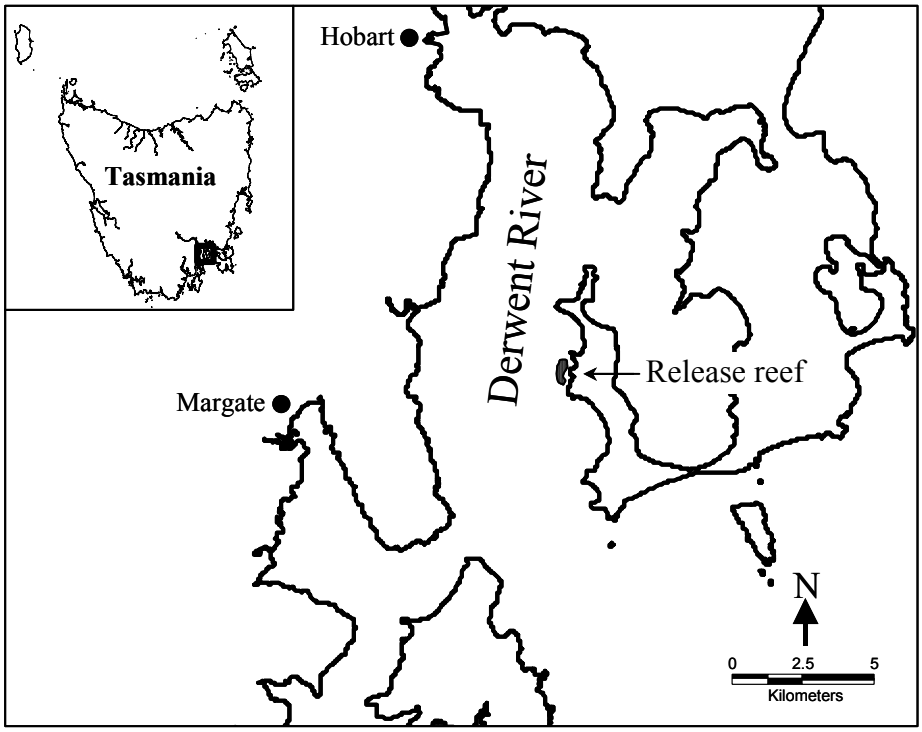

Figure 18. Location of the release reef in the Derwent River, southern Tasmania.

12.3.2 Experimental animals

Ongrown lobsters were captured as pueruli, and held in ambient water (10-19°C) for approximately 12 months. Three ongrown lobsters (hereafter referred to as O_1, O_2 and O_3) were selected randomly from a group held at high density (up to 100 m^{-3}) in a 4 m^3 tank. Bricks and bundles of plastic oyster mesh provided habitat structure in the tank. Lobsters were fed daily on fresh, opened blue mussels (*Mytlius edulis planulatus*) or commercial prawn pellets.

We compared the behaviour of ongrown lobsters with that of wild lobsters collected from the natal reef and a non-natal reef. Divers captured 6 wild lobsters by hand on the release day. 'Local' wild-caught lobsters (L_1, L_2 and L_3) were captured within the study reef, while 'translocated' wild-caught lobsters (T_1, T_2 and T_3) were captured on an area of reef 700 - 800 m south of the study reef. To minimize the risk of tags being shed, lobsters were moult-staged using the system of Turnbull (1989), and only lobsters clearly in intermoult stage were retained. All treatment groups contained lobsters of similar sizes (Table 4).

Table 4. Identification codes, carapace length (CL) and frequency emitted by tags of lobsters from the 3 treatment groups.

Treatment	Identification	CL (cm)	Tag (kHz)
Ongrown	O1	42.3	72
	O2	39.9	73
	O3	37.2	79
Local control	L1	48.3	71
	L2	39.1	75
	L3	39.4	78
Translocated	T1	49.3	74
	T2	36.6	70
	T3	37.2	77

The carapace of each lobster was dried with paper towel and compressed air prior to attaching the acoustic tag. A tag (Sonotronics IBT96-1) measuring 8 mm x 18 mm and weighing 1.5 g was glued using fast-setting epoxy resin to the dorsal surface of each lobster carapace. Each transmitter emitted a different frequency (70-79kHz) and a unique 3-digit pulse code, to allow individual identification of lobsters.

The centre of the reef was divided into a 3 x 3 grid of 10 m squares, and a single lobster was randomly assigned to each grid square. Divers released lobsters into shelters close to the centre of allocated grid squares.

12.3.3 Tracking system and methods

For each survey, lobsters were tracked initially with a boat-mounted tracking system (Sonotronics DH-4 directional hydrophone, Sonotronics USR 5W scanning acoustic receiver), usually allowing tag position to be located within a 5 m radius. A weighted buoy-line was deployed at this position, and a diver then located the lobster with a hand-held acoustic receiver (Vemco VUR-96). Subsequent positions of each lobster were marked with labelled buoys, and distance and bearings between buoys measured at the surface by 2 divers using a tape measure and hand-bearing compass. When a distance was too long to be estimated by tape measure the distance was estimated by timed runs of the research vessel at known velocity.

Lobsters were tracked using the boat-mounted receiver every 6 h for 48 h following release, and with the boat-mounted and diver-held receivers every 24 h for 5 days, then every 48 h for a further 6 days. Detailed notes on lobster habitat choice were made on day 10 of the study.

Tagged lobsters were recaptured after 11 days, along with 9 untagged lobsters. Foreguts were removed, fullness assessed and contents identified to the lowest practical taxon (usually order or class). Bivalve molluscs were further split into the 2 dominant species observed, due to the importance of these species in diets, and to the different habitats they occupy. The volume of each taxon as a percentage of total gut contents was estimated visually.

12.3.4 Environmental conditions

Water temperature ranged from 12.0 to 13.5°C. Underwater visibility varied from 5 m to 12 m, though following heavy rainfall during the second night, it dropped to 1.5 to 2 m on low tide. Time of sunrise varied from 0625 to 0600, and of sunset from 1752 to 1807.

12.3.5 Statistical Analysis

Distance moved ((1) over 24-h periods for the first 5 days and (2) over 48-h periods for the duration of the study) was analysed using repeated measures ANOVA models, with treatment group as a fixed factor. Time between surveys was dictated by time taken to complete each survey and the need for high sampling resolution in the 48 h following release, and accordingly was also considered fixed. Movement data were tested for serial correlation (Mauchly's test) and log-transformed to meet ANOVA assumptions.

Directionality of movement of individual lobsters and treatment groups was tested using circular and elliptical statistics (Batschelet, 1981). Given the small number of movement observations for individual lobsters, normality could not be assumed, and the non-parametric Rayleigh test was used. Hotelling's test, based on the positioning of group centroids and the origin relative to 95% confidence ellipses, was used to test directionality of treatment groups and differences between groups.

Log-transformed stomach fullness data were analysed using 1-way ANOVA. Differences in gut contents of treatment groups were analysed by non-metric

multidimensional scaling (MDS) performed on a matrix of Bray-Curtis similarities of square-root transformed data. This transformation has the effect of down-weighting highly abundant food items (Clarke and Green, 1988), and was deemed appropriate due to the dominance of unidentifiable soft material in lobster stomachs. Similarity percentage analysis (Clark and Warwick, 1994) highlighted prey items contributing to group separations observed in the MDS plot.

12.4 Results

12.4.1 Movement

All tagged lobsters were successfully tracked and recaptured after 11 days. A single lobster remained undetected for 18 h in the first 24-hour period, but was subsequently relocated. On 4 occasions, acoustic tags were detected by the boat-mounted receiver but could not be located by divers. In these cases, lobster position was estimated from the strongest signals received at the surface.

No movement was recorded between surveys occurring during daylight hours on the same day. Greatest distances moved were generally between the 2200 and 0400 samples, the only survey period wholly within the hours of darkness.

Longer movements occurred predominantly on an east/west axis (Figure 19). Few excursions were made into the southeast quadrant, as this contained shallow water and a rocky point headland.

Lobsters moved significantly further in the first 24 h than in the following 5 days (ANOVA: $F=4.23$, $df=4$, $P=0.0099$, Tukey's HSD $0.005<P<0.042$), and significantly further in the first 48 h period (days 1-3) than in the final 48 h period (days 9-11) ($F=5.39$, $df=4$, $P=0.003$, Tukey's HSD $P=0.023$) (Figure 20). Distance moved did not vary significantly between treatment groups for positions recorded every 24 h for the first 5 days ($F=1.3$, $df=8$, $P=0.874$) nor for positions recorded every 48 h for the duration of the study ($F=0.82$, $df=8$, $P=0.968$).

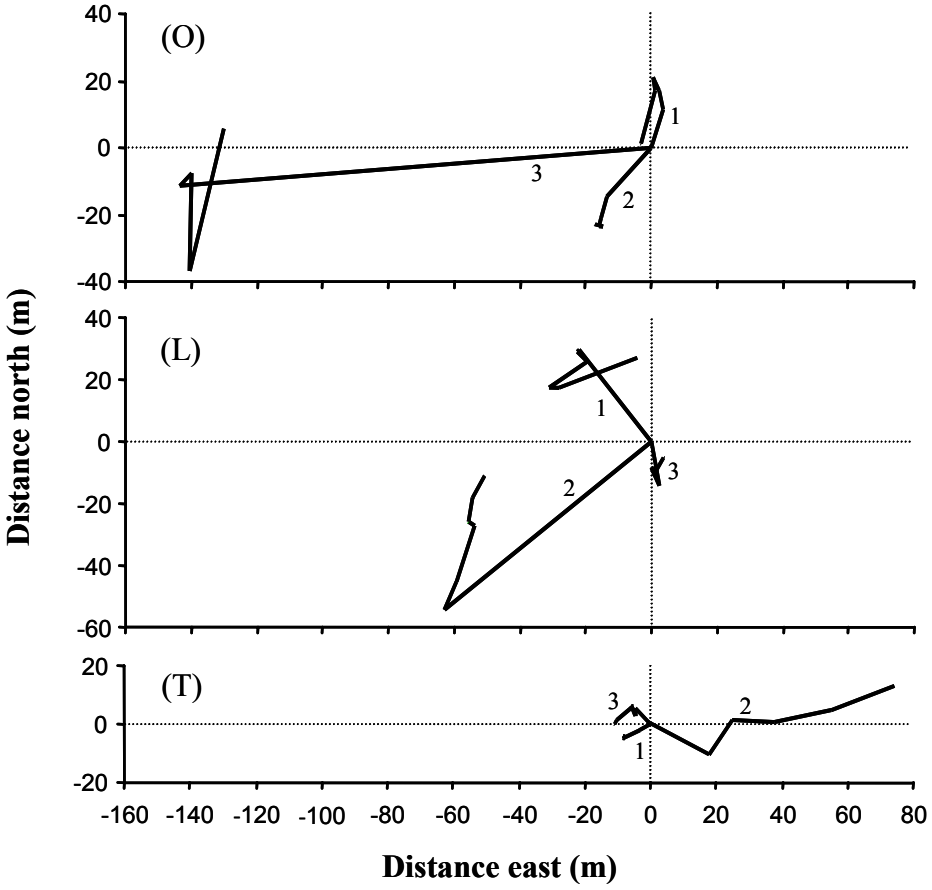

Figure 19. Movement tracks for lobsters from treatment groups ongrown (O), local control (L) and translocated controls (T) plotted every 24 h over the 11 day sampling period.

First 24 hours

Six lobsters (O_1, O_2, O_3, L_1, L_2, L_3) moved further during the initial 24 h than in any other 24 h period. Positions recorded at 6 h intervals during the first night tended to be in-line between lobster release locations and dens occupied by lobsters during the second day, reflecting predominantly linear movement. Lobster T_1 moved less than a meter during the first night, but was observed alive and responsive by divers on day 2.

Lobster O_3 was detected close to the release area 6 h post-release but was not located again until 24 h post-release. In this period, the lobster moved 144 m west (Figure 19, (O)) onto an area of reef offshore from the release reef. This was the greatest distance moved in a 24 h period by any lobster during the study, and included passage of at least 100 m over unstructured sand habitat.

24 to 48 hours

Only 2 lobsters (T_1 and T_2) moved further during this period than during the first 24 h. Five lobsters (O_2, L_3, T_1, T_2 and T_3) showed essentially linear movement between the 24 hour and 48 hour surveys, although movement was not necessarily in the same direction as in the first 24 h.

Position fixes taken every 6 h revealed exploratory or foraging behaviour by lobsters O_1, O_3 and L_1 during this period. These lobsters were recorded up to 30 m away from dens occupied on day 1 of the study, but by dawn on day 2 they had returned to be in or within 5 m of dens occupied on day 1.

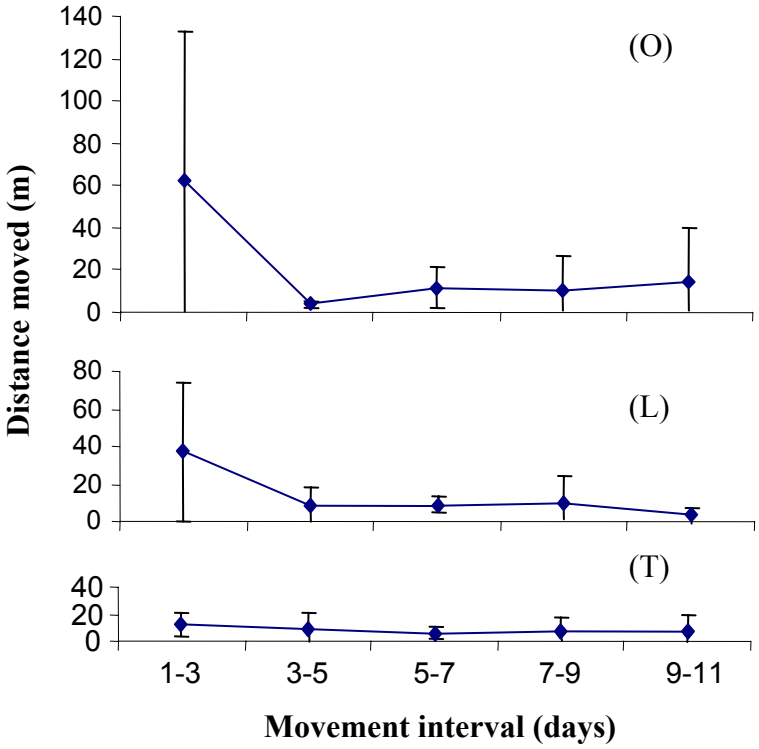

Figure 20. Distances moved (±SD, n=3) by ongrown (O), local control (L) and translocated control (T) treatment groups over consecutive 48-hour periods.

12.4.2 Directionality

Two translocated control lobsters and 1 ongrown lobster showed significant directionality in movement over the course of the trial (Rayleigh test T_1: $P=0.025$, T_2: $P=0.049$ and O_2: $P<0.001$). Translocated lobsters did not move in a consistent direction, and none of the animals moved towards their original capture reef. Confidence ellipses ($\alpha=0.05$) for grouped daily movement data (Figure 21) showed considerable overlap. The displacement of the group centroid from the origin represents the mean vector length and direction for each group. The greatest displacement was for the ongrown treatment, being 10.8 m at 268° from the origin. The centroids of all groups did not vary significantly from the origin or from the centroids of other groups (Hotelling's test, $P>0.05$; Batschelet, 1981); hence, distributions did not vary significantly from randomness.

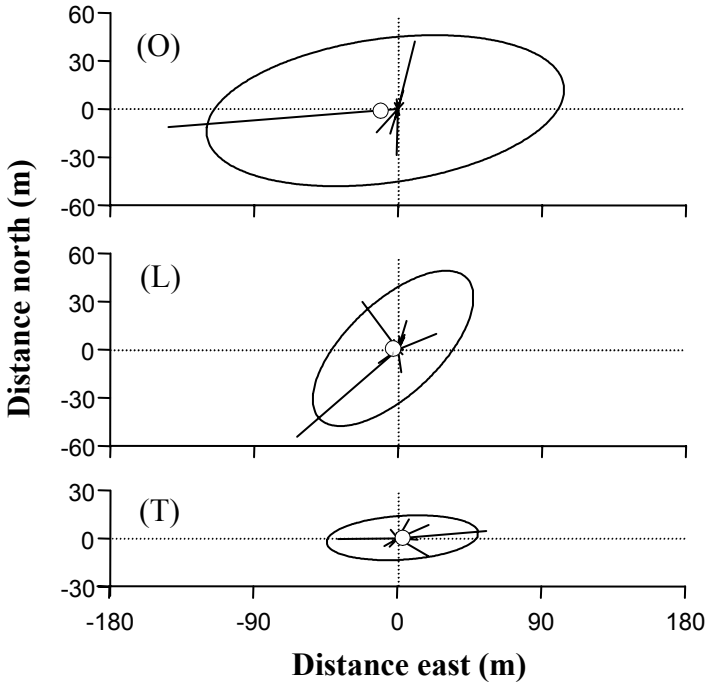

Figure 21. Distance and direction of individual daily movements for lobsters from each treatment group. Confidence ellipses (α=0.05) and group centroids are shown.

12.4.3 Den choice and habitation

Lobsters invariably sought cover within the reef during daytime. Den morphology ranged from larger open dens within boulder piles, often co-habited by wild lobsters of a similar size, to ledges or small cracks within or around the perimeter of platform reef. Ongrown lobsters were as likely as the other treatment groups to cohabit with wild lobsters.

Lobsters were more likely to reside in the same den on consecutive days as the study progressed. Two lobsters (L_1 and O_3) were in the same dens on day 2 as on day 1, but neither was relocated in the same den on day 3. Five lobsters (O_1, O_2, T_1, T_3 and L_3) were located in the same dens from day 7 to day 11. Only 1 lobster (T_2) was not seen in the same den on 2 consecutive nights at any stage during the study.

The response of wild juvenile lobsters to the approach of divers was initially an increase in activity, often involving antennal movement. On closer approach, lobsters would retreat into dens facing the den entrance. All tagged juveniles responded in the same manner, suggesting an appropriate response to the presence of predators.

12.4.4 Stomach contents

Four lobsters (2 untagged, 2 local control) had empty stomachs (Figure 22), and of these 2 (1 untagged, 1 local control) were in early pre-moult (stage D_0 of Turnbull's (1989) system) and 1 (untagged) had recently moulted. There were no significant differences in gut fullness between tagged and untagged lobsters (ANOVA: F=0.029, df=1, P=0.867) or between treatment groups (F=2.35, df=2, P=0.176). However,

statistical power to detect differences was low due to low sample sizes and high variability.

Many lobster stomachs contained well-masticated or digested unidentifiable plant and animal material. The remaining material comprised mostly shell fragments including two species of venerid clams, *Gallialaria* sp. and *Electroma georgiana* (Figure 22). Small urchin spines and crustacean appendages were present in low numbers in most stomachs, whereas gastropod shell fragments, sponges and whole foraminiferans were uncommon.

Multidimensional scaling revealed separation between the diets of ongrown and wild lobsters (Figure 23). Low volumes of *Galioleria* sp. in the stomachs of ongrown lobsters explained 32% of the difference between ongrown and translocated control groups. The total absence of *Electroma georgiana* from the stomachs of ongrown lobsters accounted for 29% of the difference between ongrown and untagged lobsters, and 23% of the difference between ongrown and translocated controls. No tests were performed on data from local control lobsters, as only one stomach from this group contained food.

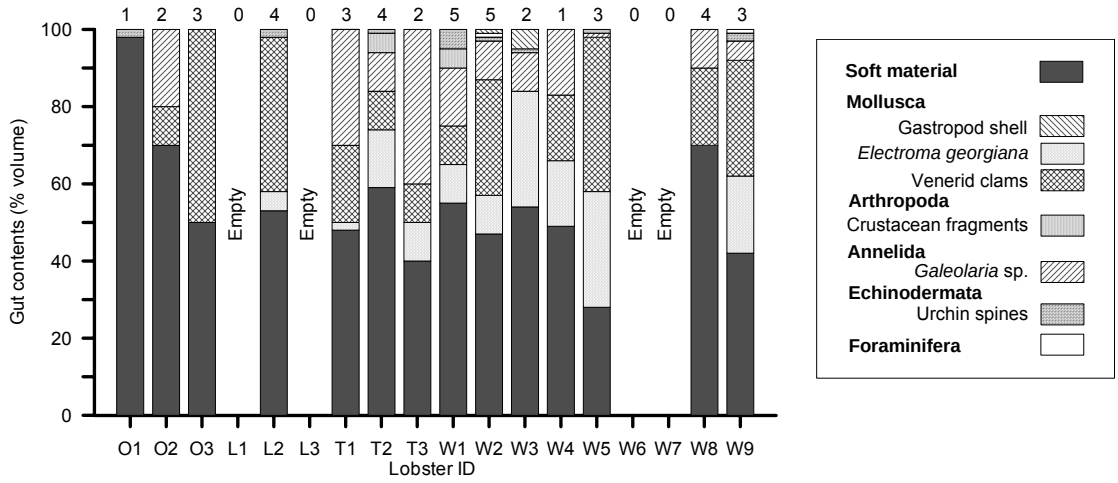

Figure 22. Stomach contents of 9 tagged (O1 - T3) and 9 untagged (U1 - U9) lobsters by percentage of total volume. Numbers above columns are stomach fullness (0 = empty to 5 = full).

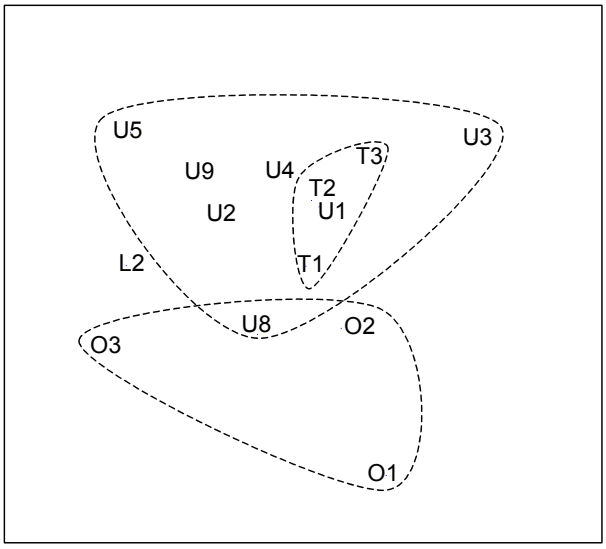

Figure 23. Non-metric multi-dimensional scaling of gut contents data (Stress =0.11). Distances are euclidean distances for square root transformed data. Polygons enclose points from the same treatment groups.

12.5 Discussion

Our tracking system incorporating boat-mounted and diver-held tracking units was effective and has some benefits over systems used elsewhere. The ability to resight and recapture lobsters provided detailed information on habitat choice, behaviour and feeding. Remote continuous acoustic tracking systems have been used to track lobster (Duggan *et al*., 1991; Tremblay *et al*., 1991), and can provide high quality information on movement. However remote systems are expensive, and to observe habitat usage and recapture tagged lobsters, manual tracking is also required. Electromagnetic tracking has proven powerful for obtaining detailed information on small-scale movements of lobsters (Phillips *et al*., 1984; Smith *et al*., 2000), and has the advantage that electromagnetic signals are less affected by reef topography than are acoustic signals. However, the relatively large size of electromagnetic tags means that this system is better suited to tracking larger crustaceans than the small juveniles used in this study (Smith *et al*., 2000). Also, the transmission range of electromagnetic tags is low, and an extensive array of underwater antennae must be constructed, requiring prior knowledge of probable movement ranges. This information was not available for juvenile southern rock lobster prior to this study.

The detectable range of acoustic tags was appropriate for this study, approximating the maximum distance moved by most lobsters over 24 h. Only a single lobster moved beyond detectable range (O_3 during night 1), and was later relocated by performing a grid search. Although acoustic tags were smaller than electromagnetic tags, the combined weight of tag and glue was nonetheless substantial relative to lobster weight (up to 10% in air). However, shelter selection and feeding were not noticeably affected by the presence of tags.

The labour-intensive nature of manual tracking restricted the number of lobsters that could be tracked simultaneously. As a result, the power to detect group differences in movement was low. Tracking and locating the 9 tagged lobsters took up to 4 h per

survey, and accordingly 2 field teams were required to conduct repeated 6-h surveys safely. A further limitation of this technique is that recorded distances moved must be taken as a minimum value, whereas the high frequency of position fixes with automated systems can provide actual distances moved.

The observed pattern of increased lobster activity when first introduced to new surroundings appears to be a common response (MacDiarmid *et al*., 1991; Nagata and Koike, 1997; Kingston, 1999). This effect was brief, lasting little more than 24 h. We infer that high-resolution sampling over the first few days should be a feature of survival estimation trials.

Adults of several lobster species display homing behaviour over distances of up to hundreds of kilometres (Pezzack and Duggan, 1986; Karnofsky *et al*., 1989; Vannini and Cannicci, 1995). Of 20 recaptures from 199 juvenile *Panulirus cygnus* tagged and transplanted away from home sites, 4 returned to their home sites within 2 months, having travelled distances of up to 400 m (Chittleborough, 1974). The apparent absence of homing behaviour of translocated lobsters in the current study may have been due to the distance of translocation or the short time period of the trial. A notable difference in behaviour between translocated lobsters and other treatment groups was that the increase in movement in the first 24 h was not as marked in translocated lobsters. This difference suggests caution be exercised in the use of translocated lobsters as controls in estimating the survival of reseeded lobsters. Where it is necessary to use a mixture of local and translocated control lobsters, lobsters should be marked to distinguish the two groups.

In contrast to the findings of MacDiarmid and Stewart (2000), two results from this study highlight that sand edges around a reef do not represent an absolute barrier to juvenile lobster movement. Several lobsters moved over small patches of sand to find reef, and 1 ongrown lobster moved across >100 m of sand to new reef. Secondly, venerid clams were a major prey item of juvenile lobsters in this study and these clams are abundant in sand (Edgar, 1997). Field protocols in survival experiments must therefore use broad survey areas that encompass adjacent reef areas separated from the release reef by sand.

The difference in stomach contents of wild and ongrown lobsters requires further investigation. While lobster behaviour and survival appeared unaffected during the trial, effects of insufficient or inappropriate diet would likely be manifest over longer periods. Under conditions of total starvation, juvenile *Panulirus cygnus* survived for 24-43 weeks (Chittleborough, 1975).

The diet differences in this study may have behavioural or morphological bases. Prey items routinely eaten by wild lobsters may not have been recognized as prey by ongrown lobsters. Culture conditions can induce morphological differences in lobster feeding appendages (Goldstein and Noetzli, 1997). It is difficult, however, to envisage a change that would prevent a lobster feeding on the soft-shelled *E. georgiana*, whilst not inhibiting feeding on hard-shelled venerid clams. Longer trials will be required to confirm that reseeded juveniles are feeding adequately.

Lobsters are opportunistic feeders, and diets vary between habitats. The volume of unidentifiable soft material and annelids from stomach contents in this study was much

higher than found by Edmunds (1995) for *J. edwardsii* of the same size on the east coast of Tasmania. Conversely, volumes of poriferans, echinoderms and crustaceans were lower. Clams were an important diet component in both studies. The differences were likely a reflection of prey availability in the oceanic habitats sampled by Edmunds (1995), compared with the estuarine site in this study. An analysis of stomach contents of ongrown and wild lobsters across a range of habitats and over longer periods may assist in gauging the likely success of reseeding operations.

Despite the small sample size, preliminary inferences can be made about the survival of reseeded ongrown juveniles. Highest activity occurred in the initial 24 h after release, and it is probable that the risk of predation is also highest during this period. All lobsters tracked in this study survived this high-risk period, chose appropriate shelter, and avoided divers in a manner that was indicative of an appropriate response to predators. Data on movement of ongrown lobsters can now be used to define appropriate search areas for future large-scale reseeding trials with tagged juvenile southern rock lobsters. Our results indicate daily movements are generally in the range of 0 to 50 m and thus within a range that can easily be searched by divers. High-resolution sampling in the first 24 h after release and detailed examination of changes in diet across time and habitats will be important components of future studies.

13. Tethering as a method of comparing predation pressure between sites

This chapter describes experiments on the use of tethering to measure relative predation. These experiments indicated that tethering can provide a useful measure of relative survival of lobsters between habitats, however only where information is collected on the species of predator. Mesocosm trials indicated that both octopus and adult lobsters have low capability of catching un-tethered juvenile lobsters, while wrasse were effective predators regardless of whether the lobster was tethered or not. These experiments provided estimates of absolute mortality in the first 48 hours after release of less than 5%. This chapter is based on Experiment 5, which utilised 10% of project resources.

13.1 Introduction

This chapter reports the results of experiment 5 and addresses questions of importance to objectives 1 and 2. Experiments conducted were expanded considerably from what was outlined in the application.

Tethering potentially represents an efficient method by which we can judge the suitability of sites for lobster releases using small numbers of lobsters. While acoustic tracking provides a means of following a small number of lobsters over a limited distance, at approximately $400 per tag this becomes an expensive exercise where multiple sites are involved. The dive time required to support such studies adds substantially to the expense. At Glenvar Reef, 9 lobsters were followed for 2 weeks with no mortalities. While much useful information was obtained from following lobsters, a series of similar results across multiple sites would provide no information on relative suitability of sites.

Using the camera system to observe predation events on tethered lobsters enabled us to identify a suite of potential predators of juvenile lobsters. However, additional research was required to confirm that these predators could catch untethered lobsters.

The primary concerns relating to experimental design when using tethering to compare predation rates across habitats is that the artefacts of tethering may not be constant across habitats (Peterson and Black 1994). The predominant artefact of tethering mobile animals is, unsurprisingly, a marked increase in predation rate. In itself this is an advantage for this type of experiment. Natural predation rates on juvenile lobsters appear to be very low. Consequently, the chance of capturing a predation event on camera without the use of tethers is extremely low. However, given different mechanisms of prey capture by various predators, there was concern that the tether would have affected the capture rate by different predators to varying degrees. If this was true, and predator abundance varied between the habitats, results may have been more a reflection of varying artefacts than real differences in predation.

Direct experimental controls for these artefacts are not possible; the reason for tethering is that the mobility of the prey species is such that observation of untethered individuals

are impractical. Peterson and Black (1994) suggest that in the absence of direct measurements of the magnitude of experimental artefacts, it may be possible to make indirect measurements by varying the intervention type. Micheli (1996) used this approach with infaunal clams that were tethered or contained within buried fences in vegetated and unvegetated habitats. The effects of the various interventions were compared to unrestrained clams. In this case, the major predators were seastars and crabs, both being capable of transiting the buried fence. This approach could not be applied to lobsters, as predators had similar levels of mobility to lobsters, so that any physical barrier capable of containing lobsters would also exclude predators.

The only option for testing predation on untethered lobsters is to do so in a 'closed' system where the number of untethered lobsters present before and after a period of exposure to a predator can be counted. Such a system is a tank based 'mesocosm', which represents a small natural reef in a tank. This provides a good approximation of the natural environment for predators and lobsters alike, promoting behaviour similar to that in the wild. After a predator trial is completed, the entire reef can be thoroughly searched and even dismantled to find the surviving lobsters.

The primary questions of interest addressed in this chapter are:

- Is tethering an effective and efficient way to measure predation pressure, and thereby identify appropriate release sites?
- What is the identity of predators likely to impact on lobster releases in Tasmania?
- Can we identify, using tethering trials, habitat features that effect predation rates, and thereby identify key site characteristics for releases?

13.2 Methods

13.2.1 Tethering and habitat analysis

Tethering trials were completed in Wellington, New Zealand and in south eastern Tasmania. Juvenile lobsters of CL 27 – 42 mm (New Zealand $\bar{x} = 39.5 \pm 0.2$ s.e., Tasmania $\bar{x} = 36.8 \pm 0.2$ s.e.) were ongrown form captured pueruli for approximately 12 months, as per other experiments in this study. On the day prior to experiments commencing, lobsters were 'saddled' for tethering. After drying the lobster carapace with compressed air or paper towel, a short length of 6 kg breaking strain nylon monofilament was passed under the lobster and the ends bought up between the 2nd and 3rd pair of walking legs to the dorsal surface of the carapace. An overhand knot was tied in the monofilament, and then a small barrel swivel with a snap hook tied in the centre of the carapace. The knot was secured with a drop of cyanoacrylate glue, and the lobsters remained in air for approximately 5 minutes to allow the glue to reach partial-cure (Figure 24). The swivel and hook allowed the tether to be attached to the lobster.

Tank tests were used to refine tethering method and ensure that lobsters would not escape from the tether.

In the field, lobsters were tethered to 200 g lead weights by a 200 to 250 mm length of 6 kg breaking-strain nylon monofilament. Lead weights had stiff galvanised wire ‘anchors’ protruding from them to allow them to be secured in rock crevices. Each lobster and each weight were tagged with individual numbers to facilitate data collection. Lobster numbers were printed on phase-3 waterproof paper, and glued to the dorsal surface of the lobster carapace using cyanoacrylate glue.

Figure 24. Juvenile lobster with 'saddle' complete showing swivel and snap hook

At each site, environmental variables including depth, algal abundance, predatory fish abundance and rugosity were measured. Algal abundance was measured by counting the number of macro-algal stipes within a 0.25 m^2 quadrat placed by divers every meter along a 20 m transect line. In New Zealand, abundance of adult and juvenile algae was recorded separately. Predator abundance was measured by diver transects in New Zealand and baited camera drops in Tasmania. Rugosity was calculated by measuring and marking a 20 m straight-line distance over the reef, then re-measuring the same distance following the contours of the reef. This was repeated 3 times for each site.

At each site, a weighted transect line was laid across the reef and secured at both ends. Tethered lobsters were placed along the transect line at distances of up to 5 m from the line. Lobsters were placed in hides assessed by divers to be appropriate for the size of lobster. The length of tether meant that they were able to move well out of the hide, but withdraw fully when approached by predators. Details of den dimensions, depth and presence of con-specifics were recorded for each lobster placement along with an ‘address’ for the location of the lobster referenced to the transect line (eg. 14 L 2.5 would indicate a position 14 m along the line and 2.5 m left of the line).

Tethered lobsters were initially deployed late in the afternoon, and were visually checked by divers at 24 h and 48 h post-deployment. On each occasion divers noted the presence or absence of the lobster and weight as well as details of any lobster remains present at the tethering site. Any lobsters still alive after 48 h were retrieved.

In Tasmania 3 replicate trials of 20 lobsters were conducted at each of 7 sites (Figure 25). As it is anticipated that most releases will take place in winter, releases were conducted at all sites during winter. Comparative summer trials of 3 further replicates

were conducted at Adventure Bay and Rheban Beach. In New Zealand, single trials of 20 lobsters each were conducted at 5 sites (Figure 26).

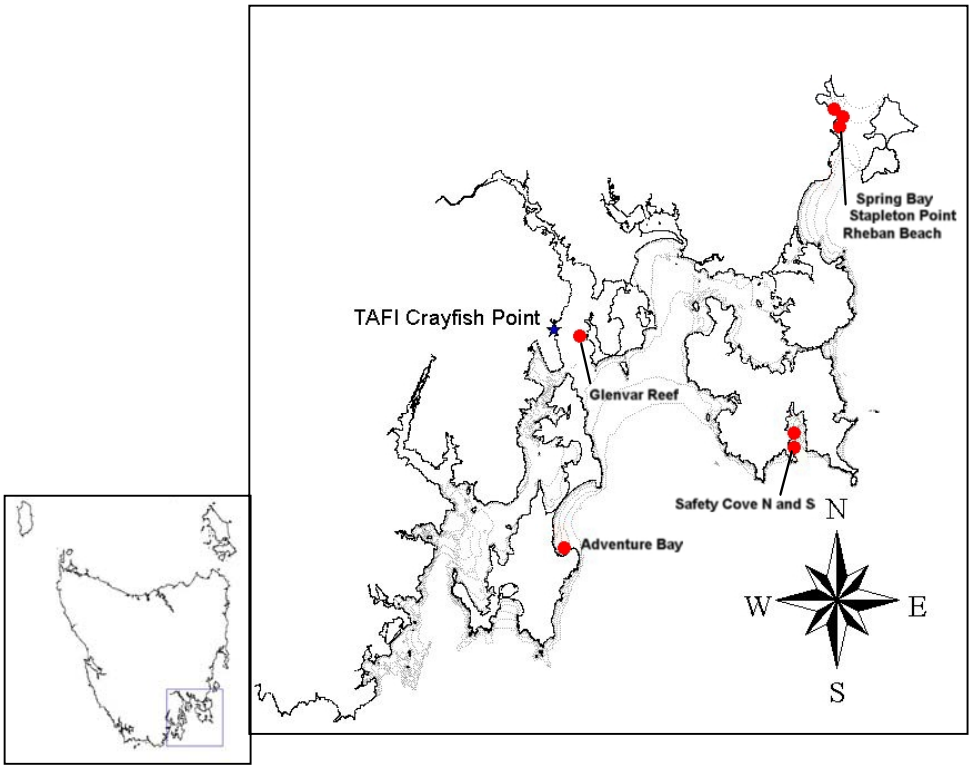

Figure 25. Sites for tethering trials in south eastern Tasmania

13.2.2 Video analysis

At 4 of the Tasmanian sites (Adventure Bay, Glenvar Reef, Safety Cove and Rheban Beach), the infrared camera system (see Chapter 7) was deployed to monitor trials. For each replicate trial at these sites, cameras and infrared lights monitored the fate of 6 of the 20 tethered lobsters. Cameras were recorded on time-lapse video with a frame rate of 1 frame every 0.8 s, and provided high-resolution multiplexed images throughout the 48 h trials. Footage was reviewed using a video splitter and 2 duplex multiplexer units so that all 6 images could be reviewed simultaneously. A 'binary search' method was used to find footage of kills. That is, the presence of all lobsters was noted at the start of the footage, then the tape was forwarded to the mid-point, at which stage we noted which lobsters were no longer visible. This process was repeated by rewinding the tape to the mid-point between the start and the middle of the tape, and noting the lobsters that were visible. This process continued to narrow down the time of each predation event without having to review the entire 48 h of footage for each trial. As images were recorded in 24 h time-lapse (24 h of footage on a 3 h video cassette), and hence reviewing the footage at standard video speed provided a review rate of 8 x recorded speed.

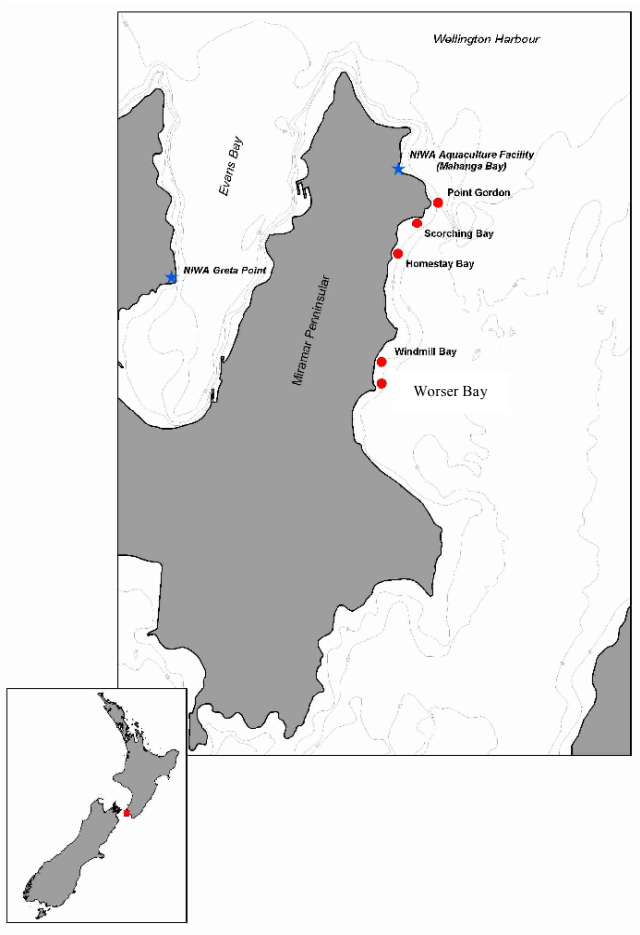

Figure 26. Tethering sites near Wellington, New Zealand

13.2.3 Mesocosm Trials

Mesocosm reef

The mesocosm reef was constructed in a 40 m^3 division of a 144 m^3 outdoor concrete raceway tank (Figure 27). The tank received unfiltered seawater from the Derwent River at a flow through rate of approximately 2000 l h^{-1}. The reef was constructed from approximately 2 m^3 of rocks ranging in size and shape from small sperical rocks of approximately 5 cm diameter, to blocks approximately 80 cm x 30 cm x 30 cm. Rocks were sourced from a shallow reef in the Derwent estuary, providing macrophytes and encrusting organisms similar to those found in lobster habitats in this area. Macroalgal densities were maintained at similar densities found in the wild on our experimental release reefs. A further reef of approximately 4 m^3 was set up in the adjacent division of the raceway tank, providing additional rocks if heavy grazing occurred, or macrophytes were lost. The mesocosm reef had been in place for > 1yr when trials began, and housed an apparently healthy community of invertebrates and small fish.

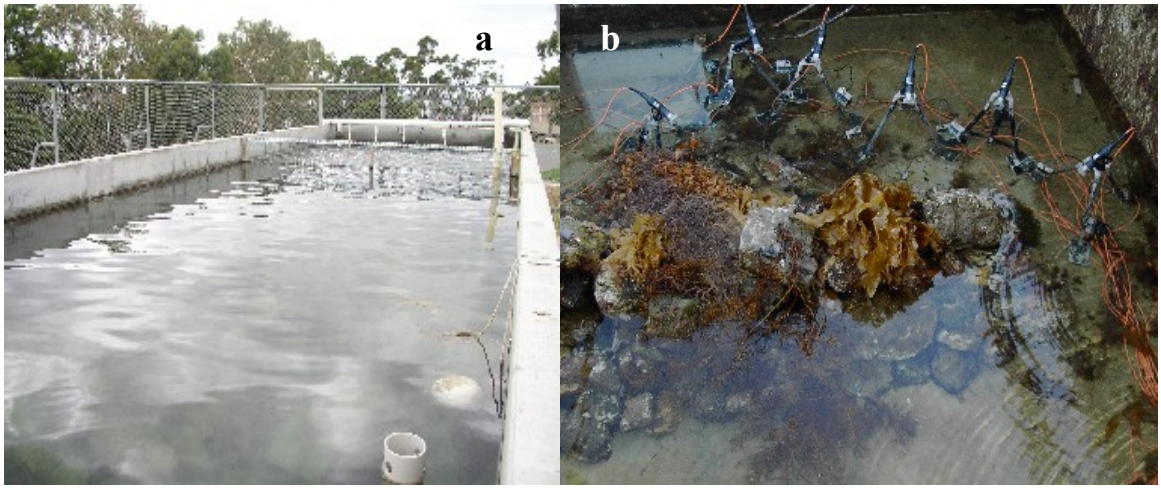

Figure 27. a) Raceway tank in which the mesocosm reef was constructed. The divider can be seen towards the far end of the tank b) mesocosm reef with water level lowered to allow thorough searching of the reef – cameras and lights can be seen deployed for this trial.

Predator trials

Camera images from tethering trials revealed predation by large wrasse species (*Notolabrus fucicola* and *N. tetricus*), octopus (*Octopus moarum*), velvet crabs (*Nectocarcinus tuberculosis*), and large con-specifics (*J. edwardsii*). Wild specimens of these species were obtained by diving, fishing or from fishermen.

For each of these predator species we ran 3 replicate experimental trials of the following 2 configurations:

1. 9 tethered lobsters and 9 untethered lobsters with predator

2. 18 untethered lobsters with predator

We also ran control trials with no predators present as a mortality control. Trial type 1 approximates the situation seen when we tethered lobsters in the wild; both tethered and untethered lobsters are present. However, this type of trial alone is inadequate, as results from tethered and untethered lobsters may not be independent. Specifically, tethered lobsters would likely be easier to catch than untethered lobsters. If the predator became satiated on tethered lobsters, it may be less likely to capture untethered lobsters, resulting in an underestimation of the predator's ability to catch untethered lobsters. Trial type 2 represents the situation where a large number of naïve lobsters are released untethered. We can thus directly compare the ability of the predators in these 2 situations.

Trials were run over a 6 month period between May and October 2003. Where possible, the order of trials was randomised, however small octopus of the size observed eating lobsters on camera footage were difficult to obtain and to maintain in captivity. Accordingly, octopus trials were performed in a block, but with trial type randomised. In all cases, feeding of captive predators was stopped 48 h prior to the commencement of a trial.

Predators were introduced into that mesocosm a minimum of 5 days prior to the trial commencing. This acclamation period provided time for the predator to become accustomed to the mesocosm reef, hopefully resulting in behaviour closer to that seen in the wild. For the larger predators (octopus and wrasse) trials were conducted with a single predator present. For lobster trials, 2 lobsters (98 – 118 mm CL) were present, and 4 crabs were used in crab trials. Juvenile lobsters were measured and sexed prior to release into the mesocosm. Juvenile lobsters were tethered and deployed as per field trials. No additional food was introduced to the mesocosm during the trials, as this may have enticed lobsters away from shelter and increased exposure to predators. Lobsters were observed actively feeding on encrusting organisms as would be expected from this sized lobster in the wild.

The length of trials varied between treatments. It was important to make sure that trials were stopped before all lobsters of any treatment group were killed. For example if trial type 1 continued until after all tethered lobsters were eaten, we would not obtain a valid ratio between kills of tethered and untethered lobsters. Close observation of early trials showed that a 4 day period was appropriate for type 1 trials, and a 10 day period was appropriate for type 2 trials. Regular snorkel dives in the tank provided additional information about when kills occurred.

13.2.4 Baited video stations

Baited video stations potentially provide a method whereby predator abundance can be evaluated at a site without the expense of diving. Baited video stations consisted of an underwater video camera mounted on a tripod with an extension arm on which was placed a bait pot (500 ml plastic jar with holes cut in the top and sides). The bait pot was filled with crushed, whole juvenile lobsters. The system was lowered to the seafloor and an image with the bait pot at the centre was recorded for 20 minutes. Three replicate drops were performed at the start of each tethering trial at sites where the infrared video system was deployed. Video footage was later reviewed and scored for the maximum number of fish and the maximum number of potential predatory fish seen simultaneously, and the total number of species seen in the 20 minutes of footage for each replicate. Fish scored as potential predatory fish were of a species and size identified in video-monitored tethering trials as likely predators.

13.3 Results

Tethering trials were successfully conducted at 7 sites in Tasmania, although at 1 site (Spring Beach) poor weather resulted in only 2 of 3 replicates being completed, and only 10 lobsters were used in the second replicate. Results from 24 h surveys (Figure 24a), while showing some variability, produced no significant differences (ANOVA, $F_{8,17}$=1.51, P = 0.227). Patterns seen in the 24 h surveys were accentuated in the 48 h surveys, with significant differences detected (ANOVA, $F_{8,17}$=2.64, P = 0.040). Significance increases when imbalance in the analysis is redressed by removing the Spring Beach site (with high variability due to missing replicate and lower numbers) is excluded from the 48 h analysis ($F_{7,16}$=3.18, P = 0.026).

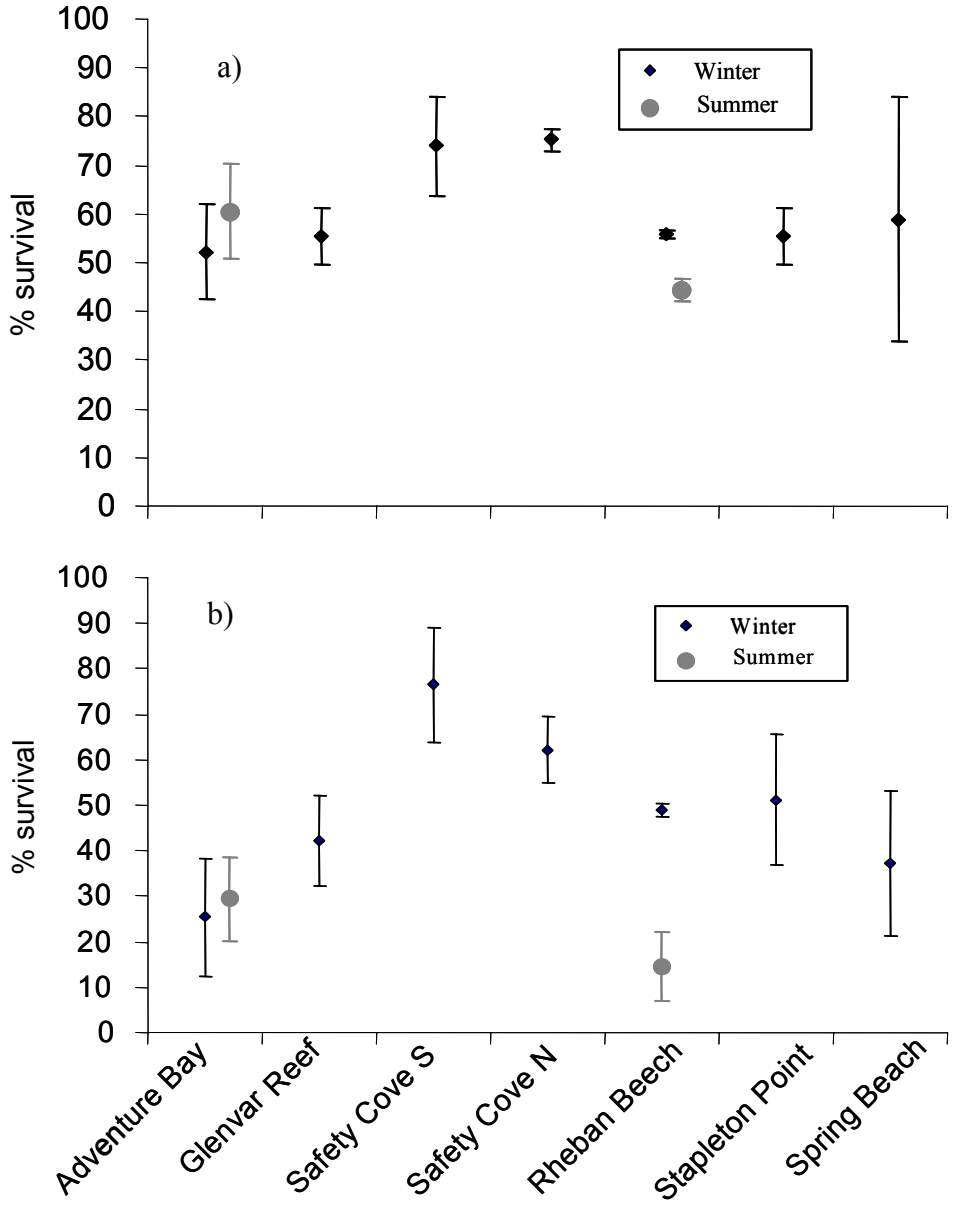

Figure 28. Percentage of tethered lobsters surviving at 24 h (a) and 48 h (b) post deployment in Tasmanian trials.

New Zealand tethering trials (Figure 28) showed few differences between sites, with survival at Windmill Bay slightly higher than at other sites. In New Zealand, lobsters that survived the first 24 h had a high probability of surviving to 48 h. Of the 67% of tethered lobsters that survived the first 24 h, 81% survived until 48 h post-deployment, giving a total of 54% survival after 48 h. This effect was also observed in Tasmania, although it was not as pronounced. For winter samples, of the 62% of lobsters that survived to 24 h, 73% survived until 48 h giving a total of 47% survival after 48 h.

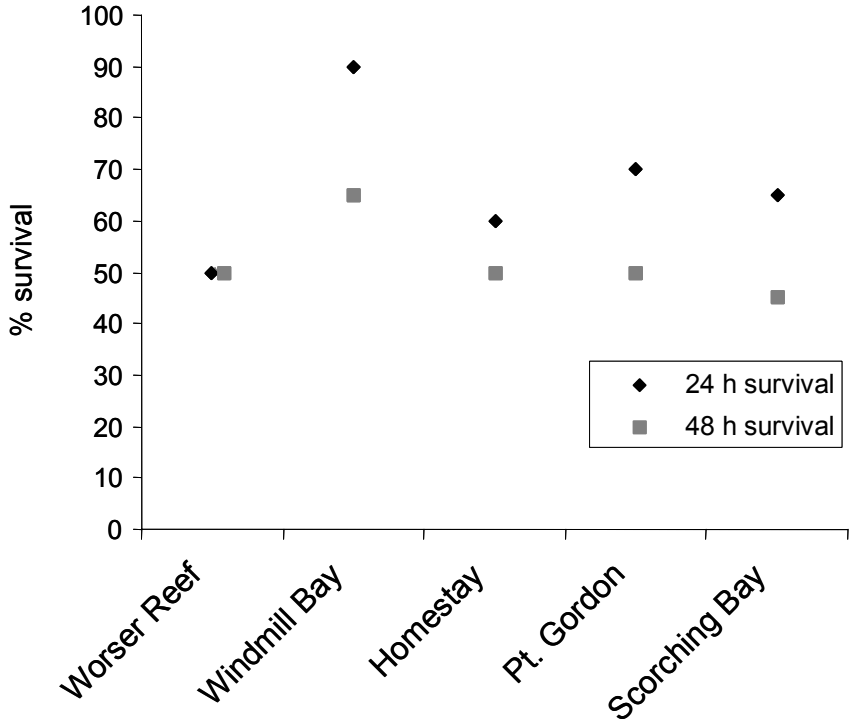

Figure 29. Percentage of tethered lobsters surviving at 24 h and 48 h post-deployment in New Zealand trials.

Preliminary binary logistic analysis was conducted to test for correlations between environmental variables and predation. While significant correlations were seen at individual sites, no consistent patterns emerged. Multiple regression of results from New Zealand suggested a degree of correlation between juvenile algae abundance and lobster survival (P = 0.030) These analyses were not pursued further due to findings from video-monitored tethering.

Thirty seven predation events were recorded by the infrared camera system across 4 sites in Tasmania. Of these, 17 (46%) were by fish, 7 were by octopus (*Octopus maorum*), 7 were by crabs (*Nectocarcinus tuberculosis*) and 6 were by larger (>80 mm CL) lobsters (*J. edwardsii*). Of the fish, 12 were blue throated wrasse (*Notolabrus tetricus*; 7 male, 5 female), 3 were purple wrasse (*Notolabrus fucicola*), 1 was an unidentified leatherjacket (family Monacanthidae) and 1 kill occurred on the edge of the field of view of a camera, providing only enough evidence to identify it as a fish kill. The proportions of kills by different predators varied considerably between sites (Figure 30).

Mechanisms of predation varied between predators. Fish predators would observe prey from a distance, then 'pick off' the lobster in a single rapid strike. This was true for all species except the leatherjacket, which was seen to persistently 'peck' the lobster until it was defenceless enough to flip over, at which time the prey was carried out of the field of view of the camera. Large lobsters could clearly 'sense' the presence of the small lobster, as they would slowly move closer, then 'pounce', wrapping the prey in their forward walking legs. Crabs used a similar method to large lobsters, although they were also seen to 'wind in' the lobster using the tether. Octopus showed variable tactics including 'pounce' and 'rapid strike' as described above.

Both octopus and wrasse predators fell within well defined size classes. All octopus were small, with an estimated leg span not exceeding 60cm; most were considerably smaller than this. Only the largest wrasses were seen to successfully attack lobsters. Of particular note is that amongst the 12 *N. tetricus* observed, 7 were male and 5 female. This species changes sex depending on intra-specific dominance and normally has a female to male ratio of about 20:1 on most reefs (S. Ibbott, TAFI, pers. comm.). Thus the predation events appear highly skewed towards large male wrasse. Also of note was a relationship between octopus and red cod (*Pseudophycis bachus*). Frequently, a single cod accompanied an octopus. This was noted amongst octopus that preyed on tethered lobsters, but also octopus that passed through the field of view of cameras without attacking lobsters. Presumably the cod feeds on animals disturbed by the octopus. Cod were not seen actively feeding at night unless they were with an octopus.

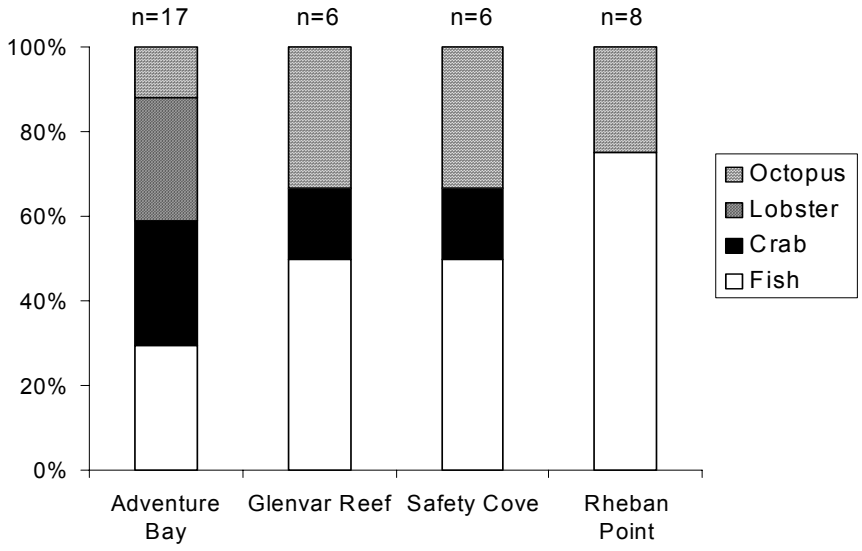

Figure 30. Identity of predators as identified from video evidence, split by site.

Time at which predation events occurred varied between predators (Figure 31). Predation by fish occurred only during daylight hours. All daylight predation was by fish with a single exception of a predation event by a lobster late in the afternoon. This occurred within minutes of deploying the tethered lobsters, and was due to the tethered lobster walking in to a large lobster den, rather than the large lobster actively pursuing the tethered animal. There were clearly 2 peaks in fish predation activity, one soon after dawn, and a second peak in late afternoon. The late afternoon peak was associated with time of release, with all these predation events occurring immediately following release. Predation by lobsters, octopus and crabs occurred almost exclusively in hours of darkness.

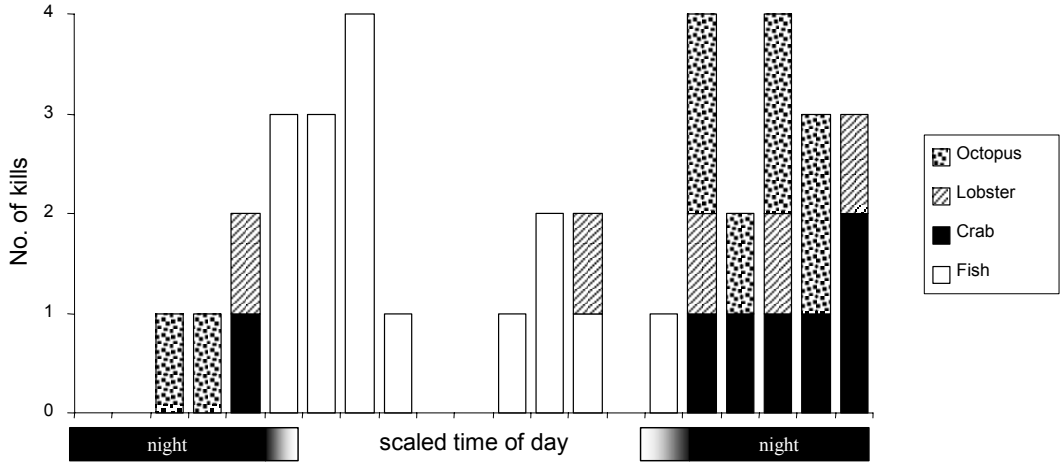

Figure 31. Time of day at which predation events by different predators occurred. Times are re-scaled around the time of sunrise and sunset to accommodate for changing day lengths.

13.3.1 Mesocosm trials

As video data showed that the predators responsible for lobster mortality varied considerably between sites, the need for mesocosm based validation trials was reinforced.

Control trials that were run for 10 days with untethered lobsters and 4 days with tethered lobsters with no predators present resulted in no deaths amongst juvenile lobsters. While this is not surprising, experimentally it is important that these trials are completed. It is possible, for example, that tethered lobsters may have become entangled, and been eaten by other juvenile lobsters once immobilised, a result that could bias predator trials.

There were clear differences in the effect the tether had on lobster catchability by different predators; Figure 32 graphically represents these differences. Generally, if the slope of the plotted line between tethered and untethered mortality rates for 2 predators were the same, then the effect of the tether was the same. It was clear that the effect of the tether on octopus and wrasse was very similar as the line slope was almost identical. In contrast, the slope from the lobster trials was clearly quite different. The ability of large lobsters to catch untethered juveniles appeared low. Only 2 untethered juvenile lobsters were captured; 1 in trial type 1, and 1 in trial type 2. Inspection of the reef by snorkel diving revealed that the capture in trial type 2 was on the first night post release. This is consistent with observations and camera footage from tethering and large-scale lobster releases. Juvenile lobsters appear most susceptible to predation by larger lobsters when they are first released, are disorientated, and move close to a larger lobster. The juvenile lobster killed in the type 1 trial was not detected by snorkel diving and was not identified as a kill until the reef was dismantled at the conclusion of the trial. We do not know when this kill occurred.

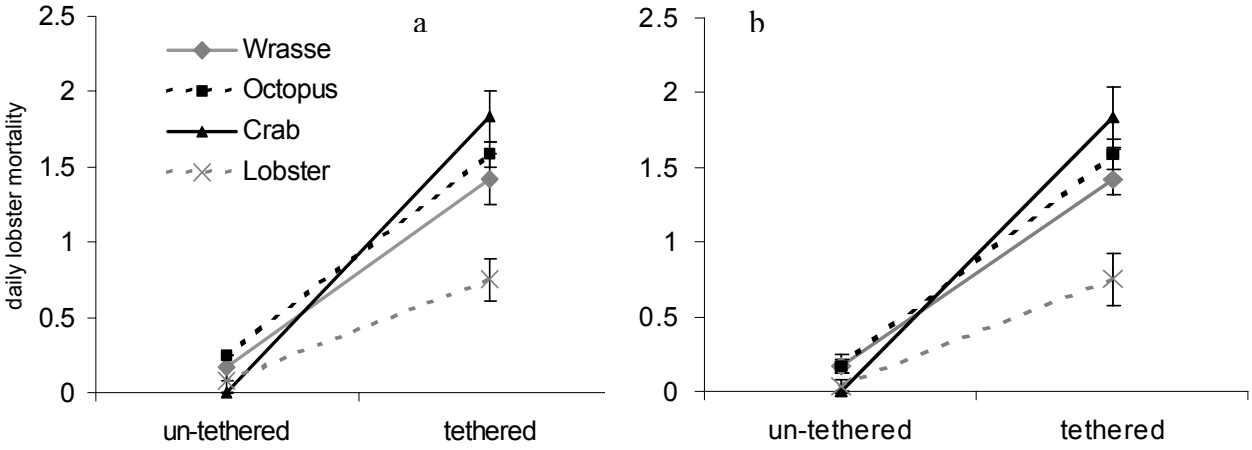

Figure 32. Daily mortality for a) untethered and tethered lobsters from trial type 1) and b) untethered lobsters from trial type 2) and tethered lobsters from trial type 1).

The graph slope from crab trials also differs considerably from all other trials. This was highlighted by plotting mortality rate on a log scale (Figure 33). No untethered lobsters were caught by crabs in any of the trials. This was consistent with video footage from tethering trials in the wild in which crabs clearly observed using the tether to 'reel in' their prey.

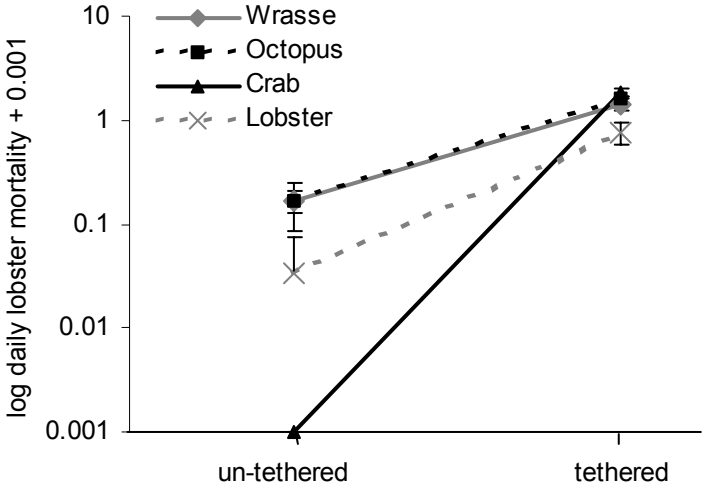

Figure 33. Untethered and tethered mortality rates plotted on a log scale (log (x + 0.001))

Given that predators were hungry (confirmed by veracious feeding after trials), and were in close proximity to a large number of lobsters, we were surprised at the low rates of predation of untethered lobsters in trial type 2 (10 days with 18 untethered lobsters), particularly by octopus. The maximum number of lobsters killed in any of the type 2 trials was 3, occurring in 1 wrasse trial. The maximum number killed in any type 2 octopus trial was 2.

13.3.2 Tethering standardisation

Mesocosm trials provided a measure of tethering artefact per predator. That is, the degree to which predation was inflated by the presence of the tether. For the 4 sites where the camera system was deployed, we have estimates of the proportion of predation events carried out by each predator type, and we can therefore standardise tethering results based on the mesocosm experiments. Adjustments were applied in 2 ways. First we rescaled tethering results to allow a clear comparison between standardised and non-standardised results. Second, we applied an absolute adjustment to obtain an estimate of likely predation rates had the tethers not been present.

As tethering has very similar effects on the rate of predation by 2 of the major predators (fish and octopus), we would expect little change in relative predation pressure where these 2 are the predominant predators. This is the case for 3 of the 4 sites. Predation at Rheban Beach was only by these 2 predators, while Glenvar Reef and Safety cove were predominantly by these 2, but with a single predation effect recorded by a crab. However, at Adventure Bay, the majority of recorded predation events were by lobsters and crab. While non-standardised tethering results suggest that survival is particularly low at Adventure Bay, this difference disappears in the standardised results (Figure 34). Once standardisations were applied, there were no significant differences between predation rates ($F_{3,8}$=3.30, P = 0.08).

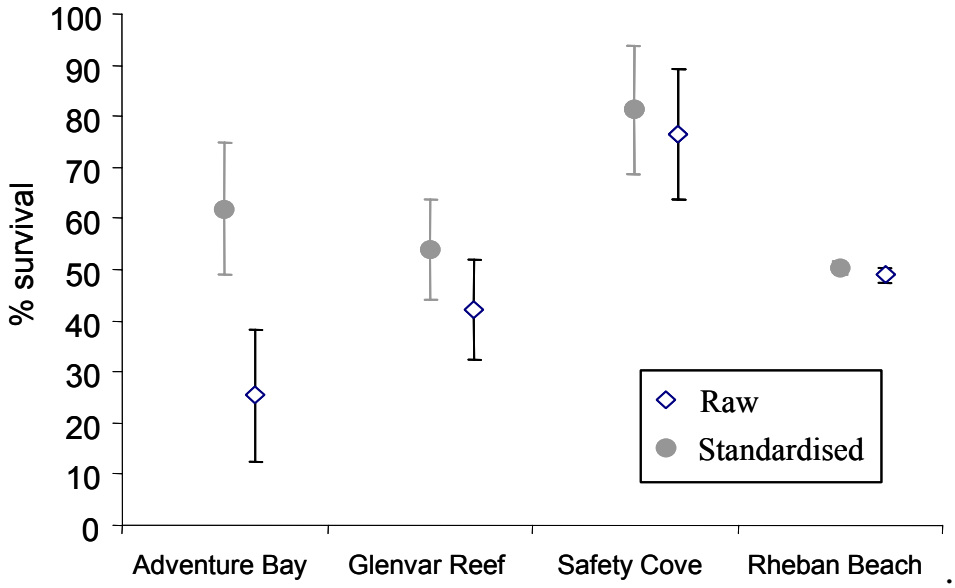

Figure 34. Relative measure of survival (± se) for standardised and unstandardised tethering results.

While this relative correction is useful for comparing standardised and unstandardised results, we can also use the validation trials as a way to estimate a likely mortality rate at these 4 sites. While we have shown that there is very little difference in the tethering effect on predation by fish and octopus, even for these predators the probability of a tethered lobster being killed is many times higher than that of an untethered lobster. For wrasse and octopus predators, lobsters are 10.8 (±2.5) and 11.0 (±3.0) times more likely to be taken than untethered lobsters. If we apply these figures to the known ratio of predators at video-monitored sites, an estimate of mortality rate at these sites can be produced (Figure 35). These estimates are likely biased high by experimental artifacts as outlined in the discussion.

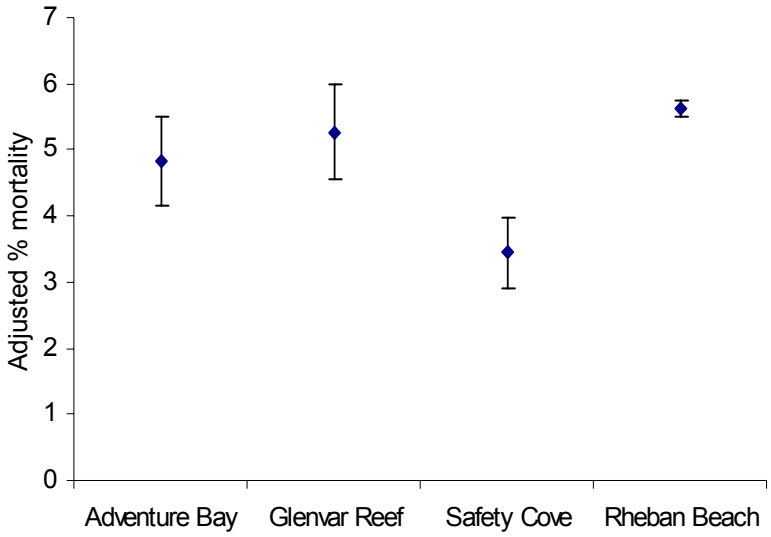

Figure 35. Estimated maximum mortality rates (± se) for the 48 h post-release at camera-monitored sites.

13.3.3 Baited video stations

Video-monitored tethering trials showed that finfish were not solely responsible for predation of juvenile lobsters, with octopus also being an important predator. It is unsurprising therefore that bait stations alone did not provide good evidence of total predator abundance. However, they provided some important insights into finfish predation patterns that confirm observations by divers. Of particular interest is the low number of predators seen (Figure 36), considering that the reported numbers are the maximum number of predators seen at any stage during a trial. Behaviour of large male *P. tetricus* appears to be at least in part responsible for this. *Notolabrus tetricus* is a protogynous hermaphrodite, that is, all fish begin life as females, and the largest female in a group will become a male when if an existing male dies. Males are fiercely territorial and will attack other males and large females to protect their territory. As it is only the largest females and males that are large enough to take reseeded lobsters, it is rare that more than one predatory *N. tetricus* was seen at any bait station, although many smaller conspecifics were seen. Where multiple predators were seen, this was generally due to the presence of large *N. fucicola*, although once again, fish of a size shown by tethering trials to be a threat to reseeded lobsters were rare.

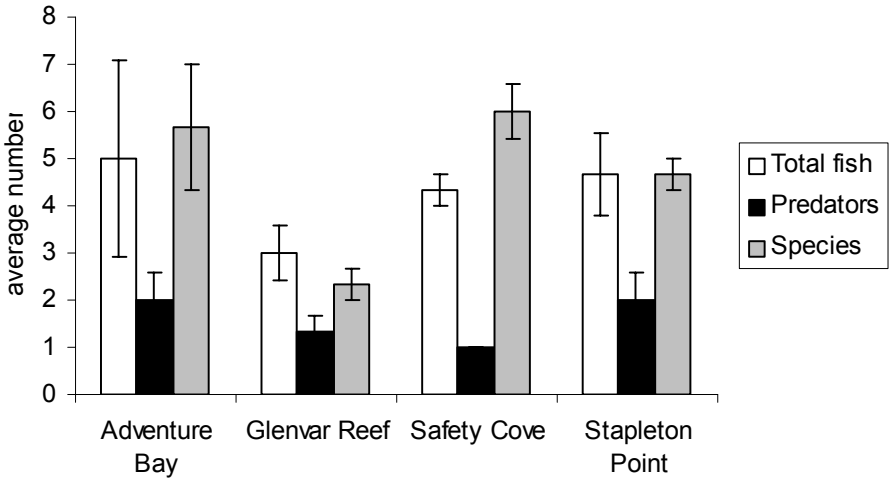

Figure 36. Maximum number of fish and predators seen at any time and total number of species seen during 20 min. baited video drops.

13.4 Discussion

Tethering experiments have been the subject of considerable debate in the scientific community, with primary concerns being that the artefacts of tethering may 'swamp' any useful results. At the simplest level, the concern is that an animal restrained by a tether may be vulnerable to predators that would not be able to catch an untethered animal. Artefacts may, however, be subtler than this, but still lead to meaningless results. If predators vary in abundance between sites, and the tether has a different effect on the predatory success rate of different predators, results will be confounded by tethering artefacts.

The first step towards separating the artefacts of tethering from true predation pressure is to identify the predators at each site. This has proven a stumbling block to investigating the usefulness of tethering experiments. The development of the infrared multi-camera system provided a unique opportunity to investigate tethering artefacts in this study. The camera footage from Tasmanian tethering sites quickly confirmed that suite of active predators varied between sites, and hence further investigation of artefacts was required. The finding that cannibalism was common (although only at 1 site) was surprising, as was the prevalence of crabs as a predator. Similarly the lack of diversity amongst finfish predators was not anticipated. We expected to see predation by species such as conger eels (*Conger verreauxi*), red cod (*Pseudophycis bachus*) and gurnards (family Triglidae), all of which were present, and at some sites abundant.

The camera footage also provided useful information of the mechanism of predation, and this in itself suggested it was likely that the effect of the tether varied between predators; crabs were clearly seen to use the tether directly to capture lobsters. The large size at which juvenile lobsters were released is clearly a reason for low predation rates by finfish. Many abundant species at the reseeding sites were too small to attack lobsters of this size. While some (eg rosy wrasse, *Pseudolabrus psittaculus*) showed considerable interest in lobsters on release, lobsters were able to successfully fend off any attacks by these species. While there were considerable numbers of predatory

species present at all sites, only the largest members of these species were seen to prey on lobsters. Generally, predation by finfish occurred by predators picking up the whole lobster; fish not large enough to do this were successfully fended off.

Every attempt was made to make the mesocosm reef resemble a natural reef. This included monitoring the species and abundance of algae present, and modifying this where necessary to resemble natural reef. For this reason, although we cannot rule out all artefacts from the use of a mesocosm, we believe the mesocosm environment was sufficiently realistic to provide a meaningful estimate of tethering artefacts on natural reef. A further useful extension of this research would be to investigate the effects of physical habitat on tethering artefacts. There is potential for interaction between tethering artefacts and the 'quality' of hides available to lobsters.

Mesocosm trials confirmed that the magnitude of tethering artefacts varied between predators. The most striking result was for the crabs, which proved incapable of catching untethered lobsters. Large lobsters only caught 'disorientated' juveniles soon after release. These species were responsible for a large proportion of mortalities at Adventure Bay, and accordingly the tethering estimate of predation pressure for this site was considerably over-inflated. Once corrections calculated in mesocosm trials were applied to the Adventure Bay results, they did not differ from those from other sites. The apparent consistency of predation pressure between sites in Tasmania appears to relate at least in part to the behaviour of the most important finfish predator, the blue throated wrasse (*Notolabrus tetricus*). This highly territorial species was an important predator at all sites. Most *N. tetricus* large enough to prey on reseeded lobsters were males or the largest of the females, and they were only observed singly at baited video stations. It is likely that tethering trials and pilot-scale releases would occur within the territories of 1 to 2 fish (S. Ibbott, TAFI, pers.comm.), with other large fish being actively excluded.

Clearly, tethering trials where the identity and proportions of predators are unknown are of limited use for measuring predation pressure. Similarly, correlations between environmental variables and un-corrected tethering results may lead to incorrect conclusions. Indeed, the chances of auto-correlations in such cases appear high. For example, if it was found that number of algal stipes at a site correlated with lobster mortality, this may be because the abundance of a species that gains particular advantage from the presence of tethers is correlated with the number of algal stipes. In such cases results are at best meaningless, and at worst, misleading.

In tethering trials, predation was consistently highest in the first 24 h post-deployment. This is not surprising, and is to some degree supported by the small number of predation events observed by divers and cameras immediately following pilot-scale releases (Chapter 15). However, artefacts of tethering may also contribute to this result. Lobsters were tethered in hides that divers considered to be appropriate based on criteria of size and position. Hide quality would be expected to vary, and it is possible that lobsters in lesser quality hides were taken early in the trial, so that tethered lobsters in good quality hides were able to avoid predators.

If those predation events that were the result of tethering artefacts are discounted (on the basis of mesocosm trials), video-monitored tethering trials show the most dangerous

time of day for juvenile lobsters is in the hours following dawn when finfish first become active. Following this, the few hours after dusk when octopus first become active also appear to be a time of high risk. Release at about midnight will mean that lobsters are not immediately susceptible to visual predators, and will have the period between midnight and dawn with low predation pressure to disperse and find shelter.

The application of mesocosm results to corrected tethering mortality rates provided an estimate of mortality independent of pilot-scale reseeding trials that were not confounded by movement. These estimates must be viewed as maximum likely mortality rates due to artefacts from the mesocosm. In the mesocosm, encounter rates between predators and lobsters were higher than on natural reefs, competition for prey lower, and escape options for lobsters more limited. Estimates of mortality in the 48 h post-release were in the range of 3 to 5.5%. This (as a maximum likely mortality estimate) is consistent with the highest apparent survival estimate from pilot-scale releases (Chapter 14) of 0.980±0.016 for Glenvar Reef. Evidence from acoustic tracking and survival estimates in pilot-scale releases suggests that mortality after the first 48 h will be negligible.

13.5 Conclusions

Tethering experiments can provide a measure of relative predation pressure, but only if results are standardised by identifying predators and quantifying tethering artefacts. The effort required to do this is considerable, and as a result tethering is not an efficient way to assess sites for lobster release. Octopus and blue-throated wrasse were primarily responsible for predation on reseeded lobsters in Tasmania, and no variation in predation pressure between sites was detected. Given this apparent consistency in predation pressure between sites, the expense and effort of measuring micro-habitat variability to select sites for lobster releases in not warranted. A conservative measure when deciding numbers of lobsters to release to compensate for puerulus harvest would be to allow for 5% mortality associated with release.

14. Refining methods for estimating survival of reseeded juvenile lobsters

Research presented in this chapter was directed towards objective 3: evaluating survival in pilot-scale enhancement experiments. It was part of experiment 7, which utilised 60% of project resources.

The research was a refinement of survival estimation methodology, which was also the subject of previous research on the same topic in FRDC1999/314. That project noted the absence of goodness-of-fit tests for multistate survival models. These goodness-of-fit tests were subsequently developed and published in 2003 by Roger Pradel of the Centre D'Ecologie Fonctionnelle and Evolutive, Montpellier, France. Dr Pradel in assisted the application of these tests to juvenile lobster survival data.

The key outcomes of this chapter for enhancement were: (a) tools for measuring survival were developed, and are applied in later chapters; and (b) the observation from this single pilot scale release that survival of naïve lobsters was equivalent to that of wild controls.

14.1 Abstract

Using multistate Arnson-Schwartz (AS) mark-recapture models, we show that naïve (captive reared) juvenile southern rock lobsters survived as well as wild-caught lobsters when released to an area of coastal reef. Lobsters captured as pueruli were ongrown in tanks for 12 to 18 months where they were fed to satiation in the absence of predators. Lobsters were marked with antennal tags each carrying a unique code, and released to coastal reef along with tagged wild-caught lobsters of similar size. During 8 dive surveys of the release reef and neighbouring reefs over a 28 day period, divers resighted 40.3% of the naïve lobsters and 70.2% of the wild lobsters. The probability of naïve lobsters moving from the release reef to neighbouring areas in the first 4 days post release (0.72±0.04 s.e) was almost twice that of wild-caught lobsters (0.38±0.08 s.e). This behavioural difference did not influence daily apparent survival (0.98±0.016 *s.e*), which was constant between groups and over time. Our results are encouraging for the potential of enhancing spiny lobster stocks by releasing juveniles, and demonstrate the utility of AS mark-recapture models as a tool for evaluating medium-term survival of released juvenile lobsters.

14.2 Introduction

A long history of restocking clawed lobster populations in Europe and North America (Addison and Bannister 1994; Waddy and Aiken 1998) has been followed by extensive research into the behaviour and survival of released hatchery-reared lobsters (Whale and Steneck 1992; review by Addison and Bannister 1994; Aganalt *et al*. 1999; van der Meeren 2000). In contrast, spiny lobster restocking has received little attention (but see Herrnkind *et al*. 1997; Phillips and Evans 1997), as commercial-scale hatchery production of spiny lobsters pueruli and juveniles is not feasible (Phillips and Kittaka 2000).

Commercial harvest of wild pueruli (first benthic post-larval stage) is being considered or trialed in several countries (Lee and Wickens 1992; Jeffs and Hooker 2000; Phillips *et al*. 2001; McVeigh 2002), and represents an alternative source of spiny lobsters for ongrowing and release. Natural mortality of spiny lobsters during settlement and the first benthic year in the wild has been estimated at 95-97% (Herrnkind and Butler 1994; Edmunds 1995). Collection and ongrowing of pueruli can overcome this survival bottleneck, with mortality rates of 5-15% being commonly reported after 1 year in captivity (Phillips *et al*. 1983; Kingston 1999; Crear *et al*. 2003); juvenile lobsters can then be released for enhancement purposes. Alternatively, if pueruli are harvested for ongrowing to a marketable product, the release of a proportion of harvested animals following a year of ongrowing may prove an efficient method for ensuring that adult stocks are not affected by this harvest (see Mills *et al*. 2004). In either case, benefits can only be realised if survival amongst released lobsters is high.

Success of release programs hinges on short-(minutes to hours), medium-(days to weeks) and long-(months to years) term processes. Short-term processes include the ability of released animals to avoid immediate predation at the time of release, and can be assessed by diver or camera observation (Howard 1983; van der Meeren 2000). Long-term processes include the ability to fully integrate with breeding populations of wild conspecifics. The development of micro-wire tagging techniques has facilitated indirect observation of these processes through fishery returns of lobsters tagged at a small size prior to release (Bannister *et al*. 1994; Agnalt *et al*. 1999). Where releases are aimed solely at fishery enhancement, such techniques provide a direct measure of success. However, where recapture or detection rates are low there is no capacity to elucidate the underlying causes of low returns. Further, there is typically a period of several years between release and obtaining results from fishery returns.

Analytical and field methods that provide robust survival estimates in the medium-term period of days to weeks rather than years facilitate an experimental approach to assessing factors determining the success of release programs. Medium-term processes affecting release success include the redistribution of animals to appropriate shelter, competition for resources with conspecifics, and the ability to find appropriate food. Acoustic tracking techniques can address some of these issues at this temporal scale (van der Meeren 1997; Mills *et al*. 2004), but these studies are typically restricted to a small number of animals.

In Tasmania, Australia, licences for pilot-scale commercial harvest of pueruli have been issued with the condition that a proportion be released back to the wild after a year of ongrowing. The relatively large size of these lobsters (approximately 35mm carapace length) and preliminary knowledge of movement from acoustic tracking (Mills *et al*. 2004) provide a basis for the use of visible external tags to assess behaviour, movement and survival in the medium-term.

Here we report on a study designed to assess survival and movement of tank-reared, naïve *J. edwardsii* over a period of 4 weeks using mark/recapture techniques. We did not attempt to estimate absolute survival, but rather survival of naïve lobsters relative to that of wild lobsters. This approach enabled us to partition variability in survival in a biologically meaningful way; parallel changes in apparent survival for both naïve and wild lobsters may be indicative of either emigration, or mortality from a process affecting both groups equally (such as release technique). Divergence in apparent

survival would suggest differences in behaviour or fitness between naïve and wild lobsters.

14.3 Methods

14.3.1 Specimen and site details

Naïve lobsters were captured as pueruli in crevice collectors deployed off southern and eastern Tasmania (Gardner *et al*. 2001). Lobsters were then ongrown in tanks for 12 to 15 months, attaining a size of 30-52 mm carapace length (CL). Hides of concrete blocks and plastic oyster mesh were provided. Lobsters were fed daily on fresh, opened blue mussels (*Mytlius edulis planulatus*) or commercial prawn pellets. Most lobsters were held in ambient flow-through water (11 to 19°C), although a small number (<10%) were used in growth trials where water temperatures were manipulated. These lobsters were returned to ambient water at least 1 month prior to release. All lobsters were held in ambient light conditions for at least a month prior to release.

Wild lobsters were collected from the study site. Despite extensive trials (Gardner *et al*. 2000), no effective trapping methods for juvenile lobsters have been identified; SCUBA diving and catching lobsters by hand proved most efficient. Although divers targeted lobsters in the same size range as naïve lobsters, lobsters up to 68 mm CL were collected and retained to increase the total number of wild lobsters available for release. We anticipated that larger lobsters could later be excluded from analyses if survival or resighting probability proved to be size dependent.

All lobsters were tagged with a visible tag carrying a unique colour code. Tags were made from 12 cm lengths of 0.75 mm diameter copper wire onto which was threaded up to 5 small coloured beads (2.5 mm diameter - black, white, blue, orange or yellow). The wire was crimped either side of the beads to hold them in place. Black beads were used as a unique identifier for wild lobsters, and were placed first on the wire. Tag retention experiments were conducted in tanks and used to refine the application process. Tags were applied to lobsters by wrapping the copper wire tightly around the right antennal base 4 -6 times. Using this method, the only tag losses observed in trials were due to moulting. As lobsters naturally position themselves with their antennae protruding from hides, antennal tag codes could be read by SCUBA divers without disturbing the animals.

Lobsters were released on an area of patch reef adjacent to Glenvar Point (43°00’11"S, 147°23'49"E) in the Derwent River, southern Tasmania. The release reef was a discrete area of medium-profile reef (maximum rise 2 m) in 5-7 m of water, and was approximately 100 m offshore from Glenvar Point (Figure 37). There were numerous resident juvenile lobsters. Low to moderate macro algal cover allowed efficient searching by divers during resighting surveys. To the west of the reef in 7-9 m of water was a larger area of patchy low to medium profile reef. Unstructured rock platform unsuitable as lobster habitat extended along the shoreline approximately 400 m north from the release reef. Shelving reef extended some 800 m south along the shore line, and provided good lobster habitat.

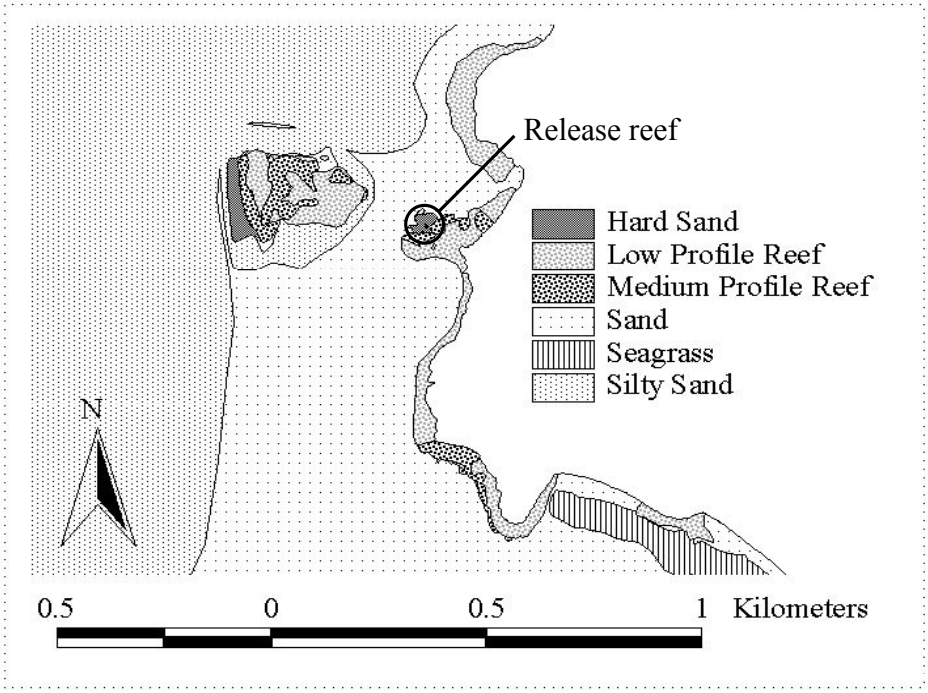

Figure 37. Detail of habitat types on the release reef and neighbouring reef areas.

Acoustic tracking of wild and naïve 1-year post-settlement juvenile lobsters released at the same site (Mills *et al*. 2004), revealed that movements in excess of 150 m in a 24 h period were possible. Accordingly, searches included the release reef and all areas of lobster habitat described above.

We released 427 naïve lobsters (average CL 43.4 mm, range 30-52 mm) and 153 wild lobsters (average CL 48.2 mm, range 32-68 mm). Of the wild lobsters, 105 (69%) were within the size range of the naïve lobsters. Lobsters were transported to the release site at dusk, in the 'wet well' of our research vessel, then transferred to a large mesh bag for release. A diver emptied the lobsters from the bag in the centre of the reef, and did not assist lobsters in finding suitable hides or in dispersing.

Divers systematically searched the release reef on days 2, 4, 7, 9, 11, 14, 18 and 28 post release, recording individual tag colour combinations of sighted lobsters. Due to the additional effort required to search the extensive area of neighbouring reef, these neighbouring areas were searched on days 4, 18 and 28 only.

14.3.2 Modelling procedures

Resighting histories from dive surveys were analysed using Arnason-Schwartz (AS) tag/recapture models (Arnason 1973; Schwartz *et al.* 1993), a multistate generalisation of Cormack-Jolly-Seber (CJS) models (Cormack 1964; Jolly 1965; Seber 1965). While CJS models provide a generalised framework for maximum-likelihood estimation of survival and resighting probabilities, multistate models add a further level of biological realism by incorporating movement data (Brownie *et al*. 1993). Models were fitted using the program MARK (White and Burnham 1999).

For naïve and wild lobsters, we estimated survival probability and the probability of lobsters moving between the release reef and neighbouring reef areas in the period between consecutive surveys, and resighting probabilities for each survey occasion. The fully parameterised (saturated) AS model can be represented by $\phi(tgs)\rho(tgs)\psi(tgs)$. That is, survival ($\phi$), resighting ($\rho$) and movement ($\psi$) probabilities are a function of time (t), group (g – wild or naïve) and state (s – lobster observed on release or neighbouring reef). Here, with 8 surveys, 2 groups and 2 states, the unconstrained saturated model has 96 parameters; 32 (8x2x2) parameters for each of ϕ, ρ and ψ. All models were initially structured using the identity design matrix and sin link function, as this provided meaningful estimates for the greatest number of parameters.

To confirm that the saturated model adequately described variability in the data, we followed goodness-of-fit (GOF) testing procedures set out by Pradel *et al*. (2003), implemented in program U-care V2.0 (Choquest *et al*. 2003). While direct tests of fit for AS models are not available, this procedure involves testing for fit of a more generalised model (model JMV, Brownie *et al.* 1993), followed by a likelihood ratio test (LRT) between the JMV and AS models.

A series of reduced models was chosen *a-priori* to test biologically and experimentally feasible hypothesis relating to factors effecting survival and movement probabilities (Lebreton *et al*. 1992). We first imposed a series of constraints relating to experimental design and sampling regime, removing several parameters from the model that coded no information:

i) Resighting probability on neighbouring reef was constrained to zero on days when this area was not searched.

ii) Movement was constrained to be equal within groups for intervals between surveys of neighbouring reef.

iii) As no lobsters were released on neighbouring reef, movement from neighbouring reef back to the release reef was constrained to zero for the first resighting occasion.

We then tested hypotheses relating to survival and movement by sequentially eliminating parameters that did not improve model parsimony (Lebreton *et al*.1992). Of a set of models, the most parsimonious model is one that adequately describes the variability in the data with the minimum number of parameters (Burnham and Anderson 1998). Parsimony was assessed using the quasi-likelihood adjusted form of the Akaike Information Criteria ($QAIC_c$), incorporating an adjustment (variance inflator factor, $\hat{c}$) for minor lack of fit of the saturated model (Burnham *et al*. 1995; Anderson *et al*. 1998). If removal of parameters of interest for a particular hypothesis resulted in a decrease in QAIC weight, the hypothesis was accepted, and the reduced model was taken as the best general model against which further comparisons would be made (Burnham *et al*. 1995; Burnham and Anderson 1998). While this method of model selection does not allow significance values to be attributed to tests between models, normalised QIACc weights provide a relative weight of evidence for a particular model best describing the data (Burnham and Anderson 1998).

We tested all possible permutations for survival by sequentially removing state, group and time dependence. As search effort varied across time and between reef areas

(states), we *a-priori* included time and state dependence for resighting probability, but tested for group dependence. We tested for group dependence of movement from release to neighbouring reef and from neighbouring reef back to the release reef. Given possible group differences and an *a-priori* expectation that movement would be greater in the first 24 hrs post release (Kingston 1999; MacDiarmid *et al*.1991; Mills *et al*. 2004), we partitioned movement on this basis, and tested for group differences for the period between release and the first survey.

To test if survival, resighting or movement of wild lobsters was influenced by size, we repeated the model reduction process, comparing models with size included as a covariate for these factors with models without a size covariate. Covariate models required the use of a full design matrix and logit link function (White and Burnham 1999).

Parameter estimates were derived from the set of reduced models by model averaging using normalised QAIC weighting, reflecting uncertainty in model selection process (Burnham and Anderson 1998).

14.4 Results

Divers recorded 624 resightings of 281 individual lobsters. Of 427 naïve lobsters released, 172 (40.3%) were resighted, while 109 of 153 wild lobsters (71.2%) were resighted. Divers located 4 tags on the seafloor during surveys, however due to their small size, we expect that most unattached tags would have remained undetected.

During the first night post release, lobsters remaining on the release reef redistributed to the areas providing the best refuge. These areas supported populations of resident juveniles and were heavily populated by tagged lobsters for the remainder of the study. Naïve and wild lobsters were seen cohabiting with resident juveniles. No lobsters were observed out of shelters during the day.

Movement patterns by the two treatment groups differed. On the release reef, the ratio of naïve to wild lobsters changed from 2.8:1 at the time of release to 1.5:1 after 1 day. The results from searches up to 800 m from the release site during the final survey (28 days post release) show that as distance from the release site increased, the proportion of naïve lobsters resighted by divers increased (Figure 38). Beyond a distance of approximately 200 m from the release site, the proportion of naïve lobsters sighted was higher than the proportion initially released.

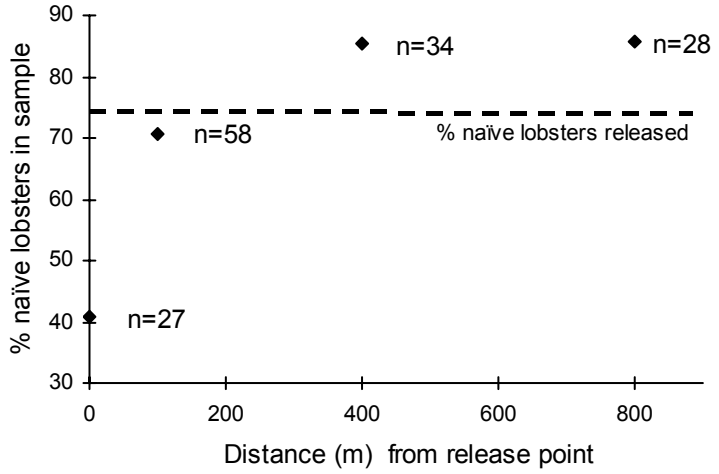

Figure 38. Percentage of naïve lobsters in total tagged lobsters sighted in the final dive survey plotted against distance from the release point. Percentage of naïve lobsters in the initial release is shown by the dashed line.

14.4.1 Goodness-of-fit testing

While most components of the GOF procedure indicated good fit, the LRT between the JMV and AS models for naïve lobsters was marginally significant (χ^2= 39.48, df= 26, p=0.044), resulting in a significant global test for the saturated model (χ^2= 42.65, df= 28, p=0.038).

Contrary to model JMV, model AS includes the assumption that resighting probability is a first order Markovian processes (Brownie *et al.* 1993). That is, the probability of a lobster making a transition between states in the time interval from t to t+1 is independent of the lobster's location at time t-1. The significant LRT points to possible violations of this assumption. Model JMV is extremely data intensive, and cannot be supported by our relatively small data set.

No systematic bias was observed from individual χ^2 cells within the GOF tests, and we see no underlying structural or biological reasons for the violation of Markovian assumptions. Accordingly, we report results from the full data set incorporating a variance inflator factor (ĉ) calculated from the global multistate GOF test ($\hat{c}$ = χ^2/df=1.520) (Lebreton *et al*. 1992; Pradel *et al.* 2003). A value of ĉ>1.0 compensates for minor lack of fit by promoting models with fewer parameters, and thereby being conservative with respect to the detection of fine-scale structural features within the data.

14.4.2 Model selection

Hypotheses tested, and the order of model reduction is given in Table 5. Constraints placed on the model to reflect the sampling regime reduced the number of parameters in the model from 96 to 64, while selection of the most parsimonious model reduced

this further to 20 parameters. Normalised QAICc weights show that the most parsimonious model ($\phi(.)\rho(ts)\Psi_1^{rn}(g)\Psi_{2-8}^{rn}(t)\Psi^{nr}(gt)$) is approximately 8 times as well supported by the data as the next best model ($\phi(.)\rho(ts)\Psi(gts)$).

The final model showed daily apparent survival to be constant over time, between groups and across release and neighbouring reef areas, and was estimated at 0.980±0.016 *s.e*.

Resighting probability did not vary between groups (release reef 0.36±0.05 to 0.62±0.08; neighbouring reef 0.03±0.01 to 0.23±0.13).

Movement of lobsters following release varied between groups, confirming direct observations from diver surveys. Probability of moving away from the release site was significantly greater for naïve than wild lobsters between release and the first survey of neighbouring reef on day 4 (Figure 39). In subsequent surveys there was no detectable differences between groups, and movement between reef areas decreased to be close to zero for the period between days 18 and 28 days post release.

The inclusion of wild lobster size as a covariate for resighting, survival or movement did not improve the fit of models. That resighting probability is independent of size is supported by the similarity in release and resighting size frequencies (Figure 40).

Table 5. Multistate model reduction process. Survival (ϕ), resighting (*p*) and movement (ψ) probabilities may be a function of group (g – wild or naïve), time (t - samples 1-8) or strata (s – release or neighbouring reef). Subscripts refer to sample occasions (1-8) while superscripts refer to strata (r=release reef, n=neighbouring reef). Column A/R denotes if the stated hypothesis was accepted (A) or rejected (R). Normalised QAICc weights provide a measure of the relative weight of evidence in support of a particular models, and are used for model averaging. Par shows the number of parameters estimated in the model.

Hypothesis	Model	QAICc	A/R	QAICc Weight	Par
Saturated model (with experimental constraints)	$\phi(gts)\rho(gts)\Psi(gts)$	2272.32		0.0000	64
Survival is equivalent on release and neighbouring reef	$\phi(gt)\rho(gts)\Psi(gts)$	2254.21	A	0.0000	47
Survival is equivalent for naïve and wild lobsters	$\phi(t)\rho(gts)\Psi(gts)$	2240.52	A	0.0000	40
Survival does not vary over time	$\phi(.)\rho(gts)\Psi(gts)$	2228.86	A	0.0001	33
Naïve and wild lobsters are equally visible on the reef	$\phi(.)\rho(ts)\Psi(gts)$	2213.51	A	0.1074	22
Probability of moving between reef areas is constant over time	$\phi(.)\rho(ts)\Psi(gs)$	2271.54	R	0.0000	16
Probability of moving from release reef to neighbouring reef is the same for wild and naïve lobsters	$\phi(.)\rho(ts)\Psi^{rn}(t)\Psi^{nr}(gt)$	2225.28	R	0.0003	19
Probability of moving from neighbouring reef to release reef is the same for wild and naïve lobsters	$\phi(.)\rho(ts)\Psi^{rn}(gt)\Psi^{nr}(t)$	2219.49	R	0.0054	20
Movement from the release reef differs between the first and subsequent time intervals	$\phi(.)\rho(ts)\Psi_1^{rn}(g)\Psi_{2-8}^{rn}(t)\Psi^{nr}(gt)$	2209.36	A	0.8559	20

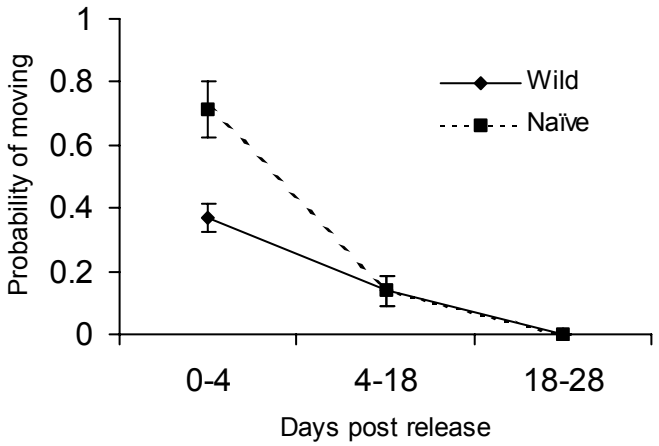

Figure 39. Probability (± 1SE – adjusted for lack of fit; $\hat{c}$ =1.52) of wild and naïve lobsters moving from the release reef to neighbouring reef.

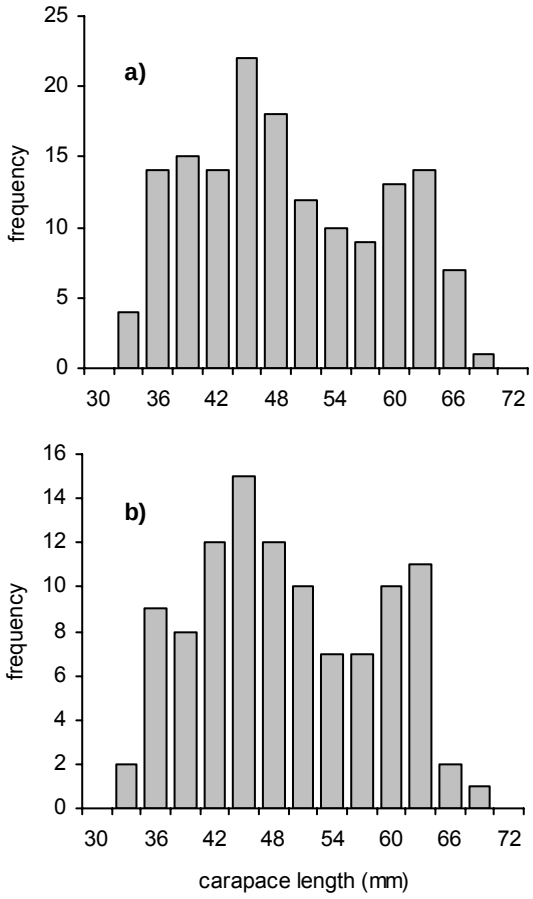

Figure 40. Carapace length-frequency of released (a) and resighted (b) wild lobsters.

14.5 Discussion

Biologically important structural features of the final model include a single parameter estimate for survival, resighting probabilities that are independent of group, and the partitioning of movement probabilities.

That apparent survival is independent of group suggests naïve lobsters are as fit as wild lobsters to survive the pressures associated with release, finding shelter and medium-term existence at the study site. Immediate exposure to predators due to release method was not a major cause of mortality, indicated by the temporal constancy of survival. This contrasts with the findings of Van der Meeren (2000) who, by diver observations, estimated immediate loss during releases of clawed lobsters (*Homarus gammarus*) to be in excess of 10%. Release method (at the sea surface) and lobsters size (12-15 mm CL) differed from this study where divers released larger animals (30-52 mm CL) on the seafloor.

The observed lack of spatial variability in survival is not surprising given the proximity of, and similarities between, release reef and neighbouring reef and their associated predator suites.

The model estimate for daily survival (0.980±0.016 *s.e*) is not an absolute measure, as it includes loss of animals due to emigration from the study site and tag loss. While searches of neighbouring reef were extensive, it is possible that some lobsters moved beyond the area searched. Tank trials suggested that tag loss due to tag failure is unlikely, however tag loss due to lobsters moulting is neither constant nor predictable. Moulting generally peaks in *J. edwardsii* at times of highest growth, coinciding with periods of elevated water temperature (Hooker *et al*. 1997). Naïve animals released in this study were ongrown in tanks supplied with flow-through water drawn from the estuary in which the release trial occurred. As wild and naïve lobsters have been subject to ambient water from the same water body, it is reasonable to expect similar moulting rates.

A breakdown in diel activity rhythms has been reported in hatchery-reared lobsters (Nagata and Koike 1997), and this was a perceived threat to the survival of released naïve lobsters by fishery managers and participants in Tasmania. Direct diver observations as well as a lack of a group effect for resighting probability implies similar daytime shelter occupancy and activity levels in wild and naïve lobsters.

Capture and handling of *J. edwardsii* has short-term effects on behaviour, with an increase in movement commonly reported (MacDiarmid *et al*. 1991; Kingston 1999; Mills *et al.* 2004). This effect on movement was seen in wild and naïve lobsters immediately post-release, and was more pronounced in naïve lobsters. The different rates of movement by naïve and wild juveniles suggests care must be taken in the use of wild lobsters as a control for emigration. Evidence from this study, and from acoustic tracking of juvenile lobsters at the same site (Mills *et al*. 2004) supports the value of wild animals as controls for emigration after the initial high dispersal period immediately following release. Accordingly, the area surveyed must be large enough to encompass all appropriate habitat accessible to lobsters during this initial high dispersal period. The maximum distance moved by acoustic tagged lobsters at the study site in a 24hr period was 144m (Mills *et al*. 2004), suggesting that our search area was adequate.

Higher movement probability amongst naïve lobsters immediately post-release implies longer periods away from shelter, and accordingly greater exposure to predators (Herrnkind and Butler 1986; Ball *et al*. 2001). However, the observed behavioural difference did not translate to a detectable difference in survival. This may be a consequence of innate predator avoidance behaviour in naïve lobsters. Alternately, it could be the product of low predation pressure at the study site. Behavioural deficiencies that would lead to mortality where predators are abundant may be inconsequential where natural predation rates are low.

Our results show multistate AS models to be an appropriate tool for estimating relative survival of reseeded juvenile lobsters. Prior knowledge of likely movement of released lobsters at the study site (Mills *et al.* 2004) enabled us to develop an experimental design and sampling regime appropriate to meet the data requirements of multistate models. Importantly, this technique has accommodated spatial heterogeneity in sampling where differences in reef area and habitat structure mean that standardising search effort across the study site was impractical. The small errors associated with survival estimates and the ability to detect differences in movement show that even with the relatively small sample sizes in this trial, tests can be powerful.

The evidence of survival estimates from naïve and wild juveniles in this study is encouraging for the potential of enhancement of spiny lobster populations. We have provided strong evidence that the habitat present at the study site is appropriate for lobster reseeding, and that robust survival estimates can be obtained from pilot scale releases of juvenile lobsters. Further experimental releases across a range of habitat types could be conducted to correlate habitat structure with lobster survival. Suitability of individual sites being considered for large-scale release could also be assessed by pilot scale releases of visually marked juveniles.

15. Survival estimation from large-scale releases

15.1 Introduction

Research presented in this chapter directly addresses objective 3: evaluating survival in pilot-scale enhancement experiments. It was part of experiment 7, which utilised 60% of project resources.

When following the fate of released animals, we have a number of choices to make about the type of data required, and how to obtain this. In Chapter 12 we reported results from following individual lobsters over a 2 week period using acoustic tags. This provided detailed information about the behaviour, movement, habitat usage and ultimately diet of 9 individual lobsters. That approach has produced valuable data that has been important for designing further experiments, however acoustic tracking is very labour-intensive, and statistical inference about treatment groups is limited because of small sample size. It was important that we also obtain data in a situation that more closely replicated that of commercial reseeding operations. Behaviour of released lobsters, predators and wild conspecifics may differ considerably if 500 lobsters are released together on an area of reef than if 9 lobsters are released.

Through project FRDC 99/314 and the current project we have developed analytical and field methods which enable us to estimate the relative survival of wild and naïve lobsters on natural reefs. The work reported in this chapter applies this developmental work across 4 sites spread around the southeast and east coasts of Tasmania where reseeding is likely to take place.

An additional component involving caging lobsters on the seafloor prior to release was added after analysing results from the first 2 releases. The intention of the caging trials was to answer questions about the 'flight response' we observed in lobsters when they were first released.

15.2 Methods

15.2.1 Experimental lobsters

Pueruli for pilot-scale releases were collected from southern and eastern Tasmania. While it was initially envisaged that lobsters for reseeding trials would be provided from commercial collections of lobster pueruli, few of the permit holders made any effort to capture pueruli. Lobsters for 1 pilot scale release (Adventure Bay, Bruny Island) were provided by a puerulus collection permit holder (Tassal Ltd.). These lobsters were collected as pueruli from heavy-mesh nets that are placed around salmon culture cages to exclude predators. Pueruli live in the fouling that grown on these cages, and were collected when cages were removed for cleaning. These pueruli were held in the aquaculture research facility at the TAFI Marine Laboratories, where growth trials were conducted for the 12 months prior to release.

Lobsters for the remaining trials were captured by TAFI staff. The crustacean research section of TAFI conducts a puerulus-settlement monitoring program which has been operating for 12 years (see Gardner *et al*. 2001). The purpose of this program is to provide insight into links between puerulus settlement rates and adult lobster abundance in subsequent years. Crevice collectors (Figure 41a) remain in-place year-round at 3 sites: Recherche Bay (43' 35.714' S, 146' 55.038' E), the Derwent River mouth (43' 03.272'S, 147' 24.931'E) and Bicheno (41' 52.343'S, 148' 17.918'E). The majority of pueruli for the remaining 3 pilot scale releases came from monthly servicing of collectors at these sites. Additional bottlebrush collectors (Figure 41b) were deployed at Bicheno to boost puerulus catches in order to provide sufficient lobsters for reseeding trials.

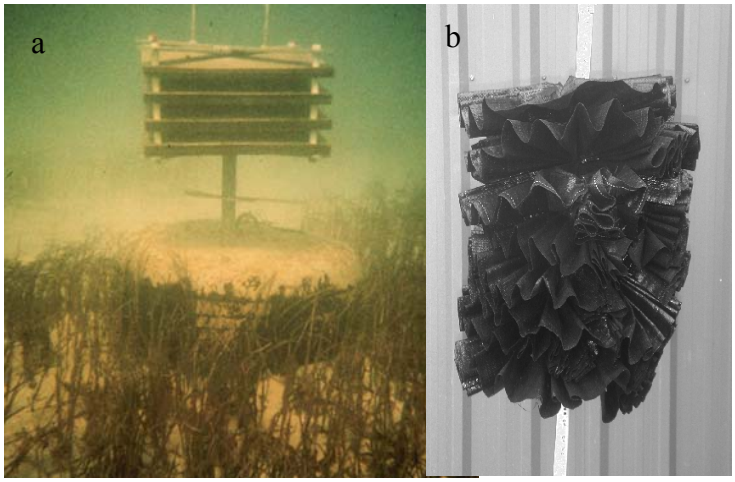

Figure 41. a) Crevice collector b) Bottlebrush collector

Pueruli were then ongrown in tanks for 12 to 15 months, attaining a size of 30-52 mm carapace length (CL). All tanks were fitted with hides of concrete blocks and plastic oyster mesh. Lobsters were fed daily on fresh opened blue mussels (*Mytlius edulis planulatus*) or commercial prawn pellets. Most lobsters were held in ambient flow-through water (11 to 19°C), although a proportion was used in growth trials where water temperatures were manipulated. These lobsters were returned to ambient water at least 1 month prior to release. All lobsters were held in ambient light conditions for at least a month prior to release.

SCUBA divers captured wild-caught lobsters of a similar size to lobsters grown from pueruli within a week of each reseeding event. While lobsters in the same size range as naïve lobsters were targeted, lobsters up to 75 mm were retained to increase available numbers. If size dependence was detected in any analyses, large lobsters could be excluded at the analysis stage. Wild lobsters were held under the same conditions as on-grown pueruli.

15.2.2 Release sites

Four sites in south-eastern and eastern Tasmania were chosen for pilot-scale reseeding releases (Figure 42). Two sites were within the Bruny bioregion, and 2 in the Freycinet bioregion. To date all commercial collections of pueruli have occurred in these regions, and it is likely that this will continue to be the case.

We did not attempt to select habitats varying greatly on physical or environmental parameters, but rather chose sites to be representative of habitats where reseeding releases may occur. In addition, sites were chosen on the basis of:

a) *Presence of appropriate habitat structure for small lobsters*. This selection criterion was based on field observations of den size and habitat structure likely to be occupied by lobsters of the size being released. For example sites consisting of sheer rock faces and large boulders are less likely to harbour large numbers of juveniles than sites consisting of small to medium boulders.

b) *Presence of juvenile lobsters*. A good indicator of the appropriateness of a habitat for releases is the presence of wild lobsters of the size to be released.

c) *'Realistic' degree of exposure*. A high-intensity period of fieldwork was required to perform dive surveys at each of the release sites. Highly exposed sites would likely have compromised our ability to carry out surveys at the optimal times to achieve robust survival estimates. Exposure level of the chosen sites varies from moderately sheltered (in the Derwent Estuary) to moderately exposed (Adventure Bay).

d) *Accessibility*. Sites had to be accessible by the small research vessels available to conduct resighting surveys.

Glenvar Bay: (43°00'11"S, 147°23'46"E; Figure 43)

The release reef was a discrete area of medium-profile reef (maximum rise 2 m) in 5-7 m of water, and was approximately 100m offshore from Glenvar Point. There were numerous resident juvenile lobsters. Low to moderate cover of macro algae allowed efficient searching by divers during resighting surveys. A larger area of patchy low to medium profile reef occurred to the west of the release reef in 7-9 m of water. Unstructured rock platform unsuitable as lobster habitat extended along the shoreline approximately 400 m north from the release reef. Shelving reef extended some 800 m south along the shoreline, and provided good lobster habitat.

Exposure was highest to southerly and south-westerly conditions, when a fetch of approximately 8 km exists from the northern tip of Bruny Island.

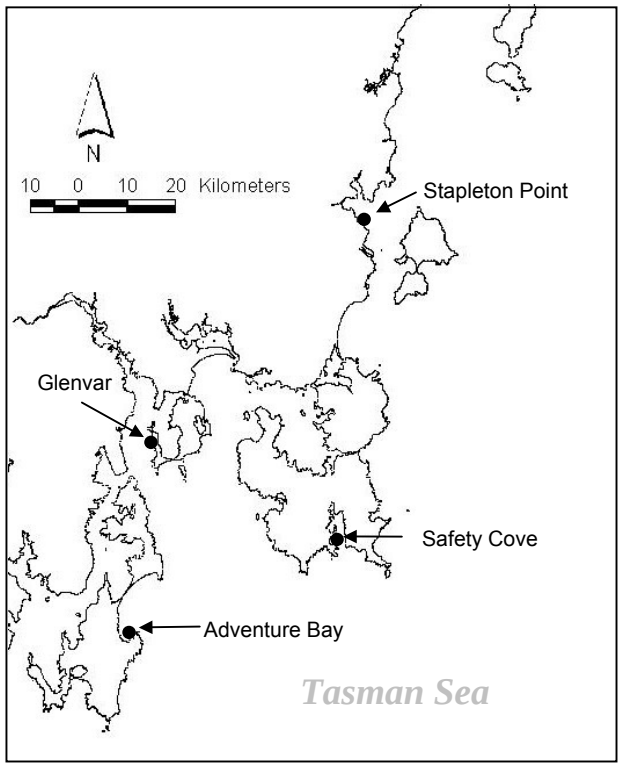

Figure 42. Sites of pilot-scale lobster releases in south eastern and eastern Tasmania

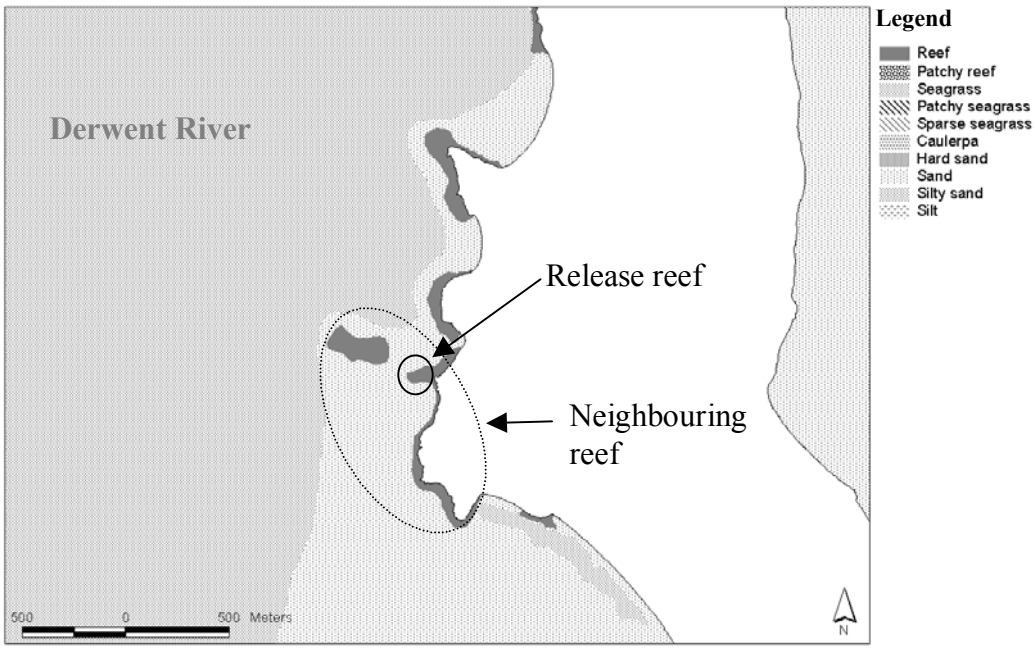

Figure 43. Habitat map for Glenvar Reef in the Derwent River (1:18000) showing release reef (solid circle) and areas of neighbouring reef searched during dive surveys.

Adventure Bay: (147°21’28"S, 43°21’254"E; Figure 44)

Our site in the southern corner of Adventure bay consisted of a small area (approx. 80 m x 40 m) of high profile reef in 7 – 9 m depth. Patchy low profile reef continued for another 50-80 m to the north to a depth of 13-14 m. There were a small number of reef patches in 2-3 m depth close to the shore, separated from the release reef by approximately 100 m of unstructured sand.

While the Adventure Bay site is only exposed directly to oceanic swells from the east, it can be classified as a ‘high energy’ reef, and has biota appropriate to this classification. The ‘neck’ between the northern and southern landmasses of Bruny Island provides little protection from regular strong winds from the northwest, and there is a fetch of approximately 40 km to the Tasman Peninsula to the NE. The site is protected from winds and swell from the southeast through to the west.

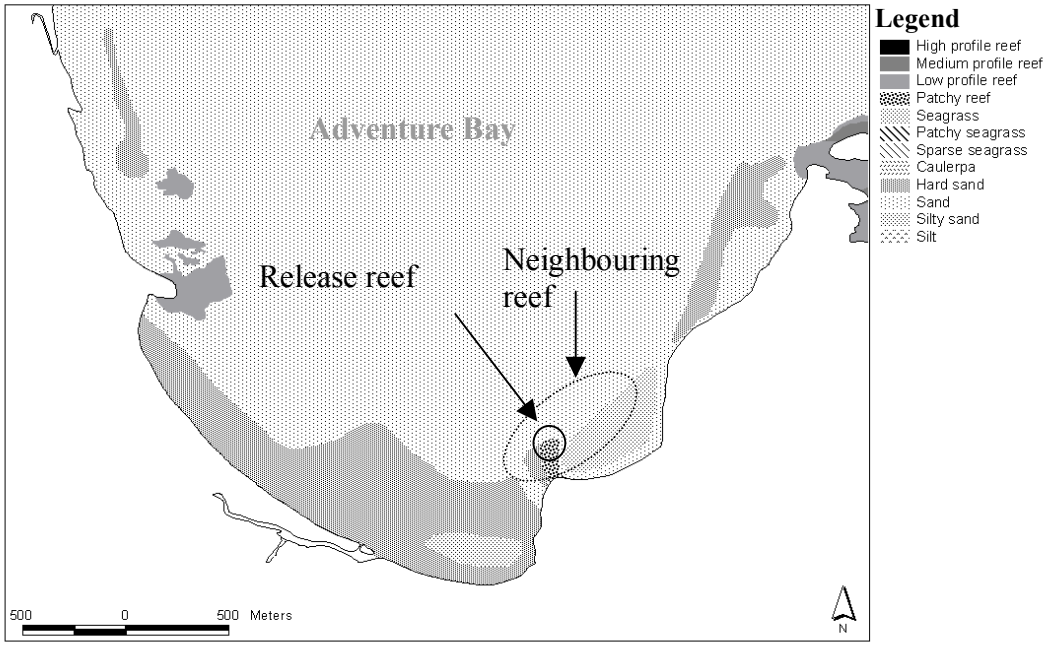

Figure 44. Habitat map for Adventure Bay, Bruny Island (1:18000) showing release reef (solid circle) and areas of neighbouring reef searched during dive surveys. Areas of neighbouring reef were small discrete patches that do not show up on the habitat map

Safety Cove: (147°51’45"S, 43°11’5"E; Figure 45)

The release site in the southern corner of Safety Cove was on an area of complex coastal fringing reef. The site was situated on the northern side of a point that runs east/west, and the reef was contiguous through several bays to the south. A long sandy beach lies to the north. The release area had a substratum of large and small boulders that extended from a rocky shoreline. A dense cover of macro algae was present in parts, dominated by members of the genera *Sargassum* and *Cystophora*. The reef was continuous to a depth of 6-7 m, and patchy to a depth of 12 m. While fetch is low (maximum 3km to the NE), the site receives considerable reflected swell from the

adjacent cliffs to the east in southerly conditions. Accordingly the fish assemblages of Safety Cove is more reflective of high exposure conditions (Jordan *et al*. 1998) than would be expected given the limited fetch.

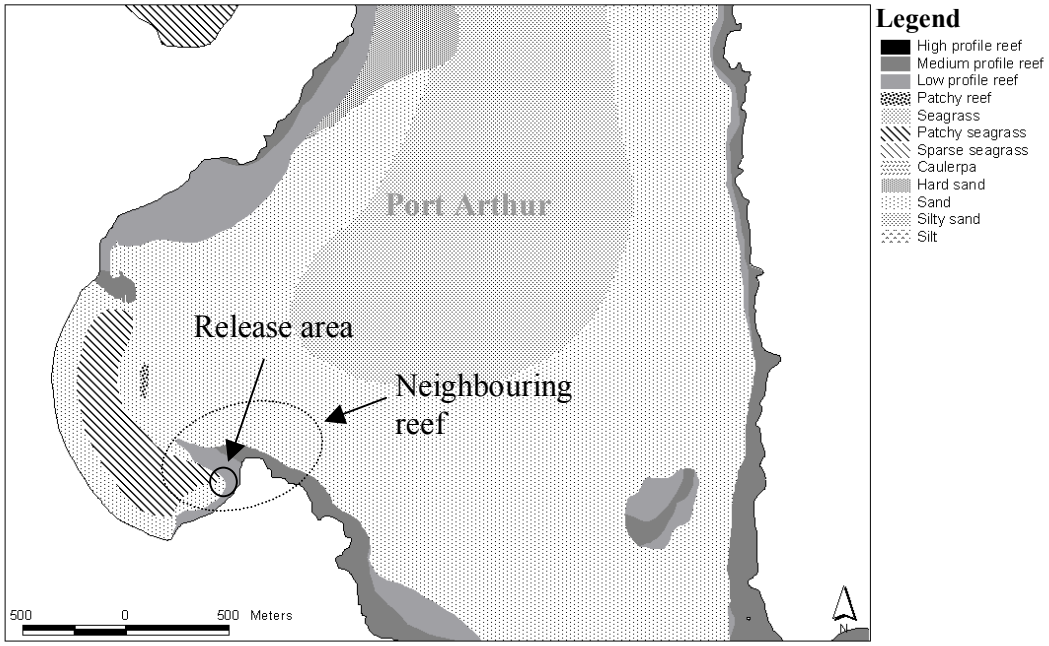

Figure 45. Habitat map for Safety Cove, Port Arthur (1:18000) showing release reef (solid circle) and areas of neighbouring reef searched during dive surveys.

Stapleton Point: (147°55’43"S, 42°35’42"E; Figure 46)

Similar to the Safety Cove site, the Stapleton Point release area was on the northern face of a point that runs east/west, and is an area of fringing reef that is contiguous with reefs that fringe several kilometres of adjacent coastline. Algal communities are similar to those at Safety cove, although extensive urchin (*Heliocidaris erythrogramma*) barrens exist in water deeper than about 7 m. Large stands of the introduced brown alga *Undaria pinnatifida* are present, but generally occupy the upper surfaces of large boulders, and accordingly do not represent a significant modification to lobster habitat. The site experiences a small arc of exposure to oceanic swells from the NE and a maximum fetch in the same direction of approximately 40 km to Schouten Island and Freycinet Peninsula.

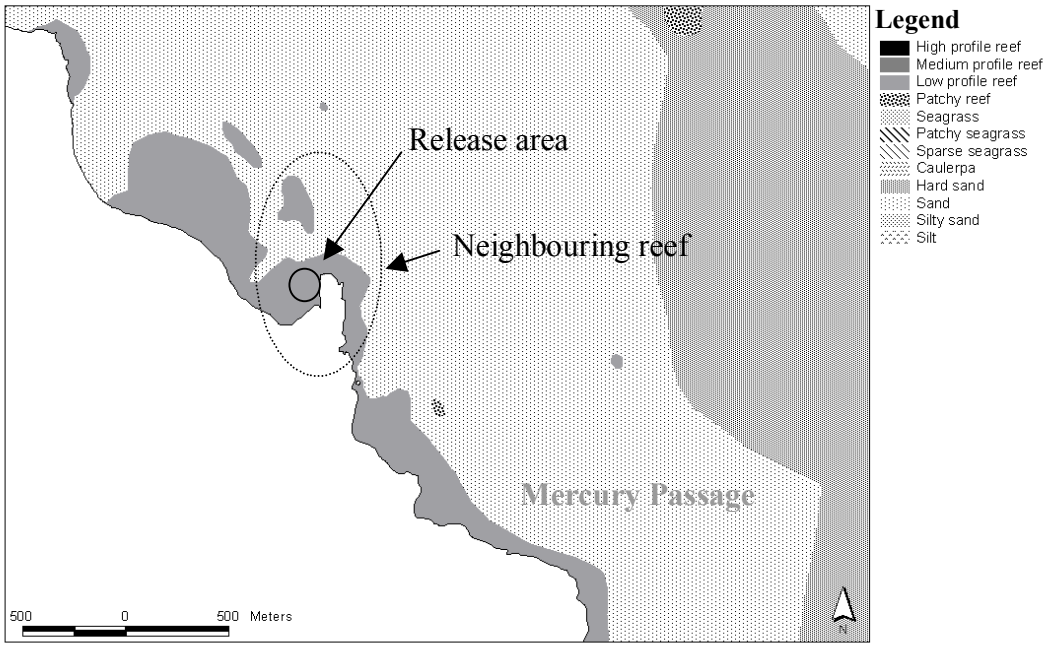

Figure 46. Habitat map for Stapleton Point, Mercury Passage (1:18000) showing release area (solid circle) and areas of neighbouring reef searched during dive surveys.

15.2.3 Tagging Methods

Three types of tag were used during pilot-scale release trials: micro-wire tags (Figure 47a and b) which could not be detected directly by divers but were retained through moult, visible antennal tags (Figure 47c) that allowed divers to individually identify lobsters and acoustic tags (Figure 47d) for tracking a small number of lobsters. Detailed methods of tag application are given in chapters 11, 15 and 12 respectively. Antennal tags consisted a length of copper wire with coloured beads threaded on to each wire to form a unique code. The wire was wrapped around the right antennal base of each lobster. Microwire tags were injected into each lobster prior to release. These tags provide for longer term assessment of reseeding success, and were used to assess moult mortality (Chapter 11). Acoustic tags were used at one site (Stapleton Point) in this study to track the movements of lobsters that had been caged on the seafloor for 48 hrs relative to that of uncaged lobsters.

Antennal and microwire tags were applied within 2 days prior to lobster releases. All lobsters were measured (carapace length ± 0.5 mm) and sexed prior to release, and this data was recorded along with tag details. Any moults occurring post-tagging but prior to release were recorded and antennal tags were re-applied to new lobsters.

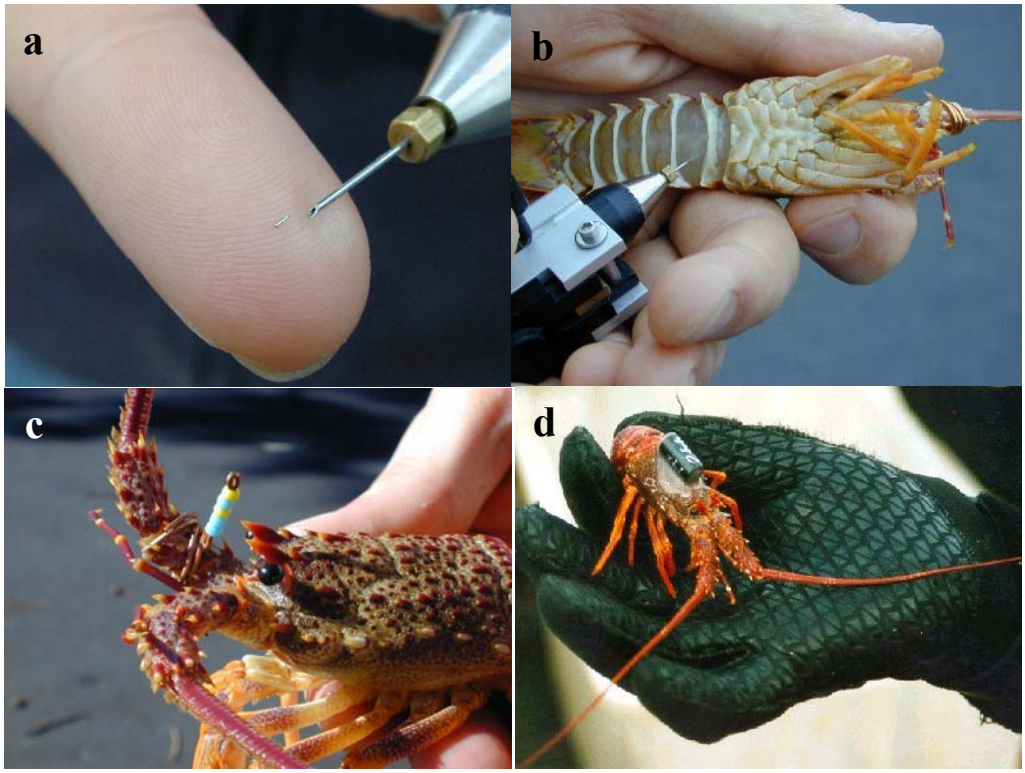

Figure 47. a) Microwire tag (on finger) with injecting needle b) injecting microwire tag into a juvenile lobster c) antennal tagged lobster d) acoustic tagged lobster

15.2.4 Lobster releases

Numbers of lobsters released at each site (Table 6) was a function of availability of appropriate sized lobsters at the time of release. This was in turn a function of the level of puerulus settlement 12 months earlier, provision of lobsters from industry participants (Adventure Bay) and the mortality rate during ongrowing.

Table 6. Numbers of tagged lobsters released at each site.

Site	Naive	Wild	Total
Adventure Bay	601	199	800
Glenvar Bay	427	153	580
Safety Cove	263	199	462
Stapleton Point	200	202	402

Lobsters were transferred from the TAFI Marine Laboratories to the release site in a fish transport trailer. This is a purpose-built fibreglass tank holding approximately 1.5 m^3 of seawater. Oxygen was provided via 2 large airstones during the transportation process. Lobsters were transferred to the wet-well of our research vessel (8 m aluminium tri-hull) at a launching ramp near the site, for transport to the release reef.

All releases occurred at or soon before dusk. Lobsters were transferred from the vessel wet-well into large mesh bags. These bags were suspended over the side of the vessel for a minimum of 45 minutes to allow time for lobsters to equilibrate to the water temperature. A diver then took the mesh bags to a pre-determined area of reef, and released the lobsters. Lobsters were not distributed around the reef, and no assistance

was given in finding shelter. The diver then retreated from the release area and observed for a period of up to 30 minutes to note any predator activity.

15.2.5 Direct observation of releases

When releasing lobsters divers observed both lobster and predator behaviour associated with release. Once releases were completed divers retreated from the release area and continued observations noting attraction of predators to the site and dispersal of lobsters from the release area. These general observations were followed up by more intensive post-release observations at 2 sites.

At Safety Cove lobsters were released on dusk (1900). Divers performed visual surveys of the release area at 2100, 0300 and 0600 and noted the presence and behaviour of lobsters and predators.

At Adventure Bay, the release site was monitored for 48 hr post-release by 6 infrared capable cameras. Two cameras were positioned to record a broad view of the release area, and the remaining cameras were focused on large cracks representing important lobster shelters within the release area. Video footage was reviewed and scored for behaviour of predators and reseeded lobsters.

15.2.6 Re-sighting surveys

Resighting surveys were conducted by SCUBA divers in the area where lobsters were released, and adjacent or adjoining areas of reef. Transect lines up to 400 m long were laid across the search area to provide a point of reference for divers. On each occasion divers equipped with a slate and a torch were instructed to search a predetermined area of the site. Divers recorded colour codes from antennal tags of resighted lobsters, and position on the transect line to an accuracy of about 10 m. On most survey days, 3 divers conducted 3 dives each, with dives lasting approximately 60 minutes (ie. approximately 9 diver-hours per survey).

Timing of re-sighting surveys varied between release trials. Early releases showed that daily sampling in the first 3 to 4 days post-release would provide valuable information on lobster movement, and that sampling areas of adjacent reef was critical from the first day post-release. Surveys on subsequent sites were altered to reflect these findings. After 4 days, surveys were conducted at increasing time intervals, ultimately up to 10 days apart until the numbers of lobsters being sighted dropped off to a point where meaningful estimates could not be obtained from survival models. The greatest number of surveys conducted at a single site was 8.

15.2.7 Survival estimation

Survival of lobsters was estimated using methods based on Cormack-Jolly-Seber (CJS) maximum likelihood models (Cormack 1964; Jolly 1965; Seber 1965). Models used here to calculate apparent survival and associated parameters are computationally complex, and details of the calculations behind the estimates are available through primary literature referenced in this report. However, some understanding of the way

that these estimates are derived and the method of representing models is necessary to understand results presented here.

The basic CJS model assumes that the proportion of tagged animals recaptured on any given occasion is a function of survival rate and the probability of tagged animals being resighted (Figure 48). The parameter estimation procedure provides estimates of survival by separating or identifying resighting parameters at each encounter opportunity.

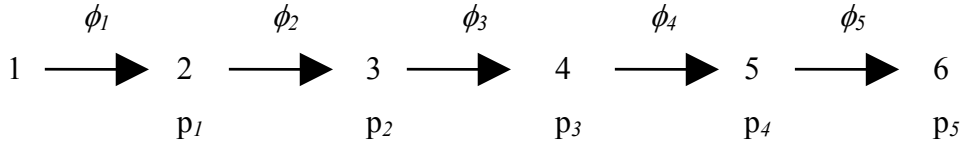

Figure 48. Schematic of a tagging study with a single "batch" release at occasion 1 as in these trials. Tagged animals seen at occasion 2, the first resighting opportunity, will be function of both survival rate over interval 1 (ϕ_1) and resighting rate at occasion 2 (p_1).

Survival and resighting rates are identifiable as animals that have survived, but are not resighted, remain available for resighting on subsequent occasions. Thus the recapture histories of an animal that was:

released occasion 1 — not seen on occasion 2 — resighted occasion 3

provides a means of estimating the resighting parameter. As only two parameters are estimated for each occasion, survival can be identified. Where both survival and resighting probability vary across time, a model for this trial may be represented by:

$\phi(t)\rho(t)$

That is, both survival (ϕ) and resighting probability (ρ) vary as a function of time (t). In all instances in the current study we are interested in the comparative survival and resighting probabilities of naïve and on-grown lobsters or caged and uncaged lobsters. This introduces another factor such that survival and resighting probabilities can be dependent on time and group:

$\phi(tg)\rho(tg)$

A further extension of these models is the multistate model, which introduces a factor for movement. Given the relatively low numbers of lobsters tagged in these studies and the rapid increase in number of parameters when moving to multistate models, we are limited to examining movement between 2 areas in these studies. Even then, number of parameters increases dramatically. Rather than simply 'surviving' between subsequent survey periods, animals can make 1 or 4 different transitions (Figure 49).

Figure 49. Schematic representation of survival probabilities between two strata as used in the rock lobster reseeding experiment. Strata A represents the release site and strata B represents the neighbouring reef.

With movement introduced to the model, the fully parameterised model can be represented by:

$$\phi(gts)\rho(gts)\Psi(gts)$$

We see that survival and resighting probabilities are now a function of group, time and the spatial strata (s) occupied by the lobster, and the probability of completing any of the 4 transitions represented in Figure 49 (Ψ) is also dependent of group, time and spatial strata occupied.

15.2.8 Goodness-of-fit testing

Once a 'starting' model for any analysis is established, it is necessary to assess whether this fully parameterised model adequately describes the variability in the data. Goodness-of-fit (GOF) tests provide a measure of whether the data fit the basic assumptions of models being tested. Further, where lack of fit is detected, procedures allow exploration of the data in a way that helps to pinpoint where and why the lack of fit has occurred. This may be followed by a process of adjusting the models tested, or allowing for lack of fit in the calculation process.

Most important amongst assumptions tested are that every animal in the population (of each group) has the same recapture probability for each resighting occasion, given that it is alive and in the survey area; and every marked animal of each group has the same probability of surviving from the i^{th} to the $(i+1)^{th}$ sample. Further assumptions are introduced with multistate models regarding movement between states, such that the probability of resighting an animal at time *i* must be independent of the state occupied by that animal at time *i*-1.

The approaches for GOF testing are distinct for single state and multistate models. For single state models we followed the guidelines set by Lebreton *et al*. (1992). Goodness-of-fit tests were done in a two-stage process. First, a parametric bootstrap test of the survival models was undertaken through program MARK using 100 simulations. The deviance of the model fitted to experimental data was compared to that of the simulated data. Where the 'real' deviance lay outside the extreme 5% of deviances of simulated data, the original data was considered to violate the GOF test (α=0.05). Where the reseeding data appeared to violate the parametric bootstrapping test of GOF, the data was further explored using program RELEASE which tests GOF by partitioning the overall χ^2 test into it's component elements.

For multistate models, we followed GOF testing procedures set out by Pradel *et al*. (2003), implemented in the program U-care V2.0 (Choquest *et al*. 2003). While direct tests of fit for AS models are not available, this procedure involves testing for fit of a more generalised model (model JMV, Brownie *et al.* 1993), followed by a likelihood ratio test (LRT) between the JMV and AS models.

Where GOF tests demonstrated over-dispersion in the data, a variance inflator factor (ĉ) was calculated and applied. For single state models there is conjecture about the best way to calculate ĉ. We employed the method generally leading to the most conservative (largest) ĉ value, which involves dividing the observed model deviance by the mean of the deviance of 100 bootstrap simulations. For multistate models, ĉ was calculated by dividing the χ^2 value from the from the global multistate GOF test by the test degrees of freedom (Lebreton *et al*. 1992; Pradel *et al*. 2003). A value of ĉ > 1.0 compensates for minor lack of fit by promoting models with fewer parameters, and thereby being conservative with respect to the detection of fine-scale structural features within the data.

15.2.9 Model selection process

For all sites we estimated survival using single and multistate models. As no formal tests are available for directly comparing the fit of single and multistate models, a series of decision rules was employed:

1. Formal goodness-of-fit tests were conducted for both model types. Where fit was particularly poor for either model, the alternative model was favoured.

2. Commonly, survival estimates were very similar for single and multistate models. Given that a fully parameterised 2-state model has 3 times the number of parameters as a single state model, in such instances the single state model was favoured. In these cases it was invariably clear that spatial parameters were coding no useful additional information about the data.

3. Where survival estimates from single and multistate models differed, and GOF tests were similar, information coded in spatial parameters was further investigated. There were instances where it was clear that the direct result of introducing additional parameters in a multistate model was to decrease precision of parameter estimates due to a low number of observations in each 'cell' of the analysis. The trap here is that as precision decreases, probability of committing a type II error increases. In this instance the result may be finding no significant difference between survival of wild-caught and on-grown lobsters where a difference does exist.

Once a starting model was chosen, we tested hypotheses relating to survival and resighting likelihood by sequentially eliminating parameters that did not improve model parsimony (Lebreton *et al*.1992). Of a set of models, the most parsimonious model is one that adequately describes the variability in the data with the minimum number of parameters (Burnham and Anderson 1998). Parsimony was assessed using the quasi-likelihood adjusted form of the Akaike Information Criteria ($QAIC_c$), incorporating the calculated ĉ value to allow for minor lack of fit of the full model

(Burnham *et al*. 1995; Anderson *et al*. 1998). If removal of parameters of interest for a particular hypothesis resulted in a decrease in $QAIC_c$, the hypothesis was accepted, and the reduced model was taken as the best general model against which further comparisons would be made (Burnham *et al*. 1995; Burnham and Anderson 1998). This stepwise reduction process is shown in detail for the Glenvar Reef site in chapter 15. While this method of model selection does not allow significance values to be attributed to tests between models, normalised QIACc weights provide a relative weight of evidence for a particular model best describing the data (Burnham and Anderson 1998).

When more than 1 model received strong support from the data (similar QAICc weights), parameter estimates were derived from the set of reduced models by model averaging using normalised $QAIC_c$ weightings, reflecting uncertainty in model selection process (Burnham and Anderson 1998).

15.2.10 Caging Experiments

In all pilot-scale releases a high percentage of both wild and naïve lobsters released were never resighted. This is reflected in the low apparent survival estimates for on-grown and wild lobsters in the first 24 to 48 h post release. As this occurs in both the on-grown and wild-caught lobsters, we know this is not the result of a behavioural artefact from the on-growing process. We know from acoustic tracking that lobster exhibit a 'flight' response when first released, and it is highly likely that they move beyond the areas searched by divers in resighting surveys. This alone could account for the low apparent survival during the period of this response. However, a further possibility is that post-release mortality in both groups is high due to the release process. While estimates of predation rates from video-referenced tethering trials (Chapter 14) provide an independent measure of maximum likely predation rates, caging was used to provide another insight into lobster behaviour, and to provide additional evidence to aid us in separating the effects of movement and mortality. The questions being posed in caging trials were: (1) By containing lobsters on an area of seafloor for 48 h, can we alter their behaviour in a way that results in an increase in apparent survival estimates? and (2) By using acoustic tags simultaneously with cages, can we show that it is lobster behaviour (movement) that causes the observed change rather than predation?

Cages were designed to contain lobsters within an area of substrata, and exclude predators. Cages were constructed from braided nylon mesh of 25 mm stretched mesh size, and had no rigid frame. Each cage covered approximately $9m^2$ of seafloor and rose 1 m above the seafloor (Figure 50). The base of each cage was open, but the edges were 'double sealed' at the seafloor with 2 chains (6 mm and 8 mm), one at the base of the cage walls, and a second on a skirt of mesh that extended approximately 50 mm beyond the walls of the cage. When cages were deployed, divers worked the chains around rocks on the reef to ensure a good seal. The 'roof' of the cage was held up in the water column with small foam floats around the perimeter of the cage and in the centre of the roof.

'Caged treatment' lobsters were released at the site into mesh cages on the sea floor. Forty-eight hours after lobsters were released into cages, cages were lifted and

'uncaged treatment' lobsters were released in the same area. Surveys of caging areas were conducted as outlined below. Caging trials were conducted at Safety Cove and Stapleton Point. At Safety Cove approximately half of the naïve juveniles were released into cages, while at Stapleton Point both naïve and wild lobsters were released into cages. At Stapleton Point 12 lobsters were acoustically tagged to provide further insights into movement. Six of these were released into seafloor cages, and 6 were released 48 h later with the uncaged lobsters.

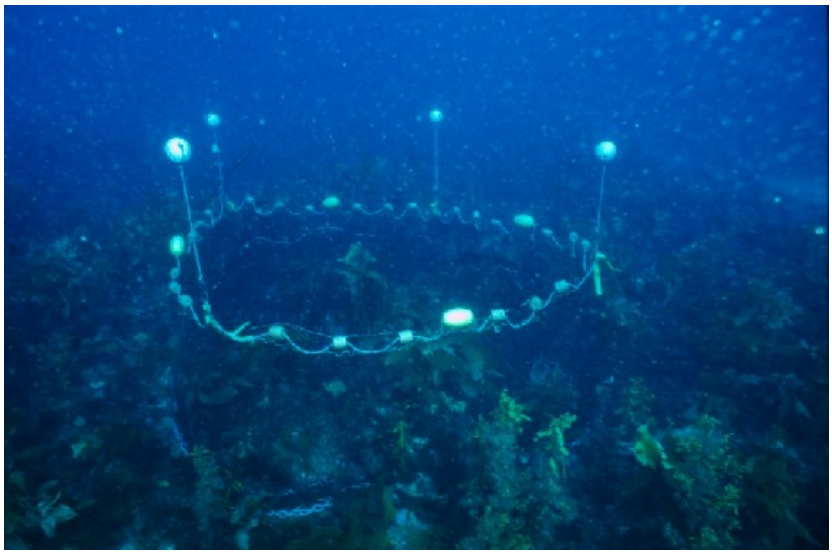

Figure 50. Deployed mesh cage. While the cage mesh is not visible, the floats at the top of cage walls can be seen, as can the chain ensuring that lobsters are unable to escape under the cage walls and predators are unable to get into the cage area (Photo by Hugh Perderson).

The sites were caging trials were performed provide a useful contrast in habitat type. From a geographic standpoint they have much in common. Both release areas were on the western face of similar sized rocky outcrops projecting to the north, were on large areas of reef that continued through adjacent embayments, and had dense stands of brown algae present. From a microhabitat perspective they differed considerably. The substratum structure at Safety Cove provided large numbers of potential lobster shelters over the entirety of the reef. Stapleton Point, however, provided widely dispersed areas of good quality shelter under large boulders, interspersed by rubble fields with little interstitial space.

To maximise information available on movement of lobsters, we have combined information from single and multistate models. At both sites the reef was searched in 2 distinct strata. The small area where seafloor cages were deployed was searched extensively on each survey occasion, with approximately half the total dive-effort spent in this area. Extensive areas of adjacent reef received the same total effort.

We first modelled apparent survival using a single state model only considering lobster resightings within the small release area. As the area searched was small, we anticipated that apparent survival estimates would be low, as emigration rates (a component of 'apparent' survival) would be high. Multistate models then provided estimates of movement from the release area to adjacent areas of reef, as well as apparent survival estimates that accounted for resightings on neighbouring reef.

Goodness-of-fit tests were conducted in all cases, and are only reported here when tests were significant.

15.3 Results

15.3.1 Glenvar Reef

Glenvar Reef was the first site chosen for a pilot-scale reseeding trial. Data from this site were used to refine field and analytical techniques. The value of the additional movement information available through regular wider-area surveys was not fully appreciated until data were analysed. Areas of adjacent reef were searched 3 times during this trial (days 5, 18 and 28) and accordingly the temporal resolution of movement modelling is restricted to the periods defined by these 3 surveys. In subsequent surveys, wider areas of reef were searched on each survey occasion.

Goodness-of-fit tests for the saturated single state model revealed a systematic violation of the two major assumptions of CJS models (test results $p<0.0001$ and $p=0.048$). The most significant of these violations relates to a lack of homogeneity in resighting probabilities. A calculated ĉ value of 2.97 when applied substantially increases the errors associated with estimates. The best supported single state model for Glenvar reef was $\phi(gt)\rho(t)$, suggesting a difference in survival between wild-caught and on-grown lobsters (Figure 51). Estimates for apparent survival were lower for naïve lobsters from release to day 5. Given the degree of violation of assumptions, this model was not accepted. However, we have included the results here to illustrate the dangers of accepting the results from a poor fitting model.

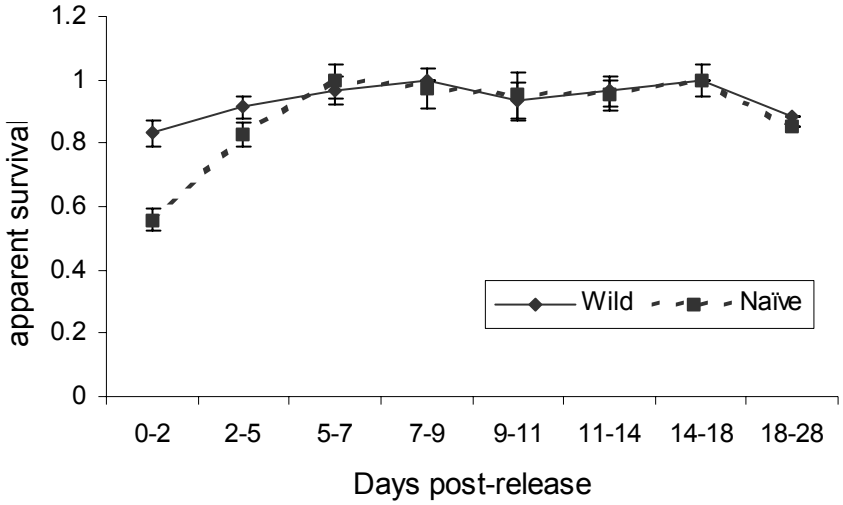

Figure 51. Single-state estimates of survival (± SE), showing how erroneous conclusions can result from inadequately representing the data

Employing a multistate model accommodated the heterogeneity in resighting probability and revealed the reason for differences in apparent survival with the single state model. The global multistate GOF test showed good overall fit, with a ĉ value of

0.998. However, the LRT between models JMV and AS for naïve juveniles was marginally significant (p = 0.044). Despite observing no systematic violation of assumptions, as a conservative measure we applied a ĉ value calculated from this test (ĉ = 1.52) to the multistate model selection process.

The full multistate model for 8 recapture occasions, 2 groups and 2 strata comprised 96 parameters. This reduced to 64 parameters when restrictions imposed by experimental design were considered. For example, no movement from neighbouring reef back to the release reef was possible between release and survey 1, as all tagged lobsters were released on the release reef. Parameters coding these movements were removed from the model. The most parsimonious model from the candidate model set can be represented by $\phi(.)\rho(ts)\Psi^{rn}_{0-4}(g)\Psi^{rn}_{4-28}(t)\Psi^{nr}(gt)$. Parameterisation for apparent survival and resighting likelihoods are straightforward. Apparent survival (ϕ) was estimated by a single parameter (0.980±0.016, Figure 52a).

We constrained resighting probability (ρ) to time and strata (reef) dependence, as search effort varied between reefs and across time. Movement was partitioned by group, time and strata (reef). Movement for time interval 1 (days 0 to 4, denoted by subscript 0-4) from release reef to neighbouring reef (denoted by superscript *rn*) was dependent on group (Figure 52b), with movement likelihood for naïve lobsters being significantly higher than that for wild-caught lobsters. Movement likelihood for the remainder of the trial (surveys 2-8 (days 4 to 28), denoted by subscripts 4-28) was dependent on time only, and decreased to near zero by the final resighting survey. Movement from neighbouring reef back to the release reef (denoted by superscript *nr*) was dependent on group and time. Given that naïve lobsters moved a greater distance from the release reef (see chapters 12 and 15) it is not surprising that the likelihood of wild lobsters moving from neighbouring reef back to the release reef is higher than that for naïve lobsters (Figure 53).

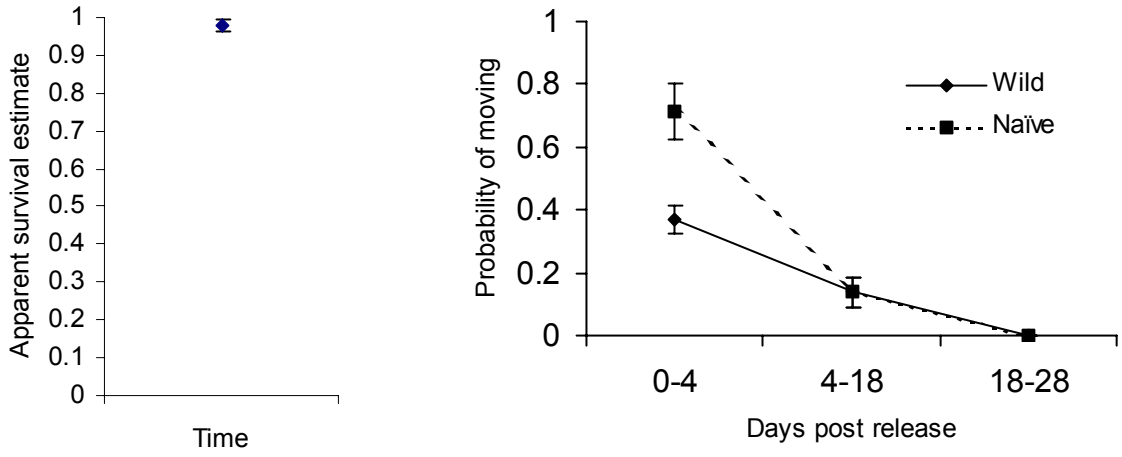

Figure 52. a) Apparent survival estimate (± SE) and b) movement likelihoods (± SE) for wild and naive lobsters released at Glenvar Reef.

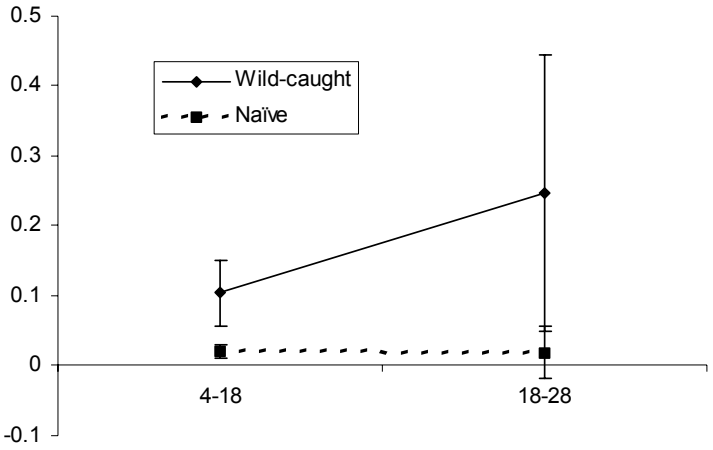

Figure 53. Likelihood of wild-caught and naive lobsters moving from neighbouring reef back to release reef (±SE).

15.3.2 Adventure Bay

The Adventure Bay trial was the largest release (800 lobsters), as the scheduling of this trial coincided with a large number of juveniles being available from commercial puerulus ongrowing trials. In contrast, the area of reef on and directly around the release site was smaller than that at any other site.

During the dive survey on the second day post-release, a diver found 1 naïve lobster on open sand approximately 250m from the release reef. This lobster, although clearly alive, was 'lethargic' when approached, indicating a likely ineffective response to predators. Although sand areas around the reef were not searched, this chance encounter may be an indication of the fate of some lobsters that move away from the reef. Similarly, approximately 1 month after the release, recreational divers reported seeing antennal-tagged lobsters at Penguin Island at the head of Adventure Bay, approximately 1km from the release site. We dived in the same area and sighted 3 antennal tagged wild-caught lobsters. Lobsters must have crossed at least 300m of sand to get to this site.

Goodness of fit for the fully parameterised single state model for Adventure Bay was poor (wild caught, p = 0.049; naive, p = 0.001). Fit improved for the full multistate model, although the LRT test for naïve lobsters was significant (wild caught lobsters p = 0.98, naïve lobsters p = 0.03). Accordingly, we applied a ĉ value (2.0) calculated from this test. The most parsimonious model ($\phi(gt_1, t_{2-27})\rho(st)\Psi(st)$, QAICc = 0.997) showed apparent survival to be dependent on group (Figure 54). For each group, apparent survival was low for the first day post-release, and higher and constant for all days thereafter. This model was over 500 times as well supported by the dataset as the next best model ($\phi(gt)\rho(st)\Psi(st)$, QAICc = 0.002), which did not group survival across days.

As this was the only site where group differences in survival were detected, we further investigated possible experimental artefacts that could be responsible for this difference. As with all sites, length-frequencies were different for wild-caught and naïve lobsters (Figure 55) with much larger wild-caught lobsters being preset in releases. First, we looked at resighting probability. A possible scenario is that divers were more likely to see larger lobsters than small lobsters in resighting surveys, leading to an underestimate of small lobster survival. Length-frequencies of all lobsters released were compared with length-frequencies of resighted lobsters. There was no consistent bias towards any size class (Figure 56).

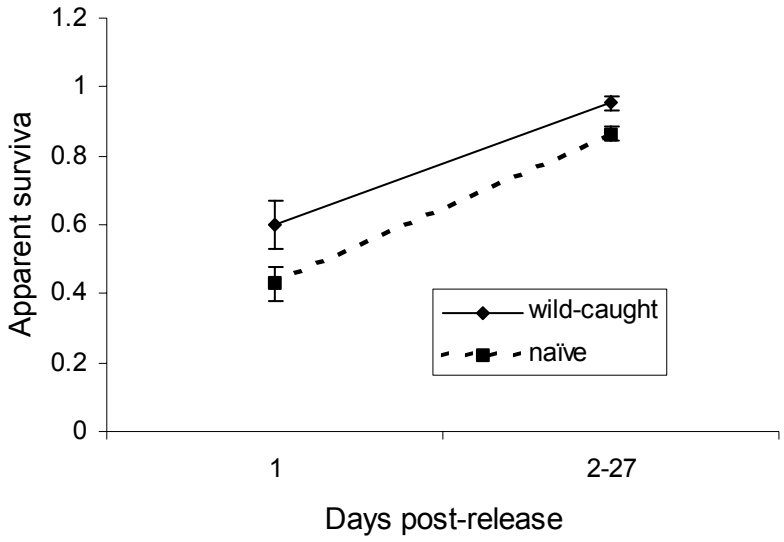

Figure 54. Apparent survival estimates for naïve and wild caught lobsters at Adventure bay (± SE)

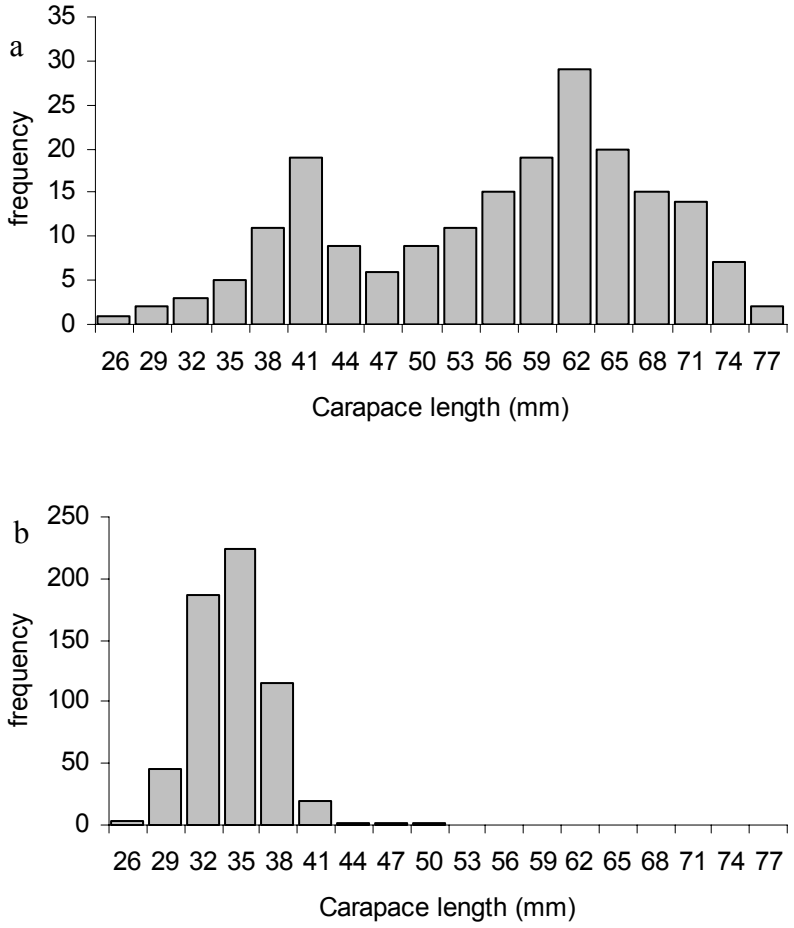

Figure 55. Carapace length frequency of a) wild caught lobsters and b) naïve lobsters.

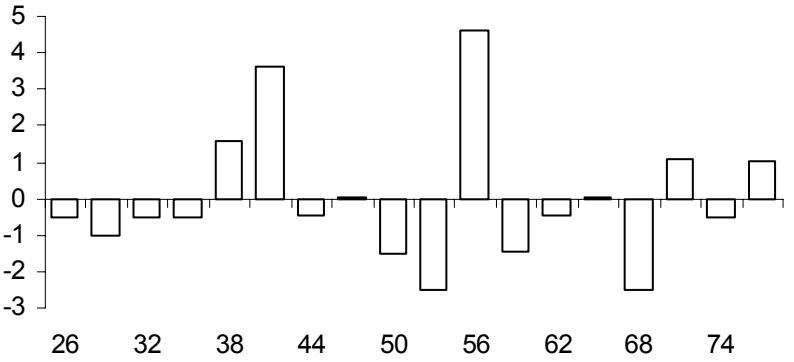

Figure 56. length frequency residuals for release/resighting of wild-caught lobsters at Bruny Island showing no consistent bias towards any size class.

We then re-ran the models formulated above using only control lobsters of CL < 55 mm. While data were too sparse to perform some GOF tests, parameter estimates were almost identical to those from the full dataset. As a further check, we divided control lobsters by size class (greater than or less than 55 mm CL) and compared apparent survival and resighting likelihoods of these groups using a CJS model. Model fit for the fully parameterised single state model was good (p = 0.808). The most parsimonious model from the candidate set chosen to test for group differences was the fully time-dependent model ($\phi(t)\rho(t)$, QAICc weight = 0.934). This was over 15 times as well supported by the data as the next best model ($\phi(t)\rho(gt)$, QAICc weight = 0.065) and over 700 times as well supported as the best fitting model including group dependence for survival ($\phi(gt)\rho(t)$, QAICc weight = 0.0013). It is clearly highly unlikely that the observed differences in survival are an artefact of size differences.

15.3.3 Safety Cove release

The Safety Cove release trial differed from previous trials in 2 ways. Evidence from the Bruny Island release suggested that using isolated areas of patch reef might influence estimates of apparent survival. The choice of the site at Safety Cove represents a move to areas of contiguous reef. This reef also differed from other release reefs in habitat complexity at a scale likely to provide shelter for lobsters of the size released. The habitat consisted of stacked boulders of varying sizes providing 10s to 100s of potential shelters per m^2 of substratum. Further, Safety Cove releases were used to test the 'flight' response of lobsters through caging experiments.

Of 263 naïve lobsters released, 100 were released in seafloor cages. Forty-eight hours after the caged lobsters were released, the remaining 163 naïve lobsters and 202 control lobsters were released in the same area.

The extreme habitat complexity and at this site and the experimental design for the caging trials dictated that dive surveys be structured differently from those at previous sites. The area where the seafloor cages had been and all lobsters were released (approximately $36m^2$) was marked out with sub-surface weighted buoys. On each survey occasion, approximately half the available dive time (generally about 4.5 diver hours) was spent surveying this area in detail.

The fully parameterised single state model for uncaged lobsters showed good fit to the data (p = 0.80 and p = 0.30 for wild and naïve lobsters respectively), however many cells in the GOF analysis had insufficient data to compute χ^2 values. Bootstrap GOF tests confirmed good fit for this model (p = 0.20). The simple time-dependent model ($\phi(t)\rho(t)$, QAICc weight = 0.988) proved the most parsimonious of the candidate model set, and was approximately 100 times better supported by the data than the next best model ($\phi(t)\rho(gt)$, QAICc weight = 0.010). Apparent survival estimates were of limited use due to large errors and associated lack of power to detect group differences (Figure 57). Resighting likelihood in the early post-release surveys was very low (Figure 58), reflecting the extreme habitat complexity, and the necessary concentration of search effort in the small release area.

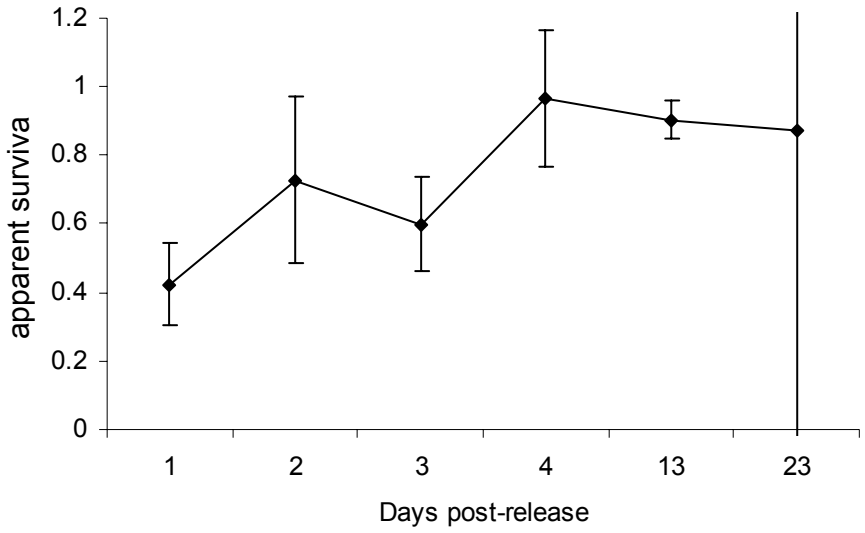

Figure 57. Apparent survival estimates (±SE) for single state model at Safety Cove.

The full multistate model also showed good fit to the data with a calculated ĉ value of 1.10. The most parsimonious model indicates time and state dependence for survival, resighting and movement likelihoods ($\phi^{r}(t_1, t_{2-21})\phi^{n}(t)p(ts)\psi(ts)$, QAICc weight = 0.887), and was over twice as well supported by the data as the next best model ($\phi(ts)p(ts)\psi(ts)$, QAICc = 0.102). The best fitting model with group dependence for survival has virtually no support from the data ($\phi(gts)p(ts)\psi(ts)$, QAICc = 0.00013). While this analysis still suffers from sparse data, spatial partitioning has resulted in a useful survival estimates for the release reef (Figure 59). Apparent survival was estimated in 2 parameters – 1 for the first day post-release, and another for the remainder of the trial.

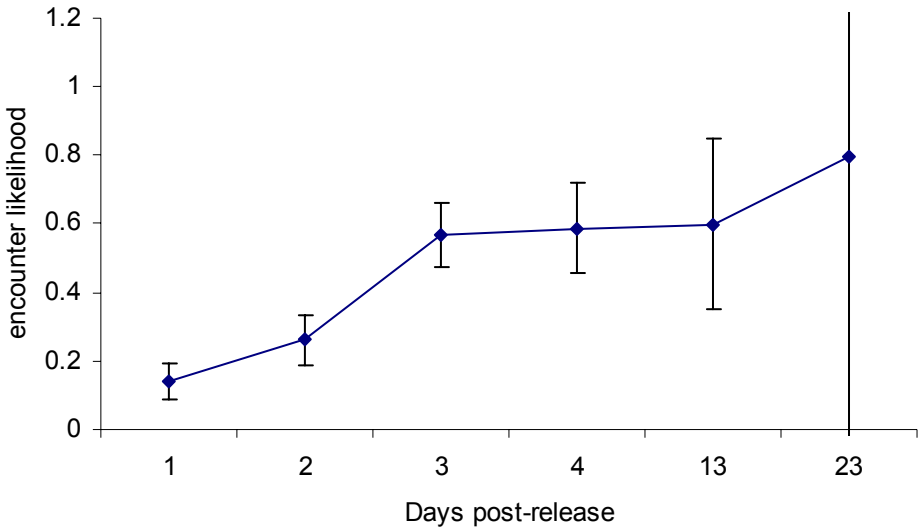

Figure 58. Resighting likelihood estimates (±SE) from single state model at Safety Cove. SE for final interval +/- 16.4.

The small errors associated with survival from days 2 to 21 post-release demonstrate the tight relationship between survival of wild and naïve lobsters on these occasions. While variability is high for the first day post-release, this is not due to between-group variability for naïve and wild lobsters, as the model allowing independent survival estimates for naïve and wild lobsters for the first recapture occasion was not well supported (QAICc weight = 0.011)

Movement from the release reef to neighbouring reef was high in the first day post-release, decreasing as the trial continued (Figure 60). This reflects the small area (36 m^2) designated as release reef in this trial. While there were no detectable differences in movement between naïve and on-grown lobsters, standard errors in the first days post-release are high, so power to detect differences is low.

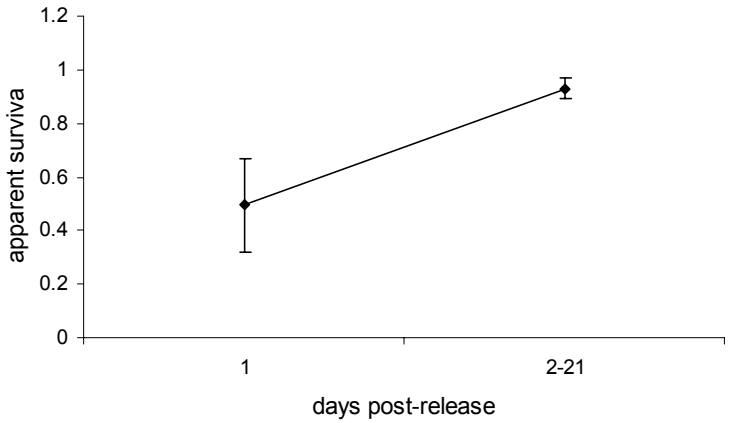

Figure 59. Apparent survival (±SE) from multistate model for naïve and wild lobsters on the release reef at Safety Cove.

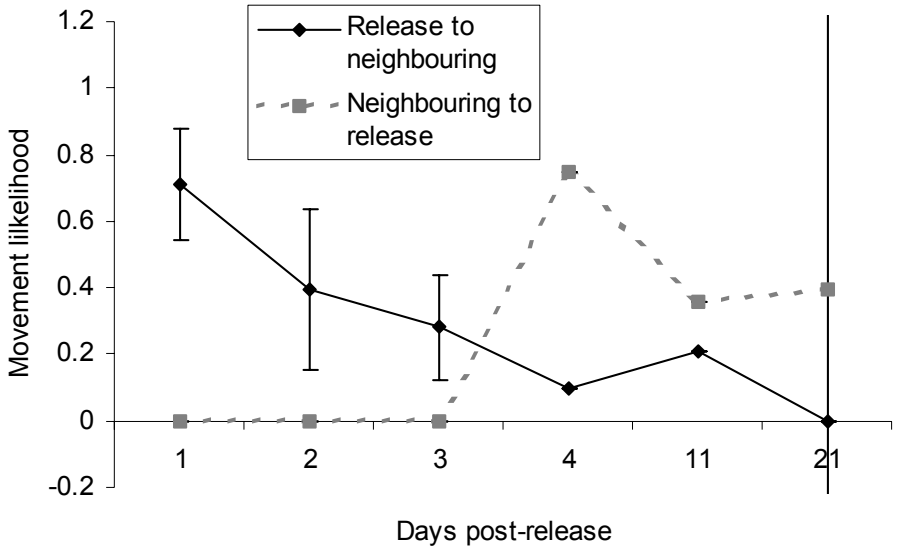

Figure 60. Combined movement likelihoods (±SE) for wild and naïve lobsters. SE for final movement from neighbouring to release reef is +/-36.

15.3.4 Stapleton Point Release

Results from single state and multistate modelling were remarkably consistent. Both showed no detectable difference between apparent survival of wild-caught and on-grown lobsters. Single state model selection processes produced a simple 9-parameter model, $\phi(t)\rho(.)$. This model was over 2 times as well supported by the data (QAICc weight = 0.674) as the next best model, which included a group effect for resighting probability ($\phi(t)\rho(g)$, QAICc weight = 0.314), and over 100 times better supported than the best fitting model which included group dependence in survival estimation ($\phi(gt)\rho(.)$, QAICc = 0.0067). For the best fitting model, while apparent survival varied across time, both apparent survival (Figure 61) and resighting probability (0.3 ± 0.03) were independent of group (wild-caught or on-grown). Model fit for the fully parametised single state model was good (p = 0.161), with a calculated variance inflation factor (ĉ) of 1.21. The selected model proved robust with respect to overdspertion in the data. Applying ĉ values as high as 5.5 had no effect on the selection of the most parsimonious model.

The introduction of 2 spatial areas (through the multistate model) further improved model fit, with a multistate ĉ value of 0.995. All multistate GOF tests were non-significant, and accordingly no ĉ adjustment need be applied. The most parsimonious multistate model ($\phi(t)\rho(st)\Psi(s)$, QAICc weight = 0.988) was over 95 times as well supported by the data as the next best model, which included group dependence for survival ($\phi(gt)\rho(st)\Psi(s)$, QAICc weight = 0.010).

Clearly there is little support for group dependence for any parameter of either single- or multi-state models. Of particular note here is the concurrence between survival

estimates from the 2 model types (Figure 61). Survival estimates are consistent for all time intervals, as errors are for most. An exception is the large errors for the multistate model on day 42 post-release. Given the concurrence of estimates for all other periods, it seems reasonable to attribute this difference to computational requirements of the multistate model, and accept that the survival estimate for this period is well approximated by the single state model (0.98 ± 2.1 for multistate, 0.97 ± 0.02 for single state).

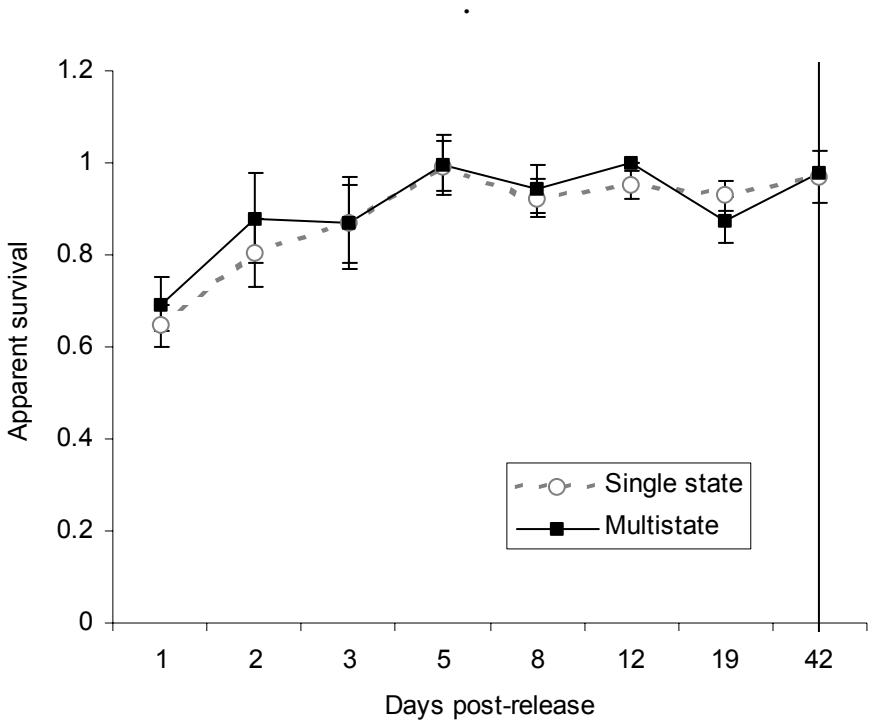

Figure 61. Single and multistate apparent survival estimates (±SE) for lobsters released at Stapleton Point.

15.3.5 Direct observation of releases

Glenvar Reef: Lobsters were released about half an hour prior to dusk. Lobsters did not immediately show a 'flight' response in an attempt to find shelter, however when a diver approached lobsters or attempted to catch them, they showed appropriate escape responses. No active predators were observed at the release reef at the time of release, although smaller fish unable to attack lobsters of this size (Little rock whiting - *Neeodax balteatus*, and cow fish - *Aracana aurita*) showed an interest in the lobsters. The release area was observed for approximately 20 minutes, and no predation events were noted. After 20 minutes most lobsters were attempting to shelter, although in many instances 'overcrowding' of shelters near the release site meant that dens would not have provided effective shelter from active predators.

Adventure Bay: The release at this site was completed approximately 90 minutes before dusk. The highly structured nature of the release reef at Adventure Bay meant that on release lobsters naturally tended to 'fall' into crevices if they did not actively move towards them. This resulted in extreme crowding in some crevices near to where

lobsters were released, however the deep nature of these crevices provided a degree of shelter despite this. Several species of leatherjacket (Pices: Monacanthidae) attempted to attack lobsters, however many were too small to be effective – no successful attacks resulting in either death or damage to lobsters were observed. Likewise, 2 large purple wrasse (*Notolabrus fucicola*) showed considerable interest in the released lobsters, but no successful attacks were observed.

Cameras set up to observe the release area at Adventure Bay proved useful for observing both predator and lobster behaviour. There was no detectable change in predator abundance in the release area within the 90 minutes prior to dusk. This confirms at least for this site that large numbers of predators were not attracted to releases. Several leatherjackets and purple wrasse continued to 'patrol' the release site. Approximately 40 minutes after release a successful capture by a large purple wrasse was clearly observed. This fish swam forcefully into a large crevice, and emerged with a lobster held by the antennae in its mouth. The fate of this lobster is unknown, as the fish swam out of the field of view with the lobster held in this way.

Soon after release there were approximately 35 lobsters within the field of view of the 4 cameras focussed directly on crevices. Ten of these lobsters moved out of the field of view of the cameras prior to dusk. Infrared light enabled continued observation of crevices after dark. Most of the lobsters moved out of the crevices in the 3 hours after sunset, with only 3 lobsters visible for a period. Numbers fluctuated throughout the night, and at dawn 9 lobsters were present. During the second night post-release all lobsters left the crevices, and by dawn 5 had returned.

Safety Cove: Seafloor cages were removed 1 hour before dusk. The complexity of this site meant that all lobsters within the cage areas were able to find good quality shelters. A small number of lobsters that had been sheltering under or adjacent to the ground chain on the cages moved rapidly to nearby shelters when the cages were removed. While fish (wrasse, leatherjackets and smaller fish) were attracted to the debris suspended during the removal of cages, no interest was shown in the lobsters. Uncaged lobsters were released at dusk, and no activity by predators was observed. Dives conducted at 2100, 0300 and 0600 similarly showed no visible predator activity, although disturbance by diver's torches may have resulted in avoidance behaviour by predators. At 2100, 8 lobsters were observed in and around the release area, including 2 within the algal canopy. The small numbers observed suggests that lobsters moved rapidly away from the site or in to shelters. Similar numbers of lobsters were seen in the 0300 and 0600 dives.

Stapleton Point: As with Safety Cove, seafloor cages were removed an hour before dusk and remaining lobsters released at dusk. When seafloor cages were lifted, it was apparent that a large number of lobsters had been using the ground chain as shelter and these lobsters swam rapidly to alternative shelter. Up to 5 female blue-throat wrasse (*Notolabrus tetricus*), and similar numbers of rosy wrasse (*Pseudolabrus psittaculus*) showed considerable interest in released lobsters, but were too small to attack successfully. Two large purple wrasse (*Notolabrus fucicola*) were also present, but where not observed attacking lobsters. The dense brown algae cover at the site provided effective cover for released lobsters, as most fish did not penetrate the algal canopy.

15.3.6 Caging trials

Safety Cove

The most parsimonious single state model for resightings in the release area at Safety Cove ($\phi(t)\rho(.)$; QAICc weight = 0.662) was twice as well supported as the next-best model, which included constant apparent survival for the caged treatment (QAICc weight = 0.330). Apparent survival estimates (Figure 62) differ dramatically for caged and uncaged treatments.

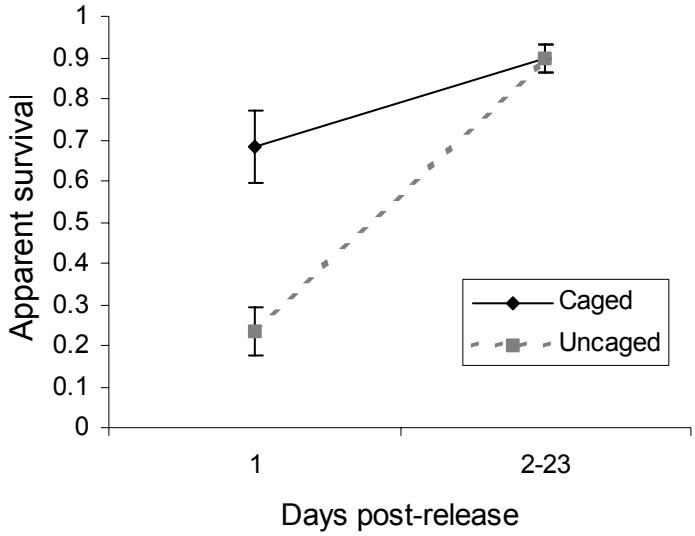

Figure 62. Apparent survival estimates (±SE) for resightings from the release area only at Safety Cove.

The most parsimonious multistate model ($\phi^{cr}(.)\phi^{ur}(t_1, t_{2-23})\phi^{a}(t)\rho(t)\Psi(st)$; QAICc weight = 0.40; superscripts c = caged treatment, u = uncaged treatment, r = release reef and a = adjacent reef) showed an increase in apparent survival for both caged and uncaged treatments, and provided a constant survival estimate (0.92±0.04) for the caged treatment (Figure 63). This model only received marginally more support than model $\phi^{r}(t_1(g), t_{2-23})\phi^{a}(t)\rho(t)\Psi(st)$ (QAICc weight = 0.31), which included individual apparent survival estimates for days 1 and 2-23 for caged lobsters. Model averaging produced an apparent survival estimate for caged lobster at time 1 of 0.86±0.06. Moving from the single state to the multistate model has resulted in an increase of approximately 18% in the apparent survival estimate for caged lobsters and 7% for uncaged lobsters. These values represent an estimate of the movement from the release reef to adjacent reef and fall within the range of the combined movement estimate for both groups for day 1 derived from the multistate model (9.8±8 %; Figure 64).

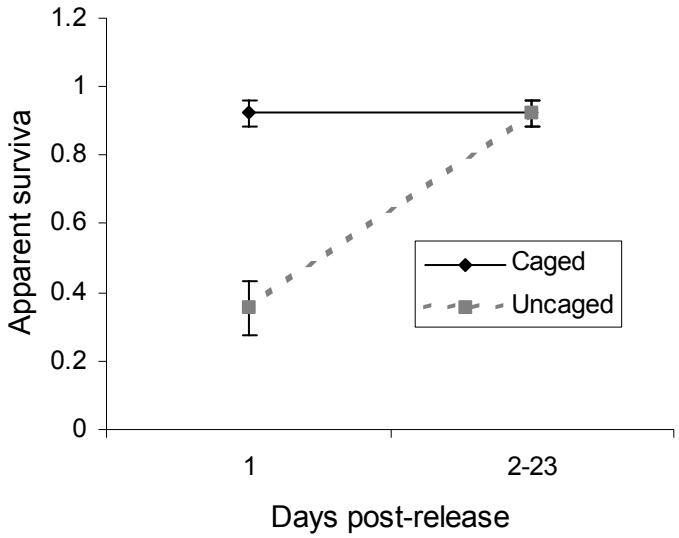

Figure 63. Multistate apparent survival estimates (±SE) for caged and uncaged lobsters on release reef and adjacent reef at Safety Cove.

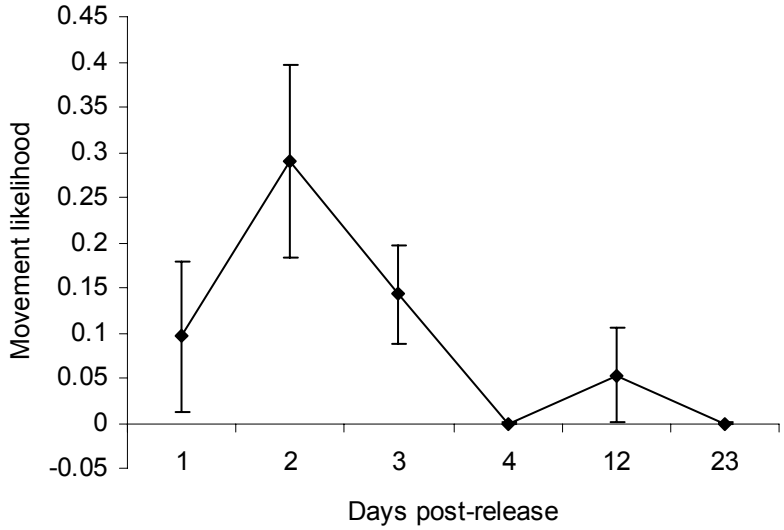

Figure 64. Likelihood (±SE) of caged and uncaged lobsters moving from the release reef to areas of adjacent reef at Safety Cove.

Stapleton Point

Goodness-of-fit tests for the single state model at Stapleton Point showed minor lack of fit ($p = 0.032$). The calculated $\hat{c}$ value (0.72) pointed to minor under-dispersion in the data, and was applied in the model selection process. Differences in apparent survival between caged and uncaged lobsters estimated for the release using a single state model were not as great as differences seen at Safety cove, however the effect was still

striking (Figure 65). The most parsimonious single state model was the same as that for Safety Cove ($\phi(t)\rho(.)$; QAICc weight = 0.986), and this model was approximately 90 times as well supported by the data as the next-best model ($\phi(gt)\rho(.)$; QAICc weight = 0.011).

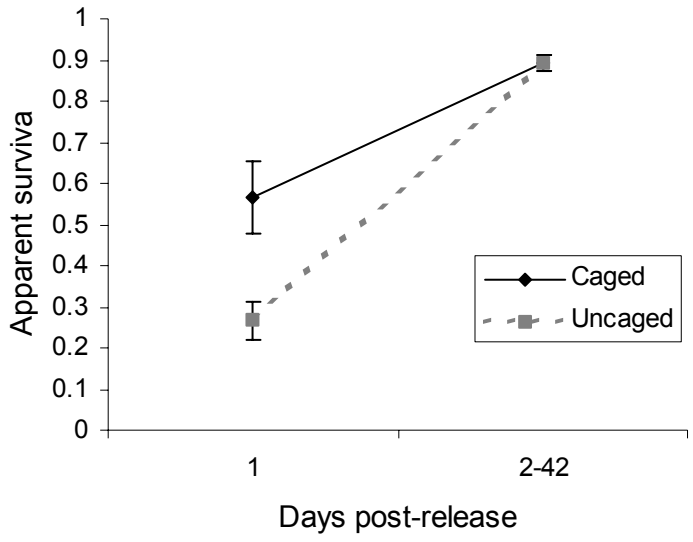

Figure 65. Apparent survival estimates (±SE) for resightings from the release area only at Stapleton Point.

The most parsimonious multistate model for Stapleton Point ($\phi(t_1, t_{2-42})\rho(st)\Psi(t_1(g), t_{2-42})$; QAICc weight = 0.742) provided apparent survival estimates that were not dependent on group (Figure 66). This model was 3 times as well supported by the data as model $\phi(t_1(g), t_{2-42})\rho(st)\Psi(t_1(g), t_{2-42})$ (QAICc weight = 0.253), which provided group dependent estimates for apparent survival (caged = 0.662±0.084; uncaged = 0.621±0.076). Estimates of movement from the release reef to adjacent reef (Figure 68) show significantly greater movement by uncaged lobsters.

The combination of the single and multi state models for Stapleton point suggest movement patterns quite distinct from those seen at Safety Cove. The multistate model shows movement of caged lobsters from the release reef to adjacent reef to be quite low. This is consistent with a minimal increase in apparent survival estimates moving from the single state to the multi state model. However, even with the multistate model, the apparent survival estimate for caged lobsters leaves about 36% of these lobster unaccounted for, the same as for uncaged lobsters.

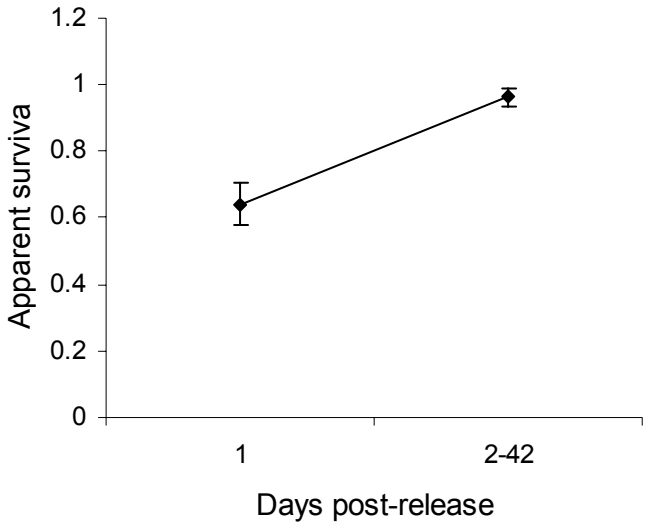

Figure 66. Multistate apparent survival estimates (±SE) for caged and uncaged lobsters (grouped) on release reef and adjacent reef at Stapleton Point.

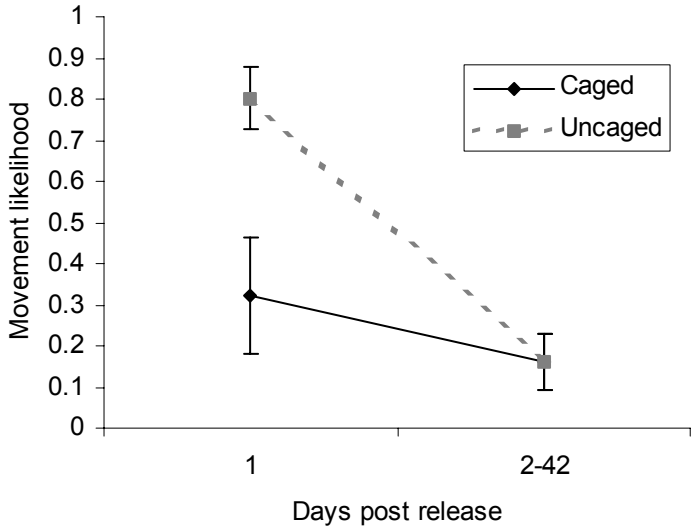

Figure 67. Movement likelihood (±SE) from the release reef to areas of adjacent reef for caged and uncaged lobsters at Stapleton Point.

15.3.7 Acoustic Tracking

Of the 6 caged and 6 uncaged lobsters released with acoustic tags, 1 caged lobster was never located after cages were lifted, and 1 uncaged lobster moulted within the first 24 h following release – the tag was recovered still attached to the exuviae. We do not know the fate of the lobster that was never located; possibilities include loss to predation, the lobster moved beyond the area surveyed, or that the tag malfunctioned.

The remaining 5 lobsters from each treatment group showed conclusively that caging has a major effect on movement during the first 24 h following release (Figure 68). Of the 5 caged lobsters 2 did not move from the areas where they were caged, 1 moved 8 m and 2 moved 15 m. Movement of 15 m coincides with the boundary between areas searched as release reef and adjacent reef. The minimum distance moved by uncaged lobsters was 20 m and 1 lobster, which moved 30 m N, was located outside the area searched by divers and under an isolated rock platform. Group differences were highly significant (1-way ANOVA, $F_{1,8}$= 16.98, P = 0.003).

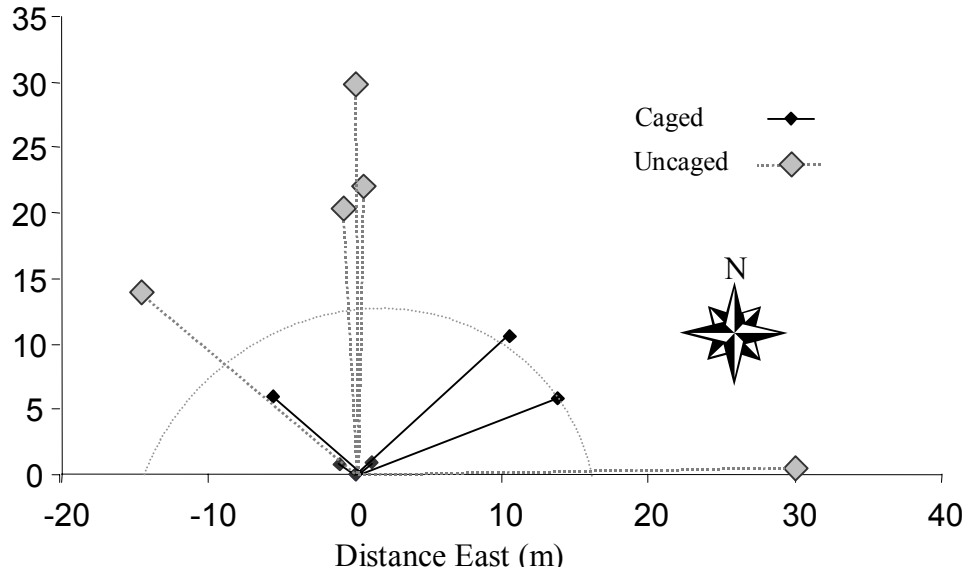

Figure 68. Distance and direction moved from point of release by caged and uncaged naïve lobsters during the first 24 h post-release. The grey semi-circle represents the approximate position of the demarcation between areas surveyed as release reef and adjacent reef.

Lobsters inhabited a combination of solitary hides and larger dens with wild juveniles present. The 2 caged lobsters that moved 15 NE and ENE were under opposite sides of a large flat boulder inhabited by at least 50 wild juveniles. The 2 uncaged lobsters that moved 20 m N were under a similar, but smaller rock while all other lobsters inhabited solitary hides.

15.4 Discussion

Pilot-scale releases and mark/recapture modelling across a range of sites have provided important insights into patterns of lobsters behaviour and survival. They have proven powerful for assessing the fitness of naïve lobsters for release at a given site compared with wild-caught lobsters. Of vital importance to developing appropriate field methods and analytical techniques was some prior knowledge of movement patterns of naïve and wild lobsters. Information from acoustic tracking and early releases revealed the likely range of movement of lobsters at different temporal scales. Similarly, early trials revealed the difference in movement patterns between naïve and wild lobsters. This information was incorporated into field methods and the detail of mathematical models used to estimate relative survival.

Understanding distances moved of particular importance given that survival models estimate 'apparent survival'. In the absence of independent estimates, apparent survival will include losses due a number of factors that result in lobsters not being visible during surveys. These include true mortality, tag loss due to tag failure or moult, lobsters moving beyond the areas searched by divers or lobsters remaining within the survey area but inhabiting shelters where they can not be seen by divers. The inclusion of wild-caught lobsters provides a control for a number of these factors. Rate of tag failure will be equivalent for both groups, although tank trials suggest this is likely to be low. Detailed observations of habitat utilisation from acoustic tracking trials at Glenvar Reef and Stapleton Point have shown that habitat utilisation is unlikely to vary between groups. Moult rate is dependent to a large degree on nutritional status and water temperature. For releases at Adventure Bay and Glenvar Reef, control lobsters were taken from the same water mass (Storm Bay/Derwent Estuary) as water was drawn from for tanks holding naïve lobsters, and released back into the same water mass. In these circumstances moult rates area unlikely to differ between groups. For release trials on the east coast (Safety Cove and Stapleton Point) lobsters were moved from cooler water in the holding facilities to warmer east coast waters. As wild-caught lobsters were still sourced from southern waters, moult rates are likely to increase, but should still be equivalent for the 2 groups. Clearly, wild-caught lobsters will not function as controls for movement, and this must be allowed for in survival modelling.

Three of the 4 pilot-scale releases (Glenvar Reef, Safety Cove, Stapleton Point) showed no detectable difference between the apparent survival of naïve and wild-caught lobsters once different movement patterns were accommodated in the model structure. Had we not employed multistate models and included searches of adjacent areas of reef, our conclusions would have been quite different. This is clearly illustrated at the Glenvar Reef site. Use of the single state model (survival estimates shown in Figure 51) even when including extensive searches of adjacent reef areas, would have lead to the erroneous conclusion that survival of naïve lobsters was lower than that of wild-caught lobsters for the first 2 resighting surveys. As naïve lobsters tended to move further than wild-caught lobsters, a higher proportion were resighted on the extensive areas on neighbouring reef. As neighbouring reef areas were large, and lobsters widely disbursed, the probability of divers encountering a tagged lobster on neighbouring reef areas was significantly lower than on the release reef. Single state models cannot account for this, and the result is a low estimate of apparent survival for naïve lobsters. Indeed it is this difference in encounter probability that also lead to a poor fit for the single state model, as the assumptions of homogeneity of resighting probabilities was violated. The multistate model, however, produced independent estimates of encounter probability for the release area and adjacent reef. A lower encounter probability on adjacent reef, where there were a higher proportion of naïve lobsters resulted in a higher estimate for naïve lobster survival, indeed one that was indistinguishable from that of wild-caught lobsters.

At a single site, Adventure Bay, apparent survival of naïve lobsters was about 10% lower than that of wild-caught lobsters. A combination of results from tethering trials, video evidence, release trials and habitat characteristics provide insights into the likely cause of this difference. Results presented in Chapter 14 show that there are no detectable differences in predation pressure between Adventure Bay and other pilot-scale release sites. Infrared video evidence from the 48 h following release confers with

this finding. However, we know that movement is likely to differ between naïve and wild lobsters. The Adventure Bay site is physically different from other sites in this study in that it is an isolated area of patch reef with little surrounding reef. The other patch reef used in the study (Glenvar Reef) had surrounding reef on all sides, and large numbers of lobsters, predominantly naïve, were re-sighted on these surrounding reefs. The Adventure Bay reef also has the smallest total reef area and is long and thin, with comparatively greater edge per area than other sites. If predation pressure is the same as at other sites as suggested by corrected tethering results, a likely cause of the observed difference is a greater rate of movement of naïve lobsters away from the release reef. With little surrounding reef, it is likely that a large number of lobsters leaving the reef would not survive. It appears that the use of patch reefs to limit lobster movement is not effective, and moreover can result in high mortality rates.

At 3 of the 4 sites (Adventure Bay, Safety Cove, Stapleton Point), apparent survival estimates for the first sampling period after release (generally 24 h) were significantly lower than for the remaining surveys. As the effect was the same for wild and naïve juveniles, this is not the result of artefacts of the captive rearing process, but rather a response to a process affecting both groups equally. Potential causes include predation due to exposure when first released, moving to hides where they cannot be seen by divers or moving beyond the survey area. The observed differences may be the result of one or any combination of these causes.

We do not believe that mortality contributes significantly to this effect. Apparent survival estimates for the 24 h post release were as low as 40%. Survival amongst tethered lobsters at these sites for the first 24 h was higher than 40%, and mesocosm trials have shown that lobsters are many times more likely to be captured by predators if tethered. Similarly, diver observations and video footage provided no evidence of large mortalities during this period. At Glenvar Reef, apparent survival was constant and high for the entire trial, yet video referenced tethering trials suggest that predation pressure at Glenvar Reef is similar to that of other sites. Baited video trials suggest daytime predators are in similar abundance across all sites, and camera-referenced tethering confirms that daytime predators are responsible for the majority of lobster mortality. Glenvar Reef and surrounding reef areas were of simpler habitat structure than the other 3 sites, so it is plausible that a greater number of lobsters that remained within the survey area were available for sighting by divers. An extensive acoustic tagging program would be required to differentiate between the effects of emigration from the survey area and remaining within the survey area in sites not observable by divers.

Caging trials provide further evidence that movement is largely responsible for low apparent survival estimates for both groups immediately following release. At Safety Cove, the response to caging was particularly dramatic, resulting in a high and constant apparent survival estimate for the duration of the trial. Apparent survival for uncaged naïve lobsters was less than 40% for the first 24 h and 86% thereafter, while that for caged lobsters was about 86% for the duration of the trial. This in itself does not provide answers as to the direct cause of the observed effect. The cages may have a) suppressed the ‘flight’ response resulting in few lobsters moving beyond the survey area or b) provided protection from predators while lobsters found shelter within the caged areas. Multistate results from Stapleton Point show that the likelihood of lobsters

moving away from the release area is far higher for uncaged lobsters than for caged lobsters, and this is confirmed by acoustic tracking results.

Multistate apparent survival estimates for caged lobsters at Stapleton Point are quite distinct from those at Safety Cove. At Stapleton Point, few caged lobsters were located on areas of reef adjacent to the release reef. That is, apparent survival estimates for caged lobsters did not increase substantially from single state estimates when using multistate models and including resightings from adjacent reef. With only 2 caging sites, it is difficult to draw conclusions about these differences. However it is notable that differences in microhabitat structure at the 2 sites meant that all caged lobsters at Safety Cove had access to high quality hides, while far fewer hides were available at Stapleton Point. When cages were lifted at Stapleton Point, it was obvious that available hides were unnaturally crowded, and large numbers of lobsters had chosen to use the edge of the cage as shelter. Once the cage was removed they moved rapidly away from the site. If these lobsters moved beyond the dive survey area, this could lead to the survival multistate survival estimates seen at this site.

In the mathematical survival modelling process there is clearly an interaction between distances moved by lobsters, trial site characteristics, and size of survey areas that must be considered. Figure 69 illustrates some simplified possibilities for such interactions. In Figure 69a, the search area is clearly too small, and the differences in movement between groups will result in an underestimate of survival of naïve lobsters. This is analogous to the situation in the Bruny Island release, although in this case the search area is equivalent to the total reef area, and lobsters moving beyond this are moving away from the reef.

In Figure 69b, the search area has covered the entire area occupied by lobsters. A single state analysis would be appropriate here to provide an absolute survival estimate. However, a caveat is that search effort is constant throughout the entire survey area. Where there are areas of extensive neighbouring reef to be surveyed, this will require a massive effort. Similarly, encounter probability may vary in different reef areas if reef structure is different. If encounter probability is not consistent throughout the survey area, assumptions on the single state CJS model will be violated. This is the situation that occurred with the single state model at Glenvar Reef, and in this instance it would lead to an erroneous conclusion that survival differed between wild and naïve lobsters.

Figure 69c represents the ideal, where all movement of lobsters is covered by multiple strata (2 strata in this instance). Search effort can differ between strata, and the model will incorporate different encounter probabilities into survival estimates. This is similar to the situation seen at Glenvar Reef using the multistate model. Surveys at this site clearly covered the majority of areas occupied by lobsters, as the apparent survival estimate was very high (0.980±0.016).

Figure 69d represents the situation we believe has occurred at Adventure Bay, Safety Cove and Stapleton Point. The flight response in the first days post-release results in a proportion of wild and naïve lobsters moving beyond the search area. As lobsters settle in hides on subsequent days, apparent survival rates increase. However lobsters that have moved beyond the search area are unlikely to return, and, in the absence of independent movement estimates, are indistinguishable from mortalities.

15.5 Conclusion

Consistent with results reported elsewhere in this study, naïve lobsters appear to adapt well to survival in the wild, generally behaving in a similar way to wild lobsters. The single exception demonstrated here is their propensity to move greater distances when first released. While this does not effect survival on large reef areas or where there are abundant areas of adjacent reef for lobsters to settle on, it dictates that areas of isolated patch reef are not appropriate for lobster reseeding. Although seafloor cages proved a useful scientific tool for investigating movement behaviour, their effectiveness for decreasing apparent survival was habitat specific, and likely to relate to suppression of the flight response rather than increasing survival.

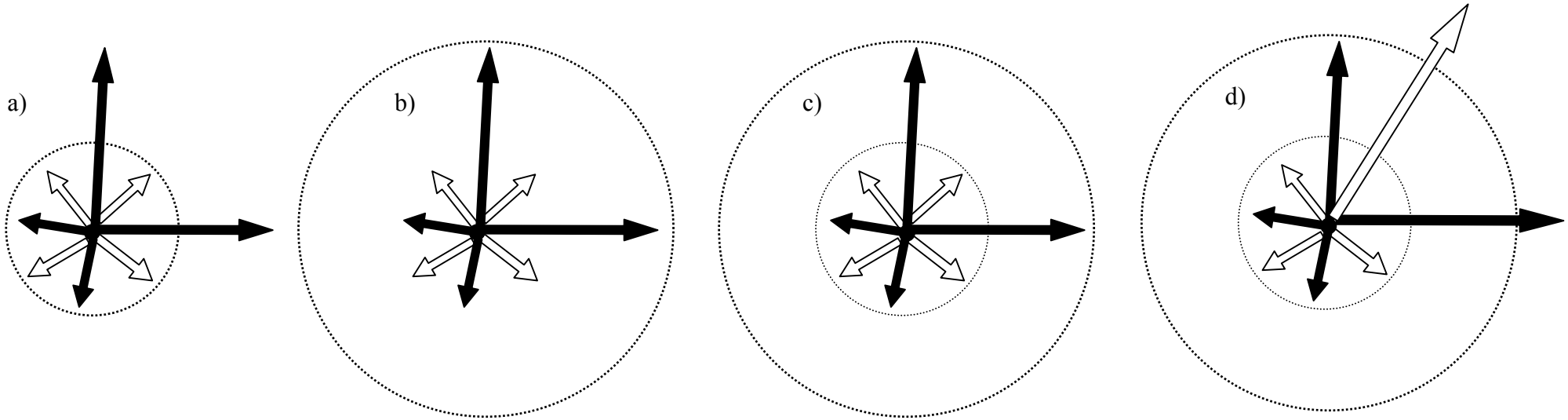

Figure 69. Simplified conceptual model of potential interactions between distance moved by lobsters and diver search area. Search areas are represented by dashed circles. We know that naïve lobsters (movement represented by black arrows) will tend to move further than wild-caught lobsters (white arrows). Under scenario a) the search area is too small, resulting in emigration of naïve lobsters and an underestimate of survival for this group. Under scenario b) the search area is appropriate for observed movement, however unless search effort is kept constant throughout the search area, violations of the assumption of equal resighting probabilities are likely. The use of multistate models as in scenario c) with independent estimates of parameters for multiple spatial zones alleviates the necessity for equal search effort in the small release area and more extensive adjacent areas of reef. Scenario d) represents a realistic outcome with non-linear movement when the entire area where lobsters can move cannot be covered in surveys. This will lead to equal apparent survival estimates for the 2 groups, but estimates will be less than 1.

16. Benefits and adoption

The project met performance indicators of: (a) defining release protocols for optimising the survival of released juvenile lobsters in relation to microhabitat type, time of day and conditioning to predators; and (b) providing precise estimates of survival of released juveniles in different bioregions.

Adoption of results by industry has not occurred yet but this research has facilitated access to puerulus collection. Future adoption of results may occur through either continued harvest of puerulus and ongrowing, or through translocation of larger animals around the state. A summary of the state of both of these industry initiatives is given to indicate the likelihood of benefits arising from the project.

16.1 Application of results

The Southern Rock Lobster Industry is now well placed to progress enhancement initiatives. Previous research through RLEAS has identified cost-effective methods for puerulus collection (Mills and Crear 2004) and methods to on-grow these puerulus to juveniles with low rates of mortality (Crear *et al*. 1998, Crear *et al*., 2003). This project has now demonstrated that survival of juveniles after release onto coastal reef is high where simple protocols for rearing, release and site-selection are followed.

16.2 Puerulus harvest and ongrowing

One of the planned applications of the project was to contribute to an aquaculture industry based on puerulus harvesting and ongrowing. That scheme-involved access to wild puerulus for aquaculture coupled with the release of a portion of juveniles after one year in culture. This project was initiated to contribute information to that industry which was set to commence with the issue of exploratory permits at the same time this project commenced.

Despite a large amount of applications for puerulus harvest permits, few of the seven successful applicants have attempted to collect puerulus. Three of the applicants did not submit a harvest plan or attempt to harvest any puerulus. Only one of the permit holders deployed collectors in a pilot-scale collection exercise and only two permits remain on issue. The fundamental potential of puerulus harvest and ongrowing was tested and proven with several thousand puerulus collected from a short deployment of 200 collectors.

Reasons cited by permit holders for lack of progress were varied.

Those interested in harvesting puerulus from other aquaculture gear during normal operations found that most animals captured had already grown above 16 mm CL and were thus too large to be retained.

Others considered that the changing focus by State Government had resulted in overly restrictive permit conditions. Specifically, several cited there was a shift in policy away from that prescribed in the 1997 Rock Lobster Fishery Policy Document which

allowed for the harvest of puerulus to enable the development of an aquaculture industry. Several of these permit holders felt that early claims about the imminent likelihood of hatchery production contributed to a shift in the role of puerulus harvest permits. That shift was away from the pragmatic development of commercially viable rock lobster aquaculture using puerulus towards small-scale experimental trials of ongrowing techniques until hatchery production was developed. Several permit holders stated their belief that this change in emphasis resulted in overly restrictive conditions, especially in relation to the proportion of animals that had to be released.

Overall, the lack of financial reward with the return of 25% of juveniles and the realisation that closure of the life cycle of the rock lobster is unlikely in the foreseeable future has diminished enthusiasm of permit holders.

The current permit conditions require that 25% of juveniles be released after 12 months in commercial culture. This number was intended to be conservative and incorporate post-release mortality. Results presented here indicate that survival of released juveniles is equivalent to that of wild controls 48 hours after release. Survival during the initial period was difficult to estimate due to emigration, but apparently low. This indicates that the proportion of juveniles that permit holders need release after one year could be reduced while still achieving fisheries enhancement through puerulus harvest. Such a change would address the concerns of permit holders about the financial viability of aquaculture grow-out.

16.3 Regional enhancement by translocation of sub-legal lobsters

Southern rock lobster fisheries across southern Australia are managed sub-optimally for economic yield and improving this situation is the most significant opportunity for expansion of lobster harvests. In Tasmania, this situation is acute due to the large differences in growth between regions. In addition, the size and colour of lobsters is increasing affecting beach price with severe discounting of large (>1.5 kg) and smaller (< 0.8 kg) lobsters.

Lobsters in the north of Tasmania (eg King Island) can increase in size by over 15 mm per annum (carapace length) while females in the south west have been tagged and recaptured 17 years later without reaching legal size and growing at less than 1 mm per year. The differences in growth mean that the resource is fished in a manner that is far from optimal for maximising both harvest and sustainability (as with most wild fisheries).

The use of a single management system for animals with very different biology around the state means that opportunity is being wasted (in terms of yield). Massive tonnages of potential harvest in the SW are simply dying from old age without reaching legal size. Animals in the north are harvested too early and potential yield benefits from growth to larger sizes are lost.

Tasmanian stocks are currently increasing steadily with legal-sized biomass growing at over 5% per annum for the last 5 years. This is due to management of the commercial fishery. Catch rates are becoming extremely high in some areas with many fishers obtaining catch rates >10 kg/potlift at the start of the 2003/04 season.

Fishers are becoming more selective in the catch that they target and retain. This is due to increasing production of lobsters elsewhere (especially WA) and reduced market demand except in premium Chinese markets. The premium prices worldwide are for rich-red coloured lobsters from inshore areas in the size range 800-1500 g. The world market for small lobsters is highly competitive with lower-value Cuban, South African, New Zealand and Western Australian lobsters (mainly 300-600 g). Many Tasmanian fishers are discarding all small yet legal-size lobsters in their catch, so attempting to develop aquaculture markets targeting small sizes appears increasingly challenging.

The idea of translocating animals from high-density, low-value, slow-growth areas in deeper waters off the west and south to northern areas would address these issues of slow growth and abundance of small animals with low marketability. Translocation is not a new idea and has been proposed and tested for over 30 years. The idea has gathered momentum again recently and has been given strong support by the Tasmanian Crustacean Research Advisory Group and was highlighted as a key opportunity in the strategic planning process.

Research conducted on release of juveniles for this project has assisted in preliminary discussions as it provides assurance that releases could be done effectively and that the success of releases could be tested effectively.

17. Further development

17.1 Aquaculture

Expansion of a rock lobster aquaculture industry based on puerulus harvest is largely dependent on promotion and support of this industry by both State Government and RLEAS. The ability of operators to collect large numbers of puerulus economically has been tested and demonstrated to be viable.

Other challenges remain such as the location of a greater number of suitable collecting sites, economically viable growout systems and provision of suitable permit conditions to promote investment. RLEAS support for continued access to puerulus harvest permits and revision of the ratios required for release of juveniles would be positive steps in the promotion of a rock lobster aquaculture industry in Tasmania.

Recent developments in the wild fishery have highlighted the marketing challenges facing rock lobster aquaculture. Demand for smaller animals of the size that could be supplied by aquaculture has been sated by increased worldwide supply. This decline in demand has lead to Tasmanian vessels releasing catches of small lobsters that could be not be sold in early 2004. This demonstrates the need for economic evaluation in rock lobster aquaculture strategic development.

17.2 Translocation

Many of the research issues associated with the release of juvenile rock lobsters as part of aquaculture operations are also required for development of increased harvests through translocation. We are well positioned to estimate the number of animals that

could be translocated through the existing assessment model, although improved information on some aspects of basic biology such as growth is needed. Preliminary modelling indicates that increases in harvests of at least 400 tonnes / annum would be achievable so this is clearly a substantial opportunity. Benefits would also be through increased proportion of catch in higher value categories (>$40/kg vs < $20/kg).

Movement of animals away from the site of release would need to be measured and we are well placed due to the development of models incorporating movement for this project. We also an extensive acoustic tracking network and have developed in-house software for analysing movement of released lobsters. Southern rock lobsters tend to move smaller distances than many other rock lobster species. Movement was recently analysed from Tasmania based on over 40,000 recaptured lobsters. Most moved less than 2 km per year, which is insignificant for translocation.

Survival of animals after release would need to be optimised and measured, which can now be done with methods developed through this project.

Many other issues are involved with translocation although previous research has indicated that none appear to be severe obstacles. In most cases existing research has already partly addressed concerns. These issues include risks of disease transfer, ecological impacts of shifting lobsters, impacts on regional egg production and payment of translocation costs.

18. Planned outcomes

Planned outcomes at the time of commencement of this research were for the facilitation of a rock lobster industry based on puerulus harvest. All issues relating to the development of puerulus harvest have now been met or are being addressed. These are:

- Development of puerulus collection methodology through FRDC 1998/302;
- Demonstrated viability of harvest of large-numbers of puerulus by commercial operators;
- Health assurance for release of juveniles from culture situations through FRDC 2001/094; and
- Quantified survival of juveniles in release operations through this project (FRDC 2000/185).

Several hurdles remain to the development of a rock lobster aquaculture industry including cost reduction through the grow-out phase. The principle issue is the development of permit conditions that facilitate and promote investment, while still ensuring biological neutrality of puerulus harvests. One important area where permit conditions could be revised on the basis of improved information is in the proportion of juveniles that need to be released after one year in culture. This ratio is largely based on two estimates of survival: survival of wild juveniles through the first year after settlement and the survival of released juveniles after release. The first of these is the

focus of research underway in FRDC 2001/070, while the second was addressed in the research reported here.

Governments in all States who wish to develop rock lobster aquaculture are faced with the choice between issue of permits for puerulus harvest and associated release of juveniles or choosing to wait for possible hatchery production in the future. The choice between these options will be influenced by opinions about the length of time before commercially viable production of lobsters could become possible, if ever. While it is appears that aquaculture based on puerulus harvest and reseeding is currently possible, the time period that research effort could continue aiming for economical hatchery production is unknown.

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20. Appendix 1: Intellectual property

No commercially valuable intellectual property arose from the research. No compelling reason was identified to restrict distribution of results so these have been made publicly available with no protection or confidentiality.

21. Appendix 2: Staff

Project staff were:

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